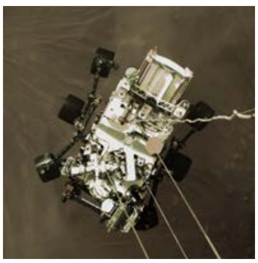
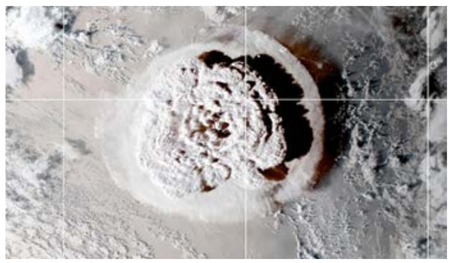
Aeronautics and Space Report of the President

Fiscal Year 2021 and 2022 Activities




Aeronautics and Space Report
OF THE PRESIDENT

Fiscal Year 2021 and 2022
Activities

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 in two fiscal years, from October 1, 2020, through September 30, 2022. 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.** Two U.S. Air Force F-35A Lightning II aircraft and two French Rafale aircraft break formation during flight over France, May 18, 2021, during a multinational exercise. Credit: Air Force Staff Sgt. Alexander Cook. **2.** Revealed on July 12, 2022, this image captured in infrared light by NASA's James Webb Space Telescope shows the nearby, young, star-forming region NGC 3324 in the Carina Nebula revealing previously obscured areas of star birth. Credit: NASA, ESA, CSA, and STScI. **3.** A UAS is seen flying into a smoke plume at Pebble Hill location Block B/Unit C2, Tall Timbers Research Station. Credit: USGS/Todd Hoefen. **4.** A Falcon 9 rocket launches from Cape Canaveral Space Force Station, Florida, on January 31, 2022. Credit: Joshua Conti, Space Force. **5.** The GOES-17 satellite captured this image of the enormous cloud generated by the underwater eruption of the Hunga Tonga-Hunga Ha'apai volcano on January 15, 2022. Credit: NASA Earth Observatory image by Joshua Stevens using GOES imagery courtesy of NOAA and NESDIS. **6.** This image taken by a camera aboard the descent stage of the Mars 2020 spacecraft shows NASA's Perseverance rover just before touching down on Mars on February 18, 2021. Credit: NASA/JPL-Caltech.

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The National Space Council

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

The Council meets regularly 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, Council meetings are livestreamed 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. The UAG members are organized into six subcommittees: Exploration and Discovery; National Security Space; Economic Development and the Industrial Base; STEM Education, Diversity, and Inclusion; Climate and Societal Benefits; and Data and Emerging Technology. These subcommittees meet regularly to produce recommendations to the National Space Council for consideration. The UAG's first meeting was held on February 23, 2023. The meeting was largely focused on planning by the UAG and its six subcommittees on topics ranging from national security to education.

Meetings of the National Space Council

The Council met on December 1, 2021, at the U.S. Institute of Peace in Washington, DC, marking the first meeting of the Biden-Harris Administration. Council members discussed developing norms of behavior to promote peaceful exploration of space and reduce the risk of miscalculation or conflict in space; the use of Earth observation data collected from space to address the climate crisis; and the use of space activities to enhance education in science, technology, engineering, and mathematics (STEM) fields.

The Council met for the second time in FY 2022 on September 9, 2022, at the NASA Johnson Space Center in Houston, Texas, where Vice President Harris announced new commitments by the U.S. Government and the private sector to advance American leadership in space. During the meeting, Space Council members discussed advancing the Council's priorities in expanding Space STEM education and workforce development, human space exploration, and rules for commercial novel space activities.

Key Announcements

Space Priorities Framework. On December 1, 2021, the White House released the United States Space Priorities Framework, a document laying out the Administration's all-of-government approach to ensuring that space activities create opportunities that benefit the American people and the world. The Framework guides the Council's efforts, maintaining focus on advancing and synchronizing U.S. civil, commercial, and national security space activities.

International Space Station Extension. On December 31, 2021, the Biden-Harris Administration announced its commitment to extend International Space Station operations through 2030 and to work with international partners to enable continuation of the groundbreaking research being conducted in this unique orbiting laboratory through the rest of the decade.

National Security Norms in Space. On April 18, 2022, Vice President Harris announced that the United States commits to not conduct destructive, direct-ascent anti-satellite (ASAT) missile testing and commits to establish this as a new international norm for responsible behavior in space. The Vice President also called on other nations to make similar commitments and to work together in establishing this as a norm, making the case that such efforts benefit all. Since this announcement, four allies have made similar pledges to not conduct destructive ASAT testing that could create space debris in orbit.

Updated Rules Framework for Commercial Space. On August 12, 2022, Vice President Harris announced the start of an interagency process led by the National Space Council to develop a new rules framework for commercial space activities.

National Aeronautics and Space Administration

NASA

Human Exploration and Operations Mission Directorate in Fiscal Year 2021

Exploration Systems Development

The Exploration Systems Development (ESD) programs—the Space Launch System (SLS), Orion, and Exploration Ground Systems (EGS)—provide the foundation for humanity's return to the Moon and exploration beyond. Progress steadily continued toward the uncrewed Artemis I mission, the first integrated test of the ESD programs that will pave the way for future crewed Artemis missions.

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 fiscal year 2021 (FY 2021), NASA finished integration of the Orion spacecraft, completing the Artemis I Orion stack. After final assembly and testing at Kennedy Space Center's (KSC) Neil Armstrong Operations and Checkout Building, the spacecraft was moved to the center's Multi-Payload Processing Facility and underwent fueling commodity servicing. It was then transferred to the Launch Abort System Facility, where the launch abort system was integrated with the spacecraft. In FY 2021, NASA also:

- Completed a series of four water impact drop tests with a test version of the Orion capsule at NASA's Langley Research Center in Hampton, Virginia. The test data will help engineers better understand what Orion and its crew may experience when landing in the Pacific Ocean after Artemis missions to the Moon and will help feed final computer models for loads and structures prior to the Artemis II flight test.
- Installed a new Orion spacecraft simulator at the agency's Johnson Space Center (JSC) in Houston, Texas. The simulator provides the ability for astronauts, engineers, and flight controllers to train and practice for scenarios they may face during Artemis missions to the Moon. The interior of the simulator is outfitted with Orion's display and control system and crew seats to mimic what astronaut will experience during liftoff to the lunar vicinity and on their way back home to Earth.
- Completed the pressure vessel for the Artemis III mission at NASA's Michoud Assembly Facility in New Orleans. The pressure vessel is the primary structure for Orion's crew module, joined together using state-of-the-art welding by technicians from lead contractor Lockheed Martin. With the Artemis I and II spacecraft manufactured as part of the design and development phase, the Artemis III pressure vessel is the first crew module structure off the line in the long-term production phase.
- Shipped the Artemis III European Service Module structure from Thales Alenia Space in Turin, Italy, to Airbus facilities in Bremen, Germany, where it will undergo final integration before shipment to KSC in Florida.
- Began the first series of human-in-the-loop testing with astronauts and Orion engineers at JSC to prepare for crucial docking and undocking operations in lunar orbit.

Space Launch System

With the powerful SLS rocket and Orion spacecraft nearing the end of testing and development, NASA has the foundation needed to send humans back to lunar orbit. At the end of FY 2022, preparations for Artemis I were well under way, as the Artemis I SLS rocket completed testing and was delivered to KSC for integration. In FY 2021, the agency:

- Conducted a successful full-duration hot fire test of the Artemis I core stage on March 18, 2021, at Stennis Space Center (SSC). All four RS-25 engines, in the same configuration launched for the Artemis I mission, successfully ignited. With the completion of this hot fire test, all eight tests that comprised the Green Run testing campaign were completed, verifying all systems were operational ahead of the Artemis I launch.
- Shipped the core stage of the SLS rocket to KSC on April 27, 2021. Engineers with EGS and lead contractor Jacobs off-loaded the core stage and moved it to the center's Vehicle Assembly Building (VAB) for integration atop the mobile launcher with the completed stack of solid rocket boosters ahead of the Artemis I launch.
- Continued stacking of the Artemis I rocket stages, including the Launch Vehicle Stage Adapter (LVSA), the Interim Cryogenic Propulsion Stage (ICPS), and the Orion mass simulator, and completed the first integrated power-up. The initial power-up was a significant checkpoint in pre-launch processing, marking the beginning of the systematic checkouts of the vehicle and ground systems.

Exploration Ground Systems

Exploration Ground Systems (EGS), based at KSC, was established to develop and operate the systems and facilities necessary to process and launch rockets and spacecraft during assembly, transport, and launch. EGS prepared the infrastructure to support government and commercial spacecraft and rockets in development, including the SLS rocket and Orion spacecraft for Artemis I. In FY 2021, NASA performed the following tasks:

- Completed stacking of the twin SLS solid rocket boosters for NASA's Artemis I mission. Over the course of several weeks, technicians inside the VAB lifted and placed ten booster segments and nose assemblies on the mobile launcher.
- Transported the SLS core stage from the Pegasus Barge into the KSC VAB, where it was lifted to vertical position and stacked between the twin solid rocket boosters on the mobile launcher.

- Integrated Artemis I critical flight hardware components, including the LVSA, Interim Cryogenic Propulsion Stage (ICPS), and Orion Stage Adapter (OSA).
- Conducted simulations of crucial portions of the Artemis I countdown to ensure launch team readiness on launch day. Engineers and test directors from KSC, JSC, and Marshall Space Flight Center (MSFC) came together to perform the first joint launch countdown simulation for Artemis I.
- Retracted all access platforms in High Bay 3 of the VAB for testing ahead of the launch of Artemis, including the integrated modal test to enable the flight software and navigation systems teams to collect data used to guide the rocket through launch and ascent.
- Continued building the new liquid hydrogen (LH2) storage tank at Launch Complex 39B at KSC capable of holding 1.25 million gallons of usable LH2 to support future launches from the pad, including Artemis missions to the Moon and on to Mars.

Advanced Exploration Systems

Through FY 2021 the Advanced Exploration Systems (AES) Division was responsible for programs critical to Artemis and NASA's Moon to Mars exploration, including the Human Landing System (HLS), Gateway, exploration spacesuit development, and surface mobility systems development. In FY 2021, the AES team developed and matured high-priority capabilities foundational for future human spaceflight, in an integrated manner, beginning with the Artemis III mission. The AES Systems Engineering and Integration (SE&I) team successfully completed the initial baseline of the AES Concept of Operations and Systems Engineering Management Plan (SEMP). Both documents are cornerstones for the integration of multiple diverse teams and programs into a cohesive campaign of missions under Artemis.

Human Landing System

The Human Landing System (HLS) Program is responsible for the spacecraft that will carry Artemis astronauts from lunar orbit to the Moon's surface and back again safely. In FY 2021, the HLS Program team made significant strides to procure innovative systems to return humans to the Moon. The agency:

- Released a solicitation for the first lander that will take humans back to the Moon on the Artemis III mission. After evaluating the proposals received, NASA selected SpaceX to continue development. The Government Accountability Office (GAO) and Court of Federal Claims later affirmed this selection, allowing NASA teams to continue collaborating closely with SpaceX as they develop their human landing system, Starship.
- Selected five U.S. companies to advance sustainable human landing system concepts, conduct risk-reduction activities, and provide feedback on NASA's requirements to cultivate industry capabilities for crewed lunar landing missions. The companies that received awards were Blue Origin Federation of Kent, Washington; Dynetics (a Leidos company) of Huntsville, Alabama; Lockheed Martin of Littleton, Colorado; Northrop Grumman of Dulles, Virginia; and SpaceX of Hawthorne, California. The selected companies began development of lander design concepts, evaluating their performance, design, construction standards, mission assurance requirements, interfaces, safety, crew health accommodations, and medical capabilities. This work will help mitigate lunar lander risks by conducting critical component tests and advancing the maturity of key technologies.

Gateway

In pursuit of a sustainable human exploration program, NASA identified the need for Gateway—humanity's first space station in lunar orbit. Gateway will provide multipurpose support for a long-term human return to the lunar surface and serve as a proving ground and staging point for sustainable deep space exploration. In FY 2021, the Gateway team 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.

Habitation and Logistics Outpost and Power and Propulsion Element

Habitation and Logistics Outpost (HALO) will provide command, control, and data-handling capabilities, energy storage and power distribution, thermal control, communications, and tracking capabilities. It will be equipped with three docking ports for visiting vehicles and future modules, as well as space for science and stowage. In FY 2021, NASA finalized a contract with Northrop Grumman to develop HALO. Power and Propulsion Element (PPE), which is being built by Maxar Technologies, is a 60-kilowatt-class solar electric propulsion spacecraft that will provide power, high-speed communications, attitude control, and the capability to move the Gateway to different lunar orbits, providing more access to the Moon's surface than ever before. Funded by NASA's Space Technology Mission Directorate (STMD) under a Tipping Point public-private partnership, Maxar Technologies and Busek Co. conducted the initial phases of testing for the PPE 6-kilowatt (kW) solar electric propulsion (SEP) subsystem, validating all major elements that will propel NASA's Gateway around the Moon. The multiweek test was the first time the hardware was operated as a fully integrated string representative of the flight system.

PPE and HALO will be integrated on Earth and launch together to be pre-staged in lunar orbit. In FY 2021, NASA announced the selection of SpaceX to provide launch services for these foundational elements. Northrop Grumman will be responsible for attaching and testing HALO and PPE and will lead the integrated spacecraft turnover and launch preparation with SpaceX and support activation and checkout of HALO during the flight to lunar orbit. Thales Alenia Space, in coordination with prime contractor Northrop Grumman, initiated the assembly of HALO in FY 2021.

International Partnerships

The Gateway team moved forward to solidify agreements that will help build the station collaboratively, growing partnerships that have been established for the International Space Station (ISS) and forging new ones. In FY 2021, NASA signed three Memoranda of Understanding (MOUs) with international partners, finalizing agreements to collaborate in the development, construction, and provisioning of Gateway. The specific objectives of Gateway MOUs are to provide a general description of the Gateway and the elements composing it; provide the basis for cooperation between the Parties and the other Gateway partners in the detailed design, development, operation, and utilization of Gateway; detail the commitments and responsibilities of the parties to one another and to other Gateway partners; establish the management structure and interfaces necessary to ensure effective planning and coordination for the detailed design, development, operation, and utilization of the Gateway; and ensure that the Gateway is operated in a manner that is safe, sustainable, and efficient. The agreements were signed with the following partners:

- ESA, which will contribute habitation and refueling modules, enhanced lunar communications to the Gateway, and two more Orion Service Modules for Artemis missions. The ESA-provided International Habitation module, I-HAB, will enhance Gateway capabilities for scientific research, life-support systems, and crew living quarters, capabilities that are necessary for longer-duration crewed Gateway missions. An ESA-provided refueling module will also include crew observation windows for lunar image capture and maintenance.
- The Canadian Space Agency (CSA), which will provide Gateway with an advanced external robotics system including a next-generation robotic arm, Canadarm3. Canadarm3 will move end-over-end to reach many parts of Gateway's exterior, where its anchoring "hand" will plug into specially designed interfaces. CSA also will provide robotic interfaces for Gateway modules, which will enable payload installation including that of the first two scientific instruments launching on the inaugural Gateway elements.
- The Japan Aerospace Exploration Agency (JAXA), which will provide I-HAB's environmental control and life-support system, batteries, thermal control, and imagery components, all of which will be integrated into the module by ESA prior to launch. These capabilities are critical for sustained Gateway operations during crewed and uncrewed time periods.

With these partners, NASA held the inaugural Gateway Multilateral Program Board meeting with international partner program managers from all four agencies. The partners discussed the Gateway schedule and were provided with an update on the PPE/HALO co-manifested vehicle and the Utilization Coordination Panel.

Gateway Science Utilization

In addition to progress on major elements, NASA selected the first three science instruments for Gateway. Two of them, the Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES) and the European Radiation Sensors Array (ERSA), will fly outside Gateway to monitor the Sun's radiation environment and space weather. HERMES, led by NASA's Goddard Space Flight Center (GSFC), will monitor lower-energy solar particles critical to scientific investigations of the Sun, including the solar winds. ERSA, led by ESA, will monitor radiation at higher energies with a focus on space weather. The Internal Dosimeter Array (IDA) will fly inside the HALO to allow for the study of radiation shielding effects and improve radiation physics models for cancer, cardiovascular, and central nervous system effects, helping assess crew risk on exploration missions. IDA is being built by ESA, with additional science instruments from JAXA.

Exploration Extravehicular Activity

The Exploration Extravehicular Activity (xEVA) project is responsible for the development of systems to support spacewalks on exploration missions, including the advanced spacesuits, tools, and interfaces that will be used for the first moonwalk ever performed by a woman and a person of color. In FY 2021, the xEVA project took the first steps to revolutionize the way NASA procures spacesuits and related systems. In FY 2021, the agency:

- Performed a series of simulated Extravehicular Activities (EVAs) with the Spacesuit Evaporation Rejection Flight Experiment (SERFE). SERFE is a high-fidelity representation of the Exploration Portable Life Support Subsystem (xPLSS) Primary Thermal Control Loop (PTCL) that was installed on the ISS in order to gather data on performance in microgravity. This series of simulated EVAs focused on stressing the system for the maximum EVA duration with heat loads at the high end of metabolic profiles. Another unit is run simultaneously on the ground to provide control data. NASA has established an EVA technical library, where these and other data relating to spacewalk systems development is being housed so that future EVA system providers can access it.

- Successfully performed the first pressurized evaluation of the Pressure Garment System (PGS) Design Verification and Testing (DVT) unit with engineering test subjects. The PGS DVT allows NASA engineers to evaluate technology designed to keep astronauts safe in hazardous deep space conditions. This is another project that contributes data to the accessible library.
- Released a Request for Proposal (RFP) asking companies to compete for NASA's future purchase of spacesuits and support services for spacewalks on the ISS, during Artemis lunar surface missions, and as needed on Gateway in lunar orbit. NASA is embracing commercial partnerships to optimize spacesuit technology and inspire innovation while building on more than 55 years of lessons learned during spacewalks. NASA will continue in-house risk reduction efforts in parallel with the services procurement and will make data available for use by commercial companies from its design and development work.

Lunar Terrain Vehicle

The Lunar Terrain Vehicle (LTV) is an unpressurized rover that Artemis astronauts will operate on the Moon while wearing spacesuits. Based on experience from the Apollo Moon landings, the addition of this mode of transportation will greatly increase the exploration range that astronauts can reach, enabling more exploration and science capability. In FY 2021, the LTV project team gathered information to enable the most effective procurement strategy possible for acquisition of the vehicle. In FY 2021, the agency released an update to the LTV unpressurized rover Request for Information (RFI). The update enabled NASA to conduct one-on-one meetings with industry to discuss solutions in providing the LTV as a commercial service or as a product NASA would purchase and own. NASA continued engagement with a follow-on industry day. The LTV RFI will help shape the Artemis mobility plans and ultimately achieve the greatest scientific and exploration value across at least a decade of missions.

AES Exploration Capabilities

Exploration Capabilities projects develop and demonstrate critical human exploration systems in order to reduce mission risk, validate operational concepts, leverage partner capabilities, and lower life-cycle costs for lunar and deep space missions. In FY 2021, under AES, these projects continued to advance deep space technologies through ground-based prototype testing, utilization of the ISS as a test bed, and preparation of payloads set to fly on Artemis I. In FY 2021, NASA launched the following AES exploration capabilities payloads to the ISS:

- The Universal Waste Management System (UWMS) is a demonstration of a compact toilet designed to require less maintenance and to integrate with multiple vehicles (including the Artemis II Orion spacecraft).
- The Spacecraft Fire Experiment-V investigation was installed to examine fire growth in the pressures and oxygen concentrations expected in future exploration spacecraft while demonstrating fire detection, combustion product monitoring, and post-fire cleanup using hardware similar to that planned for future spacecraft.
- The Airborne Particulate Monitor (APM) is a compact instrument developed to provide long-term monitoring of the number, concentration, and approximate size of airborne particles in microgravity environments such as those found in spacecraft cabins.
- The 4-bed Carbon Dioxide (CO_2) Scrubber was successfully activated and the desiccant wheel on the Thermal Amine Scrubber was replaced on the ISS. The two exploration CO_2 scrubber candidate systems were set to run for at least three years to demonstrate their reliability. The data from this testing will feed a downselect to determine the best scrubber for continued development for exploration missions.
- The Brine Processor Assembly (BPA) is designed to recover water from urine brine, the content left over after current water recovery processes are completed. BPA enabled NASA to reach its goal of recovering 98 percent of water, supporting increased loop closure for exploration life-support systems.
- The Hybrid Electronic Radiation Assessor (HERA) is a radiation sensor, planned for use on Gateway.

Also in FY 2021, the agency:

- Successfully operated the Mars Oxygen ISRU (In-Situ Resource Utilization) Experiment (MOXIE) aboard the Perseverance rover, funded jointly with STMD. MOXIE demonstrated the first production of oxygen from the atmosphere of Mars when it produced 5.4 grams of oxygen in just under an hour. While more analysis is needed to precisely determine the purity of the oxygen, preliminary indications are that the product was between 98.8 and 100 percent pure. This demonstration will enable in situ production of oxygen for future crews to breathe and propellants for future exploration vehicles to launch from Mars.
- Began 3D printing of a mockup Mars habitat that will be used for the Crew Health and Performance Exploration Analog (CHAPEA). The objectives for CHAPEA are to characterize the risk of the planned exploration food system in relation to crew health and performance and to inform NASA standards associated with vehicle mass and volume requirements. Four volunteers will live in CHAPEA for 387 days, and they will conduct simulated EVAs and teleoperate distant drones.
- Selected ten projects under Project Polaris to give early career employees hands-on experience in the development and management of technology activities. These projects will involve 60 early career employees across eight NASA centers.

In FY 2021, the agency delivered four AES exploration capabilities Artemis I payloads: Lunar IceCube, BioSentinel, LunIR, and NEA Scout.

- Lunar IceCube is designed to search for water and other volatiles in ice, liquid, and vapor states using an infrared spectrometer. Lunar IceCube will attempt to fly over the lunar surface in a low-perilune, highly inclined orbit and return valuable data to inform future Artemis missions.
- BioSentinel, a shoebox-sized CubeSat, will perform the first long-duration biology experiment in deep space. BioSentinel will carry yeast to fill critical gaps in knowledge about the health risks in deep space posed by space radiation.
- LunIRwill make a flyby of the Moon, mapping its surface using a miniature high-temperature Mid-Wave Infrared sensor. These data could help

in identifying landing sites for future Moon missions and potential risks to astronauts on their journey to the lunar surface. Following its flyby, LunIR will perform maneuvers and operations that could also help design future space missions, both crewed and robotic.

- Near-Earth Asteroid (NEA) Scout will map a target near-Earth asteroid for imaging. The spacecraft will observe the asteroid's position in space, its shape, rotational properties, spectral class, local dust and debris field, regional morphology, and regolith properties. A key element of the mission will be a solar sail—a thin and light material that uses photons from the Sun and their momentum to propel the small craft.

Systems Engineering and Integration Office

The Systems Engineering and Integration (SE&I) Office was responsible for ensuring agency strategy and goals are addressed in HEOMD mission objectives, architectures, requirements, acquisition strategies, and partnerships, while ensuring cross-directorate integration on these products.

Strategy and Architectures

The Strategy and Architectures team was responsible for developing human mission architectures for the Moon and Mars and formulating new elements to enable future missions. In FY 2021, this team:

- Conducted quarterly Sync Point Reviews in October 2020, January 2021, April 2021, and July 2021. The Sync reviews provided opportunity for the lunar and Mars architecture teams to share formulation data and the past quarter's analyses, synchronize commonalities between the architectures, baseline the Strategic Analysis Cycle manifest, and set priorities for the next quarter. Between Sync Point Reviews, the Lunar and Mars Architecture Teams dedicated time to updating and informing programs and offices across the agency on the latest analysis, forward work, and opportunities for engagement in the architecture.
- Advanced habitation concept development with U.S. companies. Under NextSTEP Appendix A, the habitation team worked with Lockheed

Martin, Sierra Nevada, and Boeing. Work with these companies included ongoing prototype testing, risk-reduction studies, and two-way exchanges regarding NASA's ground rules and assumptions for both in-space and surface habitation systems. Under a non-reimbursable space act agreement, the habitation team also conducted discussions with Blue Origin regarding habitation and life-support systems concepts.

- Conducted regular meetings under a feasibility study with JAXA to determine the potential for JAXA to provide a pressurized rover for Artemis.
- Conducted regular meetings with ESA to discuss the potential for ESA to provide the European Large Logistics Lander (EL3) to support Artemis logistics needs on the lunar surface.
- Conducted a kickoff meeting with Agenzia Spaziale Italiana (ASI). Under an agreement between NASA and ASI, the two agencies are conducting feasibility studies on possible Italian contributions to the Artemis architecture, such as development of lunar surface habitation capabilities and associated technologies for short-duration crewed missions to the lunar surface, and lunar telecommunications support.
- Sixty-six student proposals were received for the 2020–2021 Revolutionary Aerospace Systems Concepts–Academic Linkage University design competition on "Deep Space Mission Concepts." Topics included a minimal lunar surface habitat, minimal Mars ascent vehicle, crewed Venus flyby mission, crewed mission to Ceres, and lunar sample collection and delivery to the ISS. The Strategy and Architecture Team reviewed the proposals and selected 16 finalists who competed for the top prize. University of Puerto Rico–Mayagüez took first place and University of Texas at Austin took second place.
- The Mars Architecture Team engaged in discussions with American rapper, singer, songwriter, and record producer Pharrell Williams to establish YellowHab, an educational institution for underserved students in grades 3–5 in Norfolk, Virginia.

Capabilities Integration

The Capabilities Integration team was responsible for identifying, tracking, and advocating for key capabilities across NASA to fulfill human spaceflight mission plans. The team:

- Conducted agencywide data calls to establish a comprehensive list of capability gaps that represent the difference between today's capabilities and those we will need to conduct future human missions in deep space. The list included 308 gaps, spanning 17 technical areas in the domains of knowledge, architecture, technology, development, and engineering.
- Began coordination with STMD to combine human spaceflight capability gaps and space technology gaps into one system for collaborative tracking.

Science and Technology Utilization

Science and Technology Utilization was responsible for integrating NASA's science and technology utilization needs into the human spaceflight strategy. This team:

- Established the Cross-Artemis Site Selection Analysis Team (CASSA) to evaluate launch and landing options near the lunar South Pole for the 2024–2026 timeline. With membership from HEOMD, Science Mission Directorate (SMD), and STMD leadership, CASSA established multidisciplinary figures of merit and communicated the figures of merit through all affected programs and projects.
- Established the Utilization Coordination and Integration Group, a cross-directorate group that identifies NASA's science and utilization goals and flight-specific priorities that will be enabled by human missions.
- Participated in Technical Interchange Meetings with Mohammad bin Rashid Space Centre (United Arab Emirates [UAE]) about the use of analogs in preparing for human missions in deep space. The meetings were in support of UAE's requirements development for a Mars Science City analog facility outside Dubai.
- Participated on the Commercial Lunar Payload Services (CLPS) Manifest Selection Board to represent the directorate's interests in both proposed

candidate payloads and nominated candidate payloads to fly on flights commissioned by SMD.

Technical Integration

The Technical Integration team was responsible for identifying, documenting, and providing technical direction across the directorate. The team:

- Issued HEOMD-007, Strategic Campaign Operations Plan for Exploration, which connects NASA's strategic plan and policy with HEOMD activities and implementation within the divisions and corresponding programs across the directorate.
- Revised HEOMD-004, Human Exploration Requirements to ensure elements in formulation were extensible to support functions needed in later missions of longer surface durations and greater surface infrastructure.
- Issued the following Decision Memoranda/Management Directives: HEO-DM-1005, Suitport Study; HEO-DM-1004, Planning Guidance for Artemis Mission Durations as Testbeds to Reduce Risks for Human Missions to Mars; HEO-DM-1006, Updated Exploration Atmospheres; HEO-DM-1007, Lunar Communication Relay; HEO-DM-1008, Integrated Exploration Capabilities Gap List; and HEO-MD-1000, HEO Document Flowdown.

Commercial Spaceflight Development

Commercial Crew Program

FY 2021 has been an extremely exciting timeframe for NASA's Commercial Crew Program (CCP), working toward our goal of enabling U.S. Commercial Crew transportation, where NASA is one of many customers of a robust U.S. commercial space industry.

Our Commercial Crew partner, SpaceX, completed all certification design, testing, and demonstration requirements and has been certified to carry NASA and International Partner astronauts on ISS crew rotation missions.

On November 16, 2020, SpaceX launched their Crew-1 mission, their first operational Post Certification Mission (PCM). Dragon spacecraft Resilience carried four

ISS astronauts from KSC Pad 39A to the ISS. This mission marked the first ISS Commercial Crew rotational mission.

SpaceX launched their second PCM, the Crew-2 mission, on April 23, 2021. The Crew-2 mission, flying aboard Dragon Endeavour, represented the first reuse of a SpaceX Crew Dragon, having previously flown NASA crew on the Demo-2 mission. After Endeavour docking and ISS handover, Crew-1 Dragon Resilience astronauts departed the ISS and landed off the coast of Florida on May 2, 2021.

Boeing has flown the reflight of their Orbital Flight Test Mission (OFT-2) and is making progress toward their Crew Flight Test (CFT), moving closer to completing their certification effort.

International Space Station (ISS)

Over more than two decades, the ISS has evolved into an advanced microgravity laboratory for human space operations and science. The space station 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. The station'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. The research done on the ISS advances scientific understanding of our planet, improves human health, develops cutting-edge technologies, and inspires and educates the leaders of tomorrow through its successful international partnerships; it is part of a legacy that will be felt for decades to come. Through the end of Expedition 63 (October 2020), the ISS had hosted more than 3,040 investigations from more than 109 countries/areas.

Commercial Resupply Services (CRS) flights from Northrop Grumman and SpaceX are invaluable to enabling the research and provide needed supplies and hardware for ISS operations. In FY 2021, Northrop Grumman and SpaceX launched three cargo flights each to the ISS, totaling more than 42,500 pounds of science investigations, spacewalking tools, and critical supplies delivered. These cargo missions were complemented by those of our International Partners. Roscosmos provided two Progress cargo missions and a significant undock of Progress 77P, which undocked the Docking Compartment 1 module to make room for the Multipurpose Laboratory Module, which docked in July 2021. Additionally, more than 10,000 pounds of investigations and equipment were returned to researchers on Earth by the SpaceX Dragon capsule, while the Northrop Grumman Cygnus and Progress spacecraft provided significant assistance as trash removal mechanisms by performing destructive reentries. These resupply missions enabled ISS crewmembers to support research, maintenance, and other operational tasks.

In addition to the CRS missions, there were two successful Soyuz crew rotation missions in FY 2021. The departure of Soyuz 62S in October 2020 denoted the end of Expedition 63. Onboard Soyuz 62S were NASA astronaut Chris Cassidy and cosmonauts Anatoly Ivanishin and Ivan Vagner of the Russian Space Agency Roscosmos, who had arrived on the ISS six months earlier. Marking the transition from Expedition 64 to Expedition 65, the Soyuz 63S spacecraft departed the ISS in April 2021. The Soyuz 63S, which arrived in October 2020, carried NASA astronaut Kate Rubins and cosmonauts Sergey Ryzhikov and Sergey Kud-Sverchkov of Roscosmos.

There were significant crew rotation flights via NASA's CCP during FY 2021. During Expedition 64, the arrival of SpaceX Crew 1 in November 2020 aboard the Crew Dragon was the first operational commercial mission to the space station with four crew members, expanding a long-duration Expedition crew to seven people for the first time. The crew, consisting of NASA astronauts Michael Hopkins, Victor Glover, and Shannon Walker, along with Soichi Noguchi of JAXA, spent six months aboard the ISS. Their splashdown off the coast of Florida, aboard the SpaceX Crew Dragon spacecraft Resilience, was the first nighttime splashdown of a U.S. crewed spacecraft since Apollo 8's predawn return in the Pacific Ocean on December 27, 1968.

In April 2021, the SpaceX-Crew2 mission carried NASA astronauts Shane Kimbrough and Megan McArthur, JAXA astronaut Akihiko Hoshide, and ESA astronaut Thomas Pesquet to the ISS. They joined the Expedition 65 members aboard the station. Utilizing the SpaceX Crew Dragon spacecraft Endeavour, this would be the second long-duration mission to fly as part of NASA's CCP, continuing to provide the capability of regularly launching humans from American soil.

For the second consecutive year, the onboard crew and ground teams supported 13 spacewalks, or EVAs, ten of which were American EVAs. The first 2021 U.S. spacewalk in January performed several tasks, including the installation of an antenna on the station's Columbus module. A few days later, astronauts conducted another spacewalk that completed a two-year effort to upgrade the batteries of the station's power system, replacing 48 aging nickel-hydrogen batteries with 24 new lithium-ion batteries and adapter plates. With the battery work complete, the focus turned to solar array augmentation discussed below. Another focus of the FY 2021 spacewalks was to complete tasks to service the station's cooling system and communications gear. Spacewalkers successfully vented the early ammonia system, relocated one of its jumper lines, and serviced the Columbus Bartolomeo payload platform, including routing three of four cables on the Payload Position interface and configuring a cable for an amateur radio system. They replaced a wireless antenna assembly on the Unity module and installed hardware to provide additional structural integrity on the airlock.

There were six U.S. EVAs that focused on the augmentation of six of the eight existing power channels of the space station with new solar arrays, which were delivered on SpaceX's 22nd CRS mission. The current solar arrays are functioning well but have begun to show signs of degradation, as expected in their 15-year service life design. The new solar arrays, a larger version of the Roll-Out Solar Array (ROSA) technology, will be positioned in front of six of the current arrays, ultimately increasing the station's total available power from 160 kilowatts to up to 215 kilowatts and ensuring sufficient power supply for NASA's exploration technology demonstrations. The spacewalks in June 2021 installed and deployed two of the six new arrays and successfully assembled and attached support brackets in preparation for future installation of additional ISS ROSA (iROSA) solar arrays.

In FY 2021, the ISS National Laboratory (ISSNL) flew 88 payloads, the second-most ever launched in a single fiscal year, despite the COVID-19 pandemic sweeping the nation. The ISSNL Space Station Explorer education program engaged nearly 3.8 million people. Furthermore, 70 percent of the participants in the Space Station Explorers programs were female and 40 percent represented underserved communities.

All except one action from the ISSNL Independent Review Team (IRT) were closed in FY 2021. Changes to the Center for the Advancement of Science in Space (CASIS), the management entity of the ISSNL, were implemented as a result of the IRT in FY 2021. These included naming an Interim Chief Executive Officer, who oversaw the recruitment search for the permanent Chief Executive Officer, who took office in FY 2021. The CASIS Board was restructured under new leadership, and an ISSNL User Advisory Committee was created. Additionally, the NASA Liaison position was moved from the Commercial Spaceflight Division to the ISS Division.

Human Spaceflight Capabilities

Human Research Program

The Human Research Program (HRP) conducts research and gathers scientific findings that aid in developing procedures and mitigations to lessen the effects of the space environment on the health and performance of humans working in microgravity and other space settings. With the goal of traveling to Mars and beyond, the Program also utilizes ground research facilities, the ISS, and other ground-based analog environments to develop procedures and to further research areas that are unique to Mars.

In FY 2021, HRP completed the following key milestones:

- Astronaut Mark Vande Hei, who completed 355 days in space on March 30, 2022, participated in studies of an enhanced diet during spaceflight and its impact on human immune response and nutritional status, menu fatigue and food acceptability over time in a closed food system, core measurements to characterize the human body's adaptations, analysis of injuries to the crew during Soyuz landings, continuous fresh-food production and supplementation to astronaut diets, and the maintenance of biological specimens over an extended period to support studies on physiological changes.
- The JSC Human Exploration Research Analog (HERA) facility conducts four 45-day missions per year as part of a campaign of research where four crewmembers participate in a simulated mission studying the effects of

isolation and confinement. HERA Campaign 6 was initially delayed due to COVID-19, and FY 2021 was spent preparing for campaign recruiting and screening crewmembers and determining how to conduct the missions safely. Campaign 6 Mission 1 began in September 2021.

- New research was initiated in FY 2021 to award $20.8 million to fund 22 proposals from 20 institutions in 13 states as a result of the 2019 Human Exploration Research Opportunity (HERO).
- HRP supported the first ambient blood samples to be returned on a SpaceX cargo flight, providing another return option for these critical samples for a mid-mission data collection.
- The ISS Fluid Shifts inflight study completed its final data collection that helped characterize spaceflight-induced fluid shifts and their relationship to eye and brain structural changes or Spaceflight Associated Neuro-ocular Syndrome (SANS).
- The Level of Care IV Medical System Foundation to the Human Health and Performance Directorate Gateway Crew Health and Performance Systems Manager was completed. This foundation provided a model-based systems engineering tool for requirements management.
- HRP worked with the German Aerospace Center (DLR) to conduct a series of 30-day strict head-down-tilt bed rest campaigns at the :envihab facility in Cologne, Germany. Investigations included sensorimotor, cardiovascular, musculoskeletal, and behavioral responses; immunological function; and visual impairment to study potential countermeasures (CM) for Spaceflight Associated Neuro-ocular Syndrome (SANS). SANS is a unique syndrome observed in spaceflight in which changes have been found in the shape of the eye over time, a pattern of changes and symptoms that have been replicated in :envihab bed rest campaigns by following the strict head-down-tilt protocol. The SANS CM study consists of four campaigns, with Campaign 1 completed in October 2021.

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 of rocket engines. In FY 2021, RPT test facilities supported NASA, Commercial, Defense, and NASA International Space Partner requirements for purposes of component, engine, and rocket stage level of testing. RPT delivered test capabilities to support technology advancement, capability demonstration, risk retirement, and hardware qualification and launch readiness for more than 500 tests (over 20,000 seconds).

The most significant accomplishment of FY 2021 was the successful hot fire of the SLS core stage (four RS-25 engines) on the B-2 test stand at SSC in Mississippi. This test was a critical qualification milestone ahead of the agency's Artemis 1 mission. Another important achievement was completion of a series of seven Artemis RS-25 engine tests on the SSC A-1 Test Stand to evaluate manufacturing changes to the RS-25 engines in demonstration and verification of engine capabilities. In the SSC Complex-E Test Stands where engines of lesser thrust capacity and components are tested, testing for multiple commercial partners and subscale diffuser testing to validate the test system configuration for the Exploration Upper Stage (EUS) were conducted. At MSFC, Test Stands 115 and 116 completed tests primarily of NASA developmental hardware and commercial subscale engines and components. White Sands Test Facility (WSTF) personnel completed a series of Service Module tests for the ESA and in support of the Department of Defense's Minuteman Aging Surveillance Program. At the Glenn Research Center's Armstrong Test Facility, revitalization of the In-Space Propulsion Facility (ISPF) steam ejector system continued, as well as preparatory work for proto-qualification testing of the Sierra Nevada Dream Chaser Cargo System (DCCS) in the ISPF.

Launch Services Program

NASA's Launch Services Program (LSP) unites scientific and robotic spacecraft customers' needs with the appropriate rocket, managing the process to ensure the spacecraft is placed in orbit around Earth or the Sun, or powered to destinations deeper into the solar system. The LSP continuously works with the U.S. commercial launch industry, assessing their designs and providing advice in an effort to expand the selection of domestic launch vehicles available to NASA's missions, thereby nurturing a competitive commercial launch service environment.

In FY 2021, LSP successfully launched two NASA science missions. Sentinel-6 Michael Freilich launched aboard a Falcon 9 Full Thrust in November 2020, followed by Landsat-9 aboard an Atlas V in September 2021. Both missions launched from Vandenberg Space Force Base (VSFB) in California. LSP also acquired a total of three new launch services for NASA missions. All three services were competitively awarded launch services task orders under the NASA Launch Services (NLS) II contract for the National Oceanic and Atmospheric Administration (NOAA), NASA's HEOMD, and the Science Mission Directorate (SMD), respectively. The Geostationary Operational Environmental Satellite U (GOES-U) will launch aboard a Falcon Heavy in April 2024; the Gateway's PPE and HALO launching aboard a Falcon Heavy in November 2024, in support of the agency's Artemis Program; followed by the Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer (SPHEREx) spacecraft, along with the secondary payload Polarimeter to Unify the Corona and Heliosphere (PUNCH), which will launch aboard a Falcon 9 Full Thrust in February 2025. GOES-U and PPE+HALO are planned for launch from KSC in Florida, and SPHEREx and PUNCH will launch from VSFB. In addition to awarding NLS contracts, NASA also awarded two other one-off contracts for SMD's Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of SmallSats (TROPICS) and Europa Clipper missions. 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 LSP. As of the end of FY 2022, the program was currently providing these advisory services to several programs and missions, including the ISS Cargo Resupply Service missions; the CCP, Artemis, and Gateway Programs; and SMD's James Webb Space Telescope and the NASA–Indian Space Research Organization Synthetic Aperture Radar (NISAR) mission.

The Venture Class Launch Services (VCLS) contracts were established to foster a commercial launch market dedicated to flying small-satellite payloads. VCLS serves as an alternative to the current rideshare approach, in which one or more CubeSats or other small payloads take advantage of excess payload capacity on a rocket whose primary mission is to launch a larger satellite. The VCLS rockets also serve as a cost-effective launch option for small-satellite primary missions with a higher risk tolerance. In December 2020, NASA awarded a follow-on contract to VCLS called VCLS Demonstration 2 (VCLS Demo 2) to Astra Space Inc. of Alameda, California; Relativity Space Inc. of Long Beach, California; and Firefly Black LLC of Cedar Park, Texas. In January 2021, Virgin Orbit's LauncherOne launch vehicle (the second mission under the original VCLS contract) successfully launched ten NASA CubeSats to LEO.

In addition, NASA and LSP continue to partner with several universities and NASA Centers to launch small research satellites through the CubeSat Launch Initiative (CSLI), providing rideshare opportunities for small-satellite payloads to fly on upcoming launches when space is available. These partnerships have provided regular educational opportunities for students in science, technology, engineering, and mathematics disciplines, thereby strengthening the Nation's future workforce. As of the end of FY 2021, CubeSats have been selected from 42 states, the District of Columbia, and Puerto Rico, with 124 missions launched and 38 manifested on NASA, National Reconnaissance Office, U.S. Air Force, and commercial missions. In FY 2021, 20 CSLI CubeSat missions were launched.

Certification activities are also ongoing with United Launch Alliance's Vulcan, SpaceX's Falcon Heavy, and Alpha's Firefly launch vehicles. Planning activities for certification of Blue Origin's New Glenn launch vehicle is also underway. Certifying a provider's launch vehicle enhances NASA's understanding of commercially built launch vehicles and enables LSP to better identify and manage launch risks. Certification also enhances competition, as it results in multiple qualified launch vehicles and launch providers. The LSP will continue to work toward certifying new commercial launch vehicles to launch high-value payloads.

Space Communications and Navigation

NASA's Space Communications and Navigation (SCaN) program is responsible for leading NASA's space communications, navigation, and tracking activities in support of NASA's missions, including human space exploration and science missions. SCaN develops advanced space communication and navigation (C&N) technology, such as optical and quantum communications technologies, and serves as the agency's representative in domestic and internationals forums related to spectrum management; space communication architectures and data standards; and position, navigation, and timing (PNT) policy.

SCaN operates and maintains two space communications networks—the Deep Space Network (DSN) and the Near Space Network (NSN). The NSN is composed of ground networks supporting Direct-to-Earth (DTE) communications and the Tracking and Data Relay Satellite (TDRS) system, which provide space relay communications to spacecraft below geosynchronous orbit.

In FY 2021, SCaN completed the following:

- Provided 234,046 tracking passes for 300,773 hours of service while maintaining an extremely high proficiency level of over 99 percent, well above the 95 percent requirement.
- Completed 31,314 passes for 22,135 hours of service provided by SCaN's commercial DTE partners at a proficiency rate of 99.89 percent.
- Provided 24/7 global near-Earth and deep space communication and navigation services to more than 100 NASA programs and other U.S. Government, international civil space agencies, and commercial missions. This support included human spaceflight C&N requirements of the ISS, commercial crew launches, and science missions including the Mars Perseverance rover.
- Provided launch and early-orbit telemetry, tracking, and communication services to more than 6 Expendable Launch Vehicles and 11 human spaceflight missions through its networks.
- Worked transition activities with NSN customers in preparation for the completion of the Space Network Ground Segment Sustainment (SGSS) project, including support to SGSS for project integration, testing, deployment, training, and transition to operations.
- Transferred a new 34-meter antenna at the Madrid Deep Space Communications Complex to site personnel for maintenance activities and successfully delivered for operations on January 22, 2021. The new antenna, Deep Space Station 56 (DSS-56) supports the required network capacity increase for the Artemis missions.
- Reorganized SCaN's operations at GSFC, home of the former Near-Earth Network (NEN) and Space Network (SN), to better align with SCaN's

commercialization plans. Established the Advanced Communications Capabilities for Exploration and Science Systems (ACCESS) project to operate and maintain NASA's government-owned, contractor-operated ground- and flight-based systems. The ACCESS project is a service provider to the Exploration and Space Communications' NSN, which orchestrates mission communications services through both government and commercial assets.

- Awarded six Space Act Agreements with a combined value of $278.5 million for in-space demonstrations of commercial SATCOM capabilities to transition NASA away from TDRS later in the decade. Partners include Inmarsat, Kuiper Government Solutions, SES Government Solutions, Space Exploration Technologies, Telesat U.S. Services LLC, and Viasat Incorporated. NASA expects each company to match or exceed Agency contributions during the five-year development and demonstration period, totaling more than $1.5 billion of cost-share investment.
- Completed an Agency Acquisition Strategy Council Acquisition Strategy Meeting, subsequent Procurement Strategy Meeting, and industry days to release an Indefinite Delivery/Indefinite Quantity contract for near-Earth and Lunar C&N services as part of SCaN's transition to commercial services in the near-Earth domain by 2030.
- Delivered the first formal Artemis communications loading analysis to HEOMD and SMD. The analysis identified emerging risks to Artemis related to DSN and NSN capacity available to support the multiple Artemis flight vehicles, including the SLS, Orion, Gateway, HLS, and the LTV. SCaN is working with HEOMD and SMD to translate any identified capacity or capability risk into mitigation approaches to enable the Artemis campaigns while minimizing potential impacts to the rest of the agency. SCaN continues to update the Artemis loading analysis product as user needs and manifest dates are updated by HEOMD.
- Supported the Consultative Committee for Space Data Systems (CCSDS), an international organization of 11 spacefaring nations, with representation from SCaN as the General Secretary of the CCSDS Management Council.

- Supported the Interagency Operations Advisory Group (IOAG) as NASA's representative to ensure data and communications standards are developed in coordination with agency architecture plans. SCaN engaged in key discussions and studies related to interoperability and cross-support for future Moon and Mars missions, mission operations, optical communications, space internetworking, and other key issues. SCaN also continued to serve as the Executive Secretariat for the IOAG. The IOAG conducted six virtual meetings to advance the work of the various working groups in FY 2021. The IOAG is primarily focused on lunar communications, including developing a joint lunar communications architecture with defined spectrum and standards to enable interoperability. Another group focused on a similar architecture for Mars and beyond. The IOAG welcomed its newest observer agency, the Australian Space Agency (ASA), in FY 2021.
- Published the LunaNet Interoperability Specification Document as a starting point for technical discussions among industry and government experts from around the world regarding lunar communications architecture. LunaNet is a planned lunar communications and navigation architecture that brings networking, PNT, and science services to the Moon. It is based on a framework of mutually agreed–upon standards, protocols, and interface requirements that enable interoperability and missions to benefit from a diverse set of government and commercial service providers.
- Advanced studies for the 2023 World Radiocommunication Conference (WRC-23) to investigate the feasibility of using Fixed Satellite Service (FSS) systems to provide space-to-space communications support to science missions. The ability to exchange data via existing FSS providers allows space users the flexibility to connect to additional networks based on mission needs and not be limited to a single network solution.
- Established a Lunar Spectrum Manager (LSM) to coordinate, study, and identify appropriate frequency bands to support the lunar architecture, including communication, position, navigation, and science services. The institution of a globally adopted lunar spectrum plan is essential for an interference-free and sustainable environment for all lunar missions—federal, international, and commercial.

- Coordinated with the National Telecommunications and Information Administration (NTIA) to gain support and partnership for NASA's LSM to enable technical pre-coordination for all federal missions to the lunar region ahead of the regulatory filing process.
- SCaN sponsored the Lunar GNSS Receiver Experiment (LuGRE), which was selected as one of ten payloads on Firefly Aerospace's Blue Ghost Mission-1, to land on the Moon in 2024. The experiment will validate the use of Global Navigation Satellite Systems (GNSS) signals to support navigation and science throughout cislunar space and the lunar surface.
- Renewed the charter of the National Space-Based PNT Advisory Board (PNTAB) and expanded its membership to reflect the added priorities in Space Policy Directive 7. Since 2007, SCaN has supported PNTAB as its Executive Director.
- Supported the Deep Space Atomic Clock (DSAC) mission as it completed its extended mission and further cemented its record-setting long-term stability performance, reducing ground support costs by servicing multiple assets in a single antenna footprint.

Realignment of NASA's Exploration Programs

In FY 2021, after careful consideration, NASA's leadership team decided to organize the agency's exploration programs into two separate mission directorates, replacing the Human Exploration and Operations Mission Directorate: a Space Operations Mission Directorate (SOMD) will focus on launch and space operations, including the International Space Station (ISS), the commercialization of low-Earth orbit, and, eventually, sustaining operations in the vicinity of the Moon; and an Exploration Systems Development Mission Directorate (ESDMD) will define and manage systems development for programs critical to NASA's Artemis program and plan for NASA's Moon to Mars exploration approach in an integrated manner.

NASA is set on returning astronauts to the Moon as preparation for future missions to Mars, and this reorganization positions NASA and the United States for future exploration while supporting the continued commercialization of space and research on the ISS. Creating two separate mission directorates ensures these critical areas have focused oversight teams in place to support and execute for mission success. This approach allows one mission directorate to operate in space while the other builds future space systems, so we have a constant cycle of development and operations to advance our goals in space exploration.

Exploration Systems Development Mission Directorate in FY 2022 (Formerly Part of HEOMD)

Common Exploration Systems Development (Formerly Exploration Systems Development)

The Common Exploration Systems Development (CESD) programs—the SLS, Orion, and Exploration Ground Systems—provide the foundation for humanity's return to the Moon and exploration beyond. Progress steadily continued toward the uncrewed Artemis I mission, the first integrated test of the CESD programs that paves the way for future crewed Artemis missions.

Orion

Orion serves as the exploration vehicle that will carry the crew to space, provide emergency abort capability, sustain astronauts during their missions, and provide safe reentry from deep space return velocities. In FY 2022, NASA, along with the ESA, continued preparations for the Artemis I launch including integration and checkout, while concurrently completing work on Artemis II, III, and IV. The integrated Artemis I spacecraft was moved from the Launch Abort System Facility at KSC to the Vehicle Assembly Building, where engineers and technicians successfully secured the Orion spacecraft atop the fully assembled SLS rocket and completed stacking of the Artemis I vehicle. In FY 2022, the agency also:

- Completed payload integration and finalization of preparations for the Artemis I launch.
- Completed the shipment of the Artemis II European Service Module (ESM) to KSC. Built by teams at ESA and aerospace corporation Airbus, the ESM will be used with NASA's Orion spacecraft for Artemis II, the first Artemis mission flying crew aboard Orion.
- Completed the shipment of the Artemis III crew module pressure vessel from NASA's Michoud Assembly Facility (MAF) in New Orleans to KSC. The pressure vessel is the underlying frame of the crew module that provides an airtight, habitable space for astronauts during the mission.

- Began and made significant progress welding the crew module pressure vessel for Artemis IV at NASA's MAF Facility in New Orleans.
- Powered on the crew module and ESM for the Artemis II mission for the first time inside the Neil Armstrong Operations and Checkout Building at KSC. Initial power-on tests verify the health and status of Orion's core computers and power and data units, and ensure the systems communicate precisely with one another to accurately route power and functional commands throughout the spacecraft.
- Successfully tested the abort motor built by Northrop Grumman for the launch abort system at the company's facility in Promontory, Utah. During the third and final static hot fire test under ambient conditions, the abort motor produced nearly 400,000 pounds of thrust during a four-second burn and verified a new insulation material in the motor casing and exhaust manifold. The system is now qualified and ready for flight on missions with astronauts, beginning with Artemis II.
- Completed the shipment of the Artemis IV ESM structure from Thales Alenia Space in Turin, Italy, to Airbus facilities in Bremen, Germany, where it will undergo final integration before shipment to KSC.

Space Launch System

The powerful SLS rocket and Orion spacecraft represent NASA's foundation for sending humans back to lunar orbit. Stacking, mating, integration, and checkout were completed for the SLS rocket. The wet dress rehearsals and launch attempts provided tremendous learning for cryo-loading operations.

In FY 2022, the agency successfully demonstrated cryogenic operations with a tanking test during which bleed kick start and pre-press test were successfully completed.

In FY 2022, NASA continued to make progress on launch vehicle components for Artemis II, III, and IV.

- Structural assembly of the Artemis III core stage liquid hydrogen tank was completed, and the engine section underwent bracket and other hardware installation. The forward skirt barrel section for Artemis IV was also completed.

- Began testing of critical components for the Block 1B.
- Successfully conducted the static test of Flight Support Booster-2 at Northrop Grumman's plant in Promontory, Utah, on July 21, 2022, testing components and materials slated for use in flights beyond Artemis III.
- Completed and placed in storage all ten booster motor segments for Artemis III.
- Completed and shipped for integration into the Core Stage all four RS-25 engines for Artemis II and completed three of the four engines for Artemis III.
- Completed acceptance review for RS-25 engines scheduled to fly on the Artemis III mission, while also delivering the first valve actuator for installation into RS-25 Restart Certification engine 10001 for testing later this year.

In FY 2022, NASA continued work to establish the Agency Baseline Commitment (ABC) for SLS Block 1B.

Exploration Ground Systems

EGS, based at KSC in Florida, was established to develop and operate the systems and facilities necessary to process and launch rockets and spacecraft during assembly, transport, and launch. In FY 2022, the agency:

- Completed stacking the Orion Stage Adapter and Orion and performed the integrated vehicle interface verification test, end-to-end communications test, countdown sequence test, core stage Program Specific Engineering Test, flight termination test part 1, and wet dress rehearsal.
- Performed rollout of the SLS rocket and Orion spacecraft for the first two Artemis I launch attempts. Following attempts completed cryogenic tanking demonstration at Pad 39B and met all objectives in preparation for the third Artemis I launch attempt.
- Completed construction of the LH2 tank at Pad 39B, capable of storing 1.25 million gallons of liquid hydrogen, supporting future Artemis missions.
- Completed Underway Recovery Test 9, verifying the Exploration Ground System's recovery operations for Artemis I.
- Continued work on establishing the ABC for the Mobile Launcher-2.

Artemis Campaign Development (formerly Advanced Exploration Systems)

Through FY 2022, the ESDMD's Artemis Campaign Development (ACD) Division was responsible for programs that will establish sustainable human exploration through Artemis missions, including the Human Landing System (HLS), Gateway, exploration spacesuit development, and surface mobility systems development. ACD's work is composed of the former AES portfolio, with the addition of responsibility for integration work beginning with the Artemis III mission. In FY 2022, the ACD team developed and matured high-priority capabilities foundational for future human space exploration and continued planning and integration for Artemis missions beginning with Artemis III.

Human Landing System

In FY 2022, the HLS Program team made significant strides to procure innovative systems to return humans to the Moon, including increasing opportunities for U.S. companies to participate in this history-making work. In FY 2022, the agency:

- Signed contracts with the five companies that were previously selected in FY 2021 to advance sustainable HLS concepts, conduct risk-reduction activities, and provide feedback on NASA's requirements to cultivate industry capabilities for crewed lunar landing missions. The NASA HLS team conducted reviews with the companies throughout FY 2022.
- Continued to work with SpaceX as they develop their landing system for Artemis III. NASA leadership made several site visits to SpaceX facilities, meeting with the teams to confirm the status of timelines and milestones.
- Updated the approach for obtaining sustaining lunar landing services for missions beyond Artemis III. While the overall strategy remains the same, NASA separated the development of sustaining landers from the purchase of recurring services. This change allowed the agency to open a new sustaining lander acquisition to U.S. industry, excluding SpaceX, which has an opportunity to build a sustaining lander through a built-in option under its current contract for an initial lander. The requirements for sustaining landers are more advanced than the initial lander requirements, including capabilities to accommodate additional crew, and docking to the Gateway.

This updated approach increased competition and industry flexibility to achieve the agency's exploration goals under Artemis. The separate procurement for recurring services flights will begin at a later date.

Gateway

Assembled by NASA and its international and commercial partners during Artemis missions, Gateway will serve as humanity's first lunar orbiting space station. It will provide multipurpose support for a long-term human return to the lunar surface serving as a proving ground and staging point for sustainable deep space exploration. In FY 2022, the Gateway team continued building a strong coalition of international and commercial partners, while teams around the world continued assembly and testing of the initial elements of the station.

Habitation and Logistics Outpost and Power and Propulsion Element

The agency completed the Critical Design Review (CDR) of HALO. NASA and partner teams continued development of HALO systems and hardware, including the HALO Lunar Communication System (HLCS). The HLCS, an ESA contribution, is a communications relay to Earth and will launch on the outside of HALO, providing multiple paths of communication between expeditions on the lunar surface and the Gateway. The HLCS will be capable of providing live HD video streaming, allowing people around the world to view the Moon like never before. NASA continued PPE electric propulsion system testing for both the 12 kilowatt and 6 killowatt electric propulsion components.

International Partnerships

NASA supported ESA in their successful completion of the International Habitat (I-HAB) system-level Preliminary Design Review (PDR). The board, which was led by the ESA with NASA participation, noted challenges for launch mass but identified actions and mitigation options to address them, demonstrating successful integration of the teams. I-HAB entered the next stage of design, and the Gateway team performed a series of subsystem PDRs. These reviews contributed to Gateway's PDR-informed Sync Review, another critical milestone and marker of collaboration across all the teams.

Exploration Extravehicular Activity

In FY 2022, NASA stood up the EVA and Human Surface Mobility (HSM) Program (EHP) supporting both the Space Operations Mission Directorate and the Exploration Systems Development Mission Directorate. The program is composed of several key elements, including ISS EVA, Exploration EVA, or xEVA; the LTV; and EVA and HSM technology development and partnerships. The team is responsible for development of safe, reliable, and effective capabilities that allow astronauts to survive and work outside the confines of a base spacecraft in order to explore on and around the Moon. The new program worked to establish the team necessary to continue the work of the xEVA and LTV projects and began developing business rhythms. In FY 2022, NASA:

- Completed a human-in-the-loop check-out of the 20-foot Chamber, a facility used to evaluate new pre-breathe protocols at varying vehicle and suit pressures to minimize decompression sickness risk to crew when conducting lunar surface EVAs during Artemis missions.
- Released the xEVA Services (xEVAS) Request for Proposal (RFP). NASA invited companies to compete to provide next-generation spacesuits and spacewalk systems for work outside the ISS, exploration of the lunar surface on Artemis missions, and potential Gateway EVAs. After evaluating the proposals, NASA announced the selection of Axiom Space and Collins Aerospace. The contract enables the selected vendors to compete for task orders for missions that will provide a full suite of capabilities for NASA's spacewalking needs during the period of performance through 2034. The agency awarded the first task order on the xEVAS contract to Axiom Space. Axiom was selected to develop a next-generation Artemis spacesuit and supporting systems, and to demonstrate their use on the lunar surface during Artemis III.
- Completed assembly of the Exploration Extravehicular Mobility Unit (xEMU) integrated Design Verification Testing (DVT) unit—used to test spacesuit technology in an integrated manner. The team exceeded expectations by verifying additional components and functions. As with all other NASA risk reduction efforts in this area, the results will be made available to xEVAS contract vendors through the EVA technical library.

- Completed "survive the night" investigations to determine the requirements the LTV must meet in order to withstand long, cold lunar nights. The LTV team is collaborating with the Volatiles Investigating Polar Exploration Rover (VIPER) team to understand the different strategies to survive extended periods of darkness and cold.
- Completed the sixth and final on-orbit testing cycle of the Spacesuit Evaporation Rejection Flight Experiment (SERFE) ISS payload, which represents all the primary components of the xEMU thermal control system. The ISS SERFE payload successfully performed a total of 25 simulated EVAs with no maintenance over a period of 2 years. The unit was returned from the ISS for analysis. All findings will be published by the EHP EVA Development Project to the EVA Technical Library and made available to the Exploration EVA Services (xEVAS) contractor teams.

AES Exploration Capabilities

Exploration Capabilities projects continue to be critical to NASA's preparation for long-duration human exploration missions to the Moon and Mars. In FY 2022, under ACD, these projects continued to advance deep space technologies for human health, safety, and productivity through ground-based prototype testing, utilization of the ISS as a test bed, and preparation of payloads set to fly on Artemis I. In FY 2022, the agency:

- Launched ACD exploration capabilities payloads to the ISS and continued work with projects including:
  - The eXposed Root On-Orbit Test System (XROOTS), which investigates hydroponic and aeroponic techniques to grow plants without soil or other growth media.
  - An advanced hydrogen sensor used to detect leaks from the Oxygen Generation Assembly. The current hydrogen sensors drift and must be replaced every 210 days; the new sensor does not need to be changed as often.
  - The Hybrid Electronics Radiation Assessor (HERA) payload. The HERA team received a Space Flight Awareness Team Award for hardware delivery and operations.

    - The Crew Health and Performance Exploration Analog (CHAPEA), which received thousands of applications for the 1-year simulated mission. 3D printing of the habitat was completed, the airlock module of the habitat was installed, and a sandbox with enclosing dome has been built for simulated spacewalks.
- NASA contributed to South Korea's Korea Pathfinder Lunar Orbiter (KPLO) mission, successfully launched in FY 2022. NASA supplied one of five instruments aboard KPLO, the ShadowCam, which will image lunar ice in permanently shadowed craters. The Science Mission Directorate (SMD), in partnership with ACD, also supported the mission with the competition and selection of nine additional participating scientists to support NASA's ShadowCam instrument as well as the four other KPLO instrument science teams. SMD has provided three years of funding for additional support.

All four ACD exploration capabilities Artemis I payloads, Lunar IceCube, BioSentinel, LunIR, and NEA Scout, were successfully integrated into the SLS rocket's Orion stage adapter in preparation for launch. In November 2021, *Popular Science* recognized Near-Earth Asteroid (NEA) Scout as one of the greatest innovations of FY 2022.

Systems Engineering and Integration Office

Due to a directorate reorganization in September 2021, the Human Exploration and Operations Systems Engineering and Integration (SE&I) Office functions were redistributed to two new offices—the Architecture Development Office (ADO) and the Technical Integration Office (TIO)—in the newly established Exploration Systems Development Mission Directorate.

Architecture Development Office

ADO is responsible for architecture development for future human missions to Mars and integration with the international partner strategy. In FY 2022, ADO:

- Conducted quarterly Sync Point Reviews in October 2021, January 2022, March 2022, and July 2022. The Sync reviews provided the opportunity for the lunar and Mars architecture teams to share formulation data and the past quarter's analyses, synchronize commonalities between the architectures, baseline the Strategic Analysis Cycle manifest, and set priorities for the next quarter.

- Between Sync Point Reviews, the Lunar and Mars Architecture Teams dedicated time to updating and informing programs and offices across the agency on the latest analysis, forward work, and opportunities for engagement in the architecture. Under existing Space Act agreements, the Lunar and Mars Architecture Teams also were able to engage with U.S. companies to discuss architecture approaches.
- The Mars Architecture Team engaged in topics of significant internal interest, including NASA's Office of Planetary Protection's updated ground rules for human missions to Mars, Mars mission abort scenarios, propulsion system trades, cryo-fluid management, surface power, communications delays, crew health and performance, and medical systems.
- The Mars Architecture Team also consulted with the Mars Sample Return team and Mars Ingenuity team to identify synergies between the robotic missions and future human missions and possible enhancements to the human architecture enabled by the robotic missions.
- The Lunar Architecture Team assessed and shared results of surface habitat mass reduction strategies, surface architecture, infrastructure, logistics, and science deployment considerations.

- Continued Technical Interchange Meetings with the Japan Aerospace Exploration Agency (JAXA) regarding concept of operations, requirements, landed mass, lunar night survival, and medical capabilities for an Artemis pressurized rover. An expanded agreement included the ability for JAXA astronauts and engineers to participate in NASA's Desert Research and Technology Studies (D-RATS) in Arizona. As feasibility discussions mature for the potential for JAXA to provide the Artemis pressurized rover, the field test in Arizona provides a hands-on experience for NASA and JAXA to conduct field research on the pressurized rover's functionality, capabilities, and limitations.

- Released the Strategic Campaign Operations Plan for Exploration (SCOPE) on the NASA Technical Reports Server. SCOPE ensures a common baseline for discussions with existing and potential partners who may offer contributions to Artemis or initial human missions to Mars. The document introduces exploration goals, as well as ground rules and assumptions, across four human exploration campaign segments ranging from low-Earth orbit to Mars.
- Conducted technical exchanges with the CSA related to lunar surface mobility use cases for robots as future contributions to the surface architecture. A study agreement is in work to continue conversations and determine the desired contributions.
- Held discussions with Agenzia Spaziale Italiana (ASI) regarding potential lunar surface habitation collaboration, including their proposed Multi-Purpose Habitation module.
- Continued discussions with Mohammad Bin Rashid Space Centre regarding their plans for a "Mars City" near Dubai that can be used to conduct Mars analog missions.
- Conducted technical exchanges with the ESA on potential contributions including a cislunar transit vehicle (CLTV) and the European Large Logistics lander (EL3). The EL3 would be nominally used to support logistics delivery to the lunar surface. The CLTV could be used to move elements between low-Earth orbit and cislunar space.
- Hosted an architecture overview with the Taiwan Space Agency.
- Supported an initial virtual meeting with representatives from the State Space Agency of Ukraine (SSAU) and related Ukrainian space organizations. The two sides exchanged a summary of current activities and plans related to the Moon; Ukraine has signed the Artemis Accords. The Ukrainian side presented several capabilities they believe could form the basis of a lunar partnership with NASA sometime in the future.
- Forty-one student proposals were received for the 2021–2022 Revolutionary Aerospace Systems Concepts–Academic Linkage University design competition in four categories: Portable Utility Pallet, Universal Sample Containment System, Mars Water-Based In-Situ Resource Utilization

(ISRU) Architecture, and Suitport Logistics Carrier. ADO selected 15 finalists. Massachusetts Institute of Technology took the top prize with the University of Illinois at Urbana-Champaign taking second place.

- ADO took an active role in the development of the agency's Moon to Mars Objectives, including objectives development, U.S. and international stakeholder feedback, and subsequent dispositioning, to arrive at a revised set of objectives that Deputy Administrator Pam Melroy released at the International Astronautical Congress in September.

Technical Integration Office

TIO is responsible for directorate-level systems engineering and integration and requirements, pre-formulation of future elements, science and technology utilization integration, and capabilities integration.

In FY 2022, TIO completed the following:

Concept Development/Pre-Formulation

- Executed Phase 3 extensions for Next Space Technologies for Exploration Partnerships (NextSTEP) Appendix A for Boeing, Lockheed Martin, and Sierra Nevada Corporation. The Period of Performance extends through January 2023.
- Supported full-scale structural design, sub-scale inflatable structure burst tests, and material component creep testing with Lockheed Martin.
- Supported the successful burst test of Sierra Space's one-third-scale inflatable softgoods structure as part of their work under NextSTEP Appendix A.
- Continued technical interchange meetings with Boeing regarding the company's surface and transit habitat concepts.
- Observed the first-ever demonstration of in-space structural metal cutting by NextSTEP-2 Appendix A partner Nanoracks, which conducted their Outpost Mars Demo-1 flight as part of their final work under NextSTEP Appendix A.
- Took an active role in the development of NASA's Moon to Mars Objectives, including objectives development, U.S. and international

stakeholder feedback and subsequent dispositioning, to arrive at a revised set of objectives that Deputy Administrator Pam Melroy released at the International Astronautical Congress in September.

- Refurbished the Constellation-era lunar pressurized rover prototype for use in the October 2022 D-RATS analog mission.

Science and Technology Utilization

- Completed a lunar lighting assessment in support of the LTV "Survive the Night" Study. The lunar lighting assessment will continue as related to overall Artemis planning and landing site analyses. The Science and Technology Utilization (S&TU) team provided the lighting assessment to directorate management and other agency-wide stakeholders developing systems intended to operate at or near the lunar South Pole.
- Released Artemis III Candidate Landing Regions. Through the ongoing Cross-Artemis Site Selection Analysis Team, S&TU led the downselect to 13 candidate regions near the lunar South Pole that are accessible for Artemis III throughout FY 2022 and provide significant scientific value. Regions are approximately 15 × 15 km, and each region has multiple potential landing sites, which have an approximately a 100 m radius.
- Co-hosted, with the Human Research Program, "Spaceflight for Everybody" Symposium on November 8–10, 2021. The purpose was to communicate the current state of NASA spaceflight health knowledge. It was emphasized that diversity and inclusion involve more than sex, gender, age, ability, ethnicity, and race, but includes diversity and inclusion of thoughts and ideas. More than 900 participants registered for the symposium.
- Participated in Office of Planetary Protection discussions related to human missions to Mars.
- Co-hosted the first "Science Objectives for Human Exploration of Mars Workshop" to ensure community input and early integration of science into the exploration architectures for the first human mission to Mars.
- Released HEOMD-410, Lunar Traverse Data Book V1. Across Artemis, many different organizations are analyzing similar traverses, with different

purposes, and these traverses represent the highest-priority requests from four different organizations in SMD and in ESDMD.

- Supported SMD-led, agency-level response to the National Academies of Science Planetary Science Decadal Survey 2023–2032, which was the first planetary science decadal that included a dedicated chapter on human exploration.
- Based on documented utilization stakeholder objectives and architecture needs (HEOMD-006 Annex 1), S&TU defined a series of utilization requirements that were further developed within TIO and reviewed for inclusion in the HEOMD-004.

Requirements

- Issued HEO-003: Crewed Deep Space Systems Human Rating Certification Requirements and Standards for NASA Missions. HEO-003 is a consolidated set of technical requirements, standards, and processes that NASA Program Managers shall implement for human rating certification of Crewed Deep Space Systems.
- Issued Revision C of HEO-004, Human Exploration Requirements, which defined needs of the architecture in establishing an Artemis Base Camp. HEO-004 captures requirements controlled by the former Human Exploration and Operations Mission Directorate (HEOMD) for the Programs responsible for design, development, and operation of systems to meet HEOMD goals and objectives.
- Issued HEOMD-006, Exploration Systems Development Mission Directorate Utilization Plan. HEO-006 identifies and describes NASA's science and technology utilization goals and objectives that will be enabled by human missions, as defined by SMD, STMD, and ESDMD.
- Issued the following Decision Memoranda/Management Directives: ESDMD-407, Strategy & Architectures Mars-Specific Ground Rules and Assumptions; ESDMD-408, Strategy & Architectures Overarching Ground Rules and Assumptions; ESDMD-410, Lunar Surface Exploration Planning: Terrain Characteristics; ESDMD-411, Representative Utilization Instruments for the LTV and Pressurized Rover; ESDMD-415,

Reference Surface Activities for Crewed Mars Mission Systems and Utilization; and ESDMD-417, Integrated Utilization Study Requirements for the Pressurized Rover.

Standards

- Released International Docking System Standard Interface Definition Document, Rev F. This standard is the result of a collaboration of by the ISS Program International Partners to establish a standard docking interface to enable on-orbit crew rescue operations and joint collaboration endeavors utilizing different spacecraft. Rev F captures the ongoing development work in cislunar space (Gateway, Orion, HLS).
- Released International Space Power System Interoperability Standards, Rev A.

Capabilities Integration

- Issued an FY 2022 agency-wide data call, collecting 425 capability gaps and comparing them to the FY 2021 gaps to arrive at an updated consolidated set.
- Worked with the STMD Strategic Planning and Integration office to define and execute a major update to STMD's STARPort database environment to allow for integration of ESDMD capability gaps from the HEOMD-405 FY 2022, Integrated Exploration Capabilities Gap List with STMD's gap process. This allows for tighter integration across the directorates, reduced duplication of work for updating and adding gaps, and easier tracking of gap closure activities.

Space Operations Mission Directorate (SOMD) in FY 2022 (Formerly Part of HEOMD)

International Space Station

The ISS continues to generate numerous benefits that improve individual lives on Earth, inspire the next generation of scientists and engineers, foster international collaboration, and enable future exploration deeper into the solar system. Knowledge is being generated in scientific fields from cell biology to cosmology. New technology is being developed and demonstrated with applications as wide-ranging as communications, power generation, agriculture, and medicine.

In FY 2022, Commercial Resupply Services (CRS) flights from SpaceX and Northrop Grumman launched a total of three cargo flights to the ISS, totaling approximately 26,000 pounds of science investigations, spacewalking tools, and critical supplies delivered. Also in FY 2022, Northrop Grumman's Cygnus spacecraft completed its first limited reboost of the ISS. Cygnus's gimbaled delta velocity engine was used to adjust the space station's orbit through a reboost of the altitude of the space station. This capability works in concert with Russian propulsion systems that provide attitude control during the reboost. This Cygnus mission is the first to feature this enhanced capability as a standard service for NASA, following a test of the maneuver that was performed in 2018 during Cygnus's ninth resupply mission. Another first in FY 2022 was the successful cycle of the Bishop Airlock, which deployed the Nanoracks' technology to eject approximately 172 lbs of waste from the station. This successful test in July 2022 was intended to demonstrate a more efficient and sustainable model for eliminating waste aboard the station and highlight a critical new function and utility for future commercial space stations.

Additional cargo missions were complemented by NASA's Partners. Roscosmos provided three Progress cargo missions. Nearly 10,000 pounds of investigations and equipment were returned to researchers on 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.

International Partners and NASA's Commercial Crew Program (CCP) provide crew rotation missions to the ISS. The goal of NASA's CCP is safe, reliable, and cost-effective transportation to and from the ISS. This already has provided additional research time and has increased the opportunity for discovery aboard humanity's microgravity testbed for exploration, including helping NASA prepare for human exploration of the Moon and Mars. During Expedition 66, the SpaceX Crew-3, consisting of NASA astronauts Raja Chari, Tom Marshburn, and Kayla Barron, and ESA astronaut Matthias Maurer, arrived in the Dragon Endurance spacecraft in November 2021 and ultimately spent 177 days in orbit. At the time of docking, they joined the Expedition 66 crew consisting of Mark Vande Hei of NASA and cosmonauts Anton Shkaplerov and Pyotr Dubrov of Roscosmos. NASA astronaut Mark Vande Hei ended his record-breaking time on the ISS with a parachute-assisted landing on the steppe of Kazakhstan on the morning of March 30, 2022, along with Anton Shkaplerov and Pyotr Dubrov. Vande Hei arrived at the ISS in April 2021, spending 355 days in low-Earth orbit (LEO), breaking the previous record held by retired NASA astronaut Scott Kelly by 15 days.

In April 2022, the SpaceX Crew-4 mission launched to the station with NASA astronauts Bob Hines, Kjell Lindgren, and Jessica Watkins, as well as ESA astronaut Samantha Cristoforetti. Lindgren, Hines, Watkins, and Cristoforetti joined the Expedition 67 crew of Raja Chari, Thomas Marshburn, and Kayla Barron, all of NASA, Matthias Maurer of ESA, and cosmonauts Oleg Artemyev, Sergey Korsakov, and Denis Matveev of Roscosmos. For a short time, the number of crew on the space station increased to 11 people until NASA's SpaceX Crew-3 departed. These CCP-enabled crew missions contribute to a host of science and maintenance activities and technology demonstrations.

Roscosmos also provided Soyuz crew rotation missions in FY 2022. The Soyuz 66S mission consisted of Roscosmos cosmonaut Alexander Misurkin and spaceflight participants Yusaku Maezawa and Yozo Hirano. The latter two astronauts made their trek into space under a contract between Space Adventures and Roscosmos. Expedition 66 ended with the departure of Soyuz 65S in March 2022. Onboard Soyuz 65S were NASA astronaut Mark Vande Hei, along with Anton Shkaplerov and Pyotr Dubrov of Roscosmos. Marking the transition from Expedition 67 to Expedition 68, the Soyuz 67S spacecraft departed the ISS in

September 2021. The Soyuz 67S, which arrived in March 2022, carried Roscosmos cosmonauts Oleg Artemyev, Denis Matveev, and Sergey Korsakov.

In FY 2022, there were a total of nine spacewalks supported by the onboard crew and ground teams. Three of those were U.S. EVAs. The first U.S. spacewalk in December 2021 focused on replacing an S-band Antenna Subassembly with a spare already available on the station's truss structure. The second U.S. spacewalk continued to prepare the space station for upcoming solar array upgrades by assembling and installing modification kits. The crew built a support bracket onto which a future ISS Roll Out Solar Array (iROSA) will be mounted. So far, two of six iROSAs have been deployed on station with four additional arrays to be delivered. The arrays will ultimately augment six of the station's eight power channels, increasing the station's total available power from 160 kilowatts to up to 215 kilowatts. In the third U.S. spacewalk, the crew installed hoses on a Radiator Beam Valve Module that routes ammonia through the station's heat-rejecting radiators to keep systems at the proper temperature. The crew members also installed a power and data cable on the Columbus module's Bartolomeo science platform, replaced an external camera on the station's truss, and conducted other upgrades to station hardware.

During the latter spacewalk, the crew noticed a thin layer of moisture inside ESA astronaut Matthias Maurer's helmet after station airlock re-pressurization following the nearly seven-hour spacewalk. NASA identified the event as a close call and immediately declared a stop to all future planned U.S. Operating Segment spacewalks pending an investigation into the cause. NASA returned water samples and some suit hardware to Earth with Soyuz 65S and NASA's SpaceX Crew-3 mission and then returned the spacesuit as part of the agency's SpaceX CRS-25 mission for detailed analysis. Based on the findings, the team has updated operational procedures and developed new mitigation hardware to minimize scenarios where integrated performance results in water accumulation, while absorbing any water that does appear. These measures will help contain any liquid in the helmet to continue to keep crew safe. Given the results of the investigation, the additional operational procedures, and mitigation hardware, the NASA management team concurred and approved return to normal operations. The first planned spacewalk is targeted no earlier than November 2022 to continue the work to install the next iROSA.

Despite continued challenges from COVID-19, the ISS National Laboratory has been flying science, technology demonstrations, and education programs for the benefit of humanity. In FY 2022, the ISS National Laboratory extended the Cooperative Agreement with the Center for the Advancement of Science in Space (CASIS) through 2027, to help manage the U.S. segment of the ISS. In FY 2022, all the actions from the CASIS Independent Review Team (IRT) have been officially closed. The last of these actions was creating a streamlined Cooperative Agreement between NASA and CASIS, which was completed in the fourth quarter of FY 2022. All actions from the FY 2021 Government Accountability Office (GAO) review have been responded to.

Culminating several years of technical analysis and stakeholder coordination, on December 31, 2021, the Biden-Harris administration announced that the United States would continue to operate the ISS through 2030. This extension allows time to fully realize the potential of the ISS, including in technology development for Artemis, benefits for humanity, and commercial development. This extension will allow time for Commercial LEO Destinations (CLD) to come online toward the end of the decade to ensure there is no gap in U.S. human spaceflight capability in LEO. On August 9, 2022, the President signed the CHIPS and Science Act into law, which contained a NASA Authorization Act. This Act formalized Congress's consent to operate ISS through 2030. NASA continues to work with its International Partners to work with their respective governments to secure their own formal extensions of ISS. NASA is also working with the same partners to strategize what future international cooperation in LEO would look like on future U.S. CLDs.

Launch Services Office

In FY 2022, NASA's Launch Services Program (LSP) successfully launched three NASA science missions and one weather satellite for NOAA. The Lucy spacecraft launched aboard an Atlas V from Cape Canaveral Space Force Station (CCSFS) in October 2021. The Double Asteroid Redirection Test (DART) mission launched in November 2021, followed by the Imaging X-ray Polarimetry Explorer (IXPE) mission in December 2021. Both DART and IXPE launched aboard a Falcon 9

Full Thrust launch vehicle, DART from Vandenberg Space Force Base (VSFB) in California, and IXPE from the Kennedy Space Center in Florida. The LSP also managed the launch service for the Space Technology Mission Directorate's (STMD's) Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) CubeSat. CAPSTONE successfully launched aboard Rocket Lab's Electron Rocket from Mahia, New Zealand, in June 2022. In addition to launching NASA's science and technology spacecraft, LSP acquired one new launch service for NASA's Science Mission Directorate (SMD). The launch service for the Nancy Grace Roman Space Telescope (RST) is a competitively awarded launch services task order under the NASA Launch Services II contract. RST will launch aboard a Falcon Heavy in October 2026.

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 LSP. The program is currently providing these advisory services to several programs and missions, including the ISS Cargo Resupply Services missions; the CCP, Artemis, and Gateway Programs; as well as SMD's NASA–Indian Space Research Organization Synthetic Aperture Radar (NISAR) mission. LSP also provided advisory support to SMD's James Webb Space Telescope, which successfully launched aboard an Ariane V from Kourou, French Guiana, in December 2021.

NASA has also selected 12 companies to provide launch services under the Venture-Class Acquisitions of Dedicated and Rideshare (VADR) contract. This contract will enable regular, competitive acquisition of commercial launch services for small payloads, such as those successfully demonstrated through the VCLS contracts. The VADR contract was awarded in FY 2022 and will provide a broad range of Federal Aviation Administration (FAA)–licensed commercial launch services capable of delivering payloads ranging from CubeSats to Class D missions to a variety of orbits. Firm-fixed-price task orders will be issued to provide the launch services under these contracts for NASA's risk-tolerant missions. Launches under the VADR contract will align with commercial practices, using less NASA oversight to achieve lower launch costs. Award selections are ABL Space Systems of El Segundo, California; Astra Space, Inc., of Alameda, California; Blue Origin Florida LLC of Merritt Island, Florida; L2 Solutions LLC of Houston; Northrop Grumman Systems Corporation of Chandler, Arizona; Phantom Space Corporation of Tucson, Arizona; Relativity Space, Inc., of Long Beach, California; Rocket Lab USA, Inc., of Long Beach, California; Spaceflight, Inc., of Seattle; Space Exploration Technologies Corp. (SpaceX) of Hawthorne, California; United Launch Services LLC of Centennial, Colorado; and Virgin Orbit LLC of Long Beach, California. In August 2022, SMD's Total and Spectral Solar Irradiance Sensor 2 (TSIS-2) mission was awarded to SpaceX for a Falcon 9 Full Thrust VADR launch service. TSIS-2 is planned for launch from CCSFS in August 2024. In September 2022, NASA selected Firefly Space Transport Services, a wholly owned subsidiary of Firefly Aerospace, Inc., to provide launch services under the VADR contract utilizing their Alpha rocket.

In addition, NASA and LSP continue to partner with several universities and NASA Centers to launch small research satellites through the CubeSat Launch Initiative (CSLI). As of the end of FY 2022, 148 CubeSats have been launched from 42 states, the District of Columbia, and Puerto Rico, with 32 missions manifested on NASA, National Reconnaissance Office, U.S. Space Force, and commercial missions. In FY 2022, 18 CSLI CubeSat missions were launched.

In October 2022, SpaceX completed certification of its Falcon Heavy launch vehicle. GOES-U will be the first LSP-managed mission to launch aboard a Falcon Heavy in 2024. Certification activities are also ongoing with ULS's Vulcan, Alpha's Firefly, and ABL Space Systems' RS-1 launch vehicles. Planning activities for certification of Blue Origin's New Glenn and Rocket Lab's Electron launch vehicles are also in the works.

Human Spaceflight Capabilities

Human Research Program

In FY 2022, the HRP completed the following key milestones:

- Conducted two Human Exploration Research Analog (HERA) campaigns in FY 2022. 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.

- Continued an international collaboration with DLR to conduct a series of 30-day strict head-down-tilt bed rest campaigns at the :envihab facility in Cologne, Germany, to study potential countermeasures (CM) for Spaceflight Associated Neuro-ocular Syndrome (SANS). The SANS CM study consists of four Campaigns, with Campaign 2 completed in February 2022, Campaign 3 expected to start January 2023, and Campaign 4 in April 2023. NASA's research complements several DLR studies taking place during these campaigns.
- Conducted the study of Validation of the Multisystem Countermeasures Protocol for Spaceflight at the National Science Foundation's Antarctic Stations at Palmer Station (Palmer Immune Countermeasures) during Antarctic winter-over. Evaluation included the effectiveness of a suite of countermeasures to mitigate the negative effects of isolation and confinement on human immune system functionality; an adaptation of the immune system observed with long-duration stays both on the ISS and at Palmer Station. In addition, HRP Human Health Countermeasures Palmer Immune Pilot Study conducted a second winter-over data collection at Palmer Station focusing on team problem solving in long-duration isolated and confined environments.
- Conducted three HRP-funded NASA Space Radiation Laboratory (NSRL) campaigns (21C, 22A, and 22B) in FY 2022. A total of 14 teams (10 funded by NASA) completed studies during 21C, utilizing approximately 190 hours of beam time. These unique dose-rate studies are critical for adequate characterization of space radiation health risks, especially given the new space radiation standard allowing astronauts to accumulate up to 600 mSv over a career. These doses are recognized as substantially increasing health risks associated with radiation on Earth; however, our understanding of how the space radiation environment impacts health outcomes under chronic dose rate conditions is still evolving. Results from these studies will be used to inform agency decision makers on the risks to crew for long-duration missions that may surpass the 600 mSv limit.
- Coordinated with NASA's White House Liaison and Office of Science and Technology Policy to support NASA's point of contact in presenting

NASA's involvement in President Biden's Cancer Cabinet as part of the Moonshot Initiative. NASA was invited to participate.

- Completed the technology demonstration of the reusable Handheld Electrolyte and Lab Technology for Humans (rHEALTH) ISS operations in May 2022. The analyzer was developed with NASA HRP sponsorship and the Small Business Innovative Research program. This technology has the potential to reduce conditioned-stowage requirements for Artemis missions. The rHEALTH analyzer is a miniature flow cytometer for biomarker identification.

Rocket Propulsion Test

The RPT Capability Portfolio Program is responsible for strategic management and sustainment of NASA's expertise and facilities for testing of rocket engines. In 2022, RPT test facilities continued to support NASA, Commercial, Defense, and NASA International Space Partner requirements for purposes of component, engine, and rocket stage level of testing. RPT delivered test capabilities to support technology advancement, capability demonstration, risk retirement, and hardware qualification and launch readiness for more than 595 tests (over 32,823 seconds).

Testing of rocket engines and components for NASA and its collaborative commercial partners on the Artemis Program were of predominant importance in 2022. RPT continued to provide testing of the Aerojet Rocketdyne RS-25 engines in the A-1 Test Stand at the Stennis Space Center (SSC) in Mississippi. This testing provided performance data on a variety of new engine components developed with advanced manufacturing techniques in support of the Artemis Program. Modification to the SSC B-2 Test Stand, used to facilitate the SLS four-engine Core Stage test in 2021, continued throughout FY 2022, in support of a similar integrated upper stage test of the Exploration Upper Stage (EUS) engine and plume management system. The interstage test article, an important element of that planned test, arrived and will be mounted into the test stand prior to integration of the four RL-10 EUS engines. Elsewhere at SSC, in the E-Complex, diffuser testing was conducted to validate the system design planned for the EUS test on the B-2 test stand. Commercial activity in other cells in the E-Complex supported a variety of commercial engine, turbo-pump, thruster, and component test requirements.

Test stands at other NASA Centers were also busy in 2022. At MSFC, testing supported both NASA internal and collaborative projects to advance manufacturing and development techniques through the testing of engine components, including rocket nozzles. Testing was conducted in evaluation of liquid rocket engines in landers and on-orbit stages and spacecraft as well as on solid rocket motor nozzle and insulation materials. At WSTF, testing in support of NASA, International Partner, and commercial and defense customers were supported in hot firings, acceptance testing, and qualification of thrusters and thruster system components. Testing supported developmental thrusters that advanced low-temperature operations and nano-satellite propulsion. Minuteman III Propulsion System Rocket Engine deactivating propulsion stages to an inert state in support of de-militarization also continued. At Glenn Research Center's Armstrong Test Facility, preparatory work for proto-qualification testing of the Sierra Nevada Dream Chaser Cargo System (DCCS) in the In-Space Propulsion Facility (ISPF) continued as well as thermal-vacuum test support for balloon payload program elements.

Commercial Space Division

Commercial Crew Program

In FY 2022, NASA's Commercial Crew partner, SpaceX, began flying their operational Post Certification Missions (PCM) to and from the ISS.

SpaceX Crew-2 astronauts boarded the Dragon spacecraft Endeavour, departed the ISS, and returned to Earth, off the coast of Florida, on November 9, 2021, bringing the Crew-2 mission to a successful conclusion. On November 11, 2021, SpaceX launched the Crew-3 mission, aboard Dragon Endurance, carrying four astronauts to the ISS. SpaceX launched the Crew-4 mission on April 27, 2022, carrying astronauts aboard the Dragon Spacecraft Freedom on its inaugural flight. Crew-4 is noteworthy in that it was the first Commercial Crew PCM flying International Partners astronauts (three NASA astronauts and one ESA astronaut). After Crew-4 ISS docking, Crew-3 astronauts boarded Endurance for their return trip home. Crew-3 successfully landed off the coast of Florida on May 6, 2022. Crew-4 is currently planned to return to Earth after Crew-5, Endurance, arrives at the ISS.

A summary of NASA's Commercial Crew Missions in FY 2022 by SpaceX Spacecraft

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

Boeing launched their demonstration flight repeat, Orbital Flight Test-2 (OFT-2), on a flight to the ISS on May 19, 2022, to demonstrate a complete ISS transportation mission, including launch; free flyer ops; Space Station approach; docking; docked operations; and departure, entry, descent, and landing. After completion of mission objectives, OFT-2 successfully landed at White Sands Missile Range on May 25, 2022. This clears the path forward for Boeing's Crew Flight Test (CFT) demonstration mission, carrying NASA astronauts to and from the ISS.

Space Communications and Navigation

In FY 2022, SCaN completed the following:

- Operated SCaN's networks above the 95 percent network proficiency requirement, achieving 98 percent or better across the Deep Space Network (DSN) and Near Space Network (NSN), while continuing to execute plans to build, augment, or upgrade critical network assets including completed construction on the new 34-meter DSN antenna in Madrid; started construction on a new DSN antenna at Goldstone, completed upgrades to two other DSN antennas; and augmented four 11.3-meter NSN antennas to enable Ka-band capabilities.
- Supported launch and operations of multiple high-profile science and human exploration missions, including the James Webb Space Telescope (JWST) launch and first images, the Double Asteroid Redirect Test (DART) tracking for impact, and the Lucy Mission launch. SCaN worked with ESDMD to capture, in a services requirements document and concept of operations, the critical lunar relay capabilities and planning for Artemis missions.

- Completed down-selection and award to Johns Hopkins University Applied Physics Laboratory (JHU/APL) for the flight demonstration of a wideband/multilingual communications terminal. The selection occurred after the successful completion of ground demonstrations in 2021 by both NASA's Glenn Research Center and JHU/APL. The JHU/APL team completed a mission Critical Design Review (CDR) in September 2022.
- Began operations of Deep Space Station 53 (DSS-53) at the Madrid Deep Space Communications Complex in Madrid, Spain. This 34-meter antenna is the fourth of six new beam waveguide antennas providing backup to the DSN's larger 70-meter antennas while adding about eight percent capacity to the DSN.
- Launched the Laser Communications Relay Demonstration (LCRD) mission aboard the U.S. Department of Defense's Space Test Program Satellite 6 (STPSat-6) on December 7, 2021. In May 2022, LCRD passed certification to begin experiments. LCRD is NASA's first long-period optical communications project to demonstrate the benefits of optical communication systems for both deep space and near-Earth missions, utilizing advanced relay operations that could be used for future relay systems at the Moon and Mars.
- Launched the TeraByte InfraRed Delivery (TBIRD) payload on May 25, 2022, as part of the Pathfinder Technology Demonstrator 3 (PTD-3) mission on SpaceX's Transporter-5 rideshare mission. TBIRD demonstrated 100 gigabit-per-second (Gbps) downlink rates, with plans to reach 200 Gbps—the fastest downlink rate ever achieved by NASA.
- Completed the NavCube3-mini Technology Readiness Level 6 test campaign for the cislunar-capable weak-signal, multi-Global Navigation Satellite System (GNSS) receiver in September 2022. Awarded a patent for "Miniaturized Multi-Band Space GNSS Receiver." This receiver plans to reduce the burden on terrestrial networks providing navigation and timing services to cislunar/lunar users.
- Co-organized and held an Optical and Quantum Communications Forum with NASA's Australian counterparts, including the newly formed ASA, Commonwealth Scientific and Industrial Research Organisation

(CSIRO), and numerous Australian universities on July 21–22, 2022. The forum focused on sharing recent work, discussing common interests, and identifying technology gaps as future collaboration opportunities.

- Collaborated with the Mobile Satellite Service community to progress early studies for space-to-space communications identified as a potential future agenda item for the 2027 World Radiocommunication Conference (WRC-27).
- Codified the Lunar Spectrum Manager role within U.S. regulatory bodies, as well as internationally within the Space Frequency Coordination Group (SFCG), an organization under the IOAG. SCaN led efforts to establish a Lunar Spectrum Plan later adopted by the SFCG.
- Supported Boeing and CCP post-landing test objectives for Orbital Test Flight-2 (OFT-2) through the Search and Rescue (SAR) Mission Office.
- Led NASA delegation to the 15th meeting of United Nations (UN) International Committee on GNSS (ICG).
- Secured appointment of nine new members to National Space-Based PNT Advisory Board (PNTAB) and organized two sessions.
- Renewed the charter of the National Space Council User's Advisory Group (UAG) for 2022–2023, coordinated membership nominations, and secured appointment of the new Chair. SCaN supports UAG as its Executive Secretary.
- Collaborated with the 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.

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 and research organizations, academia, industry, and non-profit philanthropies 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.

In FY 2021 and FY 2022, SMD operated 70 missions across SMD's 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.

In addition to these divisions, SMD is home to the Exploration Science Strategy and Integration Office (ESSIO), the James Webb Space Telescope Program Office, the Mars Sample Return Program Office, and the Joint Agency Satellite Division, which conducts reimbursable satellite programs with the National Oceanic and Atmospheric Administration (NOAA).

SMD's Science Activation program leverages unique science infrastructure, content, and scientific experts to engage with learners of all ages. In FY 2021 and FY 2022, working with community-based institutions, such as libraries, museums, science centers, and planetariums, the Science Activation program continued its work through 37 cooperative agreements, leveraging more than 268 partners in all 50 states. In addition, the Citizen Science Initiative is composed of 29 funded projects that harness the energies of the public and use the rigors of science, resulting in new discoveries. As of September 2022, there have been 86 refereed publications with 410 named coauthors who are NASA citizen scientists.

Earth Science

Earth is a dynamic, interconnected, living planet that continues to change, due to its own system processes and the impact of humans. The Earth Science Division uses data captured by research satellites, airborne and in situ campaigns, and integrative research activities to understand 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 other areas. Through partnerships with other Federal agencies, academia, industry, research organizations, non-profit philanthropic organizations, and international governments, 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 several research and application highlights from FY 2021 and FY 2022.

Earth System Observatory

In response to a key recommendation from the most recent decadal survey, NASA is designing a new set of integrated Earth missions called the Earth System Observatory (ESO), which will provide key data as we address climate change, prepare for and respond to natural hazards, fight and mitigate forest fires, and improve agricultural processes. The missions will be organized around five major Earth systems: aerosols; clouds, convection and precipitation; mass changes, such as ice sheet melt and groundwater depletion; surface biology and geology; and surface deformation and change. The first in this series of missions is a partnership with the Indian Space Research Organization (ISRO), the NASA-ISRO Synthetic

Aperture Radar (NISAR), which uses two radar systems to measure changes in Earth's surface to within less than half an inch.

Next Earth Venture Mission Selected

In November 2021, NASA selected a new Earth Venture Mission. Investigation of Convective Updrafts (INCUS) will study tropical storms and thunderstorms in order to improve their inclusion in weather and climate models, seeking to understand how they form and what causes them to intensify. INCUS will consist of three SmallSats flying in a tight formation and is expected to launch in 2027.

EMIT Studies Desert Dust and Methane

The Earth Surface Mineral Dust Source Investigation (EMIT) is an Earth Venture Instrument mission to map the surface mineralogy of arid dust source regions via imaging spectroscopy. The maps of the source regions will be used to improve forecasts of the role of mineral dust in the radiative forcing (warming or cooling) of the atmosphere. EMIT was launched to the International Space Station (ISS) in July 2022 aboard a SpaceX Cargo Dragon. Since its installation on the ISS, EMIT has demonstrated great potential for methane detection by identifying more than 50 "super-emitters"—facilities, equipment, and other infrastructure typically in the fossil-fuel, waste, or agriculture sectors that emit methane at high rates.

Launched Sentinel-6 Michael Freilich

In November 2020, NASA launched the European Space Agency satellite Sentinel-6 Michael Freilich. The satellite was named in honor of the late NASA Earth Science Division Director, who promoted international partnerships to strengthen our understanding of Earth. Through a NASA and NOAA partnership, the radar altimeter will continue the nearly 30-year record of satellite sea level measurements until at least 2030. Since its commissioning, the satellite has returned the most precise sea level rise data ever, and this continuous record is a critical foundation for understanding changes in sea level rise globally.

NASA Analysis Shows 2020 Tied for the Warmest Year on Record

In January 2021, independent analyses carried out by both NASA and NOAA found that Earth's global surface temperatures in 2020 were tied with 2016 for the warmest since modern recordkeeping began in 1880. These temperature measurements indicate that the planet's long-term warming trend is continuing—the past seven years have been the warmest seven years on record. Global shutdowns related to the COVID-19 pandemic reduced particulate air pollution in many areas, allowing more sunlight to reach the surface and producing a small but potentially significant warming effect. These shutdowns also appear to have reduced the amount of carbon dioxide (CO_2) emissions in 2020, but cumulative CO_2 concentrations continued to increase.[1]

COVID-19 Impacts on the World

NASA continued to explore how the COVID-19 pandemic impacts our environment in FY 2021 and FY 2022. In June 2021, NASA, ESA, and JAXA hosted an Earth Observation Dashboard Hackathon. During the weeklong event, teams worked to solve socioeconomic and environmental challenges using information from the dashboard, which contained data gathered during the pandemic. More than 4,300 people from 132 countries participated, focusing on seven areas that saw changes due to the pandemic: air quality, water quality, economic impact, agricultural impact, greenhouse gases, social impacts, and interconnected Earth impacts.

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

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1 *https://www.nasa.gov/press-release/2020-tied-for-warmest-year-on-record-nasa-analysis-shows*

to Earth posed by impacts of near-Earth objects. Following are highlights from FY 2021 and FY 2022.

OSIRIS-REx Samples Asteroid Bennu

On October 20, 2020, the Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) successfully conducted its touch-and-go sample collection from the asteroid Bennu. It departed Bennu on May 10, 2021, for Earth and will return the sample on September 24, 2023.

Landing on Mars and Sample Collection by the Perseverance Rover

On February 18, 2021, the Mars 2020 Perseverance Rover successfully landed in Jezero Crater on the surface of Mars, where it is seeking out signs of ancient microscopic life on the planet, exploring the geology of Jezero Crater, and demonstrating key technologies that will help us prepare for further robotic and eventually human exploration of Mars. As of October 2022, the rover has collected 14 scientifically selected rock samples for future return through the Mars Sample Return Campaign. Perseverance also carried the Ingenuity Mars Helicopter, a technology demonstration that has accomplished more than 30 flights across the surface of Mars, testing how to fly in the thin atmosphere of Mars and helping to scout sample sites for Perseverance.

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, and the DART spacecraft impact was planned to change the period of its orbit such that ground-based telescopes could observe the change. Early data returns confirm that DART's impact changed the orbit of Dimorphos by approximately 32 minutes. Images provided by the ATLAS Telescope in South Africa and the Italian LICIACube, which rode with DART, showed ejecta from the impact.

Two Missions to Venus Selected for Discovery Program

In June 2021, NASA announced the final selections of two planetary science missions submitted to the Discovery Program, a competitive program that invites teams of scientists and engineers to design planetary science missions under a not-to-exceed cost-cap that further our understanding of the solar system and our place within it. The two selected missions will explore our nearest planetary neighbor, Venus. DAVINCI is an atmospheric probe that will measure the layers of Venus's atmosphere as it plunges to the surface, and VERITAS will explore Venus's surface and interior as it orbits the planet.

Lucy Launches to the Trojan Asteroids

The Lucy spacecraft launched in October 2021 and will tour two sets of Trojan asteroids, the L4 cloud in 2027–28 and the L5 cloud in 2033, visiting seven Trojan asteroids in total. It will also fly near a main belt asteroid in 2025 on its way to the outer solar system. Lucy is named after the fossilized skeleton of an early hominin found in Ethiopia, and just as the Lucy fossil provided unique insights into humanity's evolution, the Lucy mission promises to revolutionize our knowledge of planetary origins and the formation of the solar system, including Earth.

Juno Flies Close to Jupiter's Moon, Europa

On September 29, 2022, the Juno mission conducted a flyby of Jupiter's moon Europa, providing the first up-close images in more than 20 years and a view of the moon's heavily fractured crust of ice. Images show dark stains in the ice possibly linked to eruptions originating below the moon's surface, as well as indications of penetrating high-energy particles from the severe radiation environment around Jupiter. NASA's Europa Clipper mission, due to launch in 2024, will travel to Europa to take detailed measurements to investigate whether the moon could have conditions suitable for life.

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

NASA's Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) mission hosts the first magnetometer deployed to the Martian surface and has been measuring the geology and seismology of Mars for almost four years. InSight has detected more than 1,300 Marsquakes, and on May 4, 2022, it measured the largest quake ever detected, estimated to be magnitude 5. InSight has also "heard" meteoroids hitting the Mars surface. InSight gradually lost power due to dust on its solar panels, and NASA officially retired this mission in December 2022, after more than four years of collecting unique science on Mars .

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. Included below are four highlights from FY 2021 and FY 2022.

DRIVE Science Centers

NASA selected three hubs for the Diversify, Realize, Integrate, Venture, Educate (DRIVE) Science Centers, a key recommendation in the 2013 Solar and Space Physics Decadal Survey: Consequences Of Fields and Flows in the Interior and Exterior of the Sun (COFFIES) at Stanford University, Center for Geospace Storms at Johns Hopkins University, and Our Heliospheric Shield at Boston University. The Centers use the wide range of scientific, computational, and educational expertise in their diverse science teams to address "grand challenge" science goals in the field of heliophysics. They bring synergistic, coordinated efforts to achieve innovative, breakthrough solar and geospace science that is both ambitious and achievable.

Space Weather Program Created

NASA merged existing space weather research activities under the new NASA Space Weather Program within the Heliophysics Division to provide an improved framework to transition NASA research to NOAA and DOD operations and to inform future research goals. NASA has a long history of working with NOAA, DOD, and other stakeholders to increase our understanding of how the Sun impacts our everyday lives on Earth. The Program manages the joint NASA-NOAA Research-to-Operations-to-Research (R2O2R) program that ensures integration of new science into space weather prediction models and informs future areas of research for the solar and space physics science community. The Program also manages the Agency's overall space weather efforts in support of the PROSWIFT Act, which provides a foundation for heliophysics research at NASA. The Program is also supporting the Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES) instrument for the Lunar Gateway, which will measure space weather impacts to humans and spacecraft systems in orbit around the Moon as part of NASA's Moon to Mars campaign. HERMES will be the first NASA scientific investigation as part of Gateway.

ICON Studies Earth's Ionosphere

Launched in October 2019, NASA's Ionospheric Connection Explorer (ICON) embarked on a mission to study the ionosphere, a region of space where space weather and terrestrial weather interact, and changes in ionospheric properties can disrupt communications and satellite orbits and increase radiation risks to astronauts. The ionosphere is an extremely dynamic place with the push and pull of Earth's weather and the Sun's impacts, and ICON will measure the forces leading to these changes. Recent data from ICON show the first direct measurements of this wind-driven dynamo in space. These new results from ICON will help improve predictions of the ionosphere, which are critical to understanding how signals used by space-based communication and navigation systems travel through this environment. ICON even measured impacts to the ionosphere from the Tonga-Hunga Ha'apai volcano eruption that occurred in January 2022.

Data from Parker Solar Probe Reveal Details of Sun's Activities

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, the corona, as well as what accelerates solar winds and energetic particles. Three years after launch, Parker Solar Probe has now flown within the Sun's inner corona, sampling particles and fields still bound to the Sun's atmosphere. During Parker's eighth flyby of the Sun on April 28, 2021, the spacecraft detected the conditions scientists had long awaited, indicating that it had passed beyond the Alfvén critical surface into the solar atmosphere. Since its launch in 2018, the spacecraft has set records for the fastest man-made object and closest approach to the Sun, coming to within 5.3 million miles, in addition to producing groundbreaking science. As of September 2022, Parker has completed 13 perihelia, or closest approaches to the Sun, and has provided valuable information about the structure of coronal mass ejections. Solar Cycle 25 began at the end of December 2019, and Parker is expected to witness an increasing number of solar events as the Sun's activity ramps up.

New Space Environment Missions Selection

In February 2022, NASA selected two missions to better understand the dynamics of the Sun and the constantly changing near-Earth space environment. The Multi-slit Solar Explorer (MUSE) will seek to understand the heating of the Sun's corona, why it's millions of degrees hotter than the Sun's surface, and the forces leading to eruptions in the corona. HelioSwarm is a constellation of nine spacecraft that will measure the magnetic fields and turbulence in the solar wind. These missions will provide deeper insights into our universe and offer critical information to help protect astronauts, satellites, and communications signals such as GPS.

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 2021 and 2022.

IXPE Imaging the Extreme Universe

The Imaging X-ray Polarimetry Explorer (IXPE) launched in December 2021 and sent back its first science images in February 2022. IXPE, a partnership with the Italian Space Agency, is on a quest to study some of the most mysterious and extreme objects in the universe, using the polarization of light to provide insight into our understanding of x-ray production in objects such as neutron stars and pulsar wind nebulae, as well as stellar and supermassive black holes.

SOFIA End of Mission

The Stratospheric Observatory for Infrared Astronomy (SOFIA), a 2.5-meter telescope inside a Boeing 747 aircraft, allowed astronomers to see into the universe from above Earth's atmosphere, which blocks infrared light. The mission was completed at the end of FY 2022, with flights ending on September 29, 2022. Since its first observations in 2010, SOFIA has revealed the presence of water on the sunlit Moon and cosmic magnetic fields, and it has even allowed scientists to analyze Pluto's atmosphere.

COSI Selected to Study the Milky Way

The Compton Spectrometer and Imager (COSI) mission was selected in October 2021 from the Astrophysics Explorers Program to continue into development. COSI is a gamma ray telescope that will investigate star birth and death in our own galaxy, the Milky Way, as well as the formation of chemical elements. COSI is scheduled to launch in 2025.

Hubble Continues Apace

The Hubble Space Telescope (HST) continues to produce a wide variety of exciting science since its launch in 1990. These many years of observations have allowed astronomers to narrow the expansion rate of the universe to a precision of just over 1 percent, allowing them to predict that the universe will double in size every 10 billion years. Begun in November 2020, HST's Ultraviolet Legacy Library of Young Stars as Essential Standards (ULLYSES) program will use ultraviolet emissions from the hottest and most energetic material in newly formed and forming stars to better understand how stars form and to trace material accreting onto new stars. In October 2021, Hubble observed ice sublimating off the surface of Europa, a moon of Jupiter that is a target in the search for life in our solar system. In 2022, after six years of analyzing Hubble data, scientists were able to calculate the mass of a black hole "wandering" around our galaxy, which is 5,000 light-years away from Earth. This calculation helps us better characterize other stellar-mass black holes that are spread throughout the galaxy. After decades in orbit, Hubble keeps revealing new science about the universe, our galaxy, and even Earth's neighboring planets.

Roman Space Telescope Reaches Key Development Milestone

The Nancy Grace Roman Space Telescope (Roman) passed its Critical Design Review in late September 2021, allowing engineers to begin the process of assembling and testing the observatory. The telescope will help astronomers better understand the nature of dark energy and exoplanet diversity, and it is expected to launch in 2027.

Biological and Physical Sciences

The Biological and Physical Sciences Division (BPSD) has a twofold mission: 1) to better understand how spaceflight affects living systems and prepare for future human exploration missions beyond low-Earth orbit and 2) to advance our understanding of physical phenomena in the microgravity environment and underlying space exploration technologies, such as power generation and storage, space propulsion, life-support systems, and environmental monitoring and control. BPSD's space biology research is focused on animal biology; cell and molecular biology; microbiology; plant biology; and developmental, reproductive, and evolutionary biology. Physical science research is focused on biophysics, combustion science, complex fluids, fluids physics, fundamental physics, and materials science.

Exploring the Fifth State of Matter

The Cold Atom Lab (CAL) on ISS studied for the first time the properties of ultra-cold atoms in a "bubble" geometry that can be created only in microgravity. This research aims to explore new boundaries of quantum science, such as what happens when atoms interfere with themselves on the surface of a bubble. Additionally, CAL produced the first dual-species quantum gas in space. After replacing and characterizing the microwave source that improved the cooling and manipulation of cold quantum gases, CAL was able to produce the first dual-species atom interferometer and Bose-Einstein condensates in space, as well as improving the atom interferometer contrast by a factor of two. These are key steps on the path to producing and studying weakly bound multi atom states, quantum simulation of complex systems, and gravity science as both a quantum gravimeter and as a testbed for testing current theories of gravity.

Thriving in Deep Space

First Plants Grown in Lunar Regolith: Researchers from the University of Florida grew *Arabidopsis thaliana* plants in regolith gathered during Apollo missions. This research builds, in part, upon BPSD-supported space- and ground-based plant investigations and capabilities. This milestone could provide critical insights for growing plants on the Moon during future Artemis missions, as well as contribute to advancements in agriculture on Earth.

Tissue Chips for Joint Research Studies: In March 2022 a multi-agency collaboration led to the award of 8 contracts on 3-D Tissues and Microphysiological Systems. This solicitation is in partnership with the NIH, FDA, BARDA, and NASA to extend the longevity of these advanced in vitro platforms. This will allow NASA to study the effect of spaceflight stressors, such as combined radiation and microgravity, using human analog models to support astronaut healthcare for long-duration deep space exploration missions. The extended tissue chip lifespan would enable researchers to assess the effects of acute and chronic stressors over longer periods of time.

Benefiting Life on Earth

In 2021, 11 years of research was completed using the Light Microscopy Module on the ISS, which supported 40 experiments performed by eight countries. Results of these experiments produced nearly perfect colloidal crystals that resolved theoretical debates in physics and material science and aided the development of optical switches and battery electrodes. This research also led to three patents.

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. NASA's CLPS initiative leverages commercial capabilities and technology to deliver scientific instruments and technology demonstration payloads to the Moon's surface.

In FY 2021 and FY 2022, ESSIO awarded several CLPS contracts to deliver instruments to the lunar surface as well as selecting science instrument suites from the Payloads and Research Investigations on the Surface of the Moon (PRISM) Program. Three instrument suites were selected in June 2021 for PRISM-1 for delivery to the Moon in 2024: Lunar Vertex, the Lunar Interior Temperature and Materials Suite (LITMS), and the Farside Seismic Suite (FSS). Two instruments were selected in June 2022 from the PRISM-2 call for proposals to be delivered in 2026: Lunar Vulkan Imaging and Spectroscopy Explorer (Lunar-VISE) and Lunar Explorer Instrument for space biology Applications (LEIA). PRISM-2 offered the opportunity to propose instruments to be deployed on a rover, establishing mobility as an additional CLPS service to be provided by commercial industry.

James Webb Space Telescope Program Office

On December 25, 2021, the James Webb Space Telescope (Webb) was successfully launched from Kourou, French Guiana, by Arianespace. The launch and subsequent unfolding and commissioning proceeded nearly flawlessly, and the mission released its first stunning scientific images in July 2022. Webb performed 50 major deployments using 178 release mechanisms, 155 motors, and 600 pulleys to enable the telescope to unfold and unfurl, and its success was the product of decades of work by thousands of scientists and engineers. Webb is already changing textbooks in its first months of work. Its launch trajectory was so accurate that Webb has over 20 years of fuel, more than doubling its potential lifetime of scientific discovery. In August 2022, the James Webb Telescope Program Office was discontinued with the successful commissioning of Webb, and continued management has returned to SMD's Astrophysics Division.

On July 12, 2022, NASA revealed the deepest and sharpest infrared image of the distant universe to date, captured by the James Webb Space Telescope. Webb's First Deep Field teems with thousands of galaxies, including the faintest objects ever observed in the infrared.

Mars Sample Return Program Office

The Mars Sample Return (MSR) Program Office was created in 2020 to lead and organize NASA's efforts around the Mars Sample Return Campaign, which is a partnership with the European Space Agency (ESA). NASA and ESA will launch two spacecraft to the Red Planet to retrieve the scientifically selected samples collected by the Perseverance rover, both those already collected and those to be collected as it continues its planned surface science mission. The MSR Program will launch the contained samples into Mars orbit, using an Earth Return spacecraft to rendezvous with and capture them while in orbit around Mars, and then bring them safely to Earth. In November of 2020, an MSR Independent Review Board released its report, and the Program has been implementing the recommendations as well as making progress on mission formulation. The Program entered Phase B in October of 2022 following agency Key Decision Point-B. MSR is set to enter its development phase at the end of 2023.

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.

Aeronautics Research Mission Directorate

NASA's Aeronautics Research Mission Directorate (ARMD) during FY 2021 and FY 2022 continued to make progress on its innovative vision of cleaner, safer, and more advanced air travel and atmospheric flight at every altitude above the United States.[2]

Alongside partners and aviation experts in government, industry, and academia, NASA's aeronautics team further researched and developed new ideas and capabilities in its wide-ranging portfolio guided by a comprehensive Strategic Implementation Plan to transform aviation for the 21st century.[3]

During FY 2021 and FY 2022, ARMD initiated several new efforts through the Sustainable Flight National Partnership (SFNP) with industry, academia, and other agencies to accomplish the global aviation community's aggressive goal of net-zero carbon emissions by 2050. ARMD also continued to transform global aviation through three other broad areas of scientific and engineering work focused on Advanced Air Mobility, quiet supersonic flight, and Air Traffic Management.[4]

Sustainable Flight National Partnership

NASA Aeronautics initiated several focused projects during 2021 to enable greater efficiency and reduced environmental impact of aviation under the SFNP. Its goal is to achieve net-zero carbon emissions in aviation by 2050 by enabling next-generation sustainable aviation practices that make aviation more environmentally friendly. As part of SFNP, NASA is contributing viable solutions in four main areas of technology: electrified aircraft propulsion, small-core gas turbines, advanced high-efficiency airframes, and manufacturing of composites at a high rate.[5]

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2 *https://www.nasa.gov/topics/aeronautics/index.html*

3 *https://www.nasa.gov/aeroresearch/strategy*

4 *https://www.nasa.gov/aeroresearch/sustainable-aviation-np/*, *https://www.nasa.gov/aeroresearch/solicitations*

5 *https://www.nasa.gov/aeroresearch/programs/iasp/epfd*, *https://www.nasa.gov/aeroresearch/nasas-hytec-to-help-jets-burn-less-fuel*, *https://www.nasa.gov/aeroresearch/nasa-to-increase-sustainable-aircraft-manufacturing-with-hicam*

In 2022, NASA announced plans to partner with industry to build the Sustainable Flight Demonstrator (SFD). This will be a full-scale technology demonstrator built to test an ultra-efficient aerodynamic design and possibly other new related technologies to solve the challenges of integrating those technologies and prove their predicted benefits in flight.[6]

Researchers continued testing one of those high-efficiency airframe concepts during FY 2022: transonic truss-braced wings. Preliminary assessments indicate a single-aisle aircraft with this configuration would be 5 to 10 percent more fuel-efficient than a similarly sized airliner because of its differently shaped wings.[7]

NASA also continued to support more widespread adoption of sustainable aviation fuels (SAF), studying emissions from current-generation aircraft using 100 percent SAF. NASA also conducted joint research with the German Aerospace Center to demonstrate that cleaner-burning jet fuels made from sustainable sources can produce 50 to 70 percent fewer ice crystal contrails, a major source of pollution at cruising altitude.[8]

Advanced Air Mobility

NASA advanced concepts and technologies for Advanced Air Mobility (AAM) help emerging aviation markets safely develop an air transportation system that moves people and cargo between places previously not served or underserved by aviation using revolutionary new aircraft that are only just now becoming possible. NASA advanced key technologies critical to safely and responsibly facilitate the introduction of new aircraft at lower altitudes operating in urban environments in the National Airspace System (NAS). It will enable such aircraft to conduct missions including emergency response, civic resource management, and sustainably transporting packages and passengers.[9]

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6 *https://www.nasa.gov/aeroresearch/programs/iasp/sfd/description/*

7 *https://www.nasa.gov/image-feature/ttbw-prepares-for-more-tests*, *https://www.nasa.gov/image-feature/ames/bracing-for-fuel-efficient-flight*, *https://www.nasa.gov/aeroresearch/an-artistic-view-of-the-ttbw*

8 *https://www.nasa.gov/aeroresearch/nasa-tests-sustainable-aviation-fuel-emissions*, *https://www.nasa.gov/press-release/nasa-dlr-study-finds-sustainable-aviation-fuel-can-reduce-contrails*

9 *https://www.nasa.gov/aam*, *https://www.nasa.gov/centers/armstrong/features/aam-looks-toward-automation.html*, *https://www.nasa.gov/centers/armstrong/features/aam-plans-for-vertiports.html*

As interest rises for using drones and other unmanned aircraft systems (UAS) for these purposes, NASA's AAM mission 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.[10]

Through the X-57 Maxwell, NASA's first all-electric airplane, NASA is establishing a reference platform for integrated approaches of distributed electric propulsion technologies and sharing design and airworthiness process with regulators and standards organizations to support industry development of AAM vehicles. In 2021, NASA completed high-voltage testing, during which all the aircraft's systems were powered up and its propellers spun under electrical power for the first time. The X-57 is expected to make its first flight during FY 2023.[11]

NASA and the FAA signed an agreement to collaborate on the AAM National Campaign. The campaign is providing insight to the aviation community into the evolving regulatory and operational environment to support technology development and adaptation, as well as promoting public confidence in AAM through technology demonstrations. Five state and local governments signed agreements with NASA to begin examining how AAM can be a part of their infrastructure.[12]

In preparing for the AAM National Campaign's first set of demonstrations, called NC-1, researchers conducted the National Campaign Integrated Dry Run tests. These tests provided important baseline data and information to researchers and their industry partners.[13]

NASA then conducted developmental flight tests with partner Joby Aviation using their electric vertical take-off and landing vehicle to generate data and further mature National Campaign flight scenarios and related operational protocols.

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10 *https://www.nasa.gov/centers/armstrong/features/releases-new-concept-image-for-aam.html*, *https://www.nasa.gov/feature/for-advanced-air-mobility-safety-is-paramount*

11 *https://www.nasa.gov/specials/X57/*, *https://www.nasa.gov/centers/armstrong/features/x-57-high-voltage-testing-concludes.html*

12 *https://www.nasa.gov/aeroresearch/nasa-and-faa-sign-collaborative-agreements*, *https://www.nasa.gov/aamnationalcampaign*, *https://www.nasa.gov/aeroresearch/programs/iasp/aam/nasa-to-help-local-governments-plan-for-advanced-air-mobility*

13 *https://www.nasa.gov/centers/armstrong/features/national-campaign-dry-run-tests-conclude.html*, *https://www.nasa.gov/centers/armstrong/features/national-campaign-adds-partners.html*

NASA has continued to conduct tests and collaborate with partners in government, industry, and academia.[14]

Quesst

NASA continued its work to enable a new market in commercial supersonic air travel over land. The Quesst mission (formerly known as Low-Boom Flight Demonstration) seeks to usher in this new era by demonstrating that loud sonic booms can be reduced to quiet sonic "thumps."[15]

NASA plans on demonstrating quiet supersonic technology is possible with the help of data gathered by the X-59 airplane, currently under construction and targeted to make its first flight during 2023. The uniquely designed X-59 aircraft will first be test-flown to gather data on these sonic thumps and then flown over select communities to gauge the public's reaction. The agency will share survey data with regulators to support adoption of new rules that lift the ban on supersonic travel over land.[16]

In 2021, the mission saw developments in the assembly of the X-59 aircraft at Lockheed Martin's Skunk Works facility in California. Components such as the aircraft's nose and environmental systems were installed. For the first time, the aircraft supported its own weight after the removal of external supports, and its onboard systems were powered up. Additionally, the X-59's eXternal Vision System completed flight testing onboard a test aircraft and is ready for installation into the X-59. Due to the aircraft's long, pointed airframe, the cockpit has no forward-facing window. Instead, state-of-the-art cameras and a 4K video monitor allow the pilot to see what is ahead in virtually the same detail as a real window.[17]

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14 *https://www.nasa.gov/centers/armstrong/features/nasa-and-joby-complete-flight-tests.html*, and *https://www.nasa.gov/feature/nasa-tests-advanced-air-mobility-automation-concepts-with-sikorsky-and-darpa*

15 *https://www.nasa.gov/subject/7566/supersonic-flight/*, *https://www.nasa.gov/X59*, and *https://www.nasa.gov/feature/new-name-same-great-supersonic-mission*

16 *https://www.nasa.gov/feature/nasa-in-your-neighborhood-event-brings-x-59-to-the-people*

17 *https://www.nasa.gov/feature/x-59-resembles-actual-aircraft*, *https://www.nasa.gov/aeroresearch/x-59-nose-makes-an-appearance*, *https://www.nasa.gov/aeroresearch/lbfd/nasa-x-59-assembly-continues-with-installation-of-supersonic-technologies*, *https://www.nasa.gov/aeroresearch/nasa-x-59-stands-on-its-own*, *https://www.nasa.gov/feature/nasa-completes-tests-of-x-59-external-vision-system*

To conduct Quesst's mission, NASA researchers selected ground recording equipment and developed the Airborne Location Integrating Geospatial Navigation System (ALIGNS). ALIGNS is a visual navigation system allowing a supersonic aircraft to detect another's shockwave. The system will be used in-flight to study the X-59's acoustics.[18]

In 2022, the X-59 was transported to Fort Worth, Texas, for key structural tests. Upon returning to its assembly facility in California, the aircraft has continued the assembly process, and more key research and tests were conducted.[19]

Air Traffic Management

NASA continued to transform the NAS in FY 2021 and FY 2022 through several Air Traffic Management research activities exploring how to improve airspace and airport operations by reducing emissions, saving fuel, reducing passenger delays, and easing airport operations.[20]

NASA initiated work toward the future transformation of the NAS through the announcement of its "Sky for All" vision. To help develop this vision, NASA has asked for broad community input through a publicly accessible website on what the future of air travel should look like by mid-century. After the website went live, NASA received a great volume of input from industry, academia, and other government agencies on how a futuristic mid-century NAS beyond the 2035 timeframe could come to fruition. Additionally, NASA held several successful virtual events and webinars.[21]

For nearer-term adoption, NASA transferred to the FAA procedures and technology developed by our Airspace Technology Demonstration project. Beginning in 2017, NASA investigated new methods to reduce emissions and delays in commercial aviation by using new air traffic management procedures at three major

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18 *https://www.nasa.gov/centers/armstrong/features/how-nasa-will-measure-quiet-supersonic-flight.html*, *https://www.nasa.gov/aeroresearch/feature/nasa-precise-positioning-system-for-supersonic-science*

19 *https://www.nasa.gov/aeroresearch/nasa-x-59-calls-on-texas-for-key-testing*, *https://www.nasa.gov/centers/armstrong/features/x-59-returns-to-california.html*, *https://www.nasa.gov/feature/low-speed-wind-tunnel-test-provides-important-data*

20 *https://www.nasa.gov/aeroresearch/programs/aosp*

21 *https://www.nasa.gov/aeroresearch/nasa-invites-collaboration-to-define-future-of-air-travel*, *https://nari.arc.nasa.gov/skyforall/*

U.S. airports. Now proven, these procedures were handed to the FAA to be implemented at 27 major airports across the country.[22]

Highlights from NASA ARMD's Programs

Advanced Air Vehicles Program

A one-megawatt electric motor that could help propel more environmentally friendly and economically sustainable aircraft was tested in 2021. The focus was on an electric machine that can work either as an electric motor to turn propellers and large engine fans or a generator to produce one million watts of power—enough to power 760 average U.S. households.[23]

Using its wind tunnels in 2021, NASA successfully created a new design for a wing's leading edge that can significantly reduce the noise created by large jets. Since airport landing fees are largely tied to noise levels, this could help reduce costs and quiet the noise for residents near airports.[24]

In 2022, NASA conducted its High Ice Water Content research activity through a flight series using its DC-8 Airborne Science Laboratory aircraft. The aircraft flew through large thunderstorms over the Gulf of Mexico and the Atlantic Ocean carrying researchers and experiments to study the conditions in which airborne ice crystals accumulate inside a jet engine. NASA is seeking to understand this phenomenon in order to provide jet engine manufacturers with the information they need to mitigate the issues associated with ice accumulation.[25]

Airspace Operations and Safety Program

In 2021, the Air Traffic Management–Exploration project completed its X3 series of flight demonstrations to enable Advanced Air Mobility operations and started the next series, X4. X3 focused on simulated scenarios in air traffic management

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22 *https://www.nasa.gov/press-release/nasa-transfers-air-traffic-management-tool-updates-to-faa/, https://www.nasa.gov/aeroresearch/programs/aosp/atd, https://www.nasa.gov/aeroresearch/nasa-testing-saves-airlines-one-million-gallons-of-jet-fuel, https://www.nasa.gov/feature/nasa-delivers-on-making-gate-to-gate-flights-more-efficient*

23 *https://www.nasa.gov/aeroresearch/nasa-tests-machine-to-power-the-future-of-aviation-propulsion*

24 *https://www.nasa.gov/feature/langley/nasa-tests-new-quiet-wing-design*

25 *https://www.nasa.gov/aeroresearch/nasa-studies-source-of-ice-crystals-in-high-places*

such as rerouting aircraft and taking off from vertiports, and X4 advances these tests by introducing more tasks such as information sharing.[26]

NASA established a research transition team with counterparts at the FAA in 2021 to explore upper Class E Traffic Management capabilities. Together, the group has worked on applying the successful work of the Unmanned Aircraft Systems Traffic Management project to the unique environment of upper Class E airspace, where military aircraft, remotely-piloted research aircraft, and perhaps soon commercial supersonic jets would share the same space.[27]

Integrated Aviation Systems Program

In 2021, NASA awarded grants to two U.S. companies to support the Electrified Powertrain Flight Demonstration (EPFD) project to help mature electrified aircraft propulsion. EPFD seeks to serve as a catalyst to introduce electrified aircraft propulsion to U.S. aviation fleets no later than 2035.[28]

The Systems Integration and Operationalization series, a collaboration with the FAA and industry, concluded in 2021. The series conducted flight demonstrations of unmanned aircraft systems (UAS) to demonstrate potential public and economic benefit of UAS operations. The final demonstration saw a remotely piloted aircraft inspect a gas pipeline over a rural area in California.[29]

Transformative Aeronautics Concepts Program

The Scalable Traffic Management for Emergency Response Operations (STEReO) team in 2021 conducted a successful workshop with wildfire experts in California on all the ways STEReO can help wildfire management and prevention efforts. The team also partnered with the U.S. Forest Service, conducting simulated flight tests of UAS using data from real-world firefighting aircraft.[30]

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26 *https://www.nasa.gov/feature/nasa-sets-stage-for-future-flights-auditions-advanced-air-mobility-tech*

27 *https://www.nasa.gov/aeroresearch/nasa-working-to-bring-air-mobility-vision-to-stratospheric-heights*

28 *https://www.nasa.gov/press-release/nasa-issues-contracts-to-mature-electrified-aircraft-propulsion-technologies*

29 *https://www.nasa.gov/centers/armstrong/features/gas-pipeline-inspections-simulated.html*

30 *https://www.nasa.gov/aeroresearch/wildfire-workshop-accelerates-nasa-firefighting-solutions*

The first round of University Leadership Initiative (ULI) grants began their project close-outs with NASA in 2021, having started in 2017. ULI is helping university researchers and students, and even younger kids, to become included in solving real-world aeronautical challenges. The sixth round of participants was announced in 2022.[31]

As part of the Convergent Aeronautics Solutions project, NASA researchers made significant progress in developing a novel solid-state battery during 2021 and 2022, exceeding their initial research goals and garnering interest from government, industry, and academia. Unlike lithium-ion batteries, which have liquid in their components, solid-state batteries do not overheat, catch fire, or lose capacity over time—making them a contender for use in electric airplanes.[32]

NASA Aeronautics at Home (STEM)

As the COVID-19 pandemic affected students of all ages, NASA's aeronautical educators offered a number of options online for kids and parents alike to stay busy and have fun using aviation-themed backgrounds during video calls, and in the process learn something more about NASA's work to improve aviation and make air travel safer. A few examples include a paper model and a 3D-printable model of the X-59 created by a NASA intern.[33]

In addition to these at-home activities, NASA Aeronautics offers educational activities and curriculum to educators year-round.[34]

Additional STEM and Workforce Development Highlights

In 2021, the Advanced Air Mobility project held a poster contest for kids in grades 6–12 who, in the spirit of transforming our skies, were challenged to create

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31 *https://www.nasa.gov/feature/nasa-s-university-initiative-showing-its-worth*, *https://www.nasa.gov/aeroresearch/uli-researchers-pay-it-forward-to-high-schoolers*

32 *https://www.nasa.gov/aeroresearch/nasa-solid-state-battery-research-exceeds-initial-goals-draws-interest*

33 *https://www.nasa.gov/aero-at-home*, *https://www.nasa.gov/aero/coloring-pages/*, *https://www.nasa.gov/aero/virtualbackgrounds*, *https://www.nasa.gov/aeroresearch/resources/k-12*, *https://www.nasa.gov/connect/ebooks/aeronautics_ebooks_archive_1.html*, *https://www.nasa.gov/sites/default/files/atoms/files/x-59-paper-desktop-model_1.pdf*, and *https://www.nasa.gov/feature/x-59-3d-printing*

34 *https://www.nasa.gov/aeroresearch/new-aeronautics-activities-for-the-back-to-school-season*

an original artistic depiction of what Advanced Air Mobility looks like and how it is being accomplished. The project also held a career day with several speakers from NASA to help inspire, educate, and involve prospective aeronautical innovators.[35]

Starting in 2021, the Quesst mission created an ongoing interview series named The Quiet Crew, which showcases a member of the team of aeronautical innovators working on the X-59 or another aspect of the Quesst mission.[36]

NASA Aeronautics' Strategic Communications team created successful outreach initiatives, products, and resources to spread the word of NASA's aeronautics research activities. For example, the Dream with Us design challenge asked students across the United States to come up with original designs and concepts for the future of aviation, and winners were announced in 2022. In 2022, NASA Aeronautics launched the new Flight Log Experience. Participants who sign up online build their own flight log, including having their names flown onboard NASA's research aircraft, X-planes, and other Advanced Air Mobility flights. Each participant receives a printable, shareable "boarding pass" upon completion of the flight, and opportunities to earn "endorsement" badges for the completion of STEM-related activities.[37]

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35 *https://www.nasa.gov/aeroresearch/advanced-air-mobility-holding-poster-contest*, *https://www.nasa.gov/feature/advanced-air-mobility-career-day-held-in-may*

36 *https://www.youtube.com/playlist?list=PLiuUQ9asub3QzXTLxiWkei0b_2FAO6NqM*

37 *https://www.nasa.gov/aeroresearch/dream-with-us-design-challenge*, *https://www.nasa.gov/aeroresearch/dream-with-us-2022-winners*, *https://www.nasa.gov/aeroresearch/sign-up-to-fly-with-nasa-using-the-flight-log-experience*, *https://www.nasa.gov/flightlog/*

Space Technology Mission Directorate

Technology drives exploration and the space economy. NASA's Space Technology Mission Directorate (STMD) aims to transform future missions while ensuring American leadership in aerospace.[38] STMD's portfolio structure and programs develop, demonstrate, and transfer new space technologies that benefit NASA, commercial, and other government missions. STMD supports and invests in diverse ideas from entrepreneurs, researchers, and innovators across the country, providing solutions to challenges on Earth and in space.

In FY 2021 and FY 2022, NASA's investments in space technology demonstrated and advanced new capabilities, supported prize competitions, and initiated partnerships that helped solve complex challenges needed to fulfill the agency's goals in space.

The Perseverance Rover

After a seven-month journey, the Perseverance rover landed safely on Mars on February 18, 2021. Since landing, technologies on the rover have helped achieve science objectives and prepare for future robotic and human exploration. Many STMD programs supported research, testing, and development of various instruments, and funded two landing systems and two technology demonstrations:

- NASA's Perseverance rover was able to use its new Terrain-Relative Navigation technology to avoid hazards and find a safe place to land in Jezero Crater on Mars.[39] The system allowed the descending robot to visually map the Martian landscape, identify hazards, and then choose a safe place to land without human assistance. The autonomous system allows for safer landing in areas with hazardous terrain during future missions to the Moon, Mars, and beyond.
- The Mars Entry, Descent, and Landing Instrumentation (MEDLI) 2 collected temperature and pressure measurements on the heat shield and

38 *https://www.nasa.gov/directorates/spacetech/home/index.html*

39 *https://www.nasa.gov/directorates/spacetech/Terrain_Relative_Navigation*

backshell during entry and descent as the spacecraft slowed from 12,500 mph to just under two mph in six minutes. They are NASA's first-ever measurements of heat experienced by the backshell of an entry vehicle. All the sensors operated as expected during landing—every sensor returned a clean, high-quality signal. Post-landing, the MEDLI2 team analyzed the flight data to reconstruct the entry environment, vehicle aerodynamics, and atmospheric properties. The results will feed forward into the design of future missions, such as Mars Sample Return and Dragonfly.

- The Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) is demonstrating a new, critical capability: producing oxygen directly from the carbon dioxide–rich atmosphere. This technology is the first step to providing air for breathing, but more importantly, the vast quantities of oxygen needed to burn as fuel for rocket propellant for the long return flight home from Mars. Its first successful demonstration was in April 2021.[40] As of November 2022, MOXIE completed 12 runs and, during its 11th, hit a record when it briefly produced oxygen at a rate of nearly 10.5 grams per hour. MOXIE has produced a cumulative total of 140 minutes of breathable oxygen for an astronaut.
- The Mars Environmental Dynamics Analyzer (MEDA) weather station contains a suite of environmental sensors to record dust levels and six atmospheric conditions: wind (both speed and direction), pressure, relative humidity, air temperature, ground temperature, and radiation (from both the Sun and space). While on Mars, MEDA has continuously measured the wind, ultraviolet, infrared radiation, the temperature profile in the lower atmosphere, pressure, and relative humidity, and it has also imaged the Martian sky. With each of the recorded sols, the team generates short weather reports.[41] With MEDA's weather reports, engineers now have atmospheric data from three different locations on the Red Planet, the locations of Perseverance, Curiosity, and NASA's InSight lander, which hosts the Temperature and Wind sensors for InSight (TWINS).

40 *https://www.nasa.gov/press-release/nasa-s-perseverance-mars-rover-extracts-first-oxygen-from-red-planet*

41 *https://mars.nasa.gov/mars2020/weather/*

The trio of weather stations has enabled a deeper understanding of Martian weather patterns, events, and atmospheric turbulence that could influence planning for future missions. MEDA's information has also helped decide the best atmospheric conditions for the Mars Helicopter Ingenuity flights.

Public-Private Partnerships

On October 14, 2020, STMD announced its selection of 14 American companies, including several small businesses, as partners to develop a range of technologies to help forge a path to sustainable Artemis operations on the Moon by the end of the decade.[42] U.S. industry submitted the proposals to the fifth competitive Tipping Point opportunity, and the selections had a combined award value of about $370 million.

On November 10, 2020, STMD announced its selection of 17 U.S. companies for 20 partnerships to mature industry-developed space technologies for the Moon and beyond through the 2020 Announcement of Collaboration Opportunity (ACO).[43] NASA and industry teams will design a 3D printing system for NASA's Artemis lunar exploration program, test a simple method for removing dust from planetary solar arrays, mature a first-stage rocket recovery system for a small satellite launch provider, and more. The partnerships employ unfunded Space Act Agreements to accelerate the development of emerging space capabilities. In February 2022, STMD released Announcements for Partnership Proposals (AFPP) to advance Tipping Point technologies and ACO to be selected in 2023.

Technology Demonstrations

The Green Propellant Infusion Mission (GPIM) spacecraft also came to a successful end and re-entered Earth's atmosphere on October 20, 2020.[44] While in

42 *https://www.nasa.gov/press-release/nasa-announces-partners-to-advance-tipping-point-technologies-for-the-moon-mars/*

43 *https://www.nasa.gov/press-release/new-nasa-partnerships-to-mature-commercial-space-technologies-capabilities*

44 *https://www.nasa.gov/mission_pages/tdm/green/gpim-nears-completion.html*

orbit, GPIM tested a monopropellant, called the Advanced Spacecraft Energetic Non-Toxic (ASCENT), and propulsion system, including the thrusters, tanks, and valves, by conducting a planned series of 40 orbital maneuvers. GPIM successfully proved that a never-before-used propellant and propulsion system work as intended, demonstrating both are practical options for future missions. The mission demonstrated the propellant's projected performance, showing a 50 percent increase in gas mileage for the spacecraft compared to hydrazine.

On September 18, 2021, after over two years of pushing the timekeeping frontiers in space, NASA's Deep Space Atomic Clock mission came to a successful end.[45] The payload validated a miniaturized, ultra-precise, mercury-ion atomic clock that is orders of magnitude more stable than today's best spacecraft clocks.

STMD continued advancing In-space Servicing, Assembly and Manufacturing (ISAM) technologies for future flight demonstrations.[46] In December 2021, Redwire completed its Mission Design Review for the On-orbit Servicing, Assembly, and Manufacturing-2 (OSAM-2) technology demonstration. In February 2022, OSAM-1 successfully completed a Mission Critical Design Review. The milestone demonstrated that the maturity of the design for the spacecraft is appropriate to support proceeding with fabrication, assembly, integration, and testing.

The Laser Communications Relay Demonstration (LCRD) mission is revolutionizing the way we send and receive data, video, and other information, using lasers to encode and transmit data at rates 10–100 times faster than today's fastest radio-frequency systems, with significantly less mass and power. While other NASA efforts have used optical communications, this is NASA's first relay system using optical entirely, giving NASA the opportunity to test this method of communications and learn valuable lessons from its implementation. The payload launched aboard the U.S. Department of Defense Space Test Program-3 mission on December 7, 2021.[47] The LCRD payload completed the mission activation phase and proceeded into the experiment phase in June 2022.[48]

45 *https://www.nasa.gov/feature/jpl/working-overtime-nasa-s-deep-space-atomic-clock-completes-mission*

46 *https://nexis.gsfc.nasa.gov/isam/index.html*

47 *https://www.nasa.gov/press-release/nasa-s-laser-communications-tech-science-experiment-safely-in-space-0*

48 *https://www.nasa.gov/feature/goddard/2022/the-future-of-laser-communications*

The goal of the Deep Space Optical Communications (DSOC) technology demonstration is to test the viability of laser communications capabilities for deep space exploration.[49] Engineers completed integrating the DSOC payload with the Psyche mission spacecraft and completed ground environmental testing in FY 2022. In June 2022, NASA announced a delay of the Psyche mission launch attempt, which was unrelated to the DSOC payload.[50] The DSOC technology demonstration will continue as planned on the new Psyche asteroid mission launch target date in October 2023.

The Cryogenic Fluid Management (CFM) Portfolio project seeks to mature technologies essential to NASA's future missions in science and exploration that utilize both chemical and nuclear in-space propulsion, landers, and in situ resource utilization. Significant accomplishments through FY 2021 and FY 2022 included the completion of thermodynamic testing in May 2022 of a 20W 20K cryocooler, which demonstrated the desired lift capacity and specific mass key performance parameters. Four 2020 CFM Tipping Points contracts were executed with Eta Space, SpaceX, Lockheed Martin, and United Launch Alliance (ULA), making technical progress through design reviews and preparing for the first flight demonstration of the portfolio.

In FY 2021, two key components of the Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID), the flexible thermal protection system and inflatable structure, were completed and delivered to NASA's Langley Research Center in Hampton, Virginia.[51] Over the course of the year, engineers tested the complete system to ensure LOFTID was flight ready for its launch on a ULA Atlas V rocket as part of the National Oceanic and Atmospheric Administration Joint Polar Orbiting Satellite System-2 mission in November 2022. In September 2021, NASA and ULA dedicated the LOFTID mission to Bernard Kutter, ULA's manager of advanced programs, who passed away in 2020 and had been a key champion of the technology.

NASA led an effort, working with the Department of Energy (DOE), to advance Space Nuclear Technologies. The government team released a request for proposals

49 *https://www.nasa.gov/mission_pages/tdm/dsoc/index.html*

50 *https://www.nasa.gov/press-release/nasa-announces-launch-delay-for-psyche-asteroid-mission*

51 *https://www.nasa.gov/low-earth-orbit-flight-test-of-an-inflatable-decelerator*

and, in July 2021, selected three reactor design concept proposals for a nuclear thermal propulsion system.[52] The reactor is a critical component of a nuclear thermal engine, which would utilize high-assay low-enriched uranium fuel. The contracts, awarded through the DOE's Idaho National Laboratory (INL), were each valued at approximately $5 million. The companies will produce a conceptual reactor design that could support future mission needs:

- BWX Technologies, Inc., of Lynchburg, Virginia (the company partnered with Lockheed Martin).
- General Atomics Electromagnetic Systems of San Diego (the company partnered with X-energy LLC and Aerojet Rocketdyne).
- Ultra Safe Nuclear Technologies of Seattle (the company partnered with Ultra Safe Nuclear Corporation, Blue Origin, General Electric Hitachi Nuclear Energy, General Electric Research, Framatome, and Materion).

In June 2022, NASA and DOE, working together to advance Space Nuclear Technologies, announced the selection of three design concept proposals for a fission surface power system design that could be ready to launch by the end of the decade for a demonstration on the Moon.[53] DOE's Idaho National Laboratory awarded 12-month contracts to the following companies to each develop preliminary designs:

- Lockheed Martin of Bethesda, Maryland (the company partnered with BWXT and Creare).
- Westinghouse of Cranberry Township, Pennsylvania (the company partnered with Aerojet Rocketdyne).
- IX of Houston, Texas, a joint venture of Intuitive Machines and X-Energy (the company partnered with Maxar and Boeing).

The contracts, awarded through the DOE's Idaho National Laboratory, are each valued at approximately $5 million. The contracts fund the development of initial design concepts for a 40-kilowatt class fission power system planned to last at least ten years in the lunar environment.

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52 *https://www.nasa.gov/press-release/nasa-announces-nuclear-thermal-propulsion-reactor-concept-awards*

53 *https://www.nasa.gov/press-release/nasa-announces-artemis-concept-awards-for-nuclear-power-on-moon/*

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 has awarded more than $300 million through STMD programs to establish collaborations across industry and academia.
- In March 2021, NASA selected five companies to mature vertically deployable solar array systems for the lunar surface under the Vertical Solar Array Technology (VSAT) project.[55] In August 2022, NASA selected three companies—Astrobotic Technology, Honeybee Robotics, and Lockheed Martin—to further advance work on deployable solar array systems that will help power the agency's human and robotic exploration of the Moon under Artemis.[56] The agency will award a total of $19.4 million to three companies to build prototypes and perform environmental testing, with the goal of deploying one of the systems near the Moon's South Pole near the end of this decade.
- In March 2021, STMD expanded its partnership with the Johns Hopkins Applied Physics Laboratory (APL) to provide science and engineering integration expertise for lunar surface technology maturation. APL continued to operate the Lunar Surface Innovation Consortium (LSIC) through FY 2022, convening monthly focus groups and hosting workshop groups focused on lunar surface technology development.[57] LSIC meetings were held biannually in the spring and fall with different capability focus areas.
- In March 2021, NASA announced six inaugural Lunar Surface Technology Research (LuSTR) awards.[58] The grants of up to $2 million over two years, made to U.S. universities, sought to advance technologies

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54 *https://www.nasa.gov/directorates/spacetech/Lunar_Surface_Innovation_Initiative*

55 *https://www.nasa.gov/feature/nasa-industry-to-mature-vertical-solar-array-technologies-for-lunar-surface*

56 *https://www.nasa.gov/press-release/three-companies-to-help-nasa-advance-solar-array-technology-for-moon*

57 *https://lsic.jhuapl.edu/*

58 *https://www.nasa.gov/directorates/spacetech/strg/lustr*

related to in situ resource utilization and power systems needed for sustainable operations on the Moon. In February 2022, three LuSTR grants were awarded to U.S. universities to advance autonomous construction, resource extraction, and extremely cold electronics technologies needed for sustainable operations on the Moon.

Game Changing Development

The Safe and Precise Landing Integrated Capabilities Evolution (SPLICE) project is a suite of precision landing and hazard-avoidance technologies.[59] The system consists of a high-performance computer, lasers, a camera, and other sensors. SPLICE could be used by planetary spacecraft to avoid boulders, craters, and other obstacles in landing areas. Through FY 2021, SPLICE was tested on two Blue Origin New Shepard rocket flights, which enabled the advancement of the navigation system for use on the Moon on commercial landers.

The Polar Resources Ice Mining Experiment-1 (PRIME-1) consists of a lunar drill and mass spectrometer.[60] In October 2021, NASA selected Intuitive Machines of Houston to deliver PRIME-1 to the Moon under the agency's Commercial Lunar Payload Services initiative. The delivery of the ice-mining experiment will help NASA search for ice at the Moon's South Pole and, for the first time, harvest water from below the surface. On November 3, 2021, NASA and Intuitive Machines announced the landing site location for PRIME-1, located at the lunar South Pole on a ridge not far from Shackleton crater.[61] The team continued working toward delivery of PRIME-1 hardware to Intuitive Machines in the summer of 2023.

The Moon to Mars Planetary Autonomous Construction Technology (MMPACT) project aims to develop, deliver, and demonstrate on-demand capabilities to protect astronauts and create infrastructure on the lunar surface via construction of landing pads, habitats, shelters, roadways, and more using lunar regolith-based materials. In October 2020, NASA announced it is working with Austin-based construction technologies startup ICON via MMPACT on early

59 *https://www.nasa.gov/directorates/spacetech/game_changing_development/projects/SPLICE/about*

60 *https://www.nasa.gov/directorates/spacetech/game_changing_development/projects/PRIME-1/*

61 *https://www.nasa.gov/feature/nasa-intuitive-machines-announce-landing-site-location-for-lunar-drill/*

research and development of a space-based construction system that could support future exploration of the Moon and Mars. ICON is testing lunar soil simulant with various processing and printing technologies. In March 2021, a team of students from colleges and universities across the United States tested a 3D-printed launch and landing pad to see how it holds up to a hot rocket engine at Camp Swift in Bastrop, Texas.[62] The team won funding to print and test a small-scale prototype with help from the MMPACT project, ICON, and the Sounding Rocketry Team at Texas A&M University in College Station.

The Integrated System for Autonomous and Adaptive Caretaking (ISAAC) team is developing autonomous software to help monitor and maintain exploration spacecraft and habitats during long-duration deep space missions, particularly during extended periods when astronauts are away.[63] In April 2021, Bumble, one of the free-flying Astrobee robots aboard the International Space Station, was put to the test to investigate a simulated anomaly. In the simulation, the station's life support systems detected a high concentration of carbon dioxide.[64] Bumble navigated the station to find the location designated as a "vent" and used computer vision to automatically detect the foreign object blocking the vent, an "astronaut sock." Bumble called for help to clear the blockage. Additionally, Bumble completed a survey of part of the space station's Japanese Exploration Module and built a high-resolution multi-sensor 3D map. It ultimately persevered and completed its mission objectives, with a little timely help from ground operators. The demonstrations marked the end of the first phase of testing for the ISAAC software.

In August 2022, STMD and NASA's Jet Propulsion Laboratory in Southern California selected Microchip Technology Inc. of Chandler, Arizona, to develop a High-Performance Spaceflight Computing processor that will provide at least 100 times the computational capacity of current spaceflight computers.[65] This key capability would advance all types of future space missions, from planetary exploration to lunar and Mars surface missions.

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62 *https://www.nasa.gov/centers/marshall/news/releases/2021/nasa-partners-test-3d-printed-rocket-pad-designed-by-artemis-generation-students.html*

63 *https://www.nasa.gov/directorates/spacetech/game_changing_development/projects/ISAAC*

64 *https://www.nasa.gov/collection-asset/integrated-system-for-autonomous-and-adaptive-caretaking-research-project-completes*

65 *https://www.nasa.gov/press-release/nasa-awards-next-generation-spaceflight-computing-processor-contract/, https://www.nasa.gov/directorates/spacetech/game_changing_development/projects/HPSC/*

Small Spacecraft Technology

The Small Spacecraft Technology program launched two successful technology demonstrations, the first Pathfinder Technology Demonstrator (PTD-1) and V-R3x, in January 2021.[66] The projects were facilitated by the program's Payload Accelerator for CubeSat Endeavors (PACE) initiative. PTD-1 became the first to demonstrate a water-based electrolysis propulsion system on any type of spacecraft. The V-R3x trio of three CubeSats demonstrated new technologies and techniques for radio networking and navigation.

The Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) technology demonstration launched aboard Rocket Lab's Electron rocket from the Rocket Lab Launch Complex 1 on the Mahia Peninsula of New Zealand on June 28, 2022.[67] CAPSTONE will serve as the first spacecraft to test a unique, elliptical lunar orbit. As a pathfinder for Gateway, a Moon-orbiting outpost that is part of the Artemis program, CAPSTONE will help reduce risk for future spacecraft by validating innovative navigation technologies and verifying the dynamics of this halo-shaped orbit. CAPSTONE navigated an unusual yet efficient deep space route to the Moon. This route, called a ballistic lunar transfer, or BLT, follows gravitational contours in deep space and allows spacecraft to reach their destination expending little energy. The trajectory was designed by Advanced Space, a Colorado small business that owns and operates CAPSTONE on behalf of NASA. Toward the end of FY 2022, CAPSTONE performed six maneuvers to line up its trajectory for orbit insertion, with the team adapting to unexpected challenges to keep CAPSTONE on track to the spacecraft's arrival to the Moon.

The TeraByte InfraRed Delivery (TBIRD) communications system launched on May 25, 2022, as part of the Pathfinder Technology Demonstrator (PTD) series of missions that will test the operation of a variety of novel CubeSat technologies in low-Earth orbit.[68] Aboard PTD-3, the second to launch in the series, TBIRD

66 *https://www.nasa.gov/directorates/spacetech/small_spacecraft/Pathfinder_Technology_Demonstrator/*, *https://www.nasa.gov/ames/v-r3x*

67 *https://www.nasa.gov/directorates/spacetech/small_spacecraft/capstone*, *https://www.nasa.gov/press-release/capstone-launches-to-test-new-orbit-for-nasa-s-artemis-moon-missions*

68 *https://www.nasa.gov/feature/goddard/2022/cubesat-set-to-demonstrate-nasas-fastest-laser-link-from-space*

has already demonstrated a 100 Gbps optical downlink and is intended to achieve 200 Gbps data downlink rate, which will be the fastest ever optical downlink from low-Earth orbit.

The CubeSat Proximity Operations Demonstration (CPOD) mission will demonstrate for the first time an entire sequence of rendezvous, proximity operations, and docking (RPOD) maneuvers using two 3U CubeSats.[69] This flight demonstration will validate and characterize miniature low-power proximity operations technologies applicable to future missions. CPOD was launched on May 25, 2022, and preparations for the demonstration continued through the end of the fiscal year.

The CubeSat Laser Infrared CrosslinK (CLICK) mission will demonstrate technology to advance communication between small spacecraft as well as the capability to gauge their relative distance and location.[70] CLICK A, the first of two sequential demonstrations, is a risk reduction mission that will test elements of the optical communications system with a single 3U CubeSat. CLICK B/C will subsequently demonstrate full-duplex optical communication crosslink between two 3U CubeSats in low-Earth orbit. CLICK-A was launched to the International Space Station on July 14, 2022, and deployed on September 6. Spacecraft commissioning is complete, and the mission team continued preparing for the demonstration through the end of the fiscal year.

NASA awarded a contract to Rocket Lab USA to launch the Advanced Composite Solar Sail System (ACS3) from New Zealand in summer 2023.[71] The ACS3 demonstration will test the in-space deployment of composite boom technology. When deployed, ACS3's four composite booms support an 80-square-meter aluminized polymer solar sail, which will produce thrust from reflected sunlight. The ACS3 team completed receipt testing on ACS3's spacecraft bus, flight dispenser fit-check, and continued boom fabrication through FY 2022.

69 *https://www.nasa.gov/directorates/spacetech/small_spacecraft/cpod_project.html*

70 *https://www.nasa.gov/directorates/spacetech/small_spacecraft/cubesat_laser_infrared_crosslink/*

71 *https://www.nasa.gov/directorates/spacetech/small_spacecraft/ACS3*

Flight Opportunities

The Flight Opportunities program rapidly demonstrates promising technologies for space exploration, discovery, and the expansion of space commerce.[72]

- In FY 2021, the Flight Opportunities program supported 84 tests of technology payloads via flights with commercial suborbital providers, including nine flights on rocket-powered vehicles, nine high-altitude balloon flights, and 14 parabolic flights. U.S. commercial vendors providing flight services in the fiscal year included AM0CAL, Blue Origin, Masten Space Systems, Near Space Corp., Raven Aerostar, UP Aerospace, Virgin Galactic, World View, and Zero Gravity Corporation.
- In FY 2022, the Flight Opportunities program supported 97 tests of technology payloads via 27 flights with commercial suborbital providers. These tests advanced technologies across a variety of disciplines and applications, including in-space manufacturing techniques, an atmospheric sensor for collecting climate data, innovations for sustaining human health in space, a payload return capsule, and small spacecraft systems. U.S. commercial vendors that successfully flew Flight Opportunities–supported payloads included Astrobotic (formerly Masten Space Systems), Near Space Corporation, Aerostar, World View, and Zero Gravity Corporation.

In FY 2022, in partnership with the Small Spacecraft Technology program, Flight Opportunities began offering researchers access to flight tests for payloads hosted on orbital platforms through its annual TechFlights solicitation.[73]

Winners of the inaugural NASA TechLeap Prize, Autonomous Observation Challenge No. 1, tested their technologies on high-altitude balloon flights in Summer 2022, less than a year after the competition was launched.[74] The challenge asked innovators to propose observation technologies that could be used on small spacecraft to autonomously detect, locate, track, and collect data on transient events on Earth and beyond. Flight Opportunities also launched its second TechLeap competition, Nighttime Precision Landing Challenge No.1, in February

72 *https://www.nasa.gov/directorates/spacetech/flightopportunities/index.html*

73 *https://www.nasa.gov/center/armstrong/features/space-tech-for-suborbital-flight.html*

74 *https://www.nasa.gov/centers/armstrong/features/techleap-challenge-winners-advance.html*

2022, to identify low-cost sensing systems that can map terrain like the Moon's rocky surface in the dark from an altitude of 250 meters or higher.[75] Three winners were selected in July 2022, with flight tests planned for Spring 2023.

Early Stage Innovations and Partnerships

NASA's Small Business Innovative Research (SBIR)/Small Business Technology Transfer (STTR) program invested more than $411 million in small businesses and research institutions in FY 2021 and FY 2022.[76] Specifically, 583 SBIR and 109 STTR Phase I contracts were awarded to 585 U.S. small businesses and research institutions to establish the scientific, technical, and commercial feasibility of each proposed innovation. Additionally, the program made 266 SBIR and 42 STTR Phase II awards to further expand upon prior Phase I work. More than $83 million was awarded via post-Phase II opportunities to continue technology development towards a NASA mission and/or commercialization. In FY 2022, 24 percent of the selected research institutions were classified as Minority Serving Institutions and 25 percent of the selected small businesses were from underrepresented groups, including minority- and women-owned businesses.

In June 2021, astronauts installed new ISS Roll-Out Solar Arrays (iROSA) on the space station.[77] The technology was supported by multiple awards from the NASA SBIR/STTR program to Deployable Space Systems dating back to 2009. The company has since been acquired by large business Redwire Corporation. STMD investments also supported a ground demonstration in 2014.

Since its inception in FY 2011, Space Technology Research Grants (STRG) has funded exciting space technology research via 936 grants at 123 universities across 45 states and Puerto Rico.[78] Two new Space Technology Research Institutes were selected in FY 2021:[79]

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75 *https://www.nasa.gov/centers/armstrong/features/techleap-lunar-landings.html*

76 *https://sbir.nasa.gov/*

77 *https://www.nasa.gov/directorates/spacetech/Rolling_Out_a_Path_to_Future_Space_Travel*

78 *https://www.nasa.gov/strg*

79 *https://www.nasa.gov/directorates/spacetech/strg/New_Space_Tech_Research_Institutes_to_Advance_Electric_Propulsion_Entry_Systems*

- The Advanced Computational Center for Entry System Simulation (ACCESS) Institute will advance the analysis and design of NASA entry systems by developing a fully integrated, interdisciplinary simulation capability focusing on thermal protection systems and prediction of the extreme environments experienced during atmospheric entry.
- Joint Advanced Propulsion Institute (JANUS) will work to overcome limitations in ground testing of high-power electric propulsion systems and to improve our understanding of the reliability and performance of these devices when operating in the vacuum of space.

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.[80] Each year, these visionary ideas from innovators across America are chosen for their potential to revolutionize future NASA missions through development of bold, but credible, early-stage breakthrough technologies.

- In FY 2021, NIAC awarded sixteen Phase I awards, six Phase II awards, and one Phase III award totaling $7 million across industry, academia, and NASA centers. Fellows completed sixteen 2020 Phase I studies, six 2019 Phase II studies, and two 2019 Phase III studies.
- In FY 2022, NIAC awarded twelve Phase I awards, five Phase II awards, and one Phase III award totaling $7.1 million across industry, academia, and NASA centers. Fellows also completed sixteen 2021 Phase I studies, six 2020 Phase II studies, and one 2020 Phase III study.

Prizes, Challenges, and Crowdsourcing (PCC) conducts and promotes the use of prize competitions, challenges, and crowdsourcing projects as tools to advance NASA R&D and serve other mission needs. The program had banner years in FY 2021 and FY 2022, working on 106 projects, receiving 10,910 solutions, and awarding more than $8.2 million using procurement and prize authorities. NASA employees who used the PCC toolkit to solve a problem or meet a need reported a collective savings to NASA of almost $5 million when compared to using traditional methods.

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80 *https://www.nasa.gov/directorates/spacetech/niac/index.html*

PCC contributed to agency exploration priorities, facilitating several short- and long-duration challenges that will enable a long-term presence at the Moon and future human exploration of deep space destinations. Challenges like Lunar TORCH and Watts on the Moon awarded over $500 thousand to members of the public for ideas on power management.[81] Others like Space Robotics and Break the Ice Lunar Challenge awarded over $1 million for lunar excavation and resource transportation.[82] Even further, challenges like the CO_2 Conversion Challenge, Vascular Tissue Challenge, and Deep Space Food Challenge provided a head start on solving deep space issues where resources are scarce. [83]

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.[84] Since its inception in 2011, CIF has transitioned more than 250 projects to other NASA programs, industry partners, academia, and other government agencies. The program has generated over 300 NASA New Technology Reports and 350 publications, 90 patents and patent-pending applications, over a dozen commercial licenses, and 2 spin-off companies. Recent CIF highlights include the award of a patent for a print-assisted photovoltaic assembly that has recently been licensed by Astrobotic for lunar surface missions, industry partner commercialization of a compact fiber optic sensing system previously developed for use on multiple NASA platforms, and superconducting readout circuit for superconducting nanowire single photon detectors (SNSPD) arrays that led to a collaboration with MIT and NIST. This latter project received a $5 million DARPA award to develop large-format SNSPD focal plane arrays and superconducting electronics.

As an element of CIF, the Early Career Initiative (ECI) provides the opportunity for NASA early career civil servants to propose and work on two-year technology

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81 *https://www.nasa.gov/lunar-torch-challenge-winners, https://www.nasa.gov/directorates/spacetech/centennial_challenges/watts-on-the-moon/index.html*

82 *https://www.nasa.gov/directorates/spacetech/centennial_challenges/space_robotics/index.html, https://www.nasa.gov/directorates/spacetech/centennial_challenges/break-the-ice/index.html*

83 *https://www.nasa.gov/directorates/spacetech/centennial_challenges/co2challenge/index.html, https://www.nasa.gov/directorates/spacetech/centennial_challenges/vascular_tissue.html, https://www.nasa.gov/directorates/spacetech/centennial_challenges/spacefood/index.html*

84 *https://www.nasa.gov/directorates/spacetech/innovation_fund/index.html*

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 25 highly innovative projects through FY 2022 and recently selected 5 new projects to start in FY 2023. To date ECI projects have published over 80 papers and 19 NASA New Technology Reports, resulting in 3 U.S. patents with an additional 5 patent applications pending. Highlights for FY 2022 include the completion of a thermal control heat pipe system that will be flown on the commercial Astrobotic Peregrine 1 mission, the development of advanced rotor blades for a Mars rotorcraft currently being evaluated for use on the Mars Sample Return Helicopter, and a NASA Science Mission Directorate PICASSO award to further develop a planetary sensor package based on ECI-developed multifunctional nanosensor technology. Designed to invigorate NASA's technology base and champion innovative management processes, NASA's early career innovators continue to deliver advanced hardware solutions to invigorate our national aerospace mission capabilities.

In FY 2021 and FY 2022, the NASA Technology Transfer (T2) program saw record-breaking years of transferring technologies and software to industry and entrepreneurs.[85] T2 executed 400 licensing agreements, with 211 in FY 2021, the most the program had ever achieved in a fiscal year. T2 released a record-breaking 10,209 software usage agreements (SUAs). NASA's Spinoff publication launched a revamped website to coincide with the 2020 release of the new book.[86] The 2021 edition featured success stories of 45 companies using NASA technology, expertise, and research to create new products and services for consumers across the world.

STEM Engagement

NASA's Breakthrough, Innovative, and Game Changing (BIG) Idea Challenge, now in its eighth year, invites university students to tackle some of the most critical needs facing space exploration and to propose unique technology solutions. BIG Idea is sponsored by NASA through a collaboration between STMD's Game

85 *https://technology.nasa.gov/*

86 *https://spinoff.nasa.gov/spinoff/archives*

Changing Development program and the Office of STEM Engagement's National Space Grant College and Fellowship Project program. Throughout FY 2021 and FY 2022, activities spanned four different challenge cycles focused on lunar exploration technology concepts like dust mitigation solutions and innovative robotic systems that go beyond traditional wheeled rovers and move in different ways. In August 2022, NASA launched the 2023 competition, which invites students to design a metal production line on the Moon—from extracting metal from lunar minerals to creating structures and tools.[87]

In 2021, NASA launched the TechRise Student Challenge, inviting teams of students in grades 6 through 12 to design, build, and launch climate, remote-sensing, and space exploration experiments on suborbital rockets and high-altitude balloon flights.[88] TechRise is sponsored and managed by STMD's Flight Opportunities program.

- In January 2022, NASA selected 57 winning teams in the first TechRise Student Challenge.[89] These represented more than 600 students in grades 6 through 12 from 37 U.S. states and territories. Winning proposals included measurement of greenhouse gases, space farm irrigation systems, lunar dust mitigation, exploration of human health in space, and examination of the effects of microgravity on physical phenomena ranging from the behavior of waves in liquids to the effectiveness of ink jet printing. Throughout 2022, students worked with TechRise technical advisors to build their payloads, which are slated to fly on a suborbital rocket or high-altitude balloon flight test in 2023.
- In August 2022, NASA launched the second TechRise Challenge for student teams to submit experiment ideas for high-altitude balloon flight tests. Winners will be announced in January 2023.

STMD continued to support outreach to underrepresented and underserved communities in STEM, including working with NASA's Minority University Research and Education Project (MUREP). In July 2021, the MUREP Space Technology Artemis Research, or M-STAR, initiative awarded cooperative

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87 *https://www.nasa.gov/feature/nasa-seeks-student-ideas-for-extracting-forging-metal-on-the-moon*

88 *https://www.nasa.gov/techrise-student-challenge*

89 *https://www.nasa.gov/press-release/nasa-seeks-student-experiments-to-soar-in-second-techrise-challenge*

agreements to seven Minority Serving Institutions, including two Historically Black Colleges and Universities, for projects that will support STMD and advance lunar technologies.[90] Nearly $3.5 million was to be distributed to the selected universities over two years. M-STAR is the result of STMD's continued partnership with MUREP, supporting the agency's efforts to broaden participation and support diversity, equity, inclusion, and accessibility across NASA. In FY 2022, STMD supported the HBCU/MSI Technology Infusion Road Tour with senior leadership presenting at three different virtual and hybrid road tour events in November 2021, April 2022, and September 2022.

First Woman **Graphic Novel**

October 2021 marked the launch of NASA's first interactive graphic novel, *First Woman: NASA's Promise for Humanity*.[91] The print and digital versions of the graphic novel were made available in English and Spanish, with an audio version of the story on NASA's SoundCloud and an application with extended reality features in the Apple and Google Play stores. 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. The graphic novel's protagonist, Callie Rodriguez, is a female astronaut of Afro-Latina heritage who becomes the first woman on the Moon.

90 *https://www.nasa.gov/stem/murep/projects/mstar.html, https://www.nasa.gov/stem/murep/mstar/feature/nasa-awards-grants-to-minority-serving-institutions-to-support-artemis-space-tech*

91 *https://www.nasa.gov/specials/calliefirst/*

Department of Defense

DOD

Aeronautics

Rotorcraft

Army

Army Aviation remains committed to modernization and readiness advancements to increase the capabilities and lethality of Aviation forces in multi-domain operations and large-scale combat operations. The Aviation enterprise is doing this while maintaining a global presence and ensuring world-class support to soldiers on the ground and our multi-national partners. Army Aviation remains deployed in support of U.S. Central Command (USCENTCOM), U.S. European Command, and U.S. Indo-Pacific Command (USINDOPACOM). While supporting these deployments, aviation formations conduct home station training for their assigned Divisions and Brigade Combat Teams focused on large-scale combat operations, support humanitarian assistance and disaster relief efforts, and train for other contingencies.

The Army continues 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 ensure that Army aircraft provide capability for decades to come. Unmanned Aircraft Systems (UAS) modernization includes improvements to the MQ-1C Gray Eagle and the RQ-7B Shadow, supporting enhanced crewed-uncrewed 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 works closely with industry and is already integrating new technologies into the current force.

The AH-64D/E is the Army's attack and reconnaissance helicopter. The Army continues to field the newest AH-64E version 6 to active and National Guard units. The Army recently completed fielding the AH-64E Version 6 to Army units in Korea and the South Carolina National Guard. Fielding of Version 6 will continue in FY 2023 and beyond. 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 Crewed/Uncrewed 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 Black Hawk is the Army's combat utility helicopter. This flexible system provides air assault, aeromedical evacuation, command and control, and general support to full-spectrum operations across the multi-domain environment. The Program Executive Office for Aviation's Utility Helicopter continues to modernize the Black Hawk fleet with the UH-60V. 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 UH-60V is now in the Low Rate Initial Production (LRIP) phase with ongoing production at Corpus Christi Army Depot. The UH-60V completed the second Initial Operational Test and Evaluation Flight Testing from July 11 to August 8, 2022, at Fort McCoy, Wisconsin.

The CH-47F Chinook is the Army's only heavy-lift cargo helicopter supporting combat and other critical operations. Fielding continues in FY 2022 and concludes in FY 2025 with the delivery of five CH-47F Block I aircraft to select units as Repair Cycle Float assets. 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.

PEO Enterprise Information Systems successfully completed Aircraft Notebook training and fielding to the U.S. Army Rotary Wing fleet. Aircraft Notebook replaces the Unit Level Logistics System–Aviation (Enhanced) system and began integrating within Global Combat Support System–Army Increment 2 in mid-2020. Aircraft Notebook provides a common logistics information system for Army Aviation, streamlines user experience, improves record keeping, and provides the ability to view aircraft availability in near-real time across the fleet. To date, more than 26,500 soldiers and civilians have been trained to use Aircraft Notebook and more than 9,000 pieces of computer equipment have been converted.

Future Vertical Lift

The Future Vertical Lift 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 Air Launched Effects (ALE), and (4) the Modular Open System Approach (MOSA).

Fielding of the first units for FARA and FLRAA is programmed for FY 2030. At the end of FY 2022, FARA's competitive prototypes were more than 90 percent complete and on schedule for first test flights in FY 2023. Following a successful Joint Multi-Role Technology Demonstrator Program and Phase I Competitive Design and Risk Reduction, FLRAA's Request for Proposal was released in July 2021. FLRAA source selection was still underway, and the contract award decision was expected in FY 2023. FTUAS completed a year-long "Buy, Try, Inform" approach to replace the legacy RQ-7B Shadow, informing an approved Abbreviated Capability Document and a Directed Requirement resulting in a two-year program acceleration to field initial capability in FY 2023. MOSA capabilities were also successfully demonstrated in FY 2022, and the 700+ member Government and Industry MOSA Acquisition Working Group set defined standards.

In September 2021, the Center for Strategic and Budgetary Assessments released *Living Within One's Means: Revisiting Defense Acquisition and Affordability: A Case Study of the Army's Future Vertical Lift Program*. The report found the Army is in a window of opportunity to simultaneously procure FARA and FLRAA while remaining in the multi-decade low average of aviation procurement budgets. It also stated MOSA can reduce long-term sustainment costs while enabling mission flexibility and rapid upgrades at the speed of relevancy.

The Cross-Functional Team continues its campaign of learning through ongoing demonstration and experimentation. Significant 2022 events included Experimental Demonstration Gateway Event (EDGE) 22, building on EDGE 21 and Project Convergence 21 the previous year. EDGE 22 featured a partnered stakeholder approach with over 23 Department of Defense organizations, as well as seven international military partners focused on interoperability of FVL capabilities in joint and combined operations. Other focus areas included advanced teaming of Air Launched Effects with improved collaborative behaviors, extending and thickening aerial tier network, enhanced sustainment, electronic warfare, and multi-intelligence sensing, reach, and lethal and non-lethal effects. In support of these efforts, EDGE 22 involved robust data collection from the Army's Test and Evaluation Command, providing feedback on the 83 learning demands and 34 first-time events.

Project Convergence remains Army Futures Command's annual capstone experiment, a critical component in the campaign of learning that demonstrates the ability to overmatch adversaries in competition and conflict. At the most recent Project Convergence 22, three use cases incorporated 14 FVL technologies focused on combined joint all domain situational awareness, joint suppression of enemy air defenses, and expanded maneuvering. Distinct capabilities included more advanced employment of FARA's Modular Effects Launcher, ALE, A3I Gray Eagle, Kraus Aero K1000 solar-powered UAS (network relay/ISR), extending the aerial tier network and data packaging, Full Spectrum Targeting, and multiple Electronic Warfare effects. Initial planning is already underway for EDGE 23 focused on Project FEN (Future Vertical Lift Ecosystem Network), Project A2AD, and increased joint and allied participation.

Navy

The CH-53K Super Stallion completed Initial Operational Test and Evaluation (IOT&E), and the U.S. Marine Corps (USMC) declared Initial Operational Capability (IOC) in April 2022. Production continued with the award of Low-Rate

Initial Production (LRIP) Lot 6 for 11 aircraft. With nearly three times the external lift capacity of the CH-53E and a mission radius of up to 200 nautical miles, the CH-53K has the lift and range to support the future Marine Air Ground Task Force. Developmental test operations continue at Naval Air Station Patuxent River.

The Marine Corps declared IOC for the VH-92A in December 2021 and is conducting the White House Military Office commissioning process. All LRIP Lot 1 aircraft and associated equipment completed deliveries in May 2022. Total VH-92A inventory will be 23 aircraft. Developmental test operations continue at Naval Air Station Patuxent River.

In FY 2022, the U.S. Navy V-22 variant, the CMV-22, completed its first operational deployment alongside the F-35C on the USS Carl Vinson and its second deployment aboard the USS Abraham Lincoln. The Navy declared IOC for the CMV-22 B in December 2021. More than 400 V-22 aircraft have been delivered to the U.S. Marine Corps, the Air Force, the United States Special Operations Command, the U.S. Navy, and the Government of Japan. This tiltrotor aircraft provides unique capabilities to the warfighter, combining the flexibility of a helicopter with the speed and range of a fixed-wing aircraft.

In FY 2022, the Navy began conducting an Analysis of Alternatives for a Future Vertical Lift Maritime Strike (FVL(MS)) platform. FVL(MS) will fill capability gaps when the MH-60 and MQ-8 fleets begin to reach their end of service life.

The Marine Corps declared IOC for the AGM-179A Joint Air-to-Ground Missile on the AH-1Z Viper in March 2022.

In the fall of 2018, the United States commenced the effort to recapitalize its Advanced Helicopter Training System. The Navy pursued a non-developmental approach and received the first aircraft delivery in FY 2021. The Navy has accepted 25 TH-73A helicopters through FY 2022. The Navy is now using the same approach, and is in source selection, to recapitalize its Multi-Engine Training System to replace the aging T-44 aircraft.

Fixed Wing

Navy

The F-35 Joint Strike Fighter Program continued Initial Operational Test and Evaluation in FY 2021 and FY 2022, making significant progress. Following the August 2021 demonstration of the F-35B's first-of-its-kind ability to operate on international vessels, the U.S. Marine Corps conducted F-35B operations on the Japanese ship JS Izumo in October 2021. The F-35 Joint Strike Fighter Program continued Initial Operational Test and Evaluation throughout FY 2022 and is pressing towards a Milestone C decision planned for the end of CY 2023.

As of September 30, 2022, 63 F-35Cs have been delivered, eight of which were delivered in FY 2022. Navy and Marine Corps F-35C squadrons executed the first two F-35C deployments during FY 2022. The Navy's first operational F-35C squadron, Strike Fighter Squadron 147, embarked aboard USS Carl Vinson (CVN 70) for the first F-35C deployment in August 2021, returning home in February 2022. The Marine Corps' first operational F-35C unit, Marine Strike Fighter Squadron 314, onboard USS Abraham Lincoln (CVN 72) deployed for the second F-35C deployment in January 2022, returning home in August 2022. Additionally, the third operational F-35C squadron, Strike Fighter Squadron 97, was designated Safe-for-Flight in February 2022.

For F-35B, the Marine Corps completed the first joint UK/US F-35B deployment aboard HMS Queen Elizabeth (R08) from May to December 2021. In April 2022, 20 USMC F-35Bs participated in the Operational Test (OT-D1) of the Key Performance Parameter for F-35 integration aboard USS Tripoli (LHA-7). This demonstration of the "Lightning Carrier" concept increases operational flexibility for combatant commanders and adds complexity to adversary planning.

The E-2D Advanced Hawkeye (AHE) Program has delivered 56 USG aircraft to date on the Multi-Year Procurement Contract the United States Navy awarded in 2019. Upgrades to the platform continued in FY 2022 as the Navy built and fielded multiple Delta System/Software Configuration (DSSC) releases to pace future threats and sustain platform performance.

In FY 2022, the Navy continued its Service Life Extension Program of the E-6B while initiating the recapitalization for National Command and Control Aircraft.

The F/A-18 and EA-18G Program continues to sustain the Secretary of Defense mandate of 80 percent Mission Capability for E/F/G aircraft. In FY 2022, 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 2022 the F/A-18E/F and EA-18G pursued 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.

Army

In the area of High Altitude, the U.S. Army Space and Missile Defense Command (USASMDC) is planning to leverage the new development area of Stratospheric Solar-Powered Fixed Wing Aircraft. In FY 2022, USASMDC began the initial stages of development by documenting requirements and developing a concept of operations. USASMDC will develop and demonstrate payloads on those platforms to assess their capability to support functional areas, such as data communications, Assured Positioning Navigation and Timing, and Intelligence Surveillance and Reconnaissance for tactical applications.

Unmanned Aircraft System (UAS)

Army

The sixth MQ-1C Gray Eagle Full Rate Production (FRP) contract was awarded to procure 11 Gray Eagle Extended Range aircraft. This contract will fulfill the Gray Eagle Army Acquisition Objective of 204 aircraft. 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 is continuing its fielding of the MQ-1C Extended Range until late FY 2023.

The Army began testing multiple FTUAS that will eventually replace the RQ-7Bv2 Shadows in Brigade Combat Teams as early as FY 2023. A multi-vendor competitive prototype effort is underway for a selection of an Increment One vehicle that will be fielded to a select number of Brigade Combat Teams. The

Increment One will provide a runway-independent, expeditionary, on-the-move capability with lower acoustic signature, much lower equipment density, and transformational user interfaces. Followed by a more capable Increment Two, Program of Record by 2025. Currently, 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, an upgraded payload, weatherization (2 inches per hour), and an upgraded communications relay package. Fielding began in early FY 2022 and will continue to field until FY 2024.

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 (MPRF) 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 (EOC) assets have been operational in the Seventh Fleet Area of Responsibility (AOR) since January 2020. The EOC deployed assets will return to the continental United States (CONUS) in October 2022. The upgraded multiple intelligence (Multi-Int) capability began Flight Test in early 2022.

The MQ-8 Fire Scout UAS program provides real-time and non-real-time ISR data to tactical users without the use of crewed aircraft or reliance on limited joint theater or national assets. An MQ-8 system is composed of air vehicles (MQ-8B/MQ-8C), a Mission Control Station, Tactical Control System software, a Tactical Common Data Link, a UAV Common Automatic Recovery System for takeoffs and landings, Payloads (electro-optical/infra-red/laser designator-range finder, Automated Information System (AIS), voice communications relay, RADAR, Mine Countermeasures, and other specialty Payloads), and associated spares and support equipment. Fire Scout RADAR (MQ-8C) provides a 240-degree instantaneous field of view and a range of digital modes to include Maritime Surveillance, Synthetic Aperture, Inverse Synthetic Aperture, weather detection, and ground moving target indicator. The MQ-8 launches and recovers vertically and can operate from all suitably equipped air-capable ships (SEACS). MQ-8C achieved IOC on June 28, 2019, and achieved IOC for the Surface Warfare (SUW) increment in June 2022. The SUW increment includes the MQ-8C Endurance Upgrade Increment air vehicle plus the AN/ZPY-8 Surface Search AESA Radar. The SUW Increment provides improved maritime search capability and synthetic aperture radar (SAR)/inverse synthetic aperture radar (ISAR) imagery allowing the user to classify targets.

The MQ-25 program is rapidly developing an uncrewed capability to embark on CVNs (aircraft carriers with nuclear propulsion) as part of the Carrier Air Wing (CVW) to conduct aerial refueling as a primary mission and provide ISR capability as a secondary mission. MQ-25 extends CVW mission effectiveness range, partially mitigates the current Carrier Strike Group organic ISR shortfall, and fills the future CVW-tanker gap, mitigating Strike Fighter shortfall and preserving F/A-18E/F fatigue life. 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 Command, Control, Communications, Computers, and Intelligence networks from the control systems integrated into the CVNs. MQ-25 will initially be integrated aboard Nimitz-class aircraft carriers followed by Ford-class. In December 2021, the Navy completed an Unmanned Carrier Aviation Demonstration (UCAD) with the Boeing-owned Test Article (T1) aboard the USS George H.W. Bush (CVN 77). The Joint Precision Approach and Landing System surrogate testing was also completed with CVN 77 in that same period. During the in-port portion of the UCAD, the functionality of the Ground Control Station (GCS) was demonstrated. Once underway, T1 completed a series of test points that evaluated the functionality and capabilities of the deck handling system during both day and nighttime operations. Six GCS assets were delivered and installed this year, and the successful first-time control of the MQ-25 Hardware-in-the-Loop with the GCS was completed in June 2022.

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. The MQ-9 system will serve as a key enabler for USMC/Navy Expeditionary Advanced Base Operations (EABO), Distributed Maritime Operations (DMO), and Littoral Operations in a Contested Environment (LOCE) concepts. In FY 2022, two MQ-9A transitioned from commercially leased to government-owned assets and flew nearly continuous operations supporting Combatant Command (CCMD) objectives. In late FY 2023, the early operational capability of Increment I is planned. Increment I builds off the transition of two MQ-9A this year and includes GCS and payload/sensor capabilities that consist of Electro-Optical/Infrared (EO/IR), Lynx Radar, and SkyTower I (Airborne Network Extension [ANE]). Eight additional MQ-9A were placed on contract in FY 2022, with an additional ten MQ-9A planned to be transferred from the U.S. Air Force (USAF) beginning in FY 2023.

Weapons

Army

The Army is actively pursuing advanced precision munitions with longer ranges to allow our aircraft to operate outside of threat weapon system effective ranges. These precision munitions will make our aircraft more survivable in a peer/near-peer threat environment and help solve the anti-access, area denial challenge posed by current threats, while operating in an enemy integrated air defense system environment. Army Aviation is also developing smaller, more versatile modular missile technology that allows a more scalable and tailorable precision munition for soft/mid-range targets. Tailoring of the munitions will allow a more affordable precision munition for our UAS. These smaller precision weapons will increase lethality and provide more flexibility in targeting.

Army began fielding and improving other munitions, including the Joint Air-to-Ground Missile (JAGM). The JAGM is a multi-mode guidance munition capable of Precision Point and Fire and Forget targeting. The multiple sensor design provides a capability that enables employment in adverse weather and against countermeasures while also affording simultaneous engagements on both moving and stationary targets with increased lethality.

In February 2020, the Army Requirements Oversight Council approved a Directed Requirement to field the Spike Non-Line of Sight (NLOS) missile to our highest-priority theaters in order to satisfy two COCOM Operational Needs Statements and close one of Army Aviation's identified Large Scale Combat Operations gaps. Spike NLOS is an interim Long Range Precision Munition solution that possesses the range and many capabilities required for Army Aviation to be successful against peer adversaries in conflict. Testing and federation efforts by the Apache Program Management office and the Aviation Technology Development Directorate began in FY 2021, with the goal of fielding Initial Operational Capability in priority theaters by 2023. Competitive long-range precision munition shoot-off is ongoing at Dugway Proving Ground, Utah, that will inform the Program of Record.

Navy

During FY 2022, 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; award of the third lot 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; and continued fielding of the Long-Range Anti-Ship Missile (LRASM) as the Offensive Anti-Surface Warfare/Increment 1 material solution to meet near- to mid-term anti-access Anti-Surface Warfare (ASuW) threats.

TACTOM Block V production has commenced with contract awards in fiscal years 2020 to 2022. The FY 2022 procurement includes the first TACTOM missiles procured by other service partners.

In January 2019, the Department of the Navy entered into Engineering and Manufacturing Development of the Advanced Anti-Radiation Guided Missile–Extended Range (AARGM-ER). Combining proven AARGM sensor technology with a new rocket motor and warhead will provide a weapon with increased effective range, higher speed, and greater survivability to improve the Navy's Suppression and Destruction of Enemy Air Defenses (SEAD/DEAD) mission while optimizing affordability and risk. During FY 2022, AARGM-ER continued development testing and a contract for Low Rate Initial Production Lot 2 was awarded to the prime contractor, Northrop Grumman Defense Systems. The program is currently projected to achieve Initial Operational Capability (IOC) in late 2023.

In FY 2022, 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. Additional improvements in performance, range, and survivability, and the addition of a land attack capability, are underway. Additional platform integration efforts and execution of the first LRASM foreign military sale case ensure versatility in employment.

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 SDB II program completed USAF operational test flights in FY 2022 and fielding on the F-15E in FY 2022. The Navy began developmental test flights in 2019 on both the F/A-18E/F and the F-35B, and it is on track to field SDB II on the F-35B in FY 2022 for USMC and on the F/A-18E/F in FY 2023. The Navy will have taken delivery of 840 weapons with an additional 123 being delivered through December 2022.

Aviation Survivability Equipment

Army

Aviation Survivability Equipment (ASE) is essential to provide 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 (CMWS), Limited Interim Missile Warning System (LIMWS), Advanced Threat Infrared Countermeasures (ATIRCM), Common Infrared Countermeasure (CIRCM), APR-39C(V)1/4 and APR-39D(V)2 Radar Warning Receivers (RWR), and AVR-2B Laser Detection System (LDS).

CMWS and LIMWS are missile warning systems that detect and protect the aircraft from advanced Infrared (IR) threats in combination with CIRCM or ATIRCM and flares. LIMWS is the directed requirement to provide advanced protection on currently deployed aircraft until development of an Improved Threat Detection System (ITDS). LIMWS has begun fielding in FY 2022 and is scheduled to continue until inventory is exhausted. CIRCM and ATIRCM are both Laser Jammers for IR missiles and provide the first line of defense for defeat. ATIRCM is only fielded to the CH-47 fleet and has begun transition to upgrade to CIRCM this fiscal year. ATIRCM is scheduled for divestiture by the end of FY 2024. CIRCM has reached a major milestone by reaching Initial Operating Capability (IOC) by completing one Combat Aviation Brigade's worth of aircraft at the end of FY 2022. CIRCM will be fielded on all aviation rotary wing platforms from the current fleet.

APR-39C(V)1/4 is a radar warning system alerting aircrews of Radio Frequency (RF) threats. APR-39D(V)2 is an interim solution procured from the Navy's RWR Program, which is currently fielding and is expecting to complete First Unit Equipped by the second 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.

AVR-2B LDS provides aircrew with an alert of laser energy from enemy weapon systems and is factory modified on the AH-64 and UH-60. It has begun fielding on CH-47 Aircraft in FY 2022.

Looking to future development of systems, the requirements call for Modular Open System Approach (MOSA) and Future Airborne Compliance Environment (FACE) to reduce cost of systems and upgrades, as well as allow for rapid software and hardware upgrades to counter emerging threats on the battlefield.

Propulsion

Army

The Improved Turbine Engine program entered the Engineering and Manufacturing Development phase in January 2019 and successfully completed Critical Design Review (CDR) in July 2020 in a virtual environment despite COVID-19 impacts. The research, development, testing, and evaluation funding provides for engine development, qualification, and aircraft integration. Additionally, Future Years Defense Program (FYDP) funding begins initial procurement and supports organic depot tooling, Developmental Testing completion, milestone C, and Low-Rate Initial Production. For FY 2022, the Army restored funding from an FY 2020 rescission and FY 2021 mark, but the milestone C schedule has slipped from July 2024 to November 2024 due to the delayed funding. FY 2021 consisted of First Engine to Test hardware deliveries, component testing, engine assembly, and instrumentation. First Engine to Test initiation slipped from October 2021 to January 2022 due to hardware delays resulting from COVID-19 impacts. Engine testing required to achieve Preliminary Flight Rating to support future vertical lift flight testing occurred in FY 2022 and extends to FY 2023. The improved turbine engine has completed 103 running hours with 117 successful starts.

Space

Environmental Monitoring

Space Force

The Weather System Follow-on (WSF) program is composed of two acquisition activities: the Compact Ocean Wind Vector Radiometer (COWVR) technology demonstration and the WSF-Microwave (WSF-M) program. COWVR manifested on the Space Test Program–Houston 8 (STP-H8) and launched to the International Space Station (ISS) in December 2021. The COWVR demonstration is intended to mature smaller microwave sensors and develop ground-processing algorithms. WSF-M will collect critical observations on Ocean Surface Vector Winds and Tropical Cyclone Intensity, replacing the Special Sensor Microwave Imager/Sounder (SSMIS) sensors that fly on the Defense Meteorological Satellite Program (DMSP) satellites. WSF-M also includes a payload to assess Energetic Charged Particles in low-Earth orbit (LEO), addressing one space weather monitoring capability and supporting Space Domain Awareness. The first of up to two WSF-M satellites is scheduled to achieve initial launch capability in late 2023.

The Electro-Optical/Infrared (EO/IR) Weather System (EWS) program's prototyping activities have continued throughout FY 2022. The first EWS prototype will launch in 2023 to evaluate CubeSat-class EO/IR sensors and weather data utility. The second EWS prototype will launch by 2025 for on-orbit operationalization. EWS will replace DMSP's Operational Linescan System (OLS) sensors for EO/IR capabilities, addressing the 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. Additionally, in FY 2022, the EWS program completed a Weather Data as a Service (WxDaaS) pilot to determine the viability of buying EO/IR weather data from a commercial source. 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 (DAF) and the National Oceanic and Atmospheric Administration (NOAA). Using a residual NOAA Geostationary Operational Environmental Satellite (GOES), EWS-G provides persistent weather monitoring portions of the U.S. Central Command (USCENTCOM) and U.S. Indo-Pacific Command (USINDOPACOM 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 USCENTCOM.

The Space Situational Awareness Environmental Monitoring (SSAEM) program is a technology demonstration project to support the international Constellation Observing System for Meteorology, Ionosphere and Climate 2 (COSMIC-2) mission. The SSAEM program provides the acquisition, development, and launch/on-orbit support of 18 space/terrestrial weather sensors to COSMIC-2 partnership in coordination with NOAA and Taiwan's National Space Organization (NSPO). In June 2019, COSMIC-2 launched six satellites in an equatorial LEO with three SSAEM sensors in each spacecraft.

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 SBIRS Geosynchronous Earth Orbit (GEO)-5 and GEO-6 production contract was awarded on June 24, 2014, using a six-year Efficient Space Procurement (ESP) that provided a cost avoidance of $521 million. The SBIRS GEO constellation is nearing completion. GEO-5 was launched in FY 2021 and operationally accepted in FY 2022. Near the end of FY 2022, GEO-6 successfully launched out of Cape Canaveral and is currently undergoing on-orbit testing and calibration.

The U.S. Space Force (USSF) is taking projected threats seriously and focusing investments on maturing resilient technology. The Space Force approved acquisition strategies using Middle Tier of Acquisition (MTA) authorities for the Next Generation Overhead Persistent Infrared (Next-Gen OPIR) space and ground segments to rapidly prototype these new resilient capabilities. The space segment will replenish the SBIRS constellation by delivering five resilient and survivable Missile Warning Satellites (three GEO and two Polar Orbit), with the first GEO Satellite to be delivered by 2025. In FY 2022, most of the space vehicle flight hardware was assembled and integrated for the first 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 2022, FORGE awarded and kicked off the contract to provide mission data processing applications. Also in FY 2022, FORGE continued to deliver increased mission data procession 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 collaboration with key stakeholders and considering emerging threat assessments, rigorous analysis and wargaming in FY 2021 were used in FY 2022 to define a more resilient and more defendable Missile Warning/Missile Tracking architecture. That analysis and wargaming drove a monumental mission area architecture pivot from a geosynchronous and highly elliptical force presentation to a proliferated low and medium Earth orbit 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. In

FY 2022, Resilient Missile Warning/Missile Tracking leveraged multiple on-orbit demonstrations as the program ramped up acquisition efforts for the low and medium Earth orbit (MEO) satellites. This new architecture is fielded by the Space Force's Space Systems Command and the Space Development Agency (SDA). The first LEO satellite capability demonstration will launch in FY 2023, followed by MEO satellite launches in FY 2026.

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 direct user fees, to users worldwide. GPS has been operational since July 1995. The success of the GPS program is reflected in the total number of GPS receivers produced to date, estimated at more than four billion worldwide. The first five GPS III satellite launches occurred in December 2018, August 2019, June 2020, November 2020, and June 2021, ushering in the next generation of GPS technology with significant enhancements to the current constellation, including higher-power military signals and a new civilian signal. GPS satellites six through ten were in various stages of production in FY 2022, and the next GPS III satellite (Space Vehicle (SV) 6) launched in January 2023. GPS III SVs 7–9 have been delivered to the Government and are available for launch (AFL).

In FY 2022, the GPS III Follow-on (GPS IIIF) continued with the Production and Deployment phase, with a planned production of 22 satellites adding increased anti-jam performance and hosting a search and rescue payload developed through international partnership. The first two GPS IIIF satellites are expected to be delivered to the Government and AFL in FY 2026.

The GPS Next-generational Operational Control System (OCX) is a modernized ground system that will enable the effective use of the latest military and civilian GPS signals while providing significantly improved cyber resiliency. OCX Block 0 successfully performed the launch and on-orbit checkout of the first five GPS III satellites. The OCX Block 1/2 development phase is projected for completion in FY 2024, signaling the transition of the program into integration, test, deployment, and transition to operation. OCX 3F, a modification to OCX to enable launch and command and control of GPS IIIF vehicles, awarded a contract to Raytheon in April 2021 and is projected to complete development in FY 2025.

The Military GPS User Equipment (MGUE) program's first ground systems card completed Technical Requirements Verification in March 2019, signifying its readiness for 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. Aviation and maritime variants of the card are projected for completion in FY 2024. The MGUE Increment 2 program awarded three contracts in November 2020 for the Miniature Serialized Interface (MSI) with Next-Generation Application Specific Integrated Circuit (ASIC) to L3Harris, Raytheon, and BAE Systems.

Army

The U.S. Army Space and Missile Defense Command (USASMDC) made progress in the area of PNT support from the technology development effort called Gunsmoke. By the end of FY 2022, USASMDC concluded the Gunsmoke-J CubeSat experiments. Each Gunsmoke-J satellite was about the size of a loaf of bread and was used to demonstrate that tactical support capability was feasible from such a small satellite form factor. This particular effort was a Joint Capability Technology Demonstration (JCTD) producing a Joint Military Utility Assessment (JMUA) report. The effort was successful in achieving some key major objectives.

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; it will also increase protected satellite communications resiliency and cybersecurity. ESS awarded three rapid prototyping contracts to Northrop Grumman, Boeing, and Lockheed Martin in late FY 2020 and early FY 2021. The simultaneous prototyping and the emphasis on a modular open systems approach creates competition that drives innovation and strengthens the industrial base for the follow-on build, integrate and test, and delivery contract. In June 2022, the Space Service Acquisition Executive approved the acquisition strategy for the ground segment to begin the planning phase of the Software Acquisition Pathway. The planning phase consists of an 18-month period to develop a ground reference architecture to ensure compliance with current standards and to define responsibilities of integration and test for all systems and interfaces to ensure mission success.

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. MUOS has five on-orbit satellites and reached full operational capability in 2019. The Space Force is planning a Service Life Extension (SLE) that will extend the WCDMA capability to 2034 by developing and launching two replenishment satellites. The SLE satellite contract award will occur no earlier than FY 2025, with planned launches in FY 2030 and FY 2031 respectively. The SLE milestone decision authority (MDA) was transferred to the Space Service Acquisition Executive in FY 2021; FY 2022 was the first year of Space Force funding. In July 2022, the Space Service Acquisition Executive approved the acquisition strategy to begin the early design and risk reduction phase. This phase will address unknowns associated with satellite redesign challenges such as component obsolescence, modernization, and production readiness of unique UHF satellite attributes. Additionally, the Space Force initiated a Narrowband analysis of alternatives in FY 2022.

The Wideband Global SATCOM (WGS) system provides high-capacity and bandwidth SATCOM capability to support Unified Combatant Commanders', military services', other DOD agencies', and international partners' global operations. The space segment operates in the military X-band and Ka-band with flexible connectivity between bands and coverage areas to support classified and unclassified data distribution and backhaul communications for users worldwide. WGS is a highly successful satellite program with ten operational satellites on orbit and the eleventh currently in development. WGS has strong international partner support. Nine countries committed funding in 2022 to help fund WGS-11 in exchange for a percentage of WGS constellation access. Additionally, the WGS program office successfully completed the Critical Design Review on December 13, 2021, and is on track to launch in 2024.

The Protected Tactical Enterprise Service (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 FY 2022, PTES continued development to operationalize the PTW over WGS in 2024, and PTES will expand to include medium and geosynchronous Earth orbit commercial capability integration efforts starting in FY 2023. On June 18, 2018, the Service Acquisition Executive designated PTES as a Middle Tier of Acquisition (MTA) Rapid Prototyping Activity and authorized PTES to pursue a prototype capability in late FY 2022. On August 12, 2021, the Program Office completed the first over-the-air PTW connectivity with the first production-article Joint Hub. On September 8, 2021, the Program Office completed the Joint Hub End-Crypto Unit (ECU) critical design review. The program is on track to reach IOC in FY 2024.

The Protected Tactical SATCOM (PTS) program is the disaggregated protected tactical communications follow-on to the AEHF program and will also provide Ka-band SATCOM capability. PTS will provide advanced SATCOM capabilities to tactical users in anti-access/area denial environments leveraging the resilient PTW. PTS will also provide worldwide, beyond-line-of-sight, improved anti-jam, low probability of intercept communications to expeditionary and tactical warfighters operating in close proximity to adversarial jammers. It will do this through on-board signal processing and advanced beam-forming using a distributed, diversified, and agile constellation of hostable payloads and high-capacity free-flyers. PTS is using digital engineering to increase speed and agility of system development.

In November 2018 the first phase of PTS was designated as an MTA Rapid Prototyping Activity to deliver two prototype payloads for launch in FY 2024. On March 31, 2021, Space Systems Command selected Northrop Grumman and Boeing to continue to Critical Design Review (CDR) to produce a PTS free-flyer and a hosted payload on WGS-11, respectively. Northrop Grumman and Boeing completed the Critical Design Reviews in October 2021 and December 2021, respectively. Both contractors remain on track to have PTS prototype payloads available for launch in FY 2024.

In November 2020, U.S. Space Command accepted the Enhanced Polar System (EPS) program for operational use, with two hosted payloads on orbit and a ground Control and Planning Segment (CAPS). EPS replaces the Interim Polar System to ensure that critical protected communications requirements above 65 degrees north latitude are satisfied for joint forces. The Space Force is procuring two replenishment EPS payloads, the Enhanced Polar System-Recapitalization (EPS-R), to prevent a military satellite communications (MILSATCOM) mission gap in the polar region in the 2025 timeframe. These EPS-Recapitalization (EPS-R) payloads will be hosted on a Space Norway satellite, promoting U.S. policy to strengthen international partnerships, and potentially saving $900 million in costs for the U.S. Government. In November 2021 the Program Office successfully completed the Pre-Ship Review (PSR) for payload 2. In June 2022 the Program Office delivered payload 1 for integration with the Space Norway vehicle. Payload 2 will be delivered late October 2022.

The United States Space Force Commercial SATCOM Office (SFCSCO) was established under Air Force Space Command (AFSPC) in December 2018 and transferred to the USSF upon its establishment in December 2019. SFCSCO procures Commercial SATCOM (COMSATCOM) for the DOD by managing over 90 active customer contracts, leveraging 40 COMSATCOM providers, and delivering over 10 GHz of bandwidth. SFCSCO delivers access to the global commercial Iridium Satellite Constellation providing airtime for secure voice, and secure data services for the DOD, federal agencies, state and local governments, and foreign partners (Australia, Canada, New Zealand, the United Kingdom, and the North Atlantic Treaty Organization), leveraging a family-plan contract agreement. SFCSCO also delivers COMSATCOM capabilities through standard and custom contracts including transponder capacity, managed services, and custom solutions. In FY 2022, SFCSCO continued to advance the USSF's vision for an enterprise approach to the procurement, delivery, and management of SATCOM capabilities as the best means to create a responsive environment to Combatant Commands (CCMDs) and other users across the spectrum of conflict.

COMSATCOM Enterprise Integration of Fighting SATCOM delivers mission applications enabling warfighters to operate in all conditions by leveraging responsive DOD and commercial SATCOM as a single enterprise. Fighting SATCOM Enterprise integrates a set of tools that provide SATCOM capability to global warfighters, restore services within tactically relevant timelines, and improve resilience and operational agility in Contested Degraded and Operationally Limited (CDO) environments. Enterprise Management and Control (EM&C) applications provide the foundational framework for a SATCOM integrated Command and Control (C2) system that enables the end-to-end sensor-to-shooter execution and facilitates timely, quality-driven battlespace decisions for SATCOM allocation and use. In FY 2022, EM&C executed six prototypes to help develop advanced software capabilities that enable responsive and resilient SATCOM for various space warfighting entities. Furthermore, EM&C awarded two contract modifications to develop a mission profile registry service and expand its mission planning capabilities. At the end of FY 2022, EM&C successfully deployed its visualization suite with an initial set of prototypes onto Secure Internet Protocol Router Network (SIPRNet) for user feedback and testing.

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, low-probability-of-intercept, and low-probability-of-detection waveforms. 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, 72 terminals have been delivered, 44 terminals have been installed, and 41 are in operational use.

Space Force

National Security Space Launch: The National Security Space Launch (NSSL) program continues to successfully place satellites into orbit, launching 93/93 successful missions since its onset. As of September 30, 2022, there were six launches during FY 2022:

- December 7, 2021 Atlas V, Space Test Program-3
- January 21, 2022 Atlas V, USSF-8
- February 2, 2022 Falcon 9, NROL-87
- April 17, 2022 Falcon 9, NROL-85
- July 1, 2022 Atlas V, USSF-12
- August 4, 2022 Atlas V, SBIRS GEO-6

On August 12, 2020, under the Phase 2 contract, the U.S. Space Force's (USSF) Space Systems Command (SSC), in partnership with the National Reconnaissance Office's (NRO) Office of Space Launch, competitively awarded two Firm-Fixed-Price, Indefinite Delivery Requirement contracts to United Launch Alliance (ULA) and SpaceX to provide reliable, innovative, and affordable launch services for National Security Space (NSS) missions. Launch service task orders are awarded annually via the NSSL Phase 2 contract. Eight launches were awarded through the FY 2022 mission assignment board: ULA was awarded GPS III-7, USSF-23, USSF-43, WGS-11+, and USSF-16; SpaceX was awarded USSF-124, USSF-62, and SDA-T1TLA. ULA continues to make progress towards the development of the Vulcan Launch Vehicle, to include Cat C capability, through the Launch Service Agreement (LSA) Other Transaction Authority (OTA).

June 2021 marked the first NSS launch on a reused booster. The DAF has actively engaged in evaluating reusable launch systems and establishing common standards consistent with NSSL Mission Assurance standards since 2016. Beginning in 2020, the Space Force worked with SpaceX to recover the first two boosters from the GPS III-3 (June 2020) and GPS III-4 (November 2020) missions. The June 2021 GPS III-5 launch was the first NSS launch on a reused booster.

These three launches provided vital data to maintain mission assurance for launch vehicle reuse on the Phase 2 contract and beyond.

SSC's Mission Manifest Office maximizes the use of all spacelift capacity and acts as the single point of entry for all DOD satellites. In FY 2021, the Mission Manifest Office deployed small satellites from the USSF's SBIRS GEO-5 and NASA's Landsat 9 launches, demonstrating their capability to flexibly deliver cutting-edge technology to space and work across Government organizations to do so.

On September 24, 2021, SSC awarded four OTA development agreements for next-generation rocket engine testing (SpaceX) and upper stage resiliency enhancements (Blue Origin, ULA, and Rocket Lab). These development efforts will advance the domestic launch vehicle industrial base and foster competition for the Phase 3 procurement.

The NSSL Phase 3 procurement strategy continued its development in FY 2022 for a contract award in the fourth quarter of FY 2024 to procure launch services in FY 2025 and beyond. The NSSL Phase 3 strategy will be the follow-on to the NSSL Phase 2's ordering period that ends FY 2024.

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. On September 29, 2022, RSLP awarded a launch service contract to Firefly to support the USSF's VICTUS NOX Tactically Responsive Space mission with a 24-hour "call up" to launch, scheduled for 2023. RSLP continued its record of success with three additional space launches in FY 2022:

- November 20, 2021 — LV007, Space Test Program (STP)-27AD2
- January 13, 2022 — LauncherOne, STP-VPB
- July 2, 2022 — LauncherOne, STP-S28A

Launch Ranges: Range modernization efforts continued in FY 2022, implementing the Chief of Space Operations' Range of the Future (ROTF) 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 2022, Range Services Hosting Platform earned operational acceptance. 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. Range Command and Destruct modernization was operationally accepted at the Cape 1B site, replacing obsolete equipment critical for range safety. These efforts enhance compatibility with commercial systems and increase launch throughput on both Ranges, continuing progress to meet the ROTF vision.

Space Rapid Capabilities Office: The Space Rapid Capabilities Office (RCO) mission focuses on developing and delivering operationally dominant space capabilities in support of national defense as directed by the Secretary of the Air Force through a Board of Directors (BoD). The BoD is chaired by the Secretary of the Air Force with membership that includes the Chief of Space Operations; Chief of Staff, United States Air Force; Commander of U.S. Space Command; Assistant Secretary of the Air Force for Acquisition, Technology and Logistics; Assistant Secretary of the Air Force for Space and Integration; Undersecretary of Defense for Acquisition and Services; and Undersecretary of Defense for Research and Engineering. Through the BoD, the Space RCO has been assigned and is executing programs that fill critical portions of the space architecture as defined by the Commander U.S. Space Command to allow fulfillment of the joint, military operational needs for national defense. The Space RCO continues to develop partnerships with other government organizations, industry, academia, and Federally Funded Research and Development Centers to aid in the rapid development and delivery of U.S. space capabilities at the speed of warfighting relevance.

Space Control

Space Force

Space Innovation, Integration, and Rapid Technology Development (SIIRTD) delivers Standard Space Trainers (SSTs) and Distributed Mission Operations–Space (DMO-S) capabilities to the warfighter and provides cutting-edge analysis with critical Modeling and Simulation (M&S) tools providing analytic rigor that support the command's warfighter strategies. SIIRTD had a very successful FY 2022 with several major accomplishments:

- Held an M&S capabilities Industry Day for the Virtual Space Range, promoting competition across training solutions;
- Delivered 14 software releases across four MILSATCOM missions, and 12 software releases for SBIRS;
- Delivered 10 software releases of Black Horizon gaming app on SSTs and mobile devices; and
- Upgraded Early Warning Radar (UEWR) at Beale Air Force Base, Clear Space Force Station, and Thule Air Base.

The Counter Communications System (CCS) provides expeditionary, deployable, and reversible counter-space effects applicable across the full spectrum of conflict. CCS denies adversary satellite communications in an area of conflict. CCS is a key piece of the DOD's space control strategy and has been in operation since 2004 with the fielding of three Increment 10.0 systems. To date, CCS has gone through two subsequent preplanned product improvements and delivered 16 of 16 CCS Increment 10.2 systems.

Space Command and Control: The Space Command and Control (C2) system will provide a collaborative environment that will enhance and modernize Space Domain Awareness (SDA) and Battle Management Command and Control capabilities; create decision-relevant views of the space environment; rapidly detect, track, and characterize objects of interest; identify/exploit traditional and nontraditional sources; perform space threat analysis; and enable efficient distribution of data across the Space Surveillance Network.

This mission area encompasses both operational and tactical echelon C2. Supported by the Space C2 acquisition program, C2 investment activities deliver capability in support of multiple C2 nodes, to include the National Space Defense Center (NSDC). In addition, programs like Enterprise Ground Services (EGS) provide tactical C2 capability, and investment activities occur at the Research and Development Space and Missile Operations (RDSMO) offices.

To address the rapidly expanding threats to the space enterprise, the Space C2 program will allow the Space Force to command and control space control and SDA forces by integrating data for commanders. Future SDA and C2 development efforts are pivoting to a user-driven, rapid delivery, development security and operations (DevSecOps) approach leveraging best practices in digital engineering to defeat an advancing threat. Also included in this mission area is the Unified Data Library (UDL) program. Initiated as a prototype effort, the UDL provides a single source for accessing and managing all data in support of USSF operational systems. UDL is a cloud-based, cyber-accredited, multi-classification, data store that facilitates universal data access.

In FY 2022 the Space C2 program obtained operational acceptance of Warp Core, a Data as a Service (DaaS) platform for data ingestion, retention, processing, normalization, analysis, and visualization across the global space enterprise. Warp Core is used by over 3,000 users in the USSF, North American Aerospace Defense Command/U.S. Northern Command (NORAD/USNORTHCOM), and the DAF. The program also began Development, Test and Evaluation (DT&E) of the Advanced Tracking and Launch Analysis System (ATLAS), a significant operational C2 SDA capability that will allow for the decommissioning of legacy systems. In April 2022 the program delivered its third annual report to Congress. This third report addressed recommendations from a Government Accountability Office review of the first two annual reports. Regarding UDL, in February 2022 UDL established a direct connection with Space Fence, a Kwajalein Atoll–based SDA sensor, which will continue to expand capability to share Space Surveillance Network data. In FY 2022 more than 70 applications used UDL data.

In FY 2022, the Satellite Control Network (SCN) began development of the Enterprise Resource Management 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 completed its preliminary design review. In FY 2022 the SCN began the Modular Transitional Remote Tracking Station upgrade at Diego Garcia, providing a modern and more cyber secure architecture using one core commanding and telemetry data handling system for all antennas at a site. Software-defined radios are the key component to this upgrade that will replace obsolete equipment and facilitate future growth.

Space Domain Awareness

Space Force

Space Domain Awareness (SDA) is the identification, characterization, and understanding of any factor, passive or active, associated with the space domain that could affect space operations. To address the rapidly expanding threats to the space enterprise, SDA is pivoting to protect and defend against threats by aligning materiel and non-materiel needs to deliver parallel operational requirements simultaneously and equipping decision-makers with access to integrated data from diverse ground-based and space-based sensors. In FY 2022, the USSF continued to partner with industry and allies to augment the Space Surveillance Network (SSN), exploit data, host payloads on non-traditional satellites, and place assets in new locations that would allow for persistent space control activities. The Space Surveillance Telescope (SST) completed Operational Acceptance in September 2022. Under the Maintenance of Space Situational Awareness Integrated Capabilities (MOSSAIC) contract, sustainment, modifications, and development continued across the SSN in FY 2022 to include upgrades to the Ground-Based Electro-Optical Deep Space Surveillance (GEODSS) system. Furthermore, USSF continues to invest in government-owned, exquisite systems such as SILENTBARKER, the Geosynchronous Space Situational Awareness Program (GSSAP), and the Deep Space Advanced Radar Capability (DARC).

SILENTBARKER is a collaborative program between the USSF and National Reconnaissance Office (NRO) to satisfy common DOD and Intelligence Community (IC) requirements, which include maintaining custody of threats in Geosynchronous Orbit (GEO) and providing indications and warning. SILENTBARKER initial baseline launch is planned for FY 2023. The contract for SILENTBARKER expansion was awarded in FY 2021 with a projected launch in FY 2026.

Geosynchronous Space Situational Awareness Program (GSSAP) vehicles operate in the near-GEO regime and provide the United States with an operational capability to support U.S. Space Command's space surveillance operations as a dedicated space-based SSN sensor. GSSAPs 5 and 6 launched from Cape Canaveral Air Force Station in January 2022 and were operationally accepted by Space

Operations Command. From near-GEO, GSSAP has a clear, unobstructed, and distinct vantage point for viewing Resident Space Objects without the interruption of weather or the atmospheric distortion that can limit ground-based systems. The enhanced maneuverability of GSSAP also allows rendezvous and proximity operations to enable on-orbit object characterization and anomaly resolution.

Deep Space Advanced Radar Capability (DARC) will be a ground-based SDA radar system consisting of three geographically separated sites around the world that deliver deep space satellite tracking and custody capabilities. DARC will provide a critical, advanced, 24/7, all-weather radar system capability to counter existing and emerging threats in deep space. SSC awarded the Site 1 Prime Integrator Contract in February 2022. Site 1 will be in Australia and is expected to complete development in FY 2025. The planned location for Site 2 is the United Kingdom, and Site 3 is in the United States.

Army

The USASMDC made progress in the area of Space Situational Awareness support for the tactical warfighter from the technology development effort called Lonestar. The first Lonestar satellite, which is about the size of two loaves of bread, completed environmental testing and end-to-end testing earlier in FY 2022. The satellite was then launched into orbit on July 1, 2022, aboard a Virgin Orbit Launcher One mission, which was provided as a launch opportunity by the Department of Defense Space Test Program. The satellite has successfully completed the bus and payload checkout phase and is currently in payload characterization and performance assessment. This particular effort is planned to be completed in FY 2023.

Defensive Cyber Operations–Space

In FY 2022, Defensive Cyber monitoring and protection capabilities were deployed at Schriever and Buckley Space Force Bases to protect space operations centers. A total of 11 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.

Experimental Systems

Prototype On-orbit Experimental Testbed (POET). POET was launched on a YAM-3 satellite in FY 2021 and continues to conduct first-of-its-kind demonstrations. POET is a payload system demonstrating an experimental processor and application for edge computing capabilities as required by Space Development Agency's (SDA) Custody and Battle Management, Command, Control, and Communications (BMC3) layers. With POET's checkout and commissioning completed in early FY 2022, POET demonstrated cloud segmentation algorithms on-orbit. This success led to additional funding from a government partner and successfully demonstrated the first on-orbit data fusion via the United States Marine Corps Multi-Sensor Correlator Tracking Algorithms from Raytheon Solipsys with sensor data loaded via dockers. SDA continues to identify additional experiments suitable to be conducted on POET and to identify additional mission partners interested in taking advantage of the on-orbit capability.

Prototype Infrared Payload (PIRPL). SDA's experimental system called PIRPL was launched in FY 2021. After completing system checkout, PIRPL began collecting infrared (IR) image data in November 2021 and downlinked its data during collection. This IR data collection was the first-of-its-kind from low-Earth orbit (LEO) and will be instrumental going forward to help understand how to separate advanced missile targets from the rapidly changing Earth background. These data continue to be used to inform IR scene models and optimization of image processing algorithms to suppress IR backgrounds that enable tracking of hypersonic and advanced missiles from LEO.

Mandrake II. A pair of space vehicles nicknamed Mandrake II, launched in partnership with the Air Force Research Laboratory (AFRL) and Defense Advanced Research Projects Agency (DARPA), are currently flying two SA Photonics optical communication terminals (OCTs) with DARPA Blackjack heritage. Mandrake II launched in FY 2021 and began initialization and key component checkout of the propulsion system and OCTs the following quarter. In FY 2022 Mandrake II demonstrated space-to-space and space-to-ground optical links. Mandrake II continues to perform ongoing data quality experiments to inform SDA's Tranche 0 and Tranche 1 transport layer space vehicle deployments.

Tranche 0 (T0)

T0 Transport Layer (T0TL). York Space Systems and Lockheed Martin are delivering ten T0TL space vehicles (SV) each. Both contractors successfully completed their Test Readiness Reviews (TRR) in FY 2022 and are currently completing assembly, integration, and test (AI&T) of the SVs prior to delivery to the launch site and integration with the SpaceX Falcon-9 launch vehicle. York will be delivering eight T0TL SVs for the first launch scheduled for December 2022. York's remaining two SVs and Lockheed Martin's SVs will be delivered for the second launch scheduled for March 2023. Each vendor is also providing three SVs with a Link 16 payload to demonstrate this warfighter-critical tactical data link from space, enabling true beyond-line-of-sight operations for the first time.

T0 Tracking Layer. SpaceX and L3Harris are funded to build four Tracking SVs, each with a wide field of view (WFOV) infrared payload. Each vendor completed its Production Readiness Review (PRR) in FY 2022 and is currently completing AI&T of the SVs prior to delivery to the launch site for integration with the launch vehicle. SpaceX is delivering two SVs for the first launch. All remaining SVs will be launched on the final March 2023 launch.

T0 Support. Tranche 0 has basing locations at Blossom Point Test Facility (BPTF) and University of Alaska-Fairbanks' Alaska Satellite Facility (UAF ASF). Test Readiness Review (TRR) for the T0 ground segment was successfully held in mid–FY 2022. The Ground Segment installation of Optical Ground Terminal (OGT) 1 at Midway Research Center, Stafford, Virginia, was completed in FY 2021, and a second OGT was installed at AFRL Remote Maui Experiment (RME) Site (Maui, Hawaii) in December 2021. Two radio frequency (RF) antennas were also installed at the Alaska site in August 2022 and September 2022, with a third RF antenna to be installed at BPTF in FY 2023. Software builds for the two vendors launching space vehicles on Launch 1 (SpaceX and York) have been completed and will support the SVs when they are on orbit.

Tranche 1

T1 Transport (T1TL). T1TL SVs are similar to those in T0TL with targeted technology enhancements, mission-focused payload configurations, increased integration, and greater production efficiencies. The T1TL is providing global communications access and delivering persistent regional encrypted connectivity in support of warfighter missions around the globe by serving 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. SDA released a T1TL Request for Proposals (RFP) in October 2021 and subsequently re-released it as an Other Transaction (OT) RFP in November 2021. Lockheed Martin, York Space Systems, and Northrop Grumman were awarded contracts in February 2022 worth approximately $1.8 billion in total. Each awardee will build and deliver 42 SVs to be launched beginning in late FY 2024. The SVs will create a mesh network of 126 optically interconnected nodes that will provide a low-latency, resilient, high-data-volume transport communication system. York and Lockheed Martin completed their Preliminary Design Reviews (PDR) before the end of FY 2022, with Northrop Grumman completing theirs in early FY 2023. The T1TL is planned to consist of six near-polar orbital planes of SVs in a 1,000 km altitude proliferated low-Earth orbit (pLEO) constellation, linked together to form a global space mesh network. Each of the six planes will contain 21 T1TL SVs. Enhancing the T0 development, each T1TL SV also carries a Link 16 payload, enabling global access to the tactical data network for the warfighter. In addition, each SV also carries a second Global Positioning System (GPS) receiver so that beginning with Tranche 1, SDA will provide continuous GPS situational awareness data from a global perspective.

T1 Operations and Integration (O&I). Operation of the T1 Enterprise and future capability layers and tranches will be conducted from two functionally equivalent, geographically separated, Government-owned and Contractor-operated (GOCO) SDA Operations Centers (OC) via globally dispersed RF and optical ground entry points. SDA selected Redstone Arsenal, Alabama (South OC), and Grand Forks Air Force Base, North Dakota (North OC), as operational sites in early FY 2022. SDA conducted site surveys and is working toward completing the Network Design. T1 O&I will establish an integrated ground segment and provide operations and sustainment support for the complete T1 system. An RFP for T1

O&I was released in January 2022 with a $324.5 million cost-plus-fixed-fee contract awarded to General Dynamics Mission Systems (GDMS) in May 2022. GDMS has partnered with Iridium and will build the software and systems to manage and operate the SDA OCs and GEPs. Additionally, SDA requires SVs from multiple sources in multiple configurations to operate in an integrated fashion through a common ground system; therefore, GDMS will collaborate with each space vehicle provider to integrate Ground Segments with partner interfaces. GDMS will rely on their established process to deliver planned mission capabilities with Iridium's commercially proven systems to monitor the constellation and to manage the Enterprise, mission, and payload data. GDMS completed their Systems Requirement Review (SRR) in August 2022.

T1 Tracking. The primary mission objective of the T1 Tracking Layer 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 the T1 Transport Layer to deliver low-latency sensor-to-shooter connectivity in support of military operations around the world. In February 2022, SDA's Warfighter Council (WFC) concurred with SDA's minimum viable product for the T1 Tracking Layer. Funding was secured using the Middle Tier Acquisition (MTA) pathway to acquire the T1 Tracking prototype systems, and SDA released an OT RFP for the T1 Tracking Layer in March 2022. Two bidders were awarded contracts for a total of $1.3 billion. L3Harris and Northrop Grumman will build and deploy 14 SVs each (for a total of 28) with a wide field of view (WFOV) IR payload for missile warning, detection, and tracking. In addition to the WFOV SVs, each contractor will also build and deploy two additional SVs with a medium field of view (MFOV) IR payload for detecting dimmer targets and providing track quality data for fire control handoff. The T1 Tracking Layer will consist of four planes of seven WFOV SVs and one MFOV SV, launched to 1,000 km. This set of SVs forms the initial element of the pLEO portion of a Space Warfighting Analysis Center force design representing an integrated approach to advanced missile detection, tracking, and defeat.

Tranche 1 Demonstration and Experimentation System (T1DES). As part of WFC concurrence to the T1TL minimum viable product proposal from SDA in March 2021, T1DES was created, which will have the capability to leverage the low-latency data transfer, beyond-line-of-sight (BLOS) command and control infrastructure established by the T1TL program to field and connect additional SVs with different mission payload configurations. A final OT RFP was released in June 2022, and York Space Systems was awarded the contract before the end of FY 2022 for a total cost of $200 million. York will deliver 12 T1DES SVs and support launch integration, ground systems, and operations and sustainment services. T1DES SVs will integrate with T1TL through the use of interoperable OCTs, networking and data routing, and ground system operations. T1DES SVs will host mission payloads serving Integrated Broadcast Service–LEO (IBS-L) and Tactical Satellite Communication (TACSATCOM) missions. York will deliver three T1DES SVs to launch with each of four sets of T1 Tracking Layer SVs and to deploy into and operate from four orbital planes.

Additional Noteworthy Progress

National Defense Space Architecture (NDSA) Experimental Testbed (NExT). NExT leverages NDSA's low-latency data transfer and BLOS communications infrastructure to collect and move mission data to the tactical edge on relevant timelines. 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. An OT RFP was released in June 2022 for the development, manufacture, deployment, and operations of ten NExT SVs and mission-enabling ground systems. Ball Aerospace Technologies Corp. was awarded a $176 million contract at the end of FY 2022 for this effort.

Tranche 2 (T2) framework. In FY 2022, SDA began drafting the T2 framework. The Tranche 2 Transport Layer will complete the global pLEO mesh communications data transport capability required by the warfighter for worldwide operations. It will provide 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.

FY 2022 Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR) efforts. SDA awarded a total of 33 SBIR/STTR awards in FY 2022. Awards topics included Integrated Architecture Technologies for Modeling, Simulation and Analysis of future NDSA constellations; Free-Space

Optical Communication (FSOC) Technology for Optical Intersatellite Links (OISL); L-Band Multiband/Interleaved Electronically Scanned Array (ESA) Antenna; Advanced Space Mesh Networking; Target Recognition and Acquisition in Complex Environments (TRACE); Mesh Network NSA Certifiable Cryptographic Solution (Crypto); Compact Passive Polarimetric Microwave Radiometer and Sounder (CP2MRS); and Commercial SAR and Scatterometry (COSAS). 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.

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. The COVID-19 pandemic significantly affected air travel, the aviation industry, and the FAA, and the last few years have tested our collective resolve, flexibility, and resiliency. By 2022, the aviation industry and the nation were well on the road to recovery: air traffic had gradually returned and was slightly below pre-pandemic levels.

In November 2021, President Joseph Biden signed the Infrastructure Investment and Jobs Act, also known as the Bipartisan Infrastructure Law (BIL). The BIL gives the FAA $25 billion over five years for air traffic control facilities, airport infrastructure grants, and investments in airport terminals and airport-owned towers. The first installment of funds for FAA-owned facilities covered power systems, fuel tanks, environmental control systems, mechanical systems, radio and radar towers, and unstaffed buildings that house and protect critical equipment. On December 16, 2021, the FAA announced $2.89 billion provided under BIL to pay for runways, taxiways, and aprons—as well as terminal, intermodal, and roadway projects—for airports. On July 7, 2022, we awarded nearly $1 billion across 85 airports for improving airfield safety through terminal relocation, replacing aging facilities, improving energy efficiency, encouraging competition, and expanding access for people with disabilities.

Work continued on expanding and operationalizing NextGen during the reporting period.[1] For example, the FAA activated Data Communications capability at Cincinnati/Northern Kentucky International Airport in 2021. In 2022, the capability extended to Jacksonville and Palm Beach international airports, and Oakland and Minneapolis en route centers. The FAA has published 353 Performance Based Navigation (PBN) routes for cruising altitudes and 9,401 PBN departure, arrival, and approach procedures. We completed the Metroplex program that started in 2010 by closing out the 11th and final project in South-Central Florida in 2022. We also authorized the Established on Required Navigation Performance (EoR) separation standard at Los Angeles International Airport in 2021, and Houston expanded EoR operations to all four available downwind directions in 2022. With the installation of the Standard Terminal Automation Replacement System (STARS) at the Grand Canyon control tower in 2021, the FAA completed the system's nationwide rollout. STARS is now operational at more than 500 FAA and 200 Department of Defense facilities. With the foundational NextGen infrastructure in place, we are closer to our vision of managing air traffic more strategically through Trajectory Based Operations.[2]

COVID-19

The FAA moved to a maximum telework posture during the COVID-19 pandemic, but many FAA employees must be on-site to perform their duties. Air traffic controllers, for example, must physically be at their stations to direct traffic. Early in the pandemic, when air traffic plummeted, the FAA adjusted the number of personnel on shifts to match the reduced demand, allowing us to reduce crews' potential exposure to one another. As air traffic began to return, we increased staffing to match demand and used new federal protocols based on more data to protect our team. We used personal protective equipment, implemented frequent

1 The Next Generation Air Transportation System is the FAA's ongoing multibillion-dollar infrastructure program to modernize the U.S. National Airspace System, fundamentally changing the way we see, navigate, and communicate in the nation's skies. For more information, see: *https://www.faa.gov/nextgen*

2 Trajectory Based Operations is an air traffic management method for strategically planning and managing flights throughout the operation by using time-based management, information exchange between air and ground systems, and the aircraft's ability to accurately navigate in time and space. For more information, see: *https://ww.faa.gov/go/tbo*

cleanings, and tracked COVID-19 cases. The FAA prioritized flights carrying COVID-19 vaccines. We offered around-the-clock air traffic services to keep air cargo moving seamlessly and to provide personnel critical to the nation's response to, and recovery from, COVID-19.

Still, the FAA always strives to ensure the safety of its employees, and at the height of the pandemic, to minimize contamination risk, the FAA paused in-person controller training. To further reduce the number of personnel at facilities, the FAA also paused the deployment of new systems at air traffic control facilities. We employed remote capabilities for everything from system testing to conducting safety panels and site surveys. These decisions allowed the FAA to ensure continuity of operations throughout the National Airspace System, even under the once unthinkable stresses the last three years have placed on the system.

These measures, while necessary, came with a cost. Controllers require a lengthy training program tailored to their specific facility, and the consequences of the training pause will take years to fully rectify. The pandemic caused the postponement of many new technologies, and the FAA is working diligently with industry to prioritize these new technologies for deployment. In April 2022, FAA tasked its NextGen Advisory Committee to advise on industry's key priorities. The committee's feedback has helped us reassess our near-term priorities as we emerge from the COVID-19 pandemic. This invaluable feedback ensures we have the right balance between sustaining operations and investing in operationalizing NextGen.

Commercial Space

Commercial rocket launches achieved new highs in 2022 with 74 launches and reentries from several companies, 10 more than in 2021. 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.

In addition to the growth in the number of commercial space operations, the complexity of the missions seeking FAA approval continues to change dramatically. The FAA continued preparation for a dynamic, rapidly maturing set of future missions, which include orbital and suborbital space tourism, interplanetary travel, space-based internet services, commercial space stations, and innovative new designs for traditional launch systems.

In May 2021, four astronauts—one from the European Union, one from Japan, and two from the United States—reached the International Space Station aboard a SpaceX Falcon 9 rocket as part of the Crew-2 mission. It was the first FAA-licensed U.S. commercial space mission to fly an astronaut from the European Space Agency. SpaceX continued to provide spaceflight capability to NASA astronauts and the International Space Station, launching its fourth crewed mission in April 2022 and 25th cargo resupply mission in July 2022. This capability eliminates the United States' dependence on high-cost Russian transportation to the International Space Station. Boeing continued to develop its commercial capsule and demonstrated a second orbital flight for NASA in May 2022.

In 2021 and 2022, private space companies continued to expand commercial space transportation activities:

- On July 11, 2021, Virgin Galactic launched the SpaceShipTwo rocket carrying two pilots and four crew into suborbital space. The launch from Spaceport America in New Mexico was an operational test before establishing scheduled commercial spaceflights.
- On July 20, 2021, Blue Origin sent off its New Shepard suborbital launch vehicle from its West Texas site. The flight carried four passengers, including the oldest and youngest people ever to fly into space. It also included the first person designated as a spaceflight participant under FAA rules. Blue Origin completed six launches of the New Shepard, each carrying multiple spaceflight participants.
- SpaceX continued the development of a reusable super-heavy lift launch system, known as the Starship. This system is designed to be the world's most powerful rocket.
- Virgin Orbit launched its fifth licensed mission from the Mojave Air and Space Port in California in July 2022.

As more rocket launch operators seek to share the nation's airspace, the FAA has deployed the space data integrator (SDI). This software delivers real-time telemetry data from the vehicle operator to the FAA Air Traffic Control System Command Center. The Command Center is in charge of overseeing and coordinating all of the air traffic across the National Airspace System. Delivered data includes vehicle position and speed as well as indicators if the vehicle deviates from its expected flight path. This information enables the FAA to follow the progress of the vehicle along its planned path and monitor whether the vehicle is performing as expected. Launch and reentry vehicle operators voluntarily deliver telemetry data via SDI, and in 2021, the FAA partnered with the Alaska Aerospace Corporation, Astra, Blue Origin, and SpaceX to deliver their data for integration into SDI. This tool can inform the use of time-based launch/reentry procedures (TBLP) as well as the dynamic launch and reentry windows (DLRW) that the FAA used at launch sites in Boca Chica and Van Horn in Texas. TBLP and DLRW are ways the FAA uses data about launch and reentry operations to minimize the amount of time airspace is closed to other commercial users.

The FAA continues to improve its processes to accommodate the commercial space industry's massive growth. One example of this improvement is the implementation of Title 14 Code of Federal Regulations Part 450. First published in March 2021, Part 450 is a performance-based licensing structure for commercial spaceflight launch and reentry operations. This new regulation overhauls the FAA licensure of commercial space launches and consolidates four prescriptive rules into one performance-based standard. With performance-based regulations, the FAA focuses on achieving results rather than trying to mandate the specific processes or technologies used to achieve those results. Companies can launch the same vehicle or family of vehicles multiple times after demonstrating how they meet established safety criteria. Additionally, Part 450 licenses can be modified for new conditions instead of requiring commercial spaceflight providers to apply for a new license. While this streamlines the process for applicants, it creates new challenges for the FAA as the agency must be able to quickly review the modifications and determine the safety of systems that may not conform to traditional launch and reentry standards. The FAA granted the first Part 450 license to Astra in February 2022.

Uncrewed Aircraft Systems

It's hard to understand just how big of a leap integration of uncrewed aircraft systems (UAS), or drones as they are commonly known, has taken since the first FAA regulations regarding UAS (Registration and Marking Requirements for Small Uncrewed Aircraft interim final rule) appeared in 2015. In 2016, the FAA enabled limited operations for small UAS with a new set of regulations that are commonly called the "small UAS rule." In 2021, the FAA took strides toward integrating this new entrant into the nation's airspace. Finalized rules for Operation of Small Uncrewed Aircraft Systems (sUAS) Over People (amendment to Title 14 Code of Federal Regulations Part 107) and UAS Remote Identification (Title 14 Code of Federal Regulations Part 89) will further UAS integration.

The original Part 107 regulations authorized only certain types of operations. Flying under Part 107 meant staying in Class G airspace (airspace not managed by the air traffic control) unless authorized by the FAA, flying during the day, and keeping the UAS within the pilot's line of sight. If an operator wanted to fly over people, at night, or beyond their visual line of sight, they needed to request a waiver or an exemption from the FAA. The amendment to Part 107 permitted UAS operators to fly in more situations, increasing the economic and recreational potential of drones. Now allowed under this new rulemaking activity, routine night operations began in the spring of 2021.

Keeping pace with the UAS industry means the FAA had to adjust its development models to put those enabling regulations into action. The Low Altitude Authorization and Notification Capability, or LAANC, was established in 2017 to facilitate automated airspace access for commercial and recreational sUAS operations. Through a cohort of FAA-approved UAS Service Suppliers, LAANC streamlines the airspace access process to provide near real-time authorizations to small UAS pilots. Through rapid development and deployment of enhancements, as well as working directly with industry, LAANC adapted to reflect the aforementioned 2021 regulations updates and enabled automated access to controlled airspace for commercial night operations in September of 2021. In parallel, as a response to the Drone Advisory Committee recommendation, the FAA refined the UAS Facility Maps that establish maximum altitudes for UAS operations in controlled airspace to increase the granularity of available airspace, opening up a considerable volume of airspace for near-real time access. As a result of these enhancements, the demand for using automated process has grown significantly, reaching 1 million of airspace authorizations processed in LAANC in February of 2022.

Publishing the Remote Identification (ID) of Uncrewed Aircraft Final Rule was the next incremental step toward further integration of uncrewed aircraft in the national airspace. Remote ID is a digital "license plate" for an uncrewed aircraft. With Remote ID, law enforcement and national security partners will have a better way to locate the operator, determine if a drone is being operated inappropriately or without permission, and respond if necessary. The operator's UAS serial number and location information will be available to anyone within range with Remote ID broadcast receiver technology on their personal wireless device, such as a smartphone. However, only authorized government agencies and law enforcement can request more detailed registration information from the FAA. Full Remote ID compliance will become mandatory September 16, 2023.

One of the next steps in UAS integration involves beyond visual line-of-sight (BVLOS) operations, which are permitted only with a waiver. In June 2021, the FAA chartered a new Aviation Rulemaking Committee (ARC) to help the agency develop a regulatory path for routine BVLOS operations. The BVLOS ARC was tasked with the following:

- Identifying safety and environmental considerations for BVLOS UAS operations, accounting for the security needs of the U.S. government.
- Identifying societal benefits for BVLOS UAS operations.
- Recommending requirements and providing the rationale for such requirements to enable BVLOS drone operations.
- Submitting a recommendation report to the FAA.

The BVLOS ARC's final report was published in March 2022. This report represents a huge milestone in laying the foundation for BVLOS operations of drones in the national airspace. The report's diverse perspectives will inform the FAA's approach to safe drone integration and will help pave the way for routine package delivery, infrastructure inspection, and other more complex drone operations. The FAA's next challenge is to consider these recommendations as it develops a path toward flexible performance-based regulations that enable scalable drone operations. Stakeholder outreach is an important part of this effort. To that end, the FAA conducted two listening sessions with a broad segment of industry stakeholders to collect necessary feedback on the ARC report.

The aviation industry is ready and willing to provide resources, technology, and expertise to scale BVLOS; many companies, communities, and industrial sectors have invested substantial resources in developing UAS technologies to realize these benefits. The ARC's recommendations and industry feedback are now under consideration as FAA has begun to map out a new regulatory framework to regulate drones, enhance safety, and promote sustainable transportation solutions—all while ensuring America's continued leadership in aviation innovation.

The FAA has also been working with the Federal Communications Commission (FCC) and the National Telecommunications and Information Administration to develop federal rules for UAS communication links in the 5030–5091 MHz band. This has involved technical studies and working with industry partners through the Radio Technical Commission for Aeronautics (RTCA). These regulatory efforts will promote safety within the commercial proliferation of UAS technologies.

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 from the Aircraft Certification, Safety, and Accountability Act and the various recommendations we received from recent investigations and independent reviews. In doing so, 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 fiscal years 2021 and 2022 are:

- Rescinding on November 18, 2020, the FAA order that grounded the Boeing 737 MAX after a crash in Indonesia in 2018 and in Ethiopia in 2019 together killed 346 people. The FAA also published an airworthiness directive that specified the steps U.S. operators must accomplish before returning their existing fleet of 737 MAX airplanes to service. The decision to unground the airplane was based on the FAA's thorough and deliberate safety processes. The design and certification of this aircraft included an unprecedented level of concurrent and independent reviews by aviation authorities around the world. Those regulators have indicated that Boeing's design changes, together with the changes to crew procedures and training enhancements, give them the confidence to validate the aircraft as safe to fly in their respective regions.
- 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.
- Implementing the voluntary safety reporting program (VSRP), allowing confidential reporting of identified safety concerns for all FAA Office of Aviation Safety employees. The Aviation Safety 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 Aviation Safety VSRP uses an event review team, which is an independent body composed of FAA Aviation Safety management and union representatives. This team analyzes reported safety concerns and determines, through consensus, the need for corrective actions or other outcomes.
- Issuing the draft flightpath management advisory circular, which guides operators to help pilots maintain manual flight operations skills and avoid becoming overly reliant on automation. The advisory provides a single

framework for operations and training programs. The draft advisory circular was developed 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.

5G

On January 19, 2022, 5G telecommunications services launched in 46 U.S. markets using frequencies in a radio spectrum known as the C-band. The C-band spectrum is adjacent to the band used by aircraft radio altimeters, which raised concerns about potentially hazardous interference by 5G transmitters. The FAA requires radio altimeters to be accurate and reliable. Because the agency is charged with ensuring the safety of all aircraft equipment, the rollout of the C-band wireless network required extensive cooperation between equipment manufacturers, wireless companies, and the FAA.

Because the deployment involved changes in power levels on the frequencies near the aviation spectrum, the FAA restricted certain safety-sensitive flight operations that rely on radio altimeters. The FAA continues to work to safely reduce the effects of this disruption. The FAA firmly believes that 5G and the U.S. aviation system can co-exist, and the agency has made significant progress in support of this goal since January 2022. Daily collaboration between experts from the FAA and the wireless companies helped refine our risk-assessment model near runways. The FAA and telecommunication companies have also partnered and shared data in order to run important technical tests and develop safeguards. This enabled the wireless companies to turn on the maximum number of transmitters while protecting aviation safety.

As of October 2022, wireless companies have activated nearly 97 percent of their installed network of more than 51,000 transmitters. Key stakeholders in the aviation and wireless industries identified a process that will continue to protect commercial air travel from disruption by 5G C-band interference while also enabling wireless companies to enhance service around certain airports.

In the long term, the FAA expects to establish a new performance standard for altimeters in the presence of a 5G C-band. The FAA continues to use the information and lessons learned from the 5G launch to better prepare for spectrum and aircraft equipage policies in the future. We plan to use the same framework of interaction between the FAA, original equipment manufacturers, and wireless companies as a template for engaging new entrants—a process that has already begun.

Workforce Development

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 established two grant programs through Section 625 of the FAA Reauthorization Act of 2018 to expand the aviation workforce. The Aircraft Pilots Workforce Development Grants program encourages students to become pilots, aerospace engineers, or uncrewed 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 2022, the FAA awarded the first $10 million in Aviation Workforce Development Grants to more than 30 educational institutions across the country. The FAA published the Notice of Funding Opportunity for a second round of grants in April 2022, with another $10 million available, and received applications in June.

In addition to these 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 air transport pilot certification.
- 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, an accredited flight school, to begin this program. The FAA is committed to creating bridges to the civilian 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.

The FAA is also working to attract young talent for careers at the FAA. The FAA's Science, Technology, Engineering, and Math (STEM) Aviation and Space Education (AVSED) Program is an integral part of FAA outreach to the national education system. The program introduces students to aviation and aerospace careers and promotes STEM education through outreach events such as the Adopt-a-School program. Through this program, FAA employees volunteer to collaborate with classroom teachers to present lessons that foster curiosity about aviation. Examples of these lessons include:

- Why air traffic control is important to the safe operation of the National Airspace System and how controllers use problem-solving skills to keep aircraft safe on the ground and in the air.
- How aviation maintenance technicians use STEM skills, tools, and technologies in their jobs.
- How drones are used in the community, how they can be operated safely, and how various professions use drones to help with their work.

These lessons show that STEM skills can translate directly to careers in the FAA. Through these kinds of workforce development programs, the FAA will ensure the pipeline for aviation professionals remains healthy, diverse, and inclusive for decades to come.

Sustainability in Aviation

The FAA is committed to making aviation cleaner, quieter, and more sustainable. At the United Nations Climate Change Conference in November 2021, U.S. Secretary of Transportation Pete Buttigieg released the 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. The first is the creation of sustainable aviation fuel (SAF), which can be used today without modifying existing aircraft. SAF can be made from a range of raw materials, including crops, agricultural residue, and waste products. SAF produced from renewable and waste materials will have a significant effect on our effort to reduce greenhouse gas emissions. Such fuels will be crucial to the aviation industry's ability to meet the net-zero emissions goal, and they have the potential to completely eliminate emissions.

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

In September 2021, the departments of Transportation, Energy, and Agriculture signed a memorandum of understanding to co-lead a government-wide SAF grand challenge to dramatically expand SAF production to three billion gallons per year by 2030 and meet 100 percent of aviation fuel needs by 2050. The FAA is a proud participant in the SAF grand challenge, which promises to reduce cost, 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 fuel. The SAF grand challenge and the increased production of SAF will play a critical role in a broader set of actions by the U.S. government and the private sector to push U.S. aviation toward net-zero emissions and full decarbonization by 2050. SAF provisions in the Inflation Reduction Act of 2022, including tax incentives and grant programs, will help scale up the production and use of SAF and support the goals of the SAF grand challenge.

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 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 more aircraft technologies that reduce the effects of aviation on the environment.

Internationally, the FAA provides leadership in developing and establishing the International Civil Aviation Organization (ICAO) technology-based standards to reduce aircraft greenhouse gas emissions. Domestically, the FAA collaborates with the Environmental Protection Agency to promulgate ICAO 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 carbon dioxide emissions standard from 2017 and will mandate U.S. airplane manufacturers to use fuel-efficient technologies in newly built airplanes. Concurrently, the FAA is leading the development of a more stringent regulatory level to ICAO's standard, expected in 2025.

The FAA is reducing its own emissions by installing renewable energy at its facilities and purchasing carbon-free electricity. In 2022, work continued on solar farm installations at FAA facilities in Guam and Hawaii, which will increase the current 6,200 megawatt-hours of renewable electricity already produced. Other large-scale solar farms are being planned and designed at the FAA Mike Monroney Aeronautical Center and the Boston Consolidated Terminal Radar Approach Control Facility.

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 2021 and FY 2022, 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 operational 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 2021 and FY 2022.

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 commercial space situational awareness and space traffic management services, 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 Management Services

Supporting basic Space Situational Awareness (SSA) data and basic Space Traffic Management (STM) services: In partnership with industry, government, and academia, the OSC is implementing an operational public SSA and STM services system through the development of an open architecture data repository (OADR). The OADR is a cloud-based architecture using government and commercial data, software, and services. This public-private collaboration continues to evolve through ongoing research, integration, and testing to advance capabilities for SSA and STM through the OADR. These combined efforts will improve SSA data interoperability and increase SSA data sharing. On September 9, 2022, the Department of Commerce signed a Memorandum of Agreement (MOA) with the Department of Defense formalizing the organizations' relationship for basic SSA, STM, and coordination for civil and commercial entities. The agreement defines how the two departments will work cooperatively to implement the National Space Council's Space Policy Directive 3 (SPD-3). SPD-3 seeks to advance SSA and STM science and technology; provide federally-supported basic SSA data and STM services to the public; and improve SSA data interoperability to enable greater SSA data sharing.

Supporting the operational use of commercial SSA data: The OSC issued a Request for Proposals (RFP) related to its effort to establish the OADR and conduct pilots, prototypes, and experiments to fulfill its obligations under SPD-3. Commercial data are being acquired, processed, evaluated, assessed for potential operational uses, and archived to assess the impact of data variations on SSA forecast models. Commercial data buys have included observation data from low Earth orbit on September 7, 2022, and an additional five contracts for data from geostationary Earth orbit on September 12, 2022.

Developing STM standards and practices: The OSC and the National Institute of Standards and Technology (NIST) have coordinated input from the U.S. government for the development of internationally accepted common standards, best practices, and guidelines. Through engagement with standards-developing organizations such as the International Organization of Standardization (ISO) and ASTM International, DOC is helping to deliver the best globally accepted and internationally-agreed upon technical solutions to the space community through voluntary consensus-building processes. In addition, OSC and NIST have supported reviews of current capabilities and the development of new approaches for the integration of open-access data meshing practices for space data operations, interoperability, and communications. OSC also provided input to the planning for the National Geospatial Agency's Space Standards Working Group on Geospatial Intelligence standards.

Growing U.S. Commercial Space Solutions

Developing commercial space weather pilots: The OSC supported efforts for NOAA awards of three Commercial Weather Data Pilot (CWDP) space weather contracts to GeoOptics Inc. (Pasadena, CA), Space Sciences and Engineering LLC, PlanetiQ (Golden, CO), and Spire Global Subsidiary, Inc. (San Francisco, CA).

NOAA's Commercial Data Program (CDP) supports CWDP studies to demonstrate the quality and impact of commercial data on NOAA's weather forecast models. Awardees will provide near real-time radio occultation (RO) measurements from Global Navigation Satellite System (GNSS) receivers that will enable NOAA to derive ionospheric products that meet the current and anticipated needs of operational space weather models and applications.

Using radio occultation data through data purchases: The OSC supported efforts for the RFPs for the second purchase of space-based commercial RO data for use in NOAA's operational weather forecasts. NOAA will process commercial near-real-time satellite-based GNSS RO and ionospheric measurements into neutral atmosphere and space weather products. These derived products will be fed into NOAA's operational data systems, including weather and space weather analysis and prediction systems, and used for weather, climate, and atmospheric research purposes.

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 working group's implementation plan development.

Mitigating the impact of orbital debris: The OSC participated regularly in the Orbital Debris R&D 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. In addition, the OSC partnered with NASA's Heliophysics Division to initiate a cross-cutting strategic activity for basic R&D to address scientific questions on how the space environment impacts SSA and orbital debris.

Supporting space companies through advocacy: The OSC engaged in dialogue with U.S. space companies and organized several government-industry events. The first symposium (May 5, 2021) focused on the latest cyber threats to space infrastructure, existing space cybersecurity policies, and industry cybersecurity experience and mitigation strategies tailored to emerging and start-up companies. The second symposium (October 13, 2021) expanded upon the first symposium by focusing on applied cyber best practices, including a specific focus on cyber standards, the standards process, standards bodies, regulations, and federal acquisition requirements as they apply to commercial space. The third symposium (June 16, 2022) broadened into a global view of cybersecurity threats, geopolitical awareness, actionable ideas for securing space businesses and open data systems, and discussions of recent cyber legislation and executive orders. This symposium included a panel of international cybersecurity experts from several allied nations. Each event had more than 1,000 registered attendees from around the world.

In addition, the OSC Director signed a joint project agreement to collaborate with the Satellite Industry Association, the American Astronomical Society, the International Astronomy Union Center for the Protection of Dark and Quiet Skies, NIST, and the National Science Foundation to kick off the "Effects of Satellites on Astronomy Symposia" series. The OSC and NIST hosted a workshop on June 28, 2022, to engage with the satellite industry and astronomy community to examine how commercial space companies can participate in efforts to preserve astronomical observational data quality and analysis through technological innovations, measurements, best practices, and collaborative coordination among multiple stakeholders. OSC has taken a leadership role by expanding the dialogue between astronomers and the commercial space industry on how best to minimize impacts to optical and radio astronomy while enabling the satellite industry to successfully execute their business models.

Advancing export control for U.S. businesses: The OSC provided subject matter experts to assist the DOC Bureau of Industry and Security (BIS) 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 (EAR) 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 the Earth's atmosphere, and 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).

The Director of the OSC participated in the World Satellite Business Week (WSBW) and International Astronautical Congress (IAC) in Paris, France, in September 2022. Throughout the duration of these conferences, the OSC Director and staff joined in meetings with leadership from the European Union Space Surveillance and Tracking program, international space agencies, and other businesses. At the WSBW, there were over 1,200 business leaders and more than 450 public and private organizations attending the meeting, with 190 top-executive speakers from around 50 countries speaking throughout the four-day program. For the IAC, over 6,500 delegates were in attendance. The OSC also participated in a free, open to the public, "Space for All" day that included meetings with astronauts, virtual reality experiences, and many other opportunities for the public to learn about space.

The OSC Director provided the keynote address on the current state-of-the-field for SSA and the DOC's efforts in this area at the 2022 Advanced Maui Optical and Space Surveillance Technologies (AMOS) Conference, Maui, Hawaii, in September 2022. 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 management services.

The OSC Director also provided a presentation for the George Washington University Elliot School of International Affairs symposium "After the KE-ASAT Moratorium: What Next?" Symposium on August 24, 2022. The Director discussed the role of the government in space standards and norms of behavior. The event was open to the public with over 250 people in attendance and broadcast as a webinar to engage the international community in the dialogue.

The OSC actively participated in multilateral organizations such as the U.S. Committee on the Peaceful Uses of Outer Space (UNCOPUOS) 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 latest generation of Geostationary Operational Environmental Satellites, known as the GOES-R Series, are 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 observation of hurricanes, thunderstorms, snow, ice, fog, damaging winds, fire, and other severe weather conditions and environmental hazards from the west coast of Africa to New Zealand.

On March 1, 2022, GOES-T, the third satellite in the GOES-R Series, launched from Cape Canaveral Space Force Station. It was renamed GOES-18 once it reached geostationary orbit and is currently undergoing post-launch checkout and testing of its instruments and systems. NOAA plans for GOES-18 to replace GOES-17 as the GOES-West operational satellite in January 2023. GOES-17 will then become the primary on-orbit standby satellite.

GOES-U, the final satellite in the GOES-R Series, is in final development and is fully integrated and beginning environmental testing in preparation for a planned April 2024 launch.

The GOES satellites provided imagery and critical information during the busy 2021 Atlantic hurricane season that produced 21 named storms, including seven hurricanes. They also supported emergency responders controlling extreme wildfires in the western states and provided early warning of severe weather outbreaks across the nation. The GOES space weather instruments monitored intensifying solar activity and supported geomagnetic storm warnings as Solar Cycle 25 was reaching solar maximum.

NOAA's Geostationary Extended Observations (GeoXO) mission, the next generation program to follow the GOES-R Series, was formally initiated in November 2021. During the formulation phase, the program is refining mission requirements, detailing acquisition strategies, schedules, and cost estimates, completing resource planning and risk management, and confirming technology readiness. The GeoXO team is collaborating with industry partners on definition-phase studies for the spacecraft and each of the five planned instruments. The program was formally approved in December 2022 through its Milestone 2 review with Deputy Secretary Graves, and is now moving into the implementation phase of the mission. The first GeoXO launch is planned for 2032 to maintain continuity of geostationary observations.

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

- GOES-18 (GOES-T) March 1, 2022
- GOES West (GOES-S/GOES-17) March 1, 2018
- GOES East (GOES-R/GOES-16) November 19, 2016

Low Earth Orbiting Satellites

NOAA's latest 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 the 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 this 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.

The JPSS-2 satellite, which is the third in the JPSS series, was launched in November 2022 from Vandenberg Space Force Base in California and will ensure continuity of the JPSS measurements into the future. Once the JPSS-2 satellite reaches polar orbit, it will be renamed NOAA-21. NOAA-21 will provide 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 successful launch and on-orbit checkout of its instruments and systems, 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.

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 the 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.

Since the launch of the six COSMIC-2/ FORMOSAT-7 satellites on June 25, 2019, the joint program has commissioned the satellites and transitioned them incrementally to their operational orbital positions over the course of 19 months. During this time, the program has been calibrating and validating the data and has also been incrementally releasing space weather data products. The neutral atmosphere data has been used operationally by the NWS, the U.S. Air Force, the Taiwan Central Weather Bureau, and global weather forecast centers since the spring of 2020. The Joint Program declared Full Operational Capability in September 2021. COSMIC-2/FORMOSAT-7 data proved to be a valuable new data resource during the active Atlantic hurricane season.

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. Terrestrial platforms make various environmentally based measurements and then upload short duration messages to Argos instruments on satellites in low-Earth orbit. The Argos system supports 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. The current DCS instruments on the NOAA polar-orbiting satellites (NOAA-15, -18, -19) are operating well beyond their design life. 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. In 2018, a delivery order was awarded to General Atomics to integrate and launch the Argos-4 payload on the Orbital Test Bed-3 spacecraft by October 10, 2022. 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 new 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 (SEM), 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 gases 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 between NOAA, NASA, and international partners at EUMETSAT and the European Space Agency.

This next generation, 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 823–848 km (dependent on latitudes). There will be three satellites each of

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

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, Spitzbergen, and McMurdo, Antarctica.

The Japan Aerospace Exploration Agency (JAXA) Global Change Observation Mission–Water Satellite 1 (GCOM-W) project is a 13-year mission with a series of three satellites that aims to measure global-scale water-cycle changes over a long period of time. The GCOM-W1 is the first satellite in the GCOM-W series and was launched in May 2012 by JAXA. The Advanced Microwave Scanning Radiometer 2 (AMSR2) onboard the GCOM-W1 satellite provides observations of water vapor, cloud liquid water, precipitation, sea surface temperature, sea surface wind speed, sea ice concentration, snow depth, and soil moisture. 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 Japanese Fiscal Year 2023- April 1, 2024–March 31, 2025). JAXA will continue to transmit the 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, a Low Earth Observing (LEO) satellite portfolio was proposed 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, Department of Commerce (DOC) primary mission essential functions and strategic plans, and NOAA Mission Service Areas. The LEO 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 type 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 (POES) assets expected in late calendar year 2024. To serve as a pathfinder for LEO 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. Additionally, the LEO 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 mission is NOAA's first operational deep space mission. 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.

As part of NOAA's Space Weather Follow On (SWFO) Program, NOAA is partnering with the Naval Research Laboratory (NRL) to build three Compact Coronagraph (CCOR) instruments for future space weather observations. In FY 2020, NOAA continued assembly of the first CCOR (CCOR-1) and initiated work on a second (CCOR-2). In FY 2022, the first CCOR was integrated onto the GOES-U spacecraft which is planned for launch in 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 Lagrange-1 point. In FY 2020, NOAA, using NASA as its acquisition agent, awarded contracts for all the SWFO-L1 instruments and spacecraft. In FY 2021, NOAA awarded contracts for the Command and Control element of the ground segment and the SWFO Antenna Network.

The Space Weather Next (SW Next) Program is a loosely-coupled program implemented under the joint NOAA-NASA Space Weather Observations (SWO)

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 in the formulation stage and is refining mission requirements, schedules, cost estimates, resource planning, among other activities in this stage. The program formulation was responsive to the Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act (2020), which specified NOAA as providing space weather observational data continuity and enhanced space weather capability. In FY 2022, the SW Next program successfully completed its Mission Concept Review on August 16, 2022, and Key Decision Point 0 on September 21, 2022.

To maintain data continuity and provide enhancements for high-priority space weather observations, SW Next could potentially include observations in low Earth orbit (LEO), geosynchronous orbit (GEO), L1 orbit, as well as observations collected off the Sun-Earth Line (off-SEL) such as Lagrange point 5 (L5).

L1 Series: The L1 Series Project will develop, build, and deploy a series of dedicated space weather observatories to meet user requirements for continuity of observations at L1 beyond the SWFO-L1 mission. Each observatory will include capabilities similar to SWFO-L1 plus the priority enhancement of an instrument for x-ray irradiance measurements, as well as accommodations for an instrument of opportunity. Under the signed NOAA–ESA Agreement on Cooperation on Space-based Space Weather Observations, ESA will provide an X-ray Flux Monitor instrument that will fly on the first L1 Series observatory.

L5 Compact Coronagraph: SW Next, in partnership with NRL, will build and deliver the third Compact Coronagraph to ESA as part of the February 2022 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 will fulfill NOAA requirements for off-SEL observations.

National Institute of Standards and Technology

In FY 2021 and FY 2022, 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 and supplies, communications, and extraterrestrial research. In these areas, NIST provides much-needed calibrations, technology development, and technical guidance, and standards.

Advanced Manufacturing for Aerospace Applications

In FY 2020, NIST used measurement expertise in mass, force, networking, and other areas to partner with multiple industrial aerospace corporations. In addition to providing calibration support, NIST's broad portfolio in advanced manufacturing helped aerospace manufacturing companies address needs in many sectors, including additive manufacturing, 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 additive manufacturing (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.

In FY 2021 and FY 2022, the NIST Metals-based Additive Manufacturing Grant Program awarded nearly $8,000,000 in funds to academia. These grants, in combination with NIST's robust AM research program, enable NIST to address barriers to the adoption of AM, including surface finish and quality issues, dimensional accuracy, fabrication speed, and material properties of manufactured parts, all of which have extensive applications in the aerospace sector.

NIST contributed to workshops with the FAA, DOD, NASA, and aerospace industry representatives to identify approaches for qualification and certification of additive manufacturing materials, processes, and parts for use in load-bearing and mission-critical applications. As a result of these activities, NIST is actively engaged with U.S. regulatory agencies, government laboratories, academia, and industry to develop a qualification and certification roadmap for AM aeronautics applications. In FY 2022, NIST awarded nearly $300,000 to the University of New Hampshire to explore new paradigms in manufacturing for the equitable commercialization, industrialization, and democratization of in-space manufacturing.

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. At the 2022 AM Bench conference, NASA and the Federal Aviation Administration (FAA) partnered with NIST to hold an embedded workshop on qualification and certification for aeronautics applications.

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

NIST has robust, ongoing engagement with aerospace companies to identify technical issues and to define requirements for industrial wireless networking, cybersecurity in manufacturing environments, and prognostics and health management for manufacturing systems. For example, NIST and The Boeing Company collaborate on standards development for prognostics and health management (PHM) through the ASME PHM Subcommittee. In addition, NIST and the Aerospace Corporation collaborated with the OSC, NOAA, to build a satellite navigation reference database. NIST also provided technical guidance on appropriate architecture for building a distributed-but-federated data system.

Much of NIST's support for the aerospace supply chain came from direct interactions with the suppliers. In FY 2021 and FY 2022, the Hollings Manufacturing

Extension Partnership (MEP) National Network engaged in 622 projects with 424 individual manufacturing clients designated with an aerospace North American Industry Classification System (NAICS) number 3364. Seventy-five percent of these clients were small manufacturers (those with fewer than 100 employees). In FY 2021 and FY 2022, MEP services resulted in the creation or retention of 3,268 aerospace jobs over $1.5 billion in new and retained sales, over $109 million in new investment, and over $46 million in cost savings.

Aerospace Systems and Supplies

NIST's contributions to the manufacturing sector were complemented with support for the design, development, and calibration of aerospace systems and supplies. Contributions included collaborative robotics, material development for advanced applications, fuel development, weapons calibrations, and thrust calibrations. NIST provides 30–70 laser power and energy meter calibrations to aerospace industry and Department of Defense 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 Kerosine (High Level) is used by the aviation industry in the U.S. 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.

Calibrations and Sensor Development for Satellites

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

A NIST team pioneered a revolutionary optomechanical accelerometer to detect the extremely small accelerations that are intrinsically self-calibrating, thereby avoiding the need for periodic calibrations and expensive calibration equipment. The team also developed a new photonic readout system to measure large accelerations with extreme precision as required for aerospace applications. Accurate accelerometers are critically important for navigational guidance in satellites and spacecraft, particularly when GPS service fails or is unavailable.

NASA-built CubeSats—small boxy satellites with dimensions as small as 10 centimeters on a side—are already using NIST on a Chip instruments: bolometers that measure the power of electromagnetic radiation, specifically the irradiance of the sun. In FY 2022, the Compact Total Irradiance Monitor (CTIM) CubeSat instrument was launched demonstrating next-generation technology for monitoring total solar irradiance.

In FY 2022, NIST began offering a Calibration Service that can be used by developers of photovoltaics in space applications to assess the efficiency of their devices. This work was motivated by work between NIST and the Naval Research Lab. The current accepted approach involves aircraft flying high in the atmosphere; the laboratory-based method developed by NIST matched data from an aircraft-based calibration and provides developers of photovoltaics for space applications a significantly more convenient method of assessing performance.

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.

NIST is collaborating with the Jet Propulsion Laboratory (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 2021 and FY 2022, NIST and JPL also demonstrated SNSPDs with high performance to wavelengths as long as 10 µm. These detectors are of interest for space-based applications such as chemical sensing and exoplanet spectroscopy. In FY 2021 and FY 2022, NIST and JPL, with funding from the Defense Advanced Research Projects Agency (DARPA) Invisible Headlights program, explored techniques for reading out large arrays of SNSPDs and understanding the limitations on autonomous vehicle performance that can be achieved using arrays of SNSPDs.

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 2022, NIST contributed to several of NASA's projects including helping to provide the cryogenic readout circuitry for the successful flight of NASA's Micro-X sounding rocket and advancing the Athena X-ray satellite mission. NIST improved the maturity of two different types of far-infrared detectors that are compatible with space missions, including an upgrade to the High-resolution Airborne Wideband Camera Plus (HAWC+) far-infrared camera on NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) airborne observatory. NIST is developing a variety of future-looking technologies for NASA to study the cosmic microwave background, advancements in sensor cooling, and readout circuits that will enable larger arrays of faster-responding sensors.

NIST calibrates equipment related to space commerce. The NIST Synchrotron Ultraviolet Radiation Facility (SURF III) was used to perform vacuum ultraviolet calibrations of the LASP Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS) instrument, which is critical for space weather predictions. The NIST Greenhouse Gas Measurements Program supported NASA's Orbiting Carbon Observatory (OCO) Missions by enabling atmospheric scientists to track sources and sinks of greenhouse gases across the globe, observations that are crucial for precise and accurate calibration of satellite instruments and sensors.

To address the complexities of integrating greenhouse gas concentration data with that observed from low Earth orbiting and geosynchronous Earth orbiting satellites, NIST has been building its Urban Dome Testbeds to 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*. NIST also led the development of the IEEE P1451.5p *Standard for Radio Frequency Channel Specifications for Performance Assessment of Industrial Wireless Systems* so that wireless communications users will have greater assurance of reliability under the difficult wireless channel conditions found in operational technology environments typical in aerospace manufacturing.[2]

NIST published several reports that have applications in aerospace. NIST produced the *Foundational PNT Profile: Applying the Cybersecurity Framework for the Responsible Use of Positioning, Navigation, and Timing (PNT) Services* in response to the Executive Order (EO) 13905, *Strengthening National Resilience Through Responsible Use of Positioning, Navigation and Timing Services* to reduce the disruption or manipulation of PNT services. *Satellite Ground Segment: Applying the Cybersecurity Framework to Assure Satellite Command and Control* applied the NIST Cybersecurity Framework (CSF) to the ground segment of space operations. *Introduction to Cybersecurity for Commercial Satellite Operations* presented a specific method for applying the NIST CSF to commercial space business. Finally, *Cybersecurity Framework Profile for Hybrid Satellite Networks Annotated Outline* identified an approach to assess the cybersecurity posture of Hybrid Satellite Networks (HSN) systems.[3]

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2 *https://www.iso.org/standard/66654.html*, *https://www.omgsysml.org/*, and *https://standards.ieee.org/ieee/1451.5p/10702/#:~:text=This%20standard%20includes%20a%20model,of%20the%20radio%20channel%20environment*.

3 *https://nvlpubs.nist.gov/nistpubs/ir/2023/NIST.IR.8323r1.pdf*, *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*

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, the Airborne LUnar Spectral Irradiance (air-LUSI) system 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, NIST has set up a 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 data set by providing much more frequent measurements.

In FY 2022, NIST provided 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 Joint Polar Satellite System (JPSS). NIST performed 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 provided 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.

NIST researchers, in collaboration with the Lunar Planetary Institute, the University of Chicago, and Oak Ridge National Laboratory, studied the presence and distribution of hydrogen-bearing materials in meteorites. NIST contributed to workshops with NASA, International Space Station National Laboratory (ISSNL), other agencies, and the broader industry to identify opportunities for increased collaboration and advanced biomanufacturing in space. NIST also participated in the White House Office of Science and Technology Policy organized workshop on Microgravity R&D to help inform a national strategy to ensure sustainable microgravity R&D platform access.

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 on 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 supported the August 2022 White House Summit on Advanced Air Mobility and participated in an ongoing National Security Council-led effort to create and implement the Domestic Counter-UAS National Action Plan. Finally, OTM continues to collaborate with the Defense Innovation Unit on facilitating exports of Blue sUAS and other proven commercial capabilities, as appropriate.

Throughout FY 2022, OTM organized and led three meetings of the Industry Trade Advisory Committee on Aerospace Equipment (ITAC 1). ITAC 1 provides advice to the Secretary of Commerce and the U.S. Trade Representative on aerospace-related trade policy issues. In FY 2022, the charter for ITAC 1 was renewed and the members were vetted and reappointed. Due to the rechartering process, there were no meetings in FY 2021. The Committee provided advisory opinions to the Secretary of Commerce and the U.S. Trade Representative concerning the U.S.-United Kingdom free trade agreement negotiations, negotiations with the Government of China, the United States-Mexico-Canada Agreement, the World Trade Organization (WTO) Aircraft Subsidies case, and European Union (EU) defense policies that impact U.S. aerospace trade with Europe, supply chain issues and the 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 European Union 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.

OECD discussions continued to focus on the negative impact of the COVID-19 pandemic on demand for aircraft and the accompanying financial strains in the aircraft sector. Export credit financing levels—already at record lows due in part to unrelated interruptions in U.S. and European support for aircraft from 2016 to 2019—remained low as airlines sought to delay deliveries and postpone purchases. ASU signatories discussed, but did not adopt, temporary ASU adjustments, favoring appropriate responses by national governments. For its part, EXIM Bank enacted COVID-19 emergency response facilities that supported the working capital, supply chain, and financing needs of several U.S. aircraft manufacturers and foreign airline buyers. Signatories will continue to monitor the role of export credit financing as demand for air travel and the availability of commercial aircraft financing evolve.

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 industry interests 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 COVID-19 initiatives to provide enhanced financing support to the U.S. aerospace industry and its supply chain.

ITA and NOAA continued their active participation in the implementation of the National Space Council's policies, which include industrial base and competitiveness issues. ITA and NOAA address commercial interests by continuing to ensure that all of the policies' implementation actions are improving the U.S. industry's competitiveness, stimulating the American economy, increasing exports, and creating 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, helicopters, airport construction, communications, remote sensing satellites, commercial projects, and air traffic management projects. At the close of FY 2021, ITA's Advocacy Center had 31 active space-related cases with a total project value of $5.8 billion and U.S. export content of $5.3 billion. At the same time, the Advocacy Center had 550 active cases in the aerospace and defense sectors. At the close of FY 2022, the Advocacy Center had 28 active space-related cases with a total project value of $5.6 billion and U.S. export content of $5.1 billion. Also at the close of FY 2022, the Advocacy Center had 493 active cases in the aerospace and defense sectors.

Industry and Trade Promotion

ITA's Global Aerospace and Defense Team (Global Team) recorded approximately 261 Written Impact Narratives (WIN) in FY 2021 and is on-track to submit more in FY 2022 with 211 WINs submitted by the third quarter of FY 2022. 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 2,487 counseling sessions with over 1,633 U.S. aerospace, defense, and space companies in FY 2021 and held approximately 3,003 counseling sessions with over 1,364 U.S. companies by the third quarter of FY 2022, 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 54 shows worldwide in FY 2022. 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 14 webinars for U.S. businesses, covering topics such as export controls, advocacy, defense sales, and regional market entry strategies. Approximately 3,580 companies registered for these virtual events.

Bureau of Industry and Security

During FY 2022, the Bureau of Industry and Security (BIS) continued to support the U.S. Munitions List/Commerce Control List efforts as they relate to spacecraft. Throughout the fiscal year, the Departments of State and Commerce, in coordination with other interagency partners, reviewed public comments on spacecraft and related items enumerated and described therein submitted in response to published notices of proposed rulemaking. The feedback received has informed ongoing interagency discussions on streamlining export control regulations for both the U.S. commercial space industry and those of international partners. Consistent with the objectives of Space Policy Directive-2, the Departments of State and Commerce seek to bolster the U.S. commercial space sector by lowering the administrative burden, decreasing regulatory compliance costs, and increasing U.S. exports. BIS also participated in the Transportation Technical Advisory Committee discussions, which included aerospace-related topics such as controls on emerging technology for national security reasons in coordination with international export control partners.

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 section highlights a sample of DOI remote sensing applications and illustrates a range of technology, platforms, and specialized sensors employed.[1]

U.S. Geological Survey

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

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

2021: Alaska Statewide Satellite Imagery Mosaic Acquired

The USGS has acquired an updated statewide satellite imagery mosaic for Alaska. The 4-band (red, green, blue, and near-infrared) 0.5-meter ground resolution mosaic was orthorectified using recently acquired statewide InSAR data to meet desired accuracy requirements. Source imagery for the mosaic comes from archived satellite scenes acquired predominantly from 2017 to the present during summer months. Older scenes were used to fill gaps in more recent scenes present due to persistent cloud cover over some locations in Alaska. The mosaic is licensed for public viewing and is available through the USGS National Map Viewer and the State of Alaska's Geoportal.

Additional imagery services provided by the State of Alaska allow noncommercial users with Geospatial Information Systems (GIS) to link to and use the imagery as a backdrop within their GIS applications. Also, agencies participating in the Alaska Mapping Executive Committee (AMEC), an executive body co-chaired by the Department of the Interior and the Department of Commerce, are licensed to receive a copy for internal use. The powerful combination of an updated statewide imagery mosaic and the recently completed statewide InSAR dataset that was acquired under direction of the USGS 3D Elevation Program supports a wide variety of mapping, resource management, and public safety applications.[2] These two substantial Alaska mapping efforts have been coordinated through the AMEC, whose members represent multiple Federal agencies and the State of Alaska.

2022: Consumptive Use of Water by Riparian Vegetation on the Navajo Nation

Water use estimates are valuable to the Navajo Nation in adjudicating water rights and other environmental policy decisions. Estimates of actual evapotranspiration (ETa), precipitation, and consumptive use of riparian vegetation are used to assist the decision-making process by natural resource managers and water resources planners tasked with managing habitat and water resources. Vegetation

2 *https://www.usgs.gov/core-science-systems/ngp/user-engagement-office/alaska-mapping-initiative* and *https://www.usgs.gov/3d-elevation-program*

on select riparian reaches of Little Colorado River tributaries, streams, and springs was delineated into two classes, trees and shrubs, using a 2019 summer scene from National Agricultural Imagery Program (NAIP) data (1 meter resolution) and then rasterized using Landsat-8 OLI (30 meter) to estimate ETa for 2014–2020.[3] The objectives were to estimate the riparian land cover area for trees and shrubs, calculate their corresponding daily and annual water use, and derive riparian consumptive use in acre-feet (AF).

This project used indirect remote sensing methods based on two sources of gridded weather data, Daymet (1 kilometer) and PRISM (4 kilometer), to determine potential evapotranspiration and precipitation, as well as Landsat measurements of vegetation greenness using the two-band Enhanced Vegetation Index. Estimates of water use for the riparian vegetation range from 31,648 AF ("conservative"; using Daymet) to 36,983 AF ("best-approximation"; using Daymet) to 41,585 AF ("best-approximation"; using PRISM).[4]

2022: Detecting Early Season Invasive Plants Using Remote Sensing to Inform Monitoring, Control, and Restoration

Detecting invasive annual grasses on public lands in the western United States is a problem for land managers. Early season invasives (ESI) can out-compete native species for resources including water, and in many climates these nonnative species are expanding at a rapid rate. To address these challenges, managers may use high-resolution data on ESI cover to quantify change as well as develop and prioritize management strategies. USGS scientists are developing a pilot project to test and fine-tune methods, using spatially and temporally appropriate remote sensing platforms, to map early season/winter annual invasive vegetation (including cheatgrass, desert alyssum, and annual wheatgrass) in the Greater Yellowstone Ecosystem with managers at Yellowstone National Park.

The workflow for ESI mapping uses the new Harmonized Landsat Sentinel-2 (HLS) provisional products available through NASA and higher-resolution

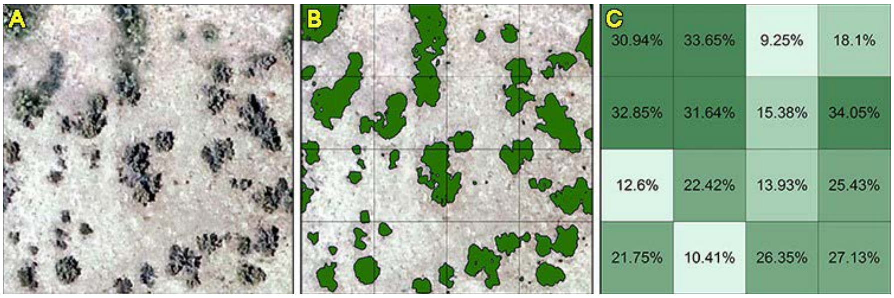
3 *https://www.usgs.gov/centers/eros/science/usgs-eros-archive-aerial-photography-national-agriculture-imagery-program-naip*

4 *https://prism.oregonstate.edu/*

multispectral images from Planet. The HLS project provides consistent surface reflectance (SR) data from the Operational Land Imager (OLI) aboard the joint NASA/USGS Landsat 8 satellite and the Multi-Spectral Instrument aboard the European Space Agency's Copernicus Sentinel-2A and Sentinel-2B satellites. Harmonization of these two datasets shows great potential for mapping ESI due to its enhanced temporal frequency, which allows more cloud-free imagery dates and a greater chance of detecting early season peak greenness without obstruction from clouds. Similarly, the higher-resolution imagery from Planet allows the identification and detection of smaller cheatgrass patches in specific areas of interest. The co-production of actionable science to generate methods to identify early season invasives may inform natural resource management and make technical contributions to time series remote sensing.

2021: Developing High-resolution Vegetation Cover Maps for Greater Sage-grouse Habitat

Accurate maps of seasonal habitat for greater sage-grouse (*Centrocercus urophasianus*) are of paramount importance to conservation efforts in sagebrush ecosystems across the Great Basin, particularly for habitat assessments and mitigation efforts. However, the ability to model sage-grouse habitat at the fine spatial scales necessary for microhabitat assessment may be constrained by the spatial and spectral resolution of most remotely sensed measurements of vegetation composition. As a continuation of previous shrub mapping efforts, the USGS Western Ecological Research Center is utilizing multispectral imagery from UAS collected by the Center for Transformative Environmental Monitoring Programs at the University of Nevada, Reno, and WorldView satellite imagery from Maxar, Inc., to generate fractional cover maps containing detailed vegetation components. These high-resolution fractional cover maps will identify sagebrush, non-sagebrush shrub, forbs, and grasses. Estimates of vegetation components in training plots derived from ultra-high-resolution (less than three-centimeter) UAS imagery and object-based image analysis are applied to high-resolution (two-meter) WorldView scenes using regression tree (RT) models. The approach yields fractional estimates of vegetation cover at a resolution that more closely correlates with actual microhabitat



Derivation of training plot vegetation cover estimates: (A) Example of Big Sagebrush (*Artemisia tridentata*) in ultra-high-resolution UAS imagery. (B) Object-based image analysis (OBIA) classification of sagebrush features. (C) Calculated percentage of sagebrush cover per 2-meter WorldView pixel.

conditions compared to other widely available fractional products better suited for macrohabitat applications. An advantage of the UAS-RT approach is that large volumes of training data can be collected rapidly from UAS compared to traditional ground-based vegetation surveys, which could ultimately yield previously lacking estimates of microhabitat availability across macrohabitat or landscape level extents.

2021: Early Warning eXplorer for Food Security Monitoring

Climate-related impacts on food security and water availability continue to affect many parts of the globe. Several regions, including sub-Saharan Africa, are not only susceptible to these impacts, but also may lack the ability to monitor climate-related risk. Earth observation (EO) satellites have been instrumental in offering large-scale monitoring capabilities for analysis of rainfall, evapotranspiration, vegetation condition, soil moisture, and other agro-climatological factors that impact food and water security in these data-sparse regions. The USGS and colleagues at the University of California Santa Barbara Climate Hazards Center have developed the Early Warning eXplorer (EWX) tool to address these regional monitoring limitations by providing easy access to and analysis of EO information in support of the U.S. Agency for International Development Famine Early Warning Systems Network (USAID FEWS NET).

The EWX implementation is based on three primary components. The first is the EWX Viewer, which is accessible via an internet browser and offers the ability to visualize various datasets in map form and to derive time series summaries for desired spatial domains (such as administrative units and crop zones). In addition to visualization and analysis, the viewer also provides the ability to download gridded data for specified subset areas. The second component is the GeoEngine processing server, which is at the heart of the EWX system. It provides web services, the graphical user interface, file system management, and time series analysis, as well as storage and retrieval of outputs to and from the EWX database. The third component, Support Applications, includes a map server, GeoServer instance, and a PostgreSQL open-source object-relational database for managing statistics and file systems, all while routinely monitoring for new and/or modified EO inputs from various FEWS NET science sources.

Major strides have been made in terms of development and real-time availability of remote sensing–based EOs; however, access to those datasets and their applications for informed decision making is limited. The EWX is a web service that aims to both fill the in situ data gap and facilitate application of EO information for decision making to support mitigating the most adverse impacts of climate extreme events and climate adaptation.

2021: Evaluating Crop Residue Bands for the Landsat Next Mission

Non-photosynthetic vegetation (NPV) includes the residual material left on a field after crop harvest, such as stalks, stubble, and seeds. Satellite-based detection and mapping of NPV supports better understanding of soil health; adoption of conservation tillage practices; and vegetation dynamics in cropland, pasture, and rangeland settings. Lignin and cellulose, which are associated with NPV, display an absorption feature near 2,100 nm that can be accurately measured using narrow-band shortwave infrared (SWIR) indices. However, no current satellites are capable of providing narrow-band SWIR reflectance data at large scales.

A Landsat Next expert review panel was convened in 2020–2021 to focus on the use of narrowband SWIR reflectance to measure ligno-cellulose absorption features. Using a published dataset of 916 surface reflectance spectra collected from agricultural fields that ranged from 0 to 100 percent NPV cover, researchers calculated mean reflectance for five SWIR bands (2,040, 2,100, 2,210, 2,260, and 2,330 nm) at varying bandwidths ranging from 10 to 50 nm. These band centers were chosen based on demonstrated NPV characterization performance from previous missions like ASTER, WorldView-3, and Hyperion. Using these band centers to calculate 13 NPV indices, the study evaluated the effects of bandwidths, atmospheric impacts, sensor signal-to-noise ratios, fractional green vegetative cover, and background soil reflectance on the ability of SWIR-derived indices to measure fractional NPV on agricultural fields and assessed spectral continuity with the existing Landsat 8 Operational Land Imager band 7. The best performing 3-band combination was adopted in the Landsat Next draft science requirements.

The results showed these three narrow-band SWIR solutions would provide a greatly improved capability for detecting crop residue cover based on characterization of ligno-cellulose absorption features. The resulting tools can enable managers to monitor the adoption of conservation tillage practices, as well as the effects of grassland management, through accurate global characterization of NPV.

2022: Evaluating Distribution and Niche Space of Eastern and Western Joshua Trees in the Mojave Desert

Understanding species status and forecasting range shifts for plants and animals is supported by accurate species distribution information, particularly at the margins of species ranges. However, most distribution studies rely on sparse species occurrence datasets from herbarium records and public databases, along with statistically derived "pseudoabsences." True absence data are rarely available. Most distribution analyses rely on statistical species distribution models (SDM). While environmental covariates used to fit SDMs are increasingly precise due to satellite data, the availability of species occurrence records is still a large source of bias in model predictions.

The first hybrid distribution models were produced for eastern and western Joshua Trees (*Yucca brevifolia* and Y. *jaegeriana*, respectively) using empirical data supplemented by statistical species distribution modeling. Joshua trees are iconic and keystone species of the desert southwest and were recently petitioned for listing under the Endangered Species Act by DOI's Fish and Wildlife Service (FWS) due to multiple threats across the range of both species. The hybrid models use as input a high-resolution grid of current adult Joshua tree distribution derived from intensive visual searches of publicly available satellite imagery evaluated for accuracy with ground truthing and other sources of distribution data. While most of the distributions were mapped empirically at a quarter-kilometer resolution across the study area, one large and important area has unacceptable remote sensing imagery quality. The research team used empirically derived data to model distributions across the region of poor image quality to create a complete model across the ranges of both Joshua tree species. The statistically modeled area is of particular ecological and management significance because the two species distributions overlap there and it guides where hybrid plants with characteristics shared by both species may occur.

The models resulting from this work identify key environmental gradients shaping the distributions of each species for comparison. Annual temperature, precipitation, and aridity best predicted occupied habitat across the species' ranges. While the environmental niches for *Y. brevifolia* and *Y. jaegeriana* were similar in terms of total aridity, they differed with respect to seasonal precipitation and temperature tolerances, suggesting a potential for disparate responses to climate change. The maps are the primary distribution information available for the FWS' Species Status Assessment. The high-resolution distributions can be used to empirically track changes in Joshua tree populations at the leading and trailing edges of the species distributions in relation to climate change and habitat disturbances. In the coming decades, numerous species and their associated communities may undergo fundamental shifts in distribution, particularly in extreme ecosystems where species have little room for migration. Such shifts are likely to create complex vegetation dynamics at range margins, where competition and lag effects are expected in response to climate change and associated disturbances.

2022: Evaluating Landscape Change Following Catastrophic Fires in National Parks

The western United States, including California, has experienced extreme weather events that have resulted in catastrophic and deadly fires. These destructive fires have resulted in loss of life and properties, as well as burning through some of the most iconic landscapes within the National Park Service (NPS).

This ongoing project measures the impact and landscape response of these fires on three National Parks in California. Whiskeytown National Recreation Area burned in 2018, when 97 percent of the park's mixed coniferous communities were impacted. Lava Beds National Monument burned in 2020, when 70 percent of its sagebrush and native grassland ecosystem were impacted. Also in 2020, more than 43,000 acres were burned across the Mojave National Preserve, damaging one of the most extensive and robust Joshua tree stands. The USGS is providing technical support and using multi-scale remote sensing tools to assess 1) fire impacts to vegetation and cultural resources and 2) vegetation landscape recovery or change. USGS staff are conducting field surveys of topography, fire effects on vegetation, and vegetation recovery following fire. Results of the field surveys are being paired with data collected using UAS and satellite imagery to create spatial products at different scales. This information is directly being used by NPS staff to inform management intervention and plan for recovery. This year, Worldview 2 imagery was acquired for Lava Beds National Monument and Mojave National Preserve to delineate the fire extent across these remote regions. UAS acquisition occurred in Whiskeytown for the third sampling year, which is being paired with Landsat imagery to estimate forest change and recovery. Field surveys were done for ground validation for all three locations. With the continued threats of wildfire to DOI lands, a multi-scale approach can help inform ecosystem change, landscape conversion, and management intervention to prevent invasive species expansion.

2022: Exotic Annual Grass Phenology in Western United States Rangelands

Developing spatial datasets (maps) of exotic annual grass (EAG) phenology allows researchers and land managers to track the timing and progression of EAG growing-season dynamics year to year. Changing phenology patterns can indicate changing environmental conditions such as progressively warming temperatures, which can cause the growing season to start earlier. In the western United States, EAGs have invaded shrub ecosystems for more than a century, and in that time a positive feedback cycle between fire and EAGs has developed. This feedback cycle has resulted in increased fine fuels that have led to increased wildfire frequency. If the growing season starts earlier in areas invaded by EAGs, the fire season could be extended and fire frequency could increase.

This project uses Harmonized Landsat 8/Sentinel-2 (HLS) satellite data to develop near-seamless, cloud-free Normalized Difference Vegetation Index (NDVI) data, which measure vegetation greenness. NDVI data are used to build a model training dataset of phenology metrics in EAG invaded areas. Analysts examined NDVI profiles at more than 11,000 pixels to identify NDVI-based metrics for 4,014 training data points, stratified by ecoregion. The training data points were then incorporated into a machine-learning framework along with environmental variables like elevation and solar radiation to develop models of phenology metrics. The model algorithms were then input into mapping software and extrapolated over the entire study area, creating Start of Season Time (SOST) and five other phenology metrics for 2017–2021. Two metrics, Amplitude and Duration, were calculated and mapped using SOST and End of Season Time data. The EAG phenology metrics are tested as drivers in a model that estimated the abundance (percent cover) of EAG. Adding the metrics as drivers showed promise as the model accuracy improved. The EAG phenology metrics time series can increase understanding of EAG dynamics and help land managers develop plans to protect entities deemed valuable to society like natural habitat, wildlife, recreational areas, and air quality.

Maps are available through ScienceBase-Catalog: USGS Rangeland Exotic Plant Monitoring System.[5]

2021: Exploring VIIRS Continuity with MODIS in an Expedited Capability for Monitoring Drought-Related Vegetation Conditions

Scientists have effectively monitored vegetation dynamics using remotely sensed time-series vegetation index (VI) data for several decades. Drought monitoring has been a common application of VI data; perhaps the most used VI data, Normalized Difference Vegetation Index (NDVI), serves as an input for drought-stress models such as the Vegetation Drought Response Index (VegDRI). NDVI composites from the expedited Moderate Resolution Imaging Spectroradiometer (eMODIS) satellite

5 *https://www.sciencebase.gov/catalog/*

platform were a main input for the VegDRI model, but as the MODIS satellite platforms approach the end of their missions, replacement satellite data were needed to continue developing VegDRI. The USGS Earth Resources Observation and Science (EROS) Center developed a parallel temporal version of eMODIS by utilizing data from the Visible Infrared Imaging Radiometer Suite (VIIRS) platform. The expedited VIIRS (eVIIRS) product consists of 7-day rolling NDVI composites at 375-meter and 1-kilometer spatial resolution.

The EROS researchers developed a simple, robust algorithm to transform eVIIRS NDVI to eMODIS-like NDVI. (The transformed eVIIRS NDVI is referred to as eVIIRS′.) They then designed a research study to test eVIIRS′ NDVI for use in the VegDRI drought monitoring production system. The geometric mean regression (GMR) transformation algorithm was developed from three years (2016–2018) of eVIIRS 375-meter and eMODIS 250-meter NDVI data. After transforming 2020 eVIIRS to eVIIRS′ using the GMR transformation algorithm, the NDVI values showed improved results with the mean bias error decreasing by more than 62 percent and the root mean square error (RMSE) decreasing by more than 17 percent. The VegDRI map using eVIIRS′ data showed similar results compared to the VegDRI map using eMODIS data. Also, when eMODIS was replaced with eVIIRS′ in the VegDRI model, the relative RMSE equaled 18 percent, which indicated the replacement of eMODIS with eVIIRS′ was a good fit for VegDRI.

The approach used to modify data inputs into the VegDRI model by using eVIIRS′ NDVI in place of eMODIS NDVI data demonstrates the ease of use of the GMR transformation for data continuity and longevity.[6] The transformation may allow eVIIRS to continue the more-than-20-year time series of eMODIS NDVI data.

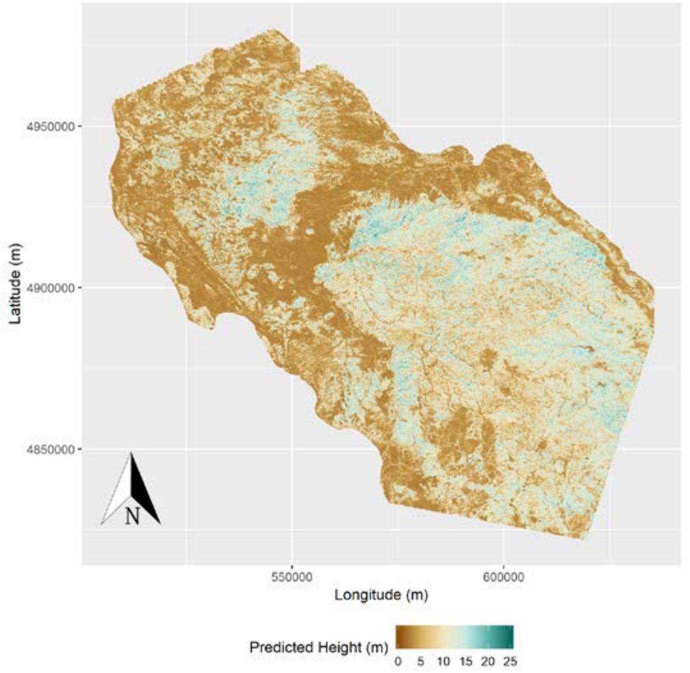
2021: Fusion of Spaceborne Lidar and Optical Data for Complete Vegetation Maps

Vegetation structure is a key attribute of forested ecosystems, influencing habitat suitability, water quality and runoff, microclimate, and wildfire behavior. The

6 *https://doi.org/10.3390/rs13061210*

Fire-Science Team at the USGS EROS Center is fusing spaceborne lidar and passive optical data to create spatially complete maps of vegetation structure at 30-meter resolution. These maps will allow land managers to make informed decisions and provide key inputs to fire simulation models.

The Global Ecosystem Dynamics Investigation (GEDI) is a lidar instrument aboard the International Space Station that makes direct observations of the vertical structure of vegetation on Earth's surface. GEDI is a sampling mission, illuminating sparsely distributed 25-meter-diameter footprints. The spatial sparsity of GEDI motivates the fusion of spatially complete optical data from Landsat 8. The optical bands of Landsat 8 are correlated with the vegetation variables of interest, allowing statistical models to learn this correlation where GEDI and Landsat 8 overlap and then make predictions where Landsat 8 data are present but GEDI data are not. In addition, the inherent spatial correlation of the GEDI observations can be used to interpolate variation in vegetation structure not explained by the Landsat 8 optical bands. The result is a statistical modeling procedure that produces spatially complete maps of vegetation structure at the 30-meter resolution of Landsat.



Predictions of canopy height at 30-meter resolution across the Black Hills, South Dakota.

The ability of the procedure to map canopy height was tested across the Black Hills of South Dakota, an area with coarsely varied canopy structure. Test data consisting of ten percent of the GEDI observations within the Black Hills were withheld and predicted with the remaining GEDI observations in addition to Landsat imagery of the area. The method predicted canopy height with a mean absolute error of 0.84 meter, demonstrating accurate prediction. A complete map of canopy height for the entire Black Hills was then generated.

2022: Hyperspectral Imaging of Critical Mineral Resources from Outcrop to Satellite

Mineral resources are essential for the security and economic prosperity of the United States. The Nation relies heavily on imports of critical minerals. Novel methods to characterize new mineral resources may support meeting the expected national and global demands and an anticipated shift to a renewable energy economy. Imaging spectroscopy (hyperspectral imaging) is a rapidly advancing technology that is increasingly applied at many points in the life cycle of minerals: remote sensing for exploration, laboratory scanning for drill core characterization, spectral identification of minerals in hand specimens, and exploitation of archives of airborne and satellite imagery. Imaging spectroscopy can assist in the mineral characterization of abandoned, legacy, and un-reclaimed mines and their potential for critical minerals, which is a recent focus of the USGS Mineral Resources Program (MRP) and the Energy and Minerals Mission Area. The project "Hyperspectral Imaging of Mineral Resources from New and Old Origins: Minerals for the Nation's Economy and Utilization of Legacy Mine Lands" is producing maps of surface mineralogy from existing hyperspectral data covering the largest contiguous area of hyperspectral imagery that has ever been assembled for the United States: over 380,000 square kilometers in California and Nevada. These data can be used to develop new methods to map critical minerals, including minerals critical for battery fabrication, and to evaluate resources available from waste on legacy mine lands. In association with the Earth Mapping Resources Initiative project, the coverage will be expanded in the western United States to cover an additional 500,000 square kilometers over the next five years.

2022: Landsat Collection 2 Level-3 Dynamic Surface Water Extent

The Landsat Collection 2 Level-3 Dynamic Surface Water Extent (DSWE) product provides raster layers relating to surface water inundation per pixel in Landsat data. Aquatic researchers and land managers who require habitat information can use DSWE to predict and understand impacts by changes in surface water extent. DSWE provides surface water inundation for Landsat data acquired for the conterminous United States (CONUS), Alaska, and Hawaii from 1984 to the present.

Several improvements were made to the Collection 2 DSWE product. Overall, there is high agreement between Collection 1 and Collection 2 for the high confidence water class. Some of the changes include using the Collection 2 Digital Elevation Model (DEM) and masking developed urban areas from some classes in the interpreted layer. For more information and to learn how to download the DSWE science product, please visit the Landsat Collection 2 Dynamic Surface Water Extent Science Product website.[7]

2022: Landsat Collection 2 Normalized Difference Snow Index

Landsat Collection 2 Normalized Difference Snow Index (NDSI) data are now available through the USGS EROS Center Science Processing Architecture (ESPA) on-demand interface. NDSI is the normalized difference between spectral bands green (G) and the shortwave infrared (SWIR). NDSI is useful for separating snow from vegetation, soils, and other spectral signatures and is delivered as a single band. The probability that snow is present is proportional to how close the NDSI pixel value is to 1 (range –1 to 1). NDSI is derived from Level-2 Surface Reflectance and is available globally for Landsat 4–9. Visit the Landsat Surface Reflectance-Derived Spectral Indices webpage for information on product constraints, citations, and reference information.[8]

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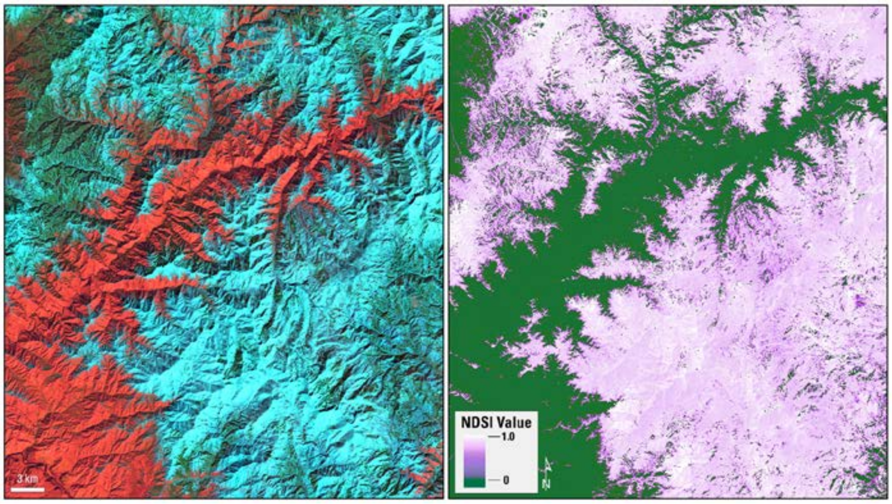
7 *https://www.usgs.gov/landsat-missions/landsat-collection-2-level-3-dynamic-surface-water-extent-science-product*

8 *https://www.usgs.gov/landsat-missions/landsat-surface-reflectance-derived-spectral-indices*



Example of the Landsat Collection 2 Normalized Difference Snow Index (NDSI) in the Boise National Forest, Idaho. Left: Landsat Collection 2 Surface Reflectance using the short-wave infrared, near infrared, and red bands (Bands 6|5|4). Right: Landsat Collection 2 NDSI.

2021: Informing Hurricane Flooding and Sea-Level Rise Vulnerability

Fusing remote sensing products from different satellite sensors allows the development of enhanced maps of the current distribution of coastal wetland plants and more accurate models of coastal elevations. This critical information about vulnerability to sea-level rise and hurricane flooding is being used by DOI partners and State and local agencies to improve management in a changing climate. In 2021, USGS scientists developed a ten-meter-resolution vegetation classification model using wet- and dry-season imagery from Sentinel-1 (SAR data) and Sentinel-2 (multispectral data) acquired from 2015 to 2017 (before Hurricane Irma in September 2017). The model successfully distinguished mangroves from grassland habitats and shows where mangroves have expanded their inland range into fresh and salt marshes across National Park Service and U.S. Fish and Wildlife Service lands.

Coastline elevation is an important characteristic for understanding floods in tidal wetlands. Even small biases in elevation estimates can translate to large differences in modeled inundation time, which is a crucial metric for estimating future flooding vulnerability. Elevation data are usually derived from airborne lidar, but dense vegetation blocks the lidar signal from reaching the soil surface, causing a positive bias in bare-earth digital elevation models (DEMs). Using a statistical model (LEAN: Lidar Elevation Adjustment using NDVI) and ground calibration datasets, USGS scientists developed a new DEM for southwest Florida that accounts for the bias from vegetation. The LEAN model assumes that plant density is correlated with the Normalized Difference Vegetation Index (NDVI), calculated from National Agriculture Imagery Program (NAIP) imagery. LEAN effectively calibrates lidar-derived DEMs to the input survey-grade ground elevation data.

2021: Land Change Assessments and Applications Supported by LCMAP Science Products

The USGS Land Change, Monitoring, Assessment, and Projection (LCMAP) project recently released an updated suite of land surface change science products based on the Landsat archive.[9] The most recent LCMAP science collection includes ten annual land change and land cover map products for the time period 1985–2019 for the conterminous United States. The integrated products are the basis for applications and assessments designed to promote an understanding of the basic drivers of change, identify potential consequences of change on human and natural systems, and offer greater insight into the impacts and feedbacks of climate change. LCMAP leverages the USGS Landsat Program's decades of land imaging, time-series modeling, and USGS EROS Center scientific expertise. The annual land cover, and its change, through 2018 was validated using published reference data, providing quantitative measures of product accuracy. An update to the product suite was released in late 2021.

LCMAP supports and engages with the user community through various forms of communication, including instructional videos that describe the land change products, workflows to expedite common data processing and analysis routines, and stakeholder workshops. The EROS Center provides geospatial products through a number of public-facing websites, including USGS's EarthExplorer, LCMAP's Web Viewer, and website download access for each annual product compiled for the entire conterminous United States. The LCMAP team also established a collaboration with researchers from the National Center for Atmospheric Research.

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9 *https://www.usgs.gov/special-topics/lcmap*

This effort focuses on developing methodology to improve and enhance tools that enable the management community to visualize, summarize, and incorporate land surface change information through time.

Having access to an annual time series of land cover and surface change enables assessments of land change to improve understanding of their causes and consequences. Several published assessments incorporated annual LCMAP land surface change products. The publications range from new insights on how urban heat islands affect surrounding rural land cover to how droughts with hotter temperatures impact the extent of tree cover within an endemic California forest type.[10] The latter research analyzed LCMAP land change data, geospatial climatic data, and wildfire mapping to reach their conclusions.

2021: Landsat Burned Area Products

The USGS Geosciences and Environmental Change Science Center and the EROS Center have led the development, validation, and production of the Landsat Burned Area products.[11] The products identify burned areas in Landsat images, which have a spatial resolution of 30 meters and a temporal resolution of 16 days or more, depending on cloud cover.[12] Fires are frequently unreported; consequently, existing fire databases are often incomplete. Furthermore, these databases often have location errors and records may be duplicated. The Landsat Burned Area products provide new and unique information about spatial and temporal patterns of fire occurrence that existing fire databases may lack, especially in areas where fire information can be incomplete, such as the Great Plains and in the western and southeastern United States.

The Landsat Burned Area products have been produced since 1984 for CONUS.[13] Scene-level products are available through the USGS EarthExplorer, and annual composites are available through the USGS ScienceBase Catalog.

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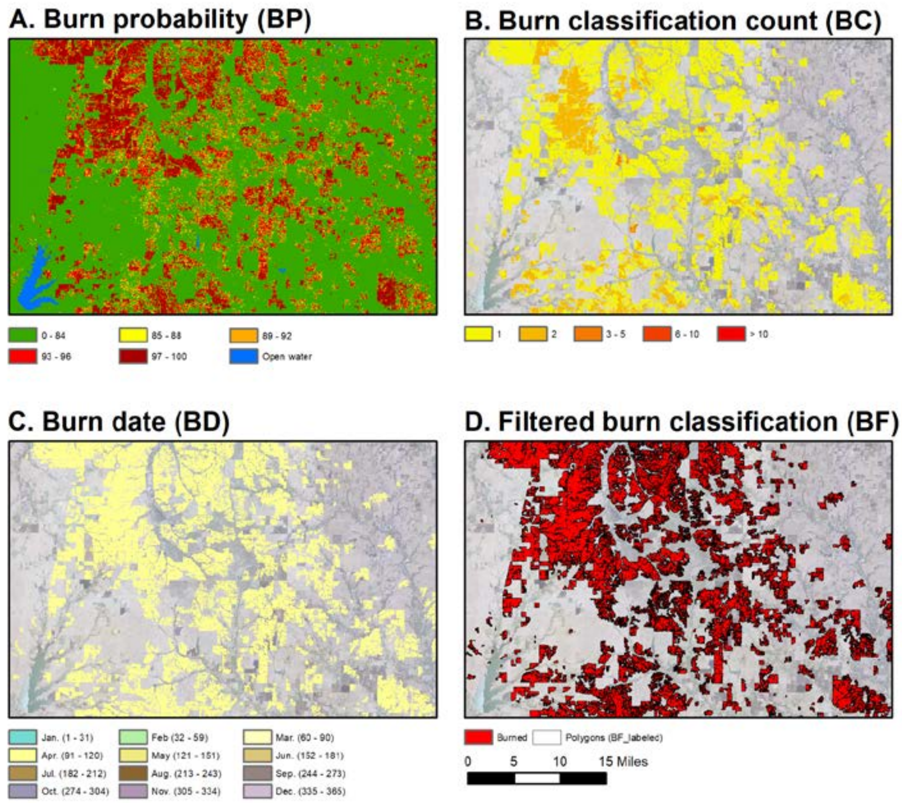
10 *https://www.usgs.gov/special-topics/lcmap/science/lcmap-change-stories*, *https://www.tandfonline.com/doi/full/10.1080/15481603.2021.1903282*, and *https://www.frontiersin.org/articles/10.3389/fclim.2021.689945/full*

11 *https://www.usgs.gov/landsat-missions/landsat-burned-area-science-products*

12 *https://doi.org/10.1016/j.rse.2020.111801*

13 *https://www.usgs.gov/landsat-missions/landsat-burned-area-science-products*



Examples of the Landsat Burned Area annual composite products.

2022: Mapping the World from Satellites: Helping Us Understand Global Food and Water Security in the Twenty-first Century

As world population continues to increase, Earth Observing (EO) satellite-derived data are crucial for assessing and managing global food and water security in an inter-connected world of virtual land and water trades and related inter-dependencies of countries and people to meet the food and nutritional needs of increasingly sophisticated populations of the 21st century. Exciting new EO technologies and tools bring together big-data analytics, machine learning/deep learning/artificial intelligence, and cloud computing to gather and analyze data of the entire planet at the highest known spatial, spectral, radiometric, and temporal resolutions. This research, conducted under the global food security support analysis data project, helps realize the power of this paradigm shift in EO technologies and tools to map and manage global agricultural croplands and their water use for food and water security in the 21st century.

Global cropland products derived from Landsat and Sentinel data are available at *www.croplands.org*, such as the global cropland extent product. Other products include irrigated and rainfed, cropping intensities, and crop types.[14] These products are produced at the global, continental, and regional level. Each product has thorough accuracy assessments, and multiple other products, such as cropland areas and other agricultural statistics, are derived from them.

2022: Monitoring and Assessing Urban Heat Island Variations and Effects in the United States

The main cause of enhanced warming across urban areas has been widely documented as the conversion of natural land cover to developed land composed of built structures such as buildings, roads, and other infrastructure. These anthropogenic features absorb and reemit the heat from the Sun more than natural landscapes, resulting in urban heat islands (UHIs). The UHI effect has a profound impact on the lives of urban residents and can exacerbate the risk of heat-related mortality associated with global climate change. Among the many damaging weather-related extremes, heat waves have the potential to cause a substantial effect on human health, energy demand, and human and ecosystem health challenges. As the climate of Earth warms, hotter-than-usual days and nights are becoming more common, and heat waves are expected to become more frequent and intense. Measures of UHI intensity complement trends in urban temperature as indicators to examine the effects of changing climate conditions over time.

The USGS and United States Environmental Protection Agency are monitoring and assessing UHI effects in the United States by integrating long-term Landsat surface temperature data and annual land cover change information from the 1980s to the present. The integration of surface temperature and land cover dynamics provides fundamental measurements for UHI intensity and temporal trends in any urban location. The UHI change analysis also identifies thermal characteristics

14 *https://www.usgs.gov/apps/croplands*

in the urban-wildland interface and UHI hotspots that are vulnerable to intense heat waves. Annual UHI patterns and trends are created as indicators of the effect of climate variation on a wide range of ecosystems processes, particularly if these extreme warming events occur frequently and more quickly than society and ecosystems can adapt.

A data processing and analysis system has been developed at the USGS EROS Center. The system processes all Landsat surface temperature records in 50 cities in the conterminous United States. By comparing surface temperatures in urban and nonurban areas, UHI intensities and their temporal trends were calculated between 1985 and the 2010s in six prototype cities: Atlanta, Georgia; Houston, Texas; Minneapolis, Minnesota; Sioux Falls, South Dakota; Phoenix, Arizona; and Seattle, Washington. Different patterns of long-term trends of UHI intensities have been found in these six cities. Temporal variations of UHI intensity indicate positive trends in five cities with magnitudes of 0.2–0.6 degree per decade but a slightly negative trend in Phoenix.[15] The positive trends of UHI intensity are more apparent in warm and wet climate regions than in dry regions.

The primary product of annual means of mean and maximum surface temperatures for the 50-city dataset has been released to the public through a USGS data publication.[16] The prototype approach has been published in peer-reviewed journal articles and implemented to investigate UHI in selected cities in the United States. The prototype results of UHI intensity change from the six selected cities have been provided to the U.S. Global Climate Research Program 5th National Climate Assessment.

2021: Monitoring Tsunamigenic Landslide Hazards

In Prince William Sound in southern Alaska, climate change–driven glacial retreat is exposing steep, unstable slopes that could generate tsunamis if they failed rapidly and entered the fjords. One such area is the Barry Arm fjord, where the rapid retreat and thinning of the Barry Glacier is associated with several slope

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15 *https://doi.org/10.3133/fs20213031*

16 *https://www.sciencebase.gov/catalog/item/5de81991e4b02caea0ece36a*

instabilities that threaten nearby communities, infrastructure, and marine interests. The largest of these landslides, measuring over 2 kilometers in width, moved 120 meters between 2010 and 2017 as the Barry Glacier retreated from the base of the slope.[17] This landslide initiated a State and Federal multi-agency response in 2020, which included ground-based, aerial, and satellite monitoring efforts; community stakeholder involvement; and public outreach. In May of 2020, the USGS began monitoring the landslide movement using RADARSAT-2 synthetic aperture radar (SAR) satellite data.

Maps of monthly landslide movement (interferograms) were created using interferometric SAR (InSAR) processing, which measures changes in the ground surface using the difference in the phase of the returning waves in the line of sight of the satellite radar sensor. Between late May and September, the landslide experienced little to no downslope movement. In October, InSAR monitoring captured landslide-wide downslope movement. Using several SAR scenes from both the RADARSAT-2 and Sentinel-1 satellites, USGS scientists determined that the center of the landslide had moved about 30 centimeters. Subsequent modeling of landslide failure and tsunami scenarios has shown that a tsunami would impact much of the Prince William Sound, with wave heights of over 200 meters in the northern part of Barry Arm fjord and peak heights of over 2 meters offshore the town of Whittier.[18] Monitoring active landslides with SAR data such as those in the Prince William Sound can improve emergency management efforts, landslide failure forecasts, and slope stability and tsunami modeling.

2022: Multiscale Spectroscopy of Intertidal Biofilm Quantity, Quality, and Composition

Microbial biofilm communities composed of bacteria, diatoms, protozoa, and fungi inhabit the surface of intertidal mudflats and represent a large proportion of shorebirds' diets. Given their major role in intertidal food webs, understanding biofilm distribution, quantity, and nutritional value for shorebirds is of vital

17 *https://doi.org/10.1029/2020GL089800*

18 *https://doi.org/10.3133/ofr20211071*

importance. South San Francisco Bay is home to the largest tidal wetland restoration project in the western United States, the South Bay Salt Pond Restoration Project, where a key uncertainty is whether adjacent mudflats will be a sediment source for the restoration, leading to erosion and potential impacts to biofilm. Given this uncertainty, the objective of this study is to identify seasonal and spatial variations in biofilm distribution, quantity (chlorophyll-a [chl-a]: an indicator of biomass), quality (lipids, total organic carbon, and glucose content) and community composition through development and scaling of multi-temporal, multispectral and hyperspectral algorithms. In a collaboration among the USGS Western Ecological Research Center (WERC), the USGS Western Geographic Science Center, the USGS National Uncrewed Aircraft Systems (UAS) Project Office, the USGS Geology, Geophysics, and Geochemistry Science Center, and California State University Monterey Bay, biofilm parameters are being modeled at different scales using data from field spectroscopy, ground-based imaging spectroscopy (HySpex, five millimeter), the Resonon Pika-L hyperspectral sensor aboard UAS (four centimeter), airborne imaging spectroscopy (AVIRIS-NG, four meter) and Sentinel-2 (ten meter).

A time series of biofilm percent cover was created through the use of multiple end member spectral feature analysis and Sentinel-2 data. Overall biofilm cover appears highest in the late spring and early summer, then drops off dramatically in the fall and winter months. Sentinel-2 chl-a maps were generated using the soil adjusted vegetation index, which will be used in an analysis to identify the best image spatial resolution for biofilm by observing the loss of information as a function of ground sample distance across sensors. This work is part of a WERC-led project entitled "Quantifying Drivers and Stressors of Intertidal Biofilm Resources at the Largest Tidal Wetland Restoration on the U.S. West Coast." Results will support measurement and visualization of habitat quality for shorebirds and understanding of the influence of wetland restoration activities on biofilm resources.

2022: On-Demand Provisional Landsat Actual Evapotranspiration for Global Extent

Provisional actual evapotranspiration (ETa) products derived from Landsat remote sensing and weather data are now available for public download at a global extent for all Landsat satellite data, including Landsat 9, dating back to 1984. The USGS EROS Science Processing Architecture (ESPA) On Demand Interface[19] provides higher-level science products derived from Landsat satellite data and actual evapotranspiration modeled with the Operational Simplified Surface Energy Balance (SSEBop) approach. These products have been released as a Provisional Level-3 Science product for any Landsat image in the archive. Landsat ETa is crucial for measuring water use and critical hydrologic components of the water budget for agricultural and natural landscapes at higher resolution. This product utilizes Collection 2 Level 2 Landsat Surface Temperature data and improved parameterization and advancements in the SSEBop modeling approach to better estimate ETa regardless of landcover type, season, location, or time period. These products have been validated using in situ eddy covariance flux tower data and found to estimate ETa within 20 percent of the ground station ETa at daily time steps. Basin-scale evaluation of the SSEBop model across 1,000 watersheds in the conterminous United States has provided accuracies within 5 percent on an annual basis.[20]

The EROS center distributes the Landsat-based ETa on request, and it is available for public download through the ESPA website providing an efficient and high-quality product for land and water resource managers and researchers to download without requiring advanced knowledge in programing, remote sensing, or ET modeling to create the product themselves. This product is provided at the overpass level (a single Landsat observation) and simply requires a list of the Landsat Collection 2 Level 2 Product IDs to place an order and initiate a download. It is useful for estimating field-scale consumptive water use, assessing historical water use, and planning water allocations to improve agricultural water management under a changing climate.

19 *https://espa.cr.usgs.gov/index/*

20 *https://www.usgs.gov/landsat-missions/landsat-provisional-actual-evapotranspiration*

2021: Parcel-based Modeling of Land Use, Water Use, and Water Availability

The intersection of land use, water use, water availability, and climate change demands attention as resource constraints increasingly threaten human health and welfare. Long-term analyses of historical-to-current feedbacks among land use, water resources, and climate may support managers' ability to anticipate potential feedbacks that could threaten human activities in the future. Remote sensing provides the consistent, synoptic data coverage to support analyses of land use and hydrologic change under a changing climate. Anticipatory, scenario-based models can leverage remote sensing–based analyses to explore potential futures and facilitate planning and mitigation activities.

The USGS EROS Center completed long-term modeling in the Delaware River Basin (DRB) using remotely sensed observations of landscape change to inform a spatially explicit model that temporally extended the land cover record both backward and forward in time. In FY 2021, work focused on linking monitoring and modeling of water use and water availability with the EROS Forecasting Scenarios of land use (FORE-SCE) model. The goal is to move toward true parcel-based water accounting, where water use and water availability are tracked at the field level, informing scenarios of future agricultural and landscape change under a changing climate.

The initial focus is on assessing feedbacks between water use and land use using a remote sensing–based approach for determining evapotranspiration. Two different approaches were applied in the DRB: the Vegetation ET (VegET) model and the operational Simplified Surface Energy Balance (SSEBop) model. VegET is a water-balance approach that uses remote sensing to categorize land-surface phenology and precipitation inputs, while SSEBop is an energy-balance approach that uses land-surface temperature from remote sensing. Each characterized ET and water use for the DRB, with an intersection of ET and land use quantifying water use trends by land use type over time. Investigations into models of water availability were also started, with PRMS, MODFLOW, and MODSIM identified as key models for potential model integration with FORE-SCE, with model choice dependent upon scale of application. FY 2021 work focused on exploring the conceptual and practical issues of water availability model coupling with FORE-SCE, with formal coupling initiated in FY 2022. Continuing work strives to improve the representation of feedbacks between land use, water use, water availability, and climate.

2021: Pre-fire, Post-fire, and Forest Recovery Using Lidar and Burn Severity Analysis

The 2012 Pole Creek Fire in the Deschutes National Forest in Oregon continues to provide an exceptional opportunity to study wildland fire effects with remote sensing data. This project builds upon wildland fire remote sensing research by addressing novel questions through the analysis of pre-fire, post-fire, and a new 8+ year post-fire forest recovery lidar acquisition. Lidar will also be fused with optical remote sensing data, such as the recently approved Planet and WorldView high-resolution multispectral imagery. Through the analysis of lidar from the recovery of the forest, researchers are assessing how pre-fire conditions and forest management activities affected the recovery potential and outcomes for a variety of forest types and along a gradient of burn severity measures.

Recently published research from this project used multitemporal lidar and corresponding field data to estimate fuel consumption for the 2012 Pole Creek Fire in Oregon and portions of the 2011 Las Conchas Fire in New Mexico.[21] Additionally, estimates for change in aboveground biomass were compared to energy release estimates using fire radiative energy observations from Moderate Resolution Imaging Spectroradiometer (MODIS) satellites to mechanistically derive a combustion coefficient for top-down estimation. Past research efforts included the evaluation of lidar- and Landsat-derived burn severity indices, as well as fuel treatment and mountain pine beetle infestation effects on fire severity using multitemporal lidar data. This research is quantifying how pre-fire forest condition affects burn severity and how various remote sensing techniques can be used to explain fire patterns and improve modeling and remote sensing of wildland fire for natural resource management and forest ecology.

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21 *https://www.sciencedirect.com/science/article/pii/S0034425720304879?via%3Dihub*

2021: Rangeland Condition Monitoring Assessment and Projection (RCMAP)

Rangeland ecosystems in the western United States are vulnerable to climate change, fire, and anthropogenic disturbances, yet available geospatial data for assessing trends in condition, fire risk, and management practices may not be sufficient to inform management practices. To address this need, scientists from the USGS EROS Center and the Bureau of Land Management developed the Rangeland Condition Monitoring Assessment and Projection (RCMAP) project.[22] This project quantifies the percent cover of rangeland components across the western United States using Landsat imagery from 1985 to 2020. The RCMAP product suite includes eight fractional components (annual herbaceous, bare ground, herbaceous, litter, non-sagebrush shrub, perennial herbaceous, sagebrush, and shrub) and the temporal trends of each, along with rule-based error maps. An automated method was developed to identify change in spectral conditions between each year in the Landsat archive and the circa 2016 base year. 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.

RCMAP fractional component time-series data spanning 1985–2020 and trends analysis products are now available for download and on the rangelands viewer application.[23] This dataset is designed for out-of-the-box application and provides a foundation for both historical and future monitoring at ecosystem scales, including research in sage-grouse habitat and population dynamics, restoration success, and treatment effect.

22 *https://www.usgs.gov/publications/rangeland-condition-monitoring-assessment-and-projection-rcmap*

23 *https://www.sciencebase.gov/catalog/item/636a6727d34ed907bf6a6859*

2022: Real-time Coastal Change Forecasts for Puerto Rico

The island of Puerto Rico is subject to numerous natural hazards, including hurricanes, coastal erosion, and flooding. Information on how the island's coastal environments respond to these events is critical for bolstering coastal resilience. Due to the dynamic nature of the coast, continuous monitoring with remote sensing technology may support rapid assessment of real-time change and maximize data collection, especially when used to guide critical decisions about emergency preparedness, response, recovery, and threats to economic security.

Scientists at the USGS St. Petersburg Coastal and Marine Science Center mounted cameras on Puerto Rico coasts to record and measure how far the waves reach up the beach as well as how the coast changes in response to waves and storms. They also installed oceanographic buoys offshore of the beach that send back data in real time on wind, waves, and water levels. These remotely sensed data help scientists better understand the processes involved in coastal change, improve the accuracy of water level and coastal change forecasts on the island, and provide these data rapidly to local stakeholders—which is especially important when a storm is approaching. These data are becoming increasingly important with climate change effects such as increased frequency and intensity of tropical storms and hurricanes compounded by the effects of sea-level rise. The scientists also use satellite data in conjunction with historical imagery to study shoreline change over long- and short-term time scales to help identify areas that are most vulnerable to these changes.[24]

This information can help residents of the territory to be more prepared for and resilient to these hazards. The team worked with other groups across the bureau to compile information on natural hazards and resources relevant to the island and share them via a series of bilingual web pages.[25] These pages are being disseminated to local partners and organizations, including those in historically underserved communities, so they have direct access to USGS science and can make informed decisions when preparing for future natural disasters.

24 *https://geonarrative.usgs.gov/puertoricoshorelinechange/*

25 *https://www.usgs.gov/mission-areas/natural-hazards/science/puerto-rico-natural-hazards-coastal-peligros-naturales-de*

2021: Release of Landsat Collection 2 U.S. Analysis Ready Data

Landsat Collection 2 (C2) U.S. Analysis Ready Data (ARD) became available in fiscal year 2021 and are the most recent publicly released Landsat science products. Landsat C2 U.S. ARD are prepackaged and pre-processed bundles of tiled Landsat data products that make the Landsat archive more accessible and easier to analyze, and they reduce the amount of time users spend on data processing for time-series analysis. The bundled data tiles consist of surface reflectance, surface temperature, top of atmosphere reflectance, brightness temperature, and quality assessment data that are consistently processed using per-pixel solar zenith angle corrections, gridded to a common cartographic projection, and accompanied by appropriate metadata to enable further processing while retaining traceability of data provenance. Subsequently, numerous products are derived from ARD that are used as direct inputs to monitoring and assessment activities, including maps of land cover and land cover change; spectral indices; temporal composites; and higher-level science products such as burned area, dynamic surface water extent, and fractional snow-covered area. Landsat C2 U.S. ARD are generated in the Albers Equal Area (AEA) Conic map projection for CONUS and Hawaii. Alaska is generated in Alaska Albers map projection. They are processed directly from Level-1 AEA scenes through Level-2 products using the World Geodetic System 1984 datum. The products cover CONUS (1982–present), Alaska (1984–present), and Hawaii (1989–1993 and 1999–present). The tiles are units of uniform dimension bounded by static corner points in a defined grid system. An ARD tile is defined as 5,000 × 5,000 30-meter pixels.

For additional information about Landsat science products, visit the Landsat Missions website.[26]

2021: Remote Sensing Model Evaluation for NetET Irrigation Water Use for the Nation

The USGS Water Availability and Use Science Program (WAUSP) systematically provides information that allows water resource managers to assess availability

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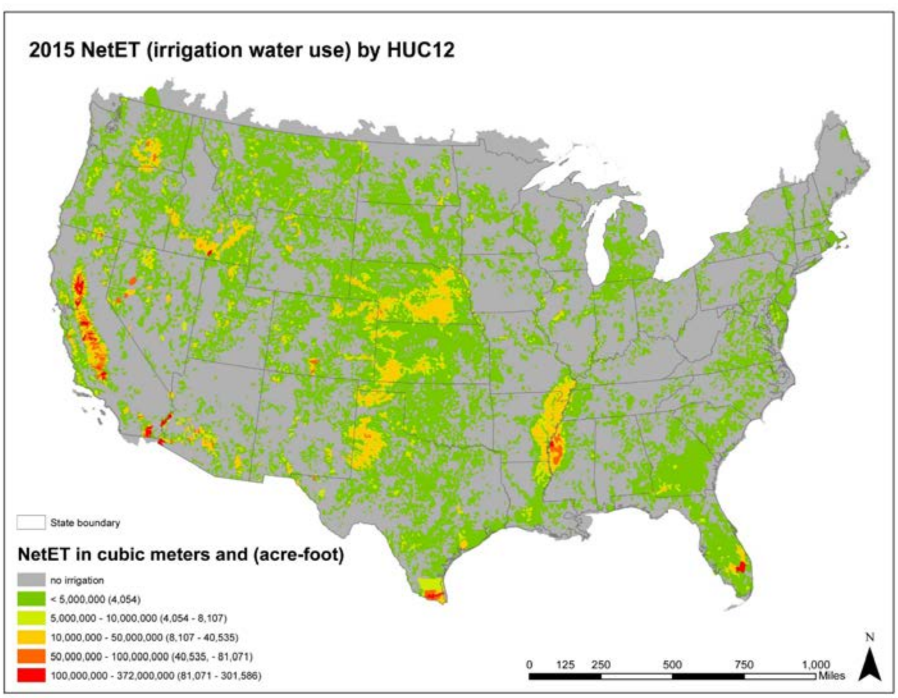
26 *https://www.usgs.gov/core-science-systems/nli/landsat*

of the Nation's water. The USGS focuses on development of advanced techniques for evapotranspiration (ET) estimates to better measure various agricultural-based water budget components for informing decision makers. Specifically, National Water Census (NWC) goals support systematic geospatial analysis and evaluation of joint performance of the Operational Simplified Surface Energy Balance (SSEBop) and Vegetation ET (VegET) models for quantifying net irrigation water use, also referred to as NetET.

Scientists at the USGS EROS Center are leveraging MODIS (250-meter) and Landsat (30-meter) remote sensing data to generate model analysis products such as VegET (rainfall-based ET), SSEBop ET (total water use), and NetET (irrigation water use), along with rainfall and other ancillary datasets. Project cloud-processing components are used for creating more accurate and timely raster data maps for CONUS for 2015 annual ET, a target study evaluation year. Data summation and integration includes national-scale irrigation layer masks within hydrologic unit boundaries (HUC12) for evaluation of measurements at consistent and appropriate scales.



Annual irrigation water use for 2015 summarized by hydrologic unit code level 12 (HUC12).

Results include accuracy assessment feedbacks of NetET information products for the improvement and implementation of current and future national water accounting methods applying satellite-driven techniques. This work supports and advances ongoing investigation of the relationships between optical and thermal datasets for ET modeling, including performance of the SSEBop ET and VegET models using best available physical and process parameters.

The EROS Center develops and shares these NetET products with USGS Water Science Centers and NWC partners around the Nation for evaluation and water use reporting needs.[27] For successful development and integration of such new accounting methods for NWC components, multi-layered collaboration from technical components to project coordination is instrumental for ensuring data aggregation and assimilation with other Federal, State, regional, local, and Tribal resource managers.

2022: Remote Sensing Time Series Research for Land Change Science Products

The USGS's Land Change, Monitoring, Assessments, and Projections (LCMAP) project was instituted to monitor and assess land use and land cover change through time, to promote understanding of the causes and consequences of land change and to offer insight into the interactions between land change and climate change. LCMAP utilizes all available observations produced by the USGS Landsat Program to monitor change and to produce annual land change products. The land cover expertise of the USGS EROS Center is involved to assess the causes and consequences of the observed historical change. In 2022, LCMAP released updated products covering a 37-year record from 1985 to 2021.[28] The LCMAP product suite includes ten annual land change and land cover maps. The annual land cover from 1985 to 2017 was formally validated using a reference dataset produced by interpreters.[29] Collection of updated reference data for validation for 2018 to 2021 was launched in 2022.

27 *https://www.usgs.gov/water-resources/water-availability-and-use-science-program*

28 *https://doi.org/10.5066/P9C46NG0*

29 *https://doi.org/10.5066/P9ZWOXJ7*

LCMAP has recently developed modifications for the change detection methodology used to produce land change maps. The modified method (Band-First Probability) calculates the statistical test for change to reduce the effect of differences in the number of available observations on change detection. Since the availability of remote sensing observations varies across space and time, it is useful to have a methodology that is consistent across a variety of scenarios, especially given increases of data availability with additional new satellite data (e.g., Sentinel-2 from the European Space Agency).

Information from the LCMAP product suite enables unique applications and assessments of land change. For example, LCMAP change information was transformed to indicate the duration of tree cover regrowth after disturbance across CONUS forested regions (Zhou et al., 2022).[30] The average tree regrowth period was estimated and validated. Trees in the southeast United States took five years to recover on average, which is faster than in other regions of the country. The Pacific Northwest coastal region was another main area of tree regrowth where trees often took multiple decades to recover.

2021: Surface Flow Velocities from Space

Conventional, field-based streamflow monitoring in remote, inaccessible locations such as Alaska poses logistical challenges and makes remote sensing an appealing alternative means of collecting hydrologic data. In an ongoing effort to develop non-contact methods for measuring river discharge, researchers evaluated the potential to estimate surface flow velocities from satellite video of a large, sediment-laden river in Alaska via particle image velocimetry (PIV) using video acquired by the Planet Labs SkySat constellation. In this setting, naturally occurring sediment boil vortices produced distinct water surface features that could be tracked from frame to frame as they were advected by the flow, obviating the need to introduce artificial tracer particles. In this study, a refined end-to-end workflow involved stabilization and georeferencing, image preprocessing, PIV analysis with an ensemble correlation algorithm, and post-processing of PIV output to filter

30 *https://doi.org/10.1080/15481603.2022.2083790*

outliers and scale and georeference velocity vectors. Applying these procedures to image sequences extracted from satellite video allowed production of high-resolution surface velocity fields. Field measurements of depth-averaged flow velocity were used to assess accuracy.

Results confirmed the importance of preprocessing images to enhance contrast and indicated that lower frame rates (e.g., 0.25 Hertz) led to more reliable velocity estimates because longer capture intervals allow more time for water surface features to translate several pixels between frames, given the relatively coarse spatial resolution of the satellite data. Although agreement between PIV-derived velocity estimates and field measurements was weak (R^2 = 0.39) on a point-by-point basis, correspondence improved when the PIV output was aggregated to the cross-sectional scale. For example, the correspondence between cross-sectional maximum velocities inferred via remote sensing and measured in the field was much stronger (R^2 = 0.76), suggesting that satellite video could play a role in measuring river discharge.31 Examining correlation matrices produced as an intermediate output of the PIV algorithm yielded insight on the interactions between image frame rate and sensor spatial resolution, which must be considered in tandem. Further research and technological development may improve the ability to measure surface flow velocities from satellite video and provide a viable tool for streamflow monitoring in certain fluvial environments.

2021: Surface Water Inundation of California's Croplands

California's croplands cover roughly 3.8 million hectares (ha) with crop products valued at $33 billion according to the USDA's 2017 Census of Agriculture. Because of the value of these areas, monitoring surface water inundation in croplands is of interest for disaster preparedness and water management. Sources of inundation include both intentional irrigation and unintentional flooding. Irrigation accounts for most intentional water inundation in California's croplands, since nearly 90 percent of crops grown in California rely on irrigation. Surface irrigation,

31 *https://pubs.er.usgs.gov/publication/70220904*

whereby fields are flooded and water flows across the surface, is the most common type of irrigation practiced in the state.

While many crops are intentionally inundated, unintentional flooding is also a threat to agricultural yields. More than 1.1 million ha of California's croplands, representing nearly $7 billion in crop value, are located within a 500-year flood plain. Although drought conditions are predicted to increase in frequency as the climate changes, so too are extreme precipitation events that contribute to flooding. As a result, monitoring surface water inundation that results from flooding can help farmers and resource managers with risk assessments for crop types and locations.

Using satellite imagery, patterns of surface water inundation can be observed in California's croplands at frequent time scales across the entire state. Researchers examined eight different crop types to extract patterns of inundation from 2003 to 2020. They then utilized the computational power of a cloud-based image-processing platform to quantify monthly composite images of surface water and extract inundation for each crop type.

Results indicate that rice crops have high winter and spring surface water inundation, which was expected based on typical irrigation patterns.[32] Relatively high surface water inundation was also found in grain and field crop types. During winter months, citrus crop parcels show a mean inundation between 1 and 1.3 percent, suggesting unintentional flooding. Regions with high proportions of surface water extent in relation to crop area include the northern Sacramento River valley, where rice is predominantly grown, and the southern San Joaquin River valley, which produces a large portion of the state's deciduous and grain crops.

2022: U.S.-Mexico Transboundary Landcover Map

Knowledge about vegetation distributions and dynamics is critical for guiding land management and conservation decisions. Current resources in the Sonoran and Mojave Deserts Bird Conservation Region (BCR 33, in North American Bird Conservation Initiative designations) are insufficient due to the area's low vegetative cover, complex vegetation communities, and the discontinuity in data availability

32 *https://linkinghub.elsevier.com/retrieve/pii/S2352938522001458*

across the United States (U.S.) and Mexico border. Existing geospatial data and tools are often inadequate for supporting critical habitat-related work. This research produced the first high-resolution, continuous United States–Mexico land cover map of BCR 33 by prototyping new methods for desert vegetation classification using a Random Forest (RF) machine learning approach. The RF classification model was based on multitemporal Landsat 8 Operational Land Imager spectral and vegetation index data from 2013 to 2020, augmented with phenology metrics tailored to capture the unique growing seasons of desert vegetation; it can classify 31 different land cover class types within the Sonoran and Mojave Deserts BCR.

The model results portrayed the vegetation cover at a much finer resolution than existing land cover maps from the United States and Mexico portions of the study area. This approach helped identify small habitat pockets, including riparian communities, which are critically important for desert wildlife and are often misclassified or nonexistent in current maps. These results supported the assumption that land cover labels provided within the U.S. portion of the study area were representative of vegetation south of the border, allowing for the extension of the U.S. classification system into the Mexican region of BCR 33. While the results were mostly consistent with respect to the Gap Analysis Project (a program to keep common species common) Landfire classification of the region, they did highlight the need for a unified land cover classification scheme across the United States and Mexico portions of BCR 33. This application and tools serve as a resource to the stakeholders, regional agencies, and non-governmental organizations involved in this research, in support of habitat conservation and land management efforts within this sensitive Sonoran and Mojave Deserts BCR.

2021: Tracking Rates of Post-fire Conifer Regeneration Distinct from Deciduous Vegetation Recovery

Post-fire shifts in vegetation composition or successional trajectory will have broad impacts for carbon storage, hydrology, nutrient cycling, and wildlife habitat. However, information characterizing post-fire recovery patterns and their drivers is lacking over large spatial extents. Researchers tracked dual-season rates of post-fire recovery for more than 12,500 burned points across the western United States.

Landsat imagery collected when snow cover was present was used in combination with growing season imagery to distinguish evergreen vegetation from deciduous vegetation. The analysis sought to (1) identify spatial and temporal patterns in the rate of post-fire recovery across the western United States, (2) relate remotely sensed patterns to plot-scale, field-measured patterns of post-fire re-vegetation, and (3) model variability in post-fire rates of recovery as a function of burn severity, site conditions, and climatological factors.

The post-fire recovery under snow cover was indicative of evergreen regeneration, while the rate of recovery in the growing season primarily represented understory vegetation (grass, herbaceous, shrubs). Furthermore, the rates of recovery in the growing season were only weakly correlated with the rates of recovery under snow cover. The seasonal distinction in vegetation type had important implications for understanding the drivers of post-fire recovery. Although temperature was important in both seasons, the seasons showed opposite directionality, with warmer conditions associated with faster rates of evergreen regeneration and cooler conditions associated with faster rates of deciduous recovery. The temperature finding suggests that in snowy, mountainous areas, conifer regeneration may react differently to warming temperatures compared to deciduous species. Efforts that use both growing season and snow cover Normalized Difference Vegetation Index to evaluate post-fire recovery can help guide predictions of where active vegetation management could be focused at the scale of the western United States. This approach provides a powerful tool to inform landscape-scale, post-fire analysis and monitor long-term impacts of fires on ecosystems across the West.

2021: Walruses Are Visible in Satellite Imagery When They Rest on Shore in Large Numbers

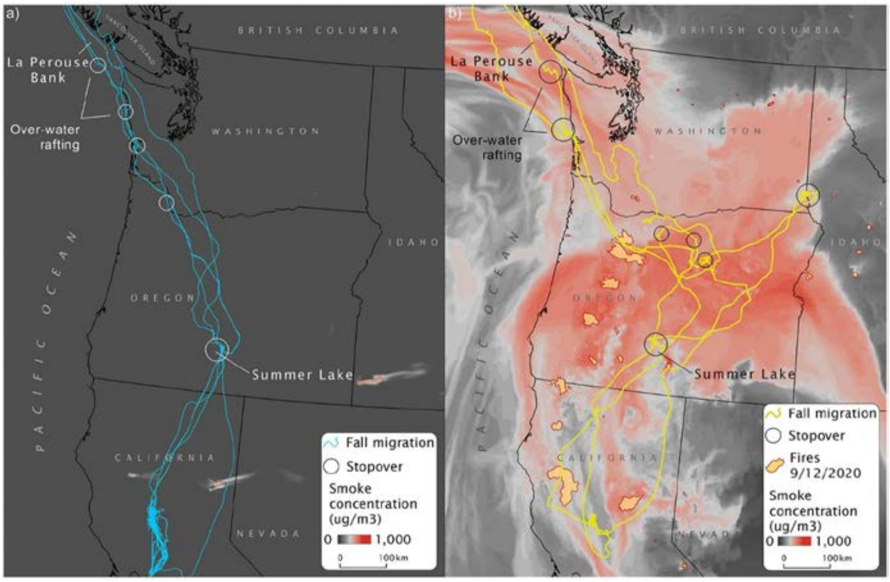
During late summer and autumn, Pacific walruses are resting on shore north of the Bering Strait more often and in larger numbers in both the United States and Russia. Historically, walruses rested primarily on floating sea ice over their offshore foraging grounds in this region, but climate warming has reduced availability of sea ice. With greater numbers of walruses gathering on shore, USGS scientists and collaborators are capitalizing on the opportunity to improve walrus population monitoring. The USGS has evaluated optical and radar satellite imagery ranging in pixel resolutions from 40 meters to about 1 meter for the detection and quantification of large walrus groups resting on shore. The USGS flew UAS orthoimagery surveys and was able to use these images to validate satellite imagery interpretation. The debut study site at Point Lay, Alaska, was optimal for remote sensing because the beach is fine-grained with negligible topography. Range-wide walrus population monitoring efforts, however, would require reconnaissance of haulouts (the large congregations of walruses on beaches), which are anticipated to be more challenging to imagery interpretations due to variable beach substrates and adjacent bluffs.

2022: Wildfire and Smoke Affect Bird Migration in Western North America

The 2020 Western fire season was among the most extreme on record. More than 100 fires were active in September; the majority occurred in California, Oregon, and Washington, where over 16,000 square kilometers burned. The 2020 fire season exemplified patterns of increased wildfire size, number, timing, return frequency, and extent, which are linked to climate-driven changes in precipitation and temperature affecting fire ignition and severity. Wildfires have increasingly coincided with the start of fall migration and may present a growing risk to migrating birds. For example, the fall migration of the tule goose (*Anser albifrons elgasi*), a subspecies of greater white-fronted goose (*A. albifrons*), occurred as smoke plumes from the wildfires reached the greatest extent.

The tule goose has a limited breeding range near the Cook Inlet in Alaska, and only a few thousand individuals exist, resulting in a designation as a Species of Concern in California, where the wintering population resides within the Sacramento Valley. Beginning in the fall of 2018, biologists with the Western Ecological Research Center have worked with California and Oregon wildlife departments to radio-collar and track tule geese from their principal stopover site at Summer Lake, Oregon. This region is used during both fall and spring migrations by virtually all tule geese as they transit between Alaska and California.

In 2020, migrating geese encountered dense smoke extending into the Pacific Ocean and across migratory routes off the coast of Vancouver Island, British



Dense smoke (more than 161 micrograms per cubic meter) from wildfires in September 2020 covered an extent equivalent to 64 percent of California, Nevada, Oregon, and Washington combined. Migration paths of tule geese (*Anser albifrons elgasi*) in 2020 (yellow in right panel) were more disorganized and resulted in longer migration times and distance flown relative to migration paths occurring in 2019 (blue in left panel), when dense smoke did not occur along migration routes. See study: *https://doi.org/10.1002/ecy.3552*

Columbia, Canada, and Washington, United States. Comparison of GPS tracks from collared geese and the High-Resolution Rapid Refresh with Smoke model allowed description of individual response to dense wildfire smoke. Over the next several weeks, individuals encountering the smoke demonstrated several atypical responses, including back-tracking and travelling around mountain ranges, extended at-sea stopovers off the Washington coast, approximately 4,000-meter (13,000-foot) flights over the smoke plumes, and loss of orientation toward traditional stopover areas (Summer Lake, Oregon). In total, these effects resulted in over 25 percent longer migration paths and a doubling of the migration duration between Alaska and Summer Lake. The detours are estimated to have resulted in an energetic deficit that could increase mortality or lower reproductive outputs and would require at least 4–6 days of elevated feeding activity to offset.[33] Monitoring of migratory bird populations using telemetry applications informs managers of the potential risk of wildfires to migrating bird populations.[34]

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33 *https://esajournals.onlinelibrary.wiley.com/doi/10.1002/ecy.3552*

34 *https://www.usgs.gov/news/national-news-release/wildfire-smoke-disrupts-bird-migration-west*

Bureau of Indian Affairs

The Bureau of Indian Affairs (BIA) applies remote sensing to activities such as land use planning, responding to non-point source pollution affecting subsistence hunting and fishing, climate change impacts such as sea-level rise for coastal Tribes, location and identification of potential dam hazards, and the generation of digital terrain data for the use of open-channel hydraulics. In collaboration with other agencies, BIA actively explores ways to improve management through remote sensing data and Geographic Information Systems (GIS) technologies.

2022: Wildfire and Climate Resilience on the San Carlos Apache Reservation

The USGS is working with the San Carlos Apache Tribe (SCAT) to identify parts of the SCAT reservation more vulnerable to wildfire. The collaboration has worked to identify restoration activities to improve climate resilience. The USGS used satellite imagery and watershed modelling to help the Tribe's natural resource managers prioritize areas for firebreak and water detention installations along large rivers. The results have demonstrated that such nature-based solutions can boost resilience to wildfire by increasing water availability and reducing water stress, while also preventing post-fire flooding and erosion. The Forest Resources Department within the San Carlos Apache Tribe is engaged in preventative thinning of vegetation and resource-benefit burns, which the USGS has also shown to reduce wildfire intensity. The United States Forest Service (USFS) is now using this guidance to consider expanding similar nature-based practices to forest service lands in collaboration with the BIA.

2022: Woodland Tree Cover Change Study Informs Restoration Activities

The San Carlos Apache Tribe wants to learn more about the historical characteristics of their woodlands, savannas, and grasslands so they have a target for restoration efforts. Restoring juniper woodland to savanna is a focus of the Tribe's intensive management activities. To determine changes in woodland canopy cover, this research developed and applied novel image geospatial analysis techniques to monitor tree cover for three study areas using 1935 and 2017 aerial imagery and compared results over the 82-year interval.[35] In general, the results depict a substantial increase in the woodland tree canopy cover in former savannas and encroachment of juniper trees into grasslands. Additionally, they show evidence of the success of Tribal woodland management efforts on Bee Flat, where managed landscape canopy cover is analogous to the natural savanna tree cover mapped there in 1935. These results are important as former savanna areas once dominated by native grasses and forbs have been replaced with higher-density juniper-pinyon-oak woodlands, along with degraded soils and limited herbaceous understories. The San Carlos Apache Tribe intends to use map results from this analysis to help locate other woodland areas suitable for restoration and as a current inventory and historical baseline of its Tribal woodlands. Pinyon-juniper expansion and infilling are increasingly a major challenge for land managers across the Intermountain West, and historical information from remote sensing may help provide much-needed data.

Bureau of Land Management

The Bureau of Land Management (BLM) leverages ground, air, and spaceborne remote sensing technologies to support its mission to sustain the health, diversity, and productivity of public lands for the use and enjoyment of present and future generations. These technologies include aerial and close-range photography; multispectral, hyperspectral, and thermal infrared camera/imaging systems; and radar and lidar. The BLM also utilizes passive and active imaging system information collected by 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

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35 *https://doi.org/10.3390/land10040393*

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.

2021: Cheatgrass Mapping

The invasion of exotic annual grasses is a widespread problem across the western United States. Of particular concern is cheatgrass (*Bromus tectorum*), which produces continuous mats of fine, highly flammable vegetation that can drive wildfires. To identify persistent and dense coverage of cheatgrass across Canyon County in southeastern Utah, the Canyon Country Fuels Program built a district-wide model based on previous research that sought to Detect Early Season Invasives (DESI). The model uses Landsat imagery to identify areas where vegetation greens up in early spring and is dry by early summer, which is a pattern typical of cheatgrass phenology, in contrast to perennial grasses. The model was based on similar research conducted through a NASA Space Grant Consortium Research Fellowship that looked strictly at national parks in southeastern Utah.[36] Expanding the scope to include a wider geographic and administrative range helps agencies like the BLM monitor and adaptively manage areas where cheatgrass is likely dominant. The broad range of ecozones in the extent of the model does result in false positives of DESI, particularly in riparian and agricultural zones. Nonetheless, DESI enables the rapid monitoring of large areas that would be difficult to cover with ground-based surveys, allowing managers to identify regional patterns and distributions of invasive cheatgrass.

2021: Collaborative Landslide Inventory Mapping

Landslides are a major geologic hazard in Oregon. To reduce the risk from future landslides, an accurate and complete landslide inventory is a fundamental requirement. In 2015, the BLM Coos Bay District began a multiyear collaborative

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36 *https://digitalcommons.usu.edu/spacegrant/2017/Session4/5/*

landslide inventory mapping project with the Oregon Department of Geology and Mineral Industries (DOGAMI). The BLM Coos Bay District has land in Douglas, Coos, and Curry Counties in Oregon. All three counties have relatively weak geologic units, steep topography, and high annual precipitation, and they are subject to large subduction zone earthquakes; they thus have relatively high landslide hazards.

The project has two primary goals: to create a detailed landslide inventory and to provide real-world training to students studying geologic hazards. The initial phase completed mapping in three watersheds that cover an area of 278.32 square miles, documenting 1,163 historic locations and 2,984 landslide deposits. The landslide deposits cover 15 percent of the watersheds, or 41.05 square miles. However, the individual watersheds range in landslide density from approximately 2 to 32 percent. Four more watersheds were mapped since the initial phase completion and publication in 2017.

To make these data easily accessible, they are published as a DOGAMI Open File Report and then compiled into the next Statewide Landslide Information Database of Oregon release.[37]

2022: Completion: LandCART (Landscape Cover Analysis and Reporting Tools)

The BLM National Operations Center (NOC), through a NASA Research Opportunities in Space and Earth Sciences (ROSES) grant, partnered with the USGS and University of California, Los Angeles, researchers to create an online mapping application called LandCART: Landscape Cover Analysis and Reporting Tools. LandCART V1.0 was released on February 16, 2022, as the NASA ROSES grant came to an end. LandCART enhances the BLM's ability to produce estimates of Assessment, Inventory, and Monitoring (AIM) indicators using NASA Earth observation data in places and times where in situ data are not available. The tool is being used to address user-defined management questions—particularly change and trend analysis questions—and to provide documentation required by

37 *https://www.oregongeology.org/pubs/ofr/p-O-17-04.htm* and *https://gis.dogami.oregon.gov/maps/slido/*

NEPA (National Environmental Policy Act). LandCART supports exporting of the predicted data with associated metadata compliant with Federal Geographic Data Committee (FGDC) standards to ensure reproducibility and appropriate NEPA documentation. Predictions are accompanied by error and confidence estimates to enhance their utility in decision making.

Four tools are available in the LandCART app:

1. The LandCART Cover Tool calculates an AIM indicator for one location at one time. It produces a predicted indicator map, a distribution histogram, and simple summary statistics.
2. The LandCART Cover Change Tool calculates an AIM indicator for one area at two different times. It produces two indicator maps, a difference map, and comparative histograms; conducts a two-sample Kolmogorov-Smirnoff test of differences for the histograms; and conducts a one-sample Kolmogorov-Smirnoff test for similarity between the difference histogram and a normal distribution.
3. The LandCART Time Series Tool calculates a time series for a chosen AIM indicator and a difference map to illustrate what change has taken place between the first and last step of the time series. It produces multiple indicator maps and comparative histograms for each time step in the time series, plots the time series median values, and conducts a Sen's slope test for trend. Annual predictions can be developed for 1984 to the present.
4. The LandCART Spatial Compare Tool calculates an AIM indicator for two different locations at one time. It produces two indicator maps and comparative histograms and conducts a Kolmogorov-Smirnoff test of differences for the histograms. LandCART is a powerful tool for land managers to include in a decision-making framework for ecological transformation and adaptive management.[38]

2021: Monitoring Managed Lands Using Synthetic Aperture Radar

The emergent proliferation of Synthetic Aperture Radar (SAR) imaging systems, related advancements in image processing and exploitation capabilities, and the

38 The application can be accessed at *http://landcart.org*.

increasing availability of analysis-ready SAR data products have enhanced the BLM's ability to use remote sensing–derived information to support resource management. SAR is valuable to land managers for multiple reasons: 1) the data can be collected regardless of time of day or weather condition, unlike optical imagery, which requires clear daytime conditions; 2) SAR systems that can transmit and receive multiple polarization states offer the ability to differentiate and classify land cover types; and 3) Interferometric Synthetic Aperture Radar (InSAR) techniques can be used to resolve fine-scale surface changes over time.

Two important examples where SAR imagery is being used to help address key BLM management concerns are wetlands monitoring and wildfire management. Sentinel-1, a moderate-resolution SAR constellation offering repeat, consistent worldwide coverage, is being used for each of these applications.

Wetland inundation dynamics mapping leverages Sentinel-1's spatial resolution, polarization, and revisit capabilities to provide a further understanding of surface water cover trends.

The National Operations Center (NOC) also uses Sentinel-1 to develop products that support the BLM's Emergency Stabilization and Rehabilitation (ESR) program, as well as for other post-fire monitoring activities. Change detection analysis of pre- and post-fire SAR imagery is used to delineate burn extents. Coherence products developed using InSAR techniques are used to provide fire severity estimates for affected rangeland and forest cover. InSAR coherence tends to be negatively correlated with severity, so extremely low coherence values typically represent moderate- to high-severity burned areas. Sentinel-1 SAR products are especially useful for post-fire management when electro-optical imagery is unavailable or unreliable due to weather and fire effects.

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.

2022: Mapping at Sea Wildlife Communities from Air and Space

The Bureau of Ocean Energy Management and U.S. Fish and Wildlife Service deployed very-high-resolution, multi-camera sensor arrays on fixed-winged aircraft to develop digital aerial imagery surveys in support of the Atlantic Marine Assessment Program for Protected Species (AMAPPS). In 2021, AMAPPS collected more than 1.8 million images from aerial surveys over the Atlantic Ocean Outer Continental Shelf, which includes data from migratory, summer, and winter seasons. The U.S. Geological Survey and University of California Berkeley are developing annotation databases using the imagery and training machine learning algorithms for the automated detection and classification of seabirds, marine mammals, and sea turtles at sea. Automating these steps improves processing efficiency because the data volume prohibits manual processing, as less than three percent of imagery contains images of wildlife. A central imagery database is active and will enable the coordination of data annotation by experts from multiple agencies and institutions to develop species-level classifications. The project plan is to investigate unsupervised data selection and active semi-supervised learning to optimally grow the model with larger-scale data and more wildlife targets of interest. The results will improve knowledge of seabird, cetacean, and sea-turtle distribution and abundance to inform environmental assessments and impact analyses of offshore energy development and other population assessments.[39]

The recent advancements in very-high-resolution (VHR) satellite imagery have tremendous potential for the development of an operational system to detect

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

marine mammals worldwide. Recent research has demonstrated the feasibility of identifying whales from VHR satellite imagery using manual and machine learning approaches. The Bureau of Ocean Energy Management, in collaboration with NOAA Fisheries, the Naval Research Laboratory, and the British Antarctic Survey, has been exploring developing an operational system to detect marine mammals from VHR imagery. While still in the early stages, the project has acquired large volumes of Maxar imagery over known seasonal aggregations of the North Atlantic right whale, the Cook Inlet beluga whale, and bowhead whales from WorldView-3, WorldView-2, and GeoEye satellites. Work with Maxar's GeoHive platform is being finalized to crowdsource the annotation of this imagery to build up a sample dataset of satellite imagery containing whales. Creating an extensive, standardized dataset of high-quality annotations is a precursor to successful machine learning approaches.[40]

Bureau of Reclamation

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

2022: Estimates of Evapotranspiration Along the Lower Colorado River

The Colorado River is the principal source of water for agriculture and riparian vegetation in Arizona, southern California, and southern Nevada. In the Lower Colorado River Basin, the BOR accounts for water use in each state, verifies water conservation programs, and fulfills other water management information needs.

40 *https://www.fisheries.noaa.gov/new-england-mid-atlantic/science-data/artificial-intelligence-detecting-marine-animals-satellites*

To accomplish this suite of responsibilities, BOR monitors more than 3.5 million acres of agricultural land, riparian vegetation, and open water areas along the Lower Colorado River, from Hoover Dam south to the international boundary with Mexico.

Four times per year, BOR performs supervised classifications on every field of rotational crops along the main-stem Colorado River, Imperial and Coachella Valleys, and Gila River. This task is conducted using a combination of multispectral satellite data (Landsat 7 and 8, Sentinel-2), aerial imagery from the National Agriculture Imagery Program, and ground-based field verifications. Roughly half of the collected verified fields are used to train the satellite imagery and determine the crop growing on each field for each time period. The other half of verified field data is used to assess the accuracy of the classifications. Fields that have static crops such as citrus and dates are manually mapped each year. Changes in these crops are identified during field verification trips and through inspection of high-resolution satellite imagery (primarily WorldView).

Data about the crop type and acreage, along with evapotranspiration (ET) crop coefficients, are then used to estimate the ET from crops within each area. Total ET from agricultural irrigation is typically close to three million acre-feet per year. The most prevalent crops by acreage are alfalfa, lettuce, Sudan grass, small grains, and Bermuda grass.

BOR also maintains riparian vegetation and open water datasets to determine ET and evaporation from these sources. Each year, these datasets are updated using the best possible imagery (satellite or aerial) by performing change detection analyses. Results from these efforts are reported annually in the report "Lower Colorado River Annual Summary of Evapotranspiration and Evaporation." Annual ET from riparian vegetation is usually more than 400,000 acre-feet, and annual evaporation from open water sources is more than 300,000 acre-feet.

This information assists the BOR in meeting its U.S. Supreme Court mandate to provide detailed and accurate records of diversions, return flows, and consumptive use estimates of water diverted from the main stem of the Lower Colorado River. This program is an example of implementing remote-sensing-based methodologies to meet the BOR's water management needs.[41]

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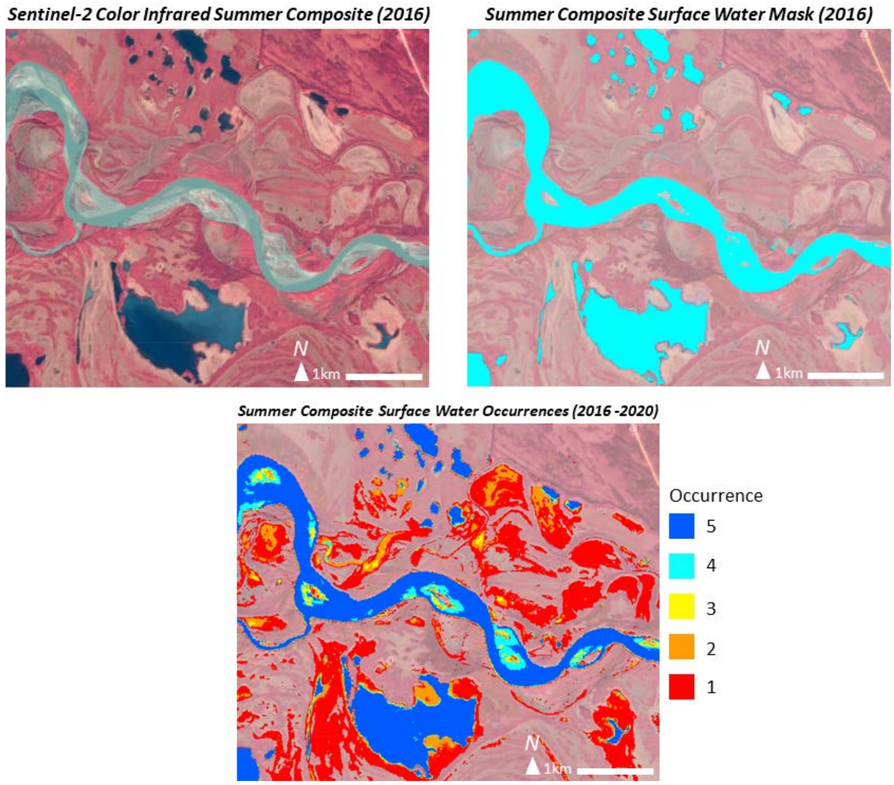
41 *https://www.usbr.gov/lc/region/g4000/wtracct.html*

Fish and Wildlife Service

The U.S. Fish and Wildlife Service (FWS), in concert with its international, Federal, Tribal, state, local, and non-government organization (NGO) 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, 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.

2021: Development of an Automated and Cloud-Based Remote Sensing Routine for Surface Water Monitoring in Alaska Refuges

The potential for large changes in the amount and distribution of surface water in arctic landscapes is high given climate-induced changes in permafrost. Because changes in surface water have broadscale implications for the structure and function of ecosystems, understanding and tracking surface water change is a high priority for some Alaskan refuges. As such, the primary objective of this project is to build an end-to-end, scalable remote sensing infrastructure that allows for the efficient production of cloud-free, high-resolution composite imagery with associated surface water estimates for refuge lands across Alaska. To accomplish this goal, the Google Earth Engine JavaScript platform is used to script a process for querying, filtering, and extracting water pixels from dense stacks of multi-temporal and multispectral, ten-meter-resolution, Level-1C imagery from the European Space Agency's Sentinel-2 mission. The team employs a cloud detection algorithm to mask out cloudy pixels from all available images and achieve a cloud-free composite for a given timestep and over an entire region. Surface water features are then extracted using an automatic image thresholding approach based on the Normalized Difference Water Index calculated from each composite's green and near-infrared (NIR) bands. To mitigate misclassification of persistent burned areas



Google Earth Engine outputs displaying (top left) 2016 Sentinel-2 color-infrared summer image composite in Tetlin NWR; (top right) automatic surface water extraction for 2016 summer composite; (bottom) surface water occurrence for summer composites (2016–2020).

and topographic shading as water, the process automatically masked out areas in the resulting surface water extraction that are identified as either severe burns from a Normalized Burn Ratio calculated from each composite's NIR and SWIR bands or areas representing steep topography as observed in an InSAR-derived slope map. The algorithm returns a cloud-free color-infrared image composite and final surface water extraction for each timestep specified by the user.

To better understand the uncertainty of extracted surface water outputs, they are validated against ground truth water features digitized from high-resolution, co-occurring airborne imagery (downsampled to match target resolution) in a 4.7-square-kilometer region of Alaska's Tetlin National Wildlife Refuge (NWR). This initial validation shows a precision of 97 percent, recall of 81 percent, intersection over union of 79 percent, and overall pixel accuracy of 97 percent. The current methodology appears to be excluding waterbodies smaller than 2 acres. Future efforts will employ Sentinel-1 SAR imagery to increase the amount of usable imagery and higher-resolution commercial datasets for observations of finer-scale surface water dynamics. An immediate priority is to evaluate the spatiotemporal changes of surface water estimates observed within Tetlin NWR as an initial case study. This work should provide an operational workflow and a product that provides surface water estimates at temporal and spatial resolutions useful for current and future management and modeling efforts.

2022: Inundation Frequency Explorer: Landscape Scale Assessment Using a Google Earth Engine App

In large river ecosystems, the timing, extent, duration, and frequency of floodplain inundation greatly affect the quality of fish and wildlife habitat and the supply of important ecosystem goods and services. Seasonal high flows provide connectivity from the river to the floodplain, and seasonal inundation of the floodplain governs ecosystem structure and function. River regulation and other forms of hydrologic alteration have altered the connectivity of many rivers with their adjacent floodplain. These changes impact the function of wetlands on the floodplain and, in turn, impact the mainstem river function. Conservation and management of remaining floodplain resources can be improved through a better understanding of the spatial extent and frequency of inundation at scales that are relevant to the species and/or ecological processes of interest. Spatial data products describing dynamic aspects of floodplain inundation are, however, not widely available.

Google Earth Engine provides cloud-based access to a vast catalog of satellite imagery. Sentinel-2 imagery can be used to evaluate the extent of inundation for any single cloud-free image. Relative inundation frequency can then be estimated by stacking many images captured under varying hydrologic conditions. Details of this workflow have been published,[42] and the results are now available online as a Google Earth Engine App.[43] The App allows the user to analyze inundation conditions anywhere in CONUS using their own spatial and temporal specifications to

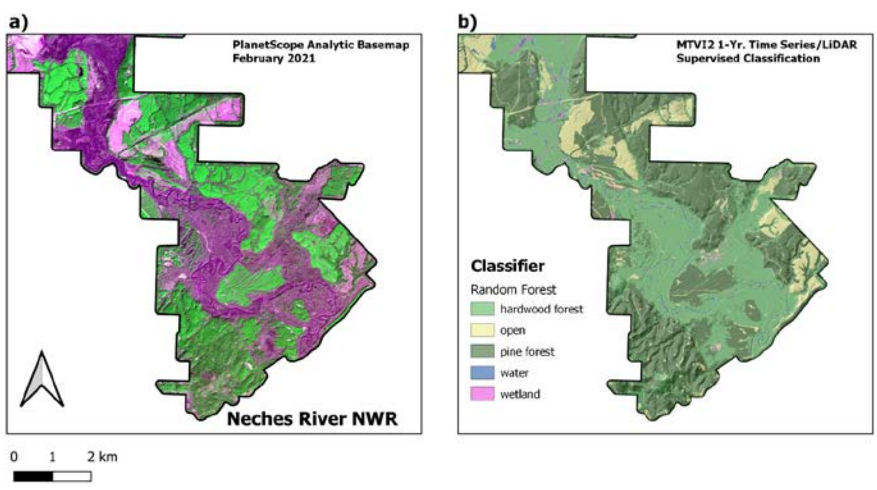
42 *https://onlinelibrary.wiley.com/doi/abs/10.1002/rra.2987*

43 *https://yallen.users.earthengine.app/view/inundation-frequency-explorer---sentinel-2*

customize the results. With publication of the Inundation Frequency Explorer App, technology that was once a static product available to only a single user is now freely available online.

2021: Lidar and PlanetScope Fusion to Classify Forest Types

Mixed composition and bottomland hardwood forests are essential to maintaining imperiled songbird populations on Texas and Oklahoma National Wildlife Refuges (NWR). Point-count data were collected for focal songbird species on five refuges together with remotely sensed data to estimate densities and model habitat relationships. Forest vegetation was classified into general composition categories that may influence avian species distributions, including deciduous forest, coniferous forest, and wetland vegetation. To develop mapped categories, researchers used PlanetScope 4-band (red, green, blue, and near-infrared channels) analytic basemaps for generating monthly modified triangular vegetation index 2 (MTVI2) and time series MTVI2 minimum, maximum, and amplitude (that is, minimum to maximum) values. Laser altimetry data from airborne lidar was used to generate a canopy height model (CHM) and 3D voxel metrics associated with canopy leaf area index and density. All data were developed and combined at 4-meter pixel resolution. Classification training and test data for mapped categories were



Monthly analytic basemap from composite PlanetScope imagery (a) and general vegetation categories mapped for the Neches River NWR (b). Analytic basemaps are corrected using radiometric normalization.

developed from satellite and high-resolution (less than 1-meter pixels) aerial imagery. The preliminary classification model for Neches River NWR using supervised random forest classification trees showed good results with model accuracy ranging from 82 to 84 percent correctly classified pixels from training samples left "out-of-bag" with replacement. Sparse test data held out of model training yielded 77 percent overall accuracy. The most important variable for separating coniferous and deciduous forest was MTVI2 coefficients of variation from a one-year growing season cycle and lidar CHM. Wetlands showed complex relationships to individual MTVI2 dates, and lidar metrics were less important for this vegetation category. Mapped categories provide accurate but general vegetation categories for evaluating habitat conditions and spatial patterns through time. Detailed classification models to distinguish tree species groups or wetland types will require field data or measures associated with inundation patterns to help distinguish potential composition differences. Eight-channel PlanetScope imagery aboard the recently launched SuperDove satellites may further aid mapping detailed vegetation categories in these environments.

2021: Mapping Endangered Species Potential Habitat

Nearly 1 million Attwater's greater prairie-chickens (*Tympanuchus cupido attwateri*) once occupied 6 million acres of coastal prairie grasslands in Texas and Louisiana. Loss and fragmentation of habitat nearly drove this species to extinction, and it was listed as endangered in 1967. Today, two populations have been established in the wild through release of captive-reared birds. Establishment of additional populations is limited by the availability of grassland habitat, much of which has been degraded through invasion by woody species.

This project identified areas of potential habitat throughout the historical range for consideration as additional release sites. Woody vegetation encroachment was assessed using the 2016 National Land Cover Database derived from Landsat imagery and the 2019 Global Forest Canopy Height layer derived from NASA Global Ecosystem Dynamics Investigation (GEDI) satellite-based lidar.

The probability of use of grassland habitat by greater prairie-chickens for annual mating rituals ("booming grounds") and nest sites declines sharply as tree canopy cover exceeds two percent. Based on this knowledge, potential habitat was delineated as shrub/scrub, herbaceous, or hay/pasture, with less than two percent canopy cover taller than three meters within one kilometer. The largest patch of this potential high-quality habitat consisted of 41,877 acres within Goliad County, Texas. Additional large patches meeting the criteria were located in Texas north of Anahuac National Wildlife Refuge (30,030 acres) and west of the Whitmire Unit of Aransas National Wildlife Refuge (16,632 acres). This assessment reaffirmed that Goliad County retains the greatest extent of potential high-quality habitat and provided a map of additional areas to evaluate for use as future release sites.[44]

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.

44 *https://ecos.fws.gov/docs/tess/species_nonpublish/995.pdf*

Glaciers are important sentinels of a changing climate, crucial components of the global cryosphere and integral to the ecosystems of their local landscapes. Until now, the commonly used methods for mapping glacier change were labor-intensive and thus limited in temporal and spatial scope. This work addresses some of those limitations by developing a novel deep learning–based method called GlacierCoverNet, a deep neural network that relies on an extensive, purpose-built training dataset. Using this model, project scientists mapped glaciers at a temporal cadence of every two years for the state of Alaska.

The workflow consisted of a series of algorithms that create a spectrally homogenous time series of optical imagery, followed by an initial classification of debris-free and debris-covered glacier ice using a deep neural network. The initial optical imagery time series was created from the Landsat archive using the LandTrendr algorithm run on the Google Earth Engine platform. To train the deep learning model, a training dataset was constructed of predictor variables from LandTrendr outputs, topographic information, and class labels based on the Randolph Glacier Inventory.

LandTrendr data characterize changes in debris-free glaciers and supraglacial debris over the last 35 years.[45] The deep learning model could produce maps comparable to existing approaches in the capture of areal extent but without manual editing. The overall model accuracy was 97 percent when compared to existing products with 6 and 9 percent omission and commission rates in the southern portion of Alaska. Overall, glacier-covered area retreated by 8,425 square kilometers (–13 percent) between 1985 and 2020, and supraglacial debris expanded by 2,799 square kilometers (64 percent) during the same period across the state of Alaska. The largest net glacier loss occurred in the most heavily glaciated areas of southcentral Alaska. The largest changes in overall glacier-covered area occurred in the mid elevations of 800–2,200 meters and in the last decade as mean annual temperatures have increased more rapidly.

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45 *https://www.fs.usda.gov/pnw/tools/landtrendr-and-timesync*

2022: Monitoring of Permafrost Ice Wedge Degradation in the Arctic National Parks

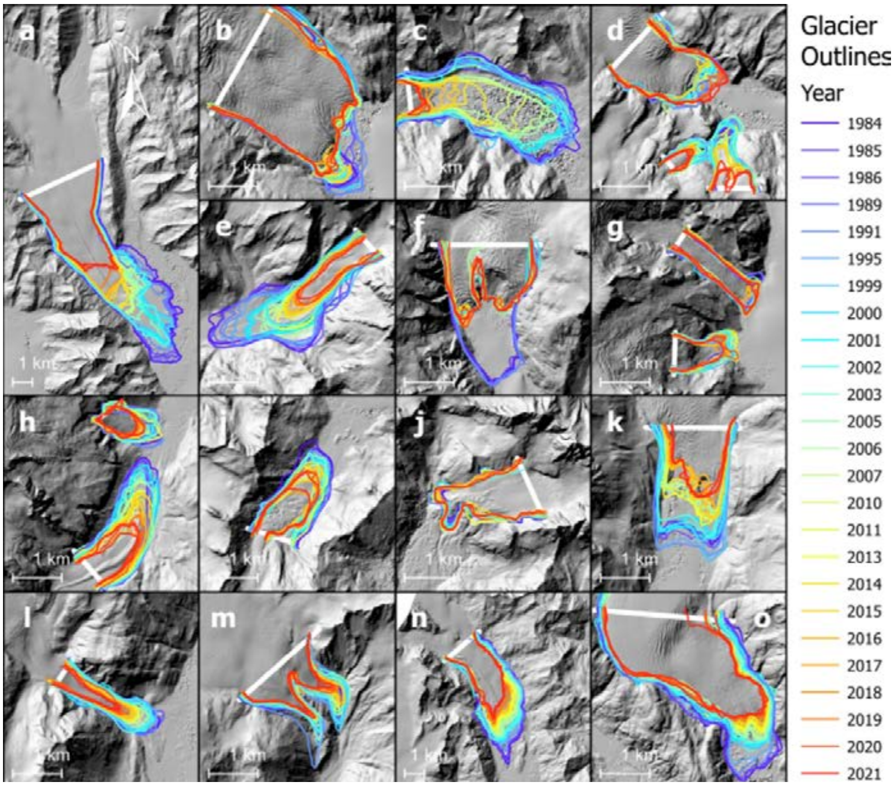
Ice wedges, a common type of ground ice in permafrost regions, are susceptible to thaw and can be an early warning sign of permafrost loss. They are also responsible for much of the unique polygonal patterned ground in the Arctic. The NPS Arctic Inventory and Monitoring Network (ARCN) monitors ice wedges by remote sensing at three study areas in northern Alaska. Network scientists monitor ice wedge degradation by analyzing the presence and location of small ponds that form in depressions left behind when wedges melt. Comparison of images from around 1950 (aerial photographs) with high-resolution satellite images from 2006–2009 (Ikonos) and 2019–2020 (Worldview-2) showed significant degradation in one study area between 1950 and 2006–2009, but little new degradation in any of the areas between 2006–2009 and 2019–2020.[46] This result was surprising given record warm temperatures in the study area during 2014–2019. Apparently, the recent warming did not force the ice wedges to cross any thresholds that would trigger immediate and widespread visible changes. However, new drainage channels continued to form by linkage of pits from previous ice-wedge degradation, and in one case this led to drainage of a lake.

2022: Quantifying 38 Years of Seasonal Glacier Change

Glaciers are an iconic part of the landscape in southcentral Alaska and cover approximately half of Kenai Fjords National Park. Glaciers play a role in local terrestrial, freshwater, and marine ecosystems and are one of the highlights for local tours. Like most glaciers in Alaska, the glaciers in Kenai Fjords have been shrinking. Although these changes have been documented via repeat photos and have been quantified in decadal and multi-decadal studies, annual changes of most glaciers in the fjords were previously unquantified.

The project team developed a database of annual and, when imagery was available, seasonal terminus positions for 19 maritime glaciers in Kenai Fjords National Park from the last 38 years. Landsat 4–8 imagery from 1984 through 2021 was used

46 *https://www.nps.gov/articles/000/permafrost-resource-brief.htm*



Maps of all seasonal outlines traced for the 19 glaciers in the study. The color scale ranges from purple as the oldest (1984) to red as the youngest (2021). Glacier reference lines are shown in white. Maps (a) and (n) are shown at 1:250,000 scale, and all others are at 1:100,000 scale. The base image is a hillshade of a DEM from a U.S. Fish and Wildlife Service–led structure-from-motion data acquisition in 2016.

to manually map the lower glacier ice margins and to measure seasonal changes of each glacier. Glacier retreat rates were compared based on termination types. Of these glaciers, six were tidewater, three were lake-terminating, six were land-terminating, and four terminated in more than one environment throughout the study period. The mapped ice margins were used to quantify seasonal terminus position and areal change, including distinguishing between ice loss at glacier termini and along glacier margins. Overall, 13 glaciers substantially retreated, 14 lost substantial area, and only two underwent both net advance and area gain. The glaciers that had insubstantial length and area changes were predominantly tidewater, and the glaciers that experienced the greatest rates of change were lake-terminating. Cumulatively, the lower reaches of these 19 glaciers lost 42 square kilometers of ice, which was nearly evenly distributed between the terminus and the lateral margins.

The rapid rate of glacier change and subsequent land cover changes are highly visible to visitors and park managers at Kenai Fjords National Park. This study quantifies those changes in terms of glacier length and area and highlights the value of continuous monitoring in dynamic landscapes such as Kenai Fjords National Park.

2022: Satellite Images Solve the Mystery of Water Chemistry Change in an Alaskan Lake

Scientists from the National Park Service had been monitoring water quality in a small lake in Yukon-Charley Rivers National Preserve since 2005, when they noticed a sudden and persistent increase in the ionic concentration beginning in 2019. The specific conductance of the lake water increased from less than 200 MicroSiemens per centimeter (µS/cm) in 2005–2018 to about 700 µS/cm in 2022. Examination of high-resolution Worldview-2 and Planet satellite images revealed that two small patches of dead vegetation, suspected to be new groundwater seeps, appeared at the foot of a slope near the lake in 2019. Field visits to the seeps revealed that the dead vegetation was caused by water with conductance in excess of 6,000 µS/cm, and flow paths to the lake confirm that the seeps are the source of the ions in the lake. The images also revealed that water lilies (*Nuphar lutea*) disappeared from the lake, coincident with the rise in conductance and in accordance with their known sensitivity to high ionic concentrations. The seeps probably formed in response to permafrost thaw that occurred due to climate warming and wildfires in the lake's watershed.[47]

Office of Surface Mining Reclamation and Enforcement

The Office of Surface Mining Reclamation and Enforcement (OSMRE) remote sensing program provides OSMRE offices, states, and Tribes with the necessary tools to use remote sensing technologies to support Titles IV (Abandoned Mine Lands) and V (Regulation of Current Mining) of the Surface Mining Control and

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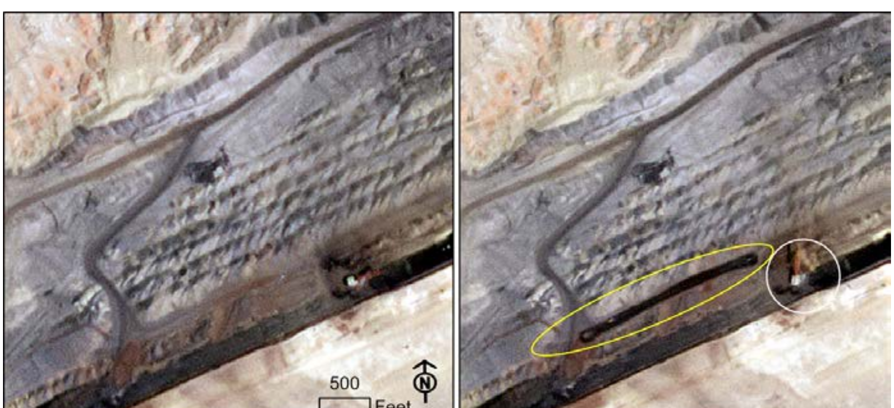
47 *https://www.nps.gov/im/cakn/shallowlakes.htm*

Reclamation Act of 1977. As part of this support, the OSMRE remote sensing program provides high-resolution satellite imagery, aerial photography, and lidar data to conduct analysis of terrain, vegetation, and hydrologic function on active mine sites to ensure reclamation is consistent with the approved mining permit. These data are also used to support inventory, monitoring, and assessment of abandoned mine land features to ensure there is no threat to the environment or to health and human safety.

2022: CubeSat Imagery Captured 35 Minutes Apart Shows Mining Activity

OSMRE has a contract with a CubeSat imaging company, Planet Labs, for access to PlanetScope SuperDove CubeSat imagery.[48] The PlanetScope CubeSats are small, inexpensive imaging satellites about the size of a shoebox that are launched on a regular basis to provide electro-optical imagery of the entire Earth every day. At the end of their operational life of a few years, the CubeSats are de-orbited and replenished with new ones. As the CubeSat numbers grow, the temporal coverage grows. The spatial resolution of SuperDoves is three- to five-meter ground sample distance. This image below shows two scenes captured 35 minutes apart by two SuperDoves, of a coal mine. The left image was captured on June



The left image was captured on June 21, 2022, at 11:02 AM local time, and the right image was captured 35 minutes later at 11:37 AM. Note the changes within the yellow and white outlined areas. Image source: Planet Labs

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

21, 2022, at 11:02 AM local time, and the right image was captured at 11:37 AM local time. Comparing the two scenes shows active mining, demonstrated by the readily observed position changes of the dragline and other mining equipment. Note the surface change within the yellow outlined area as well as the position of the dragline equipment within the white outlined area. CubeSats provide temporal capabilities for electro-optical imaging that enhance OSMRE's ability to observe mining and reclamation activities for mines that are remote and difficult to access. Daily imagery improves the ability of OSMRE to evaluate mining production activity as well as measure the performance of reclamation processes over time.

2022: Using Synthetic Aperture Radar and Electro-optical Images to Observe Critical Infrastructure on Former Coal Mines

Electro-optical satellite imagery is available commercially in spatial resolutions down to 25 centimeters. However, electro-optical satellite imaging is hampered by clouds. OSMRE has purview of two mine sites in the state of Washington over which it has been difficult to obtain cloud-free imagery. OSMRE worked with the Civil Applications Committee to evaluate solutions for overcoming the limitations of electro-optical imaging by using high-resolution SAR. SAR is an active remote sensing system, which means it is essentially a radio-image that is not hampered by clouds. Knowing the physical properties and surface characteristics observable within the specific radio-frequency band as well as application of advanced multi-looking techniques, SAR can aid in observing features that can be difficult to see in electro-optical imagery. OSMRE tasked a Planet Labs SkySat electro-optical collection, which was collected nearly a month later on December 29, 2021. OSMRE is working to incorporate more SAR products into the virtual inspection workflow, particularly for critical infrastructure and emergency situations. Access to both SAR and electro-optical helps OSMRE meet its mission requirements under the Surface Mining Control and Reclamation Act of 1977 and better prepare for climatic impacts on active, inactive, and abandoned coal mines in the United States.

Federal Communications Commission

FCC

The Federal Communications Commission (FCC) formulates rules to facilitate the provision of commercial satellite services in the United States. It also issues licenses for the deployment and operation of all non-Federal U.S. satellites. Internationally, the FCC coordinates satellite radio-frequency usage with other countries. The FCC's activities in FY 2021 and 2022 related primarily to commercial communications satellites, including satellites providing broadband service, as well as experimental satellites.

The FCC took a number of significant actions in administrative rulemaking proceedings in FY 2021 and FY 2022, including the following:

- On November 18, 2020, the FCC adopted revisions to its rules to streamline the authorization process for satellites and certain types of earth stations by creating an optional process for applicants to obtain a single unified license covering satellite and earth station operations.
- On November 19, 2021, the FCC proposed revisions to its rules to expand use of certain frequencies in the 17 GHz band by geostationary orbit satellites operating in the fixed-satellite service, and on August 3, 2022, the FCC adopted these revisions. The FCC adopted rules that would facilitate sharing in this frequency band between the fixed-satellite service and other services and alleviate the growing need for additional spectrum in the fixed-satellite service, enabling greater flexibility and efficiency for advanced satellite system operations for the benefit of American consumers. Also on August 3, 2022, the Commission sought comment on

a proposal to expand use of certain frequencies in the 17 GHz band to include non-geostationary satellites operating in the fixed-satellite service.

- On December 15, 2021, the FCC proposed new rules applicable to non-geostationary orbit satellite systems operating in the fixed-satellite service. The FCC proposed rules that would provide additional clarity regarding the radiofrequency interference protection afforded to various satellite systems operating in the fixed-satellite service, with a goal of facilitating deployment of systems capable of providing broadband and other services on a global basis and promoting competition among systems, including market entry of new competitors.
- On August 8, 2022, the FCC initiated a new proceeding concerning space innovation, in particular seeking comment on the opportunities and challenges of in-space servicing, assembly, and manufacturing (ISAM) activities. The FCC sought information on the status of ISAM capabilities, how the FCC can support its sustainable development, and what tangible economic and societal benefits may result from development of these capabilities.
- On September 29, 2022, the FCC adopted revisions to its orbital debris mitigation rules requiring operators of commercial, experimental, and amateur satellites in low-Earth orbit to dispose of satellites within five years following completion of their mission. This revision updates the prior benchmark of 25 years for low-Earth orbit satellite post-mission disposal.

During FY 2021 and 2022, the FCC issued rulings facilitating the deployment and operations of several non-geostationary systems designed to provide and support communications services, including high-speed broadband, the "Internet of Things," and connectivity for cellular devices. These rulings include the following:

- On January 8, 2021, and April 23, 2021, the FCC granted a request from Space Exploration Holdings, LLC (SpaceX), for modification of its authorization for a non-geostationary orbit constellation utilizing Ku- and Ka-band spectrum in order to slightly reduce the number of satellites in the constellation, modify the operational altitude specified for a portion of the constellation from the 1,100–1,300 kilometer range to the 540–570 kilometer range, and modify certain other technical parameters. The FCC also approved, subject to conditions, SpaceX's plan for satellite orbital debris mitigation.

- On November 2, 2021, the FCC authorized The Boeing Company to construct, deploy, and operate a new non-geostationary orbit satellite system consisting of up to 132 satellites operating at an altitude of approximately 1,056 kilometers and 15 satellites in a highly inclined orbit operating at altitudes between approximately 27,355 and 44,221 kilometers, utilizing the Ka-band and V-band. The Boeing Company would provide broadband and communications services to residential, commercial, institutional, governmental, and professional users in the United States and globally.
- On November 18, 2021, the FCC issued a ruling outlining the conditions under which Kinéis can obtain a license for earth stations in the United States, including Internet of Things devices, to communicate with its constellation of up to 25 satellites authorized by France.
- On September 16, 2022, the FCC authorized Lynk Global, Inc., to deploy and operate a constellation of ten non-geostationary, low-Earth orbit satellites that would provide satellite connectivity for cellular devices in certain areas outside of the United States.

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 8, 2020, the FCC authorized Loft Orbital Solutions Inc. to construct, deploy, and operate one non-geostationary orbit satellite to be known as YAM-2, at an altitude of approximately 550 kilometers, to conduct imaging and experimental operations.
- On October 9, 2020, the FCC authorized Astro Digital US, Inc., to operate its non-geostationary orbit remote sensing Landmapper BC-5 satellite using additional frequencies and also modified certain license conditions.
- On December 17, 2020, the FCC authorized Capella Space Corp. to construct, deploy, and operate a low-Earth orbit, non-geostationary orbit satellite, at an altitude of approximately 525 kilometers, for the purpose of conducting Synthetic Aperture Radar (SAR) imaging. The FCC authorized Capella Space Corp. to construct, deploy, and operate additional

satellites to operate in its constellation on May 4, 2021, December 15, 2021, and May 11, 2022.

- On December 18, 2020, the FCC authorized R2 Space, Inc., to construct, deploy, and operate one low-Earth orbit, non-geostationary orbit satellite, at an altitude of approximately 550 kilometers, for the purpose of conducting SAR imaging.
- On May 24, 2021, the FCC authorized Loft Orbital Solutions Inc. to construct, deploy, and operate one non-geostationary orbit satellite to be known as YAM-3, at an altitude of approximately 525 kilometers, to conduct imaging and experimental operations.
- On December 13, 2021, the FCC authorized Umbra Lab Inc. to construct, deploy, and operate two satellites as part of a constellation of low-Earth orbit, non-geostationary orbit satellites for purposes of conducting SAR imaging. On March 28, 2022, the FCC authorized Umbra Lab LLC to construct, deploy, and operate the remaining four satellites in its constellation.
- On December 2, 2021, the FCC authorized ICEYE US, Inc., to deploy and operate a low-Earth orbit satellite, deployed to an altitude of approximately 550 kilometers, for the purpose of conducting SAR imaging. On April 21, 2022, the FCC authorized deployment and operation of two additional ICEYE US, Inc., satellites, and on August 4, 2022, the FCC authorized an additional satellite as part of the ICEYE US, Inc., satellite constellation.
- On May, 11, 2022, the FCC authorized Spaceflight, Inc., to deploy and operate a spacecraft known as Sherpa-AC1, deployed to an altitude of approximately 550 kilometers, for a period of up to one year, with operations including demonstration of a space-based position, navigation, and timing signal.

In FY 2021 and FY 2022, the FCC authorized a number of other commercial communications satellite deployments and operations. These authorizations included the following:

- June 17, 2021: To Intelsat License LLC, as debtor-in-possession, to construct, deploy, and operate a C-band satellite to be located at the longitude 121.0° west orbit location.

- October, 21, 2021: To Intelsat License LLC, as debtor-in-possession, to construct, deploy, and operate a C-band satellite to be located at the longitude 129.0° west orbit location.
- February 28, 2022: To Intelsat License LLC, to construct, deploy, and operate a C- and Ku-band satellite to be located at the longitude 91.0° west orbit location.
- March 14, 2022: To SES Americom, Inc., to construct, deploy, and operate four C-band replacement satellites: SES-18 at the longitude 131° west orbit location, SES-19 at the longitude 103.05° west orbit location, SES-20 at the longitude 135° west orbit location, and SES-21 at the 103.05° west orbit location.
- June 16, 2022: To SES Americom, Inc., to deploy, test, and operate an additional C-band satellite to be located at the longitude 135° west orbit location.

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.

The FCC also granted authority for several Earth stations in the United States to communicate with the Astroscale Ltd. ELSA-d spacecraft, operated under the authority of the United Kingdom. The ELSA-d spacecraft is designed to conduct demonstrations of rendezvous operations and debris removal in space.

In FY 2021 and FY 2022, 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 December 14, 2020, the FCC granted the request of Hawkeye 360, Inc., for modification of the license for its low-Earth orbit non-geostationary orbit satellite system to reflect changes to satellite antennas for sensing operations. On May 5, 2021, the FCC granted another license modification to Hawkeye 360, Inc., to reflect further changes to the satellite antennas and updates to the satellite propulsion system.

- On October 30, 2020, May 14, 2021, and January 10, 2022, the FCC granted the request of Spire Global, Inc., for modification of the grant of market access for its non-geostationary satellite orbit MINAS satellites to permit deployment of additional satellites, operating under the authority of Luxembourg. Also on October 30, 2020, and May 14, 2021, the FCC granted Spire Global, Inc.'s request for modification of its non-geostationary orbit LEMUR constellation to permit deployment of additional satellites.
- On December 7, 2020, and July 1, 2021, the FCC granted the request of Swarm Technologies, Inc., for modification of the license for its non-geostationary satellite constellation to reflect technical changes to the satellites, including addition of a propulsion system.
- On May 28, 2021, the FCC granted special temporary authority to Spaceflight, Inc., to deploy and operate two non-geostationary orbit spacecraft, known as the Sherpa-FX2 and Sherpa-LTE1. The FCC authorized the Sherpa-FX2 to operate for a period of less than 24 hours to deploy up to 25 spacecraft. The FCC authorized the Sherpa-LTE1 to operate for a period of up to 180 days in order to deploy up to 10 spacecraft and conduct additional testing. The FCC extended special temporary authority for the Sherpa-LTE1 on July 21, 2022, for an additional 180 days, and again on November 3, 2022, for an additional 180 days.
- On May 28, 2021, the FCC granted Astro Digital US, Inc.'s request for modification of its license to permit the launch and operation of two additional satellites for technology demonstration missions.
- On December 20, 2021, the FCC granted special temporary authority to Spaceflight, Inc., to deploy and operate a spacecraft, known as the Sherpa-LTC1, for up to 180 days, including to deploy up to ten spacecraft and for communications during additional testing and de-orbit.
- On March 2, 2022, the FCC granted special temporary authority to Spaceflight, Inc., to deploy and operate a non-geostationary satellite,

known as the Sherpa-FX5, to deploy eight spacecraft over a period not to exceed 36 hours.

- On April 8, 2022, the FCC granted the request of Maxar License Inc. for modification to update the orbital parameters for its non-geostationary orbit WorldView-Legion satellite constellation, which will conduct remote sensing operations.
- On April 28, 2022, the FCC granted special temporary authority to Momentus Space LLC to deploy and operate a spacecraft known as Vigoride-3 for a period of up to 180 days in order to deploy up to nine spacecraft. On June 9, 2022, July 13, 2022, August 17, 2022, and September 15, 2022, the FCC granted special temporary authority to Momentus Space LLC to operate the Vigoride-3 using additional frequencies in order to recover communications following a satellite anomaly.
- On August 18, 2022, the FCC granted special temporary authority to Intelsat License LLC to conduct operations with the Galaxy 15 satellite outside of its previously assigned longitude due to a satellite anomaly.

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

- On November 10, 2021, the FCC added Telesat Canada's ANIK F1 satellite to the permitted list, operating under the authority of Canada and using the Ka-band at the longitude 109.2° west orbit location.
- On February 3, 2022, the FCC added Astranis Bermuda Ltd.'s Arcturus satellite to the permitted list, operating under the authority of Bermuda and using the Ku-band at the longitude 163° west orbit location.
- On March 3, 2022, the FCC added Embratel TVSAT Telecomunicações S.A.'s Star One C4 satellite to the permitted list, operating under the authority of Brazil and using the Ku-band at the longitude 70° west orbit location. The grant was subsequently surrendered on March 31, 2022.
- On March 10, 2022, the FCC added Hispamar Satelites, S.A.'s Amazonas Nexus satellite to the permitted list, operating under the authority of Brazil and using the Ka- and Ku-bands at the longitude 61.0° west orbit location.

- On May 3, 2022, the FCC added Avanti Hylas 2 Ltd.'s HYLAS-4 satellite to the permitted list, operating under the authority of the United Kingdom and using the Ka-band at the longitude 35.5° west orbit location.
- On October 6, 2022, the FCC added Embratel TVSAT Telecomunicações S.A.'s Star One D2 satellite to the permitted list, operating under the authority of Brazil and using the Ku-band at the longitude 70° west orbit location.

U.S. Department of Agriculture

USDA

USDA's 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." The statement indicates that the organization seeks the best strategies to induce growth and progress in all the areas that it oversees.

Remotely sensed data and derived information directly support mission-critical work of the USDA. A wide variety of data and technology, including aerial and satellite imagery, high-quality elevation data, uncrewed vehicles, and ground-based collections validated with GPS, are used in daily operations that impact mission elements including forest fire management, pandemic response, conservation, climate change resilience, smart agriculture, rural development, invasive species eradication, emergency response, carbon sequestration, greenhouse gas management, food safety, and food security.

Agricultural Research Service

The Agricultural Research Service (ARS) is the intramural research branch for USDA involved with Earth science, environmental monitoring, spaceflight, and advanced analytics. For many years, ARS has been integral to the 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 retrieval of cropland coverage and soil moisture data for satellites in development, including the NASA-ISRO Synthetic Aperture Radar (NISAR) mission, set to launch in 2024. ARS scientists served on multiple satellite science teams, including those for SMAP, NISAR, Ecostress, and Landsat, providing invaluable expertise in agricultural monitoring and interpretation. In FY 2021 and FY 2022, the SMAP Validation Experiment 2019–2022 was led by ARS to improve the retrieval of soil moisture data over mixed agriculture/forest landscapes, like those found along the eastern seaboard of the United States.

ARS, in collaboration with NASA's Applied Sciences Water Resources Program under the GRAPEX 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 and grazing projects. Crop emergence dates were estimated on a biweekly basis during the growing season, for the five Corn Belt states at a 30 m resolution and delivered to the National Agricultural Statistical Service for state-level crop progress reports. 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 (~30 m) 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. This work includes studies on carbon modeling and land surface flux based on data from in situ sensors and space-based instruments on the Orbiting Carbon Observatory-2 and -3 missions.

To improve these collaborations, a Memorandum of Understanding was established between USDA and NASA in 2020, 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 and an official source of comprehensive information, 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 2021 and 2022 June Area Survey and the 2022 Census of Agriculture. In addition, NASS finished updating a new area-based sampling frame for Louisiana and Puerto Rico.

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 2020 and 2021 crop seasons via the USDA Geospatial Data Gateway, CroplandCROS, and CropScape.[1]

NASS, working cooperatively with USDA/ARS, brought a newly developed website called CroplandCROS online in 2021. Both CroplandCROS and CropScape 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. 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.

In 2021, NASS developed new 30-meter crop-type prediction layers and corresponding entropy (uncertainty) layers derived from historic CDLs using machine learning techniques. The new geospatial products are called Predictive CDLs (PCDLs). In 2021, the new PCDLs were produced for 12 major corn production states. 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. In 2022, the PCDLs were produced for the 48 conterminous states and made available for internal use for the June Area Survey.

In FY 2021 and FY 2022, geospatial decision-support data products were delivered for disaster inundation and wildfire assessments to assess impacts on agriculture from Hurricanes Delta and Zeta (October 2020), Delta Regional Flooding (June 2021), Western U.S. Drought and Extreme Heat Event (July/August 2021), Hurricane Ida (August 2021), Kansas Wildfires (December 2021), Kentucky Tornadoes (December 2021), Texas Wildfires (March 2022), Midwest Flooding (July/August 2022), and Hurricanes Fiona and Ian (September 2022). 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.[2] This information was used to assess

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1 *https://croplandcros.scinet.usda.gov* and *https://nassgeodata.gmu.edu/CropScape*

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

real-time storm inundation or wildfire impact over crop and pasturelands and shared with both USDA and the Federal Emergency Management Agency (FEMA).

NASS utilized NASA MODIS NDVI and the NASA Global Inventory Modeling and Mapping Studies (GIMMS) Global Agricultural Monitoring application for modeling corn and soybean yield estimates covering the 16 largest corn and 11 largest soybean production 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.[3] 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.

CropCASMA was publicly released on April 1, 2021, providing both volumetric and categorical topsoil and subsoil moisture from the NASA SMAP mission.[4] The development of CropCASMA originated from a NASA Western Water Applications Office Grant titled "Higher Spatial and Temporal Resolution Soil Moisture Product," for FY 2018–FY 2021 (Grant # NNG18JA25P). CropCASMA was used to assess excessive heat and drought events as well as regional flooding based on observed soil moisture. For example, CropCASMA was used for nine weekly assessments of the Western U.S. Drought and Extreme Heat Event between July and August 2021 and posted on the NASS Disaster Analysis website.[5] 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 now incorporate CropCASMA percentages of soil moisture into their weekly Crop Progress and Condition Reports.

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3 *https://nassgeodata.gmu.edu/VegScape*

4 *https://nassgeo.csiss.gmu.edu/CropCASMA/*

5 *https://www.nass.usda.gov/Research_and_Science/Disaster-Analysis/2021/index.php#Western_US_Drought*

Research efforts began on the NASA AIST grant titled "Digital Twin Infrastructure Model for Agricultural Applications" during late FY 2022. 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.

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. 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 provided assistance to farmers and ranchers impacted by natural disasters, including hurricanes and fires. In FY 2021 and FY 2022, 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 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. Ortho-imagery, elevation data, and GPS information were essential geospatial data integrated into RMA program applications. RMA offices used geospatial data daily to support crop insurance.

RMA staff were active participants in science teams, such as the USDA Soil Moisture Working Group, 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.

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 U.S. Department of Agriculture's (USDA) 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 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.[6]

During FY 2021 and FY 2022, 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 displayed global imagery products on several application web sites. Global crop conditions and relative crop yields were primarily monitored and measured by NASA's MODIS sensors onboard the Aqua and Terra satellites. Crop type and crop area were primarily mapped and estimated from Landsat 7 and 8 and Sentinel 2A and 2B satellite imagery.

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

FAS/GMA is also the host for Crop Explorer,[7] 12 Commodity Explorers,[8] and the Global Agricultural and Disaster Assessment System (GADAS)[9] web application systems. Crop Explorer allowed public users to monitor and analyze seasonal rainfall over global croplands and extreme temperatures that may cause crop damage. The 12 Commodity Explorers web apps are crop-specific and monitored Normalized Difference Vegetation Index (NDVI) crop conditions over global croplands for corn, wheat, rice, cotton, soybeans, barley, palm oil, rapeseed, sorghum, sunflower seeds, peanuts, and millet. GADAS is a state-of-the-art geographic information system that displays 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 were processed, archived, and displayed from a variety of satellite imagery products. The USDA-NASA Global Agricultural Monitoring (GLAM)[10] and Global Reservoir and Lake Monitor (G-REALM)[11] web systems are hosted and operated by NASA's Goddard Space Flight Center and display time series satellite data and products over global croplands and major inland water bodies. The GLAM-NDVI-MODIS web interface system compares current vegetation conditions with past years by utilizing NDVI satellite imagery from NASA's MODIS-Terra and MODIS-Aqua satellite systems. In addition, G-REALM monitors and displays 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.

Farm Service Agency

The Farm Service Agency (FSA) administers several safety net, price support, conservation, disaster assistance, and loan programs as laid out by Congress through a network of Federal, state, and county offices. Land-based information

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7 *https://ipad.fas.usda.gov/cropexplorer/*

8 *https://ipad.fas.usda.gov/cropexplorer/cropview/*

9 *https://geo.fas.usda.gov/GADAS/index.html*

10 *http://glam1.gsfc.nasa.gov/*

11 *https://ipad.fas.usda.gov/cropexplorer/global_reservoir/*

has always played a fundamental role in daily operations and administration of those programs. 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 drones this past reporting period; however, it did issue several remote sensing contracts to acquire airborne imagery that required the use of the National Airspace System (NAS). The main contracts supported orthorectified imagery collection for the National Agriculture Imagery Program (NAIP). NAIP is a multi-department-funded program that provides current high-resolution imagery of CONUS, Hawaii, Puerto Rico, and U.S. Virgin Islands into the public domain. The NAIP imagery is collected every two years for CONUS and every four years for Hawaii, Puerto Rico, and U.S. Virgin Islands. 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. 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 2022, imagery for Edwards Air Force Base, California; Vandenberg Space Force Base, California; Fort Bragg, North Carolina; and Nevada Test and Training Range, Nevada, were not collected due to restricted airspace.

In 2022, 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 received imagery from the National Geospatial-Intelligence Agency (NGA) through Maxar's Global Enhanced GEOINT Delivery (G-EGD) (formerly known as Digital Globe's Enhanced View Web Hosting Service), along with Maxar's VIVID Web Map Service. 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.

FSA uses Positioning, Navigation, and Timing (PNT) equipment to collect, update, and maintain data for agency programs. Some of these uses include the following: Common Land Unit data, compliance programs, ground control points, disaster support, and conservation programs. The data may be a single point or an area. Support data such as photographs and attribute information may also be included. Funding, administration, training, and maintenance of the PNT equipment and software are largely done by FSA at the national level with extensive coordination and involvement of the FSA state personnel. Coordination, research, joint acquisition, and other involvement also occurs with NRCS, FPAC, and at times other government agencies. Almost all of the data collection and use of the equipment are done by FSA state and service center personnel. Major equipment and/or software acquisitions by FSA have occurred in 2001, 2014, 2019, and 2021, with additional acquisitions planned for 2023 and beyond.

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); 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 2021 and FY 2022, the USFS collaborated with NASA, NOAA, the USGS, other agencies, and other external agency partners and cooperators to apply operational satellite and airborne imagery and the most advanced remote sensing and geospatial technologies.

Specific accomplishments included the following:

- Within the Applied Earth Observations Innovation Partnership (AEIOP),[12] the Forest Service co-hosted a series of monthly webinars during the fall and winter of 2021–2022 to highlight available Earth

12 *https://pikesmeetings.wixsite.com/aeoip*

observation missions and data, demonstrate the utility of Earth observation data to address land management needs, and share successful applications of Earth observations into operational land management decision making.

- The AEOIP hosted a virtual workshop: *Integrating Remote Sensing Data for Land Management Decision-Making* in March 2022. The workshop enabled participants to build connections across the research-to-applications spectrum with subject matter experts from a variety of Federal agencies and other affiliations, and continued partnership efforts to promote interagency collaboration within the Earth Observations (EO) applications field. The workshop included interactive panels and guided discussion sessions that addressed ways to improve research-to-operations pathways and highlighted new tools and techniques to promote NASA EO data uptake. The overarching goal of the workshop was to foster improved communication and collaboration between data providers and data users.
- Partnered with NASA to provide comprehensive Earth Observing System Terra and Aqua MODIS and Suomi National Polar-orbiting Partnership (Suomi NPP) and NOAA-20 VIIRS near-real-time imagery and active fire data for the United States and Canada. This partnership included efforts to provide a web portal to visualize and disseminate these data. Additional efforts included 1) coordination with partners to develop and integrate ultra-real-time MODIS and VIIRS active fire detection data, which provides fire detection data within one to two minutes of satellite observation; 2) integration of low-latency imagery and data products at relatively higher spatial resolution, such as true- and false-color composite Harmonized Landsat Sentinel-2 imagery and Landsat active fire detection data; 3) optimization and integration of near-real-time harmonized geostationary active fire detection data from GOES 16/17 ABI, Himawari AHI, and Meteosat SEVIRI; and 4) inclusion of near-real-time geocolor GOES imagery. Provided and disseminated operational near-real-time fire mapping and geospatial data products to fire managers and the public.
- Collaborated with the NASA Goddard Space Flight Center Terrestrial Information Systems Laboratory/Direct Readout Laboratory to complete

the 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.[13] Also available for download on this site is the full archive of global active fire detections from MODIS and VIIRS.

- Utilized MODIS and Landsat imagery to conduct coarse-level 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.
- Continued coordination with NASA Ames Research Center to upgrade the Automated Modular Sensor (AMS) electronics and sensor components and further develop the AMS firmware and software for use on USFS aircraft.
- Operationally applied Landsat 7 Enhanced Thematic Mapper (ETM), Landsat 8/9 Operational Land Imager (OLI), and Sentinel 2 imagery to respond to 224 requests to map the location, extent, and severity of large wildfires amounting to more than 9.2 million acres in FY 2021 and FY 2022. These rapid-response products support post-fire emergency stabilization/hazard mitigation activities conducted by Forest Service Burned Area Emergency Response (BAER) teams.
- Operationally applied Landsat 7 ETM, Landsat 8/9 OLI, and Sentinel 2 imagery to map and estimate post-fire basal area loss and canopy cover loss for 208 large wildfires totaling more than ten million acres in FY 2021 and FY 2022. These products support forest restoration planning management activities and efficient use of resources to support those activities.

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13 *https://firms.modaps.eosdis.nasa.gov/*

- Continued to operationally apply Landsat 4/5 Thematic Mapper (TM), Landsat 7 ETM, Landsat 8/9 OLI, and Sentinel 2 imagery to inventory, map, and characterize historical large fires to assess the effectiveness of national fire management policies as part of the Monitoring Trends in Burn Severity (MTBS) project. MTBS mapping activities through FY 2021 and FY 2022 included the completion of more than 6,400 new and/or revised fire mappings, increasing the extent of the historical MTBS data record to include 29,533 fires covering more than 205 million acres of burned lands.
- Coordinated with NASA and the USGS to implement the Landsat active fire detection algorithm and the operational production of active fire detection data at the USGS EROS Data Center. Operational production covers all of CONUS, southern Canada, and northern Mexico. The value of this product is greatly enhanced by USGS EROS efforts to provide near-real-time Landsat 8 and Landsat 9 OLI imagery within 20 minutes of satellite overpass.
- Continued technical collaboration activities 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.
- Used imagery from Landsat 8 OLI and the USDA National Agriculture Imagery Program (NAIP) to initiate, complete, and update mid-level vegetation mapping, riparian mapping, land cover change, and FSVeg spatial update products for national forest lands and adjacent land areas throughout the country. Mapped areas included 12 National Forests encompassing approximately 25 million acres.
- Worked toward publishing tree canopy cover data updates for 2019/2021 for the contiguous United States, interior Alaska, Hawaii, Puerto Rico, and the Virgin Islands, using imagery from Landsat and NAIP.

- Used Landsat TM/ETM/OLI and NAIP imagery 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, which the USFS, Natural Resources Conservation Service, and other agencies apply to resource management, planning, and decision making.
- 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 Google Earth Engine 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 2022, the 1985–2020 CONUS change product was extended to include 2021. This effort is being conducted in collaboration with several Federal and academic partners.
- Continued to develop and refine standards and practices for integrating lidar into forest and resource management (i.e., defining acquisition specifications, data-quality assessment, analysis/modeling procedures for forest parameters).
- Continued to expand USFS 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.
- Continued to provide operational web mapping and data services for NAIP and other high-resolution aerial and satellite imagery data. Additionally, 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.

- Forest Inventory and Analysis (FIA) and Forest Health Protection (FHP) staff continue to utilize Landsat 8/9 OLI, Terra and Aqua MODIS, and NAIP imagery products to support inventory and monitoring of the Nation's forests, including mapping and use in post stratification to improve forest attribute estimates.
- USDA continued ongoing work with NASA scientists to use NASA Goddard's LiDAR, Hyperspectral and Thermal (G-LiHT) imager to collect data that augments the forest inventory of interior Alaska, which includes investigations for improving carbon monitoring.
- NASA and USDA are continuing 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, originally scheduled to launch in August 2022. This collaboration continues the legacy of "Moon Trees" grown from seeds that orbited the Moon in 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[14] and NASA's Office of STEM Education.[15]
- USFS scientists serve on the Global Ecosystem Dynamics Investigation (GEDI) science team. NASA's GEDI instrument on the International Space Station 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 CO_2 concentrations. Additionally, these investigations of the three-dimensional structure of forests help elucidate habitat quality and biodiversity at local to regional scales.
- 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

14 *https://www.naturalinquirer.org/Artemis-Moon-Trees-v-397.html*
15 *https://www.nasa.gov/stem/about.html*

Lead and participating members. A Forest Service scientist serves as co-investigator 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 FS-FIA and Natural Resources Conservation Service (NRCS) data together with Landsat.
- The Forest Inventory and Analysis program has an agreement to share Forest Service data with NASA (JPL, 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 field data to calibrate or validate observations or combine with observational data for scientific studies.
- SilvaCarbon is an interagency technical cooperation program of the U.S. Government to enhance the capacity of selected tropical countries to measure, monitor, and report on carbon in their forests and other lands. The USFS, USGS and NASA partnership hosted the following workshops during fiscal year 2022:
    - Forest Carbon Measurement and Monitoring Research, Tools and Methods Workshop – February 14–16, 2002; University of Maryland.
    - Forest Carbon Measurement and Monitoring Research, Tools and Methods Workshop – April 19–22, 2002; Oregon State University.
    - Remote Sensing Tools and Technical Assistance Webinar; June 14, 2022; Latin America and Caribbean Region.
    - Silvacarbon/Committee on Earth Observation Satellites (CEOS) Regional Workshop – Biomass Measurements; June 27–July 2, 2022; Asuncion, Paraguay.
    - Regional Seminar on Experience Exchange in FREL/FRL and REDD+ Technical Annex Assessment for the UNFCCC and Other Initiatives; June 30, July 7, July 14, and July 21, 2022; Online.
    - Regional Seminar on Gender, Forests, and Carbon; September 22 and September 29, 2022; Online.

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 assesses, 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.

Orthoimagery, elevation data, and Global Positioning Systems are essential geospatial data integrated into NRCS program applications, service centers, state offices, and national centers. Since the 1930s, NRCS (formerly the Soil Conservation Service) used aerial photography and orthoimagery for conservation and soil survey purposes. Today, NRCS offices use geospatial data daily to support conservation programs.

NRCS coordinates acquisitions of orthoimagery and digital elevation data with other Federal and state agencies through interagency committees like the National Digital Orthoimagery Program (NDOP) and the USGS 3D Elevation Program (3DEP). Participation in NDOP and 3DEP assists NRCS in maximizing geospatial investments and avoiding duplication of acquisitions for orthoimagery and digital elevation datasets.

Aerial Imagery

In FY 2022, NRCS executed a contract to acquire high-resolution digital aerial photography (four-inch ground-resolving distance) for more than 70,000 sites in the contiguous United States, Puerto Rico, U.S. Virgin Islands, and Hawaii. NRCS started using digital cameras for natural color aerial imagery acquisitions in 2020. The digital imagery is interpreted at one of NRCS's three Remote Sensing Labs. The resulting data were sent to the Center for Survey Statistics and Methodology at Iowa State University for compilation and statistical estimation.[16]

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16 *https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri/*

In FY 2022, NRCS surpassed 5.7 million acres on approximately 24,290 conservation easements enrolled in NRCS agricultural conservation easement programs. Also, in FY 2022, NRCS acquired 15-cm high-resolution direct digital imagery for 22,648 conservation easements covering approximately 4.7 million acres. Starting in FY 2023, through the Agricultural Conservation Easement Program–Wetland Reserve Easements (ACEP-WRE), the Healthy Forest Reserve Program (HFRP), and the Emergency Watershed Protection Program–Floodplain Easements (EWPP-FPE), and all Farm Bill 2018 Regional Conservation Partnership Program (RCPP) U.S.-held easements, RCPP-HFRP, and RCPP-WRE easements, NRCS will hold title or enforcement rights to approximately 19,783 Stewardship Land easements covering more than 3.7 million acres nationally. Stewardship land easements are U.S.-held easements where the agency (as NRCS, the Soil Conservation Service, or the Commodity Credit Corporation) is named as grantee on the conservation easement deed. The remainder, approximately 3,908 easements covering approximately 1,316,195 acres, consist primarily of the Agricultural Conservation Easement Program–Agricultural Land Easements (ACEP-ALE) and Farm and Ranchland Protection Program (FRPP) easements. These are Non-Stewardship Lands where the United States is not named as a grantee and a cooperating entity as grantee is responsible for monitoring. NRCS has a contingent right of enforcement. NRCS has long-term responsibility through annual monitoring of these conservation easements to ensure the objectives of each easement program and relevant easement authorities, as well as legal requirements, are being met. Additionally, NRCS is required to annually report the "condition" of its stewardship lands as required by the Statement of Federal Financial Accounting Standards 29. Through NRCS agricultural conservation easement programs, the NRCS and its cooperating entity partners are providing protection to more than five million acres nationally. The number of easements and number of acres of conservation easements that require annual monitoring increase every fiscal year.[17] 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.

17 Information on easement programs can be found at *https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/easements/*.

The National Agriculture Imagery Program (NAIP) is a high-resolution imagery program that usually collects data during leaf-on time periods during the summer months. This dataset is the foundation layer for geospatial data used in USDA offices and those of our cooperators. NRCS; USFS; USGS-DOI; and the NAIP Leader, FSA, have successfully funded and supported NAIP since the program's inception in 2003. NAIP orthoimagery is used extensively within NRCS and is at most NRCS offices in the continental United States. NAIP orthoimagery is delivered to NRCS at a 0.6-meter/60-cm or higher ground resolution and with four multispectral bands (Natural Color and Color Infrared [CIR]). NRCS makes use of NAIP in many programs, such as the Web Soil Survey and Conservation Planning, and it is used as the base imagery for NRI for orthorectification.[18] NRCS makes NAIP data available to the public via compressed county imagery mosaics on the USDA Geospatial Data Gateway.[19] In FY 2022, NAIP collected imagery covering 18 states. All were collected at 0.6-meter or higher resolution and in four multispectral bands (Natural Color and CIR). NAIP collects data from all areas of the United States, including agricultural land, public lands (Federal, state, and local), and urban areas.

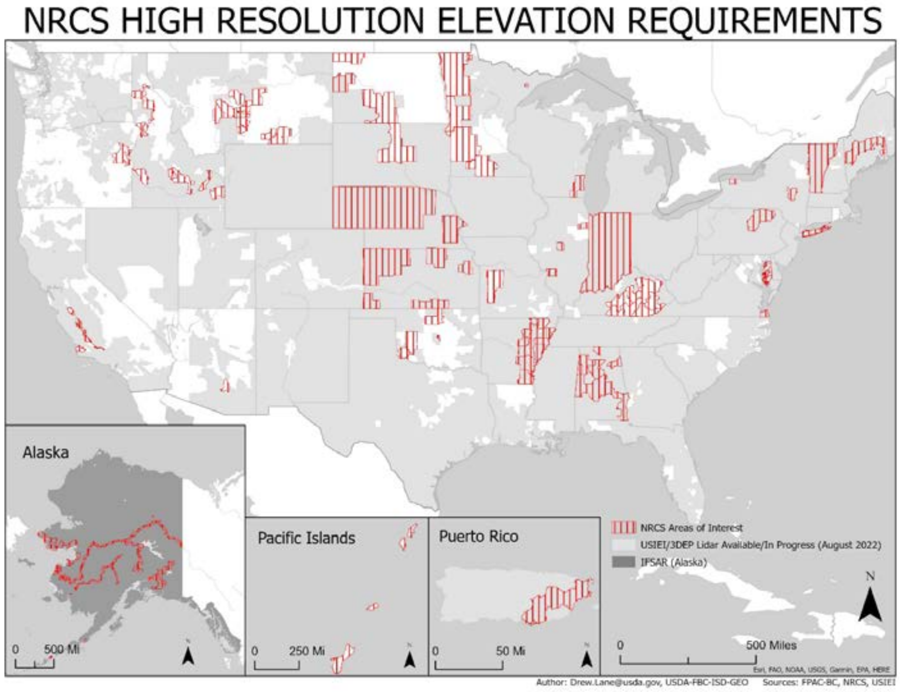
Satellite Imagery

Starting in 2021 and continuing in 2022 NRCS responded to geospatial imagery needs from all states and territories, including Puerto Rico, the U.S. Virgin 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 was challenging because of their remoteness and weather. NRCS used satellite imagery from the Maxar EnhancedView Web Hosting Service and purchased imagery from commercial sources for areas such as these and lands with restricted airspace.[20] NRCS also used Maxar imagery for pre- and post-event disaster response and in cases where other imagery is outdated.

18 *https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/cgate/*

19 *https://gdg.sc.egov.usda.gov/*

20 *https://evwhs.digitalglobe.com*



Elevation

NRCS has national requirements for high-quality elevation data, and the agency has a national strategy to acquire, integrate, and deliver high-quality digital elevation data that meet the agency's geospatial requirements. High-quality digital elevation data support the agency's business activities by improving employee effectiveness and efficiency in helping our customers. NRCS participates in the USGS 3DEP to acquire high-quality 3D elevation data through remote sensing.[21] The map depicts areas of actual lidar topographic acquisition projects that NRCS and 3DEP partners have completed or are in work in FY 2022.

By the end of FY 2022, 3DEP and its partners significantly increased its lidar coverage with 89 percent of the continental United States and Hawaii now complete or in progress. Interferometric Synthetic Aperture Radar (IfSAR) for Alaska is 100 percent complete. NRCS contracted $29.2 million of the $87.7 million total 3DEP investments for FY 2022 awards. The goal of 3DEP is to complete the acquisition of nationwide lidar (IfSAR in Alaska) in eight years to provide the first-ever

21 *https://nationalmap.gov/3DEP/*

national baseline of consistent high-resolution elevation data—both bare-earth and 3D point clouds—collected in a timeframe of less than a decade.

Use of Positioning, Navigation, and Timing Signals from Space

The United States Global Positioning System (GPS) is the primary source of space-based signals for Positioning, Navigation, and Timing (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 put 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."[22]

22 See *https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/newsroom/features/?cid=nrcseprd1441031* for more information regarding NRCS conservation activities enabled and enhanced by GPS PNT services.

National Science Foundation

NSF

The National Science Foundation (NSF) continued to serve as the lead Federal agency for the support of ground-based astronomy and space science. Through the divisions of Astronomical Sciences, Physics, and Atmospheric and Geospace Sciences, and the Office of Polar Programs, the 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 cover the most distant reaches of the universe and the earliest moments of its existence, all the way to nearby stars and planets, including our Sun and its planets, as well as Earth's atmosphere and its space environment.

Division of Astronomical Sciences

The Division of Astronomical Sciences (AST), within the Directorate for Mathematical and Physical Sciences (MPS), supported the development of advanced technologies and instrumentation for astronomical sciences, in addition to providing core support for the optical and radio observatories with state-of-the-art instrumentation and observing capabilities accessible to the community on the basis of scientific merit. The NSF's national astronomical facilities included the National Radio Astronomy Observatory, the Arecibo Observatory, the Green Bank Observatory, the National Solar Observatory, and NSF's National Optical-Infrared Astronomy Research Laboratory (NOIRLab).

During FY 2021 and FY 2022, 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 continued to receive 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 frequencies of up to 900 gigahertz. During this period, ALMA provided unique insights across a broad range of topics, including 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. ALMA's frequency range and unique capabilities allowed discoveries in molecular chemistry, in particular about the formation of exoplanets. Science highlights include the discovery of circumplanetary disks (disks of material around exoplanets where moons are forming), observations of the supermassive black hole in the center of our Milky Way galaxy, and large galaxies in the early universe, observations that will complement those by the James Webb Space Telescope.

The Very Large Array (VLA), located in central 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 investigates 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 include the discovery in a distant galaxy of the most powerful pulsar known and growing insight into the nature of the enigmatic objects called Fast Radio Bursts (FRBs).

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 Hawai'i. It operates between 0.3 gigahertz and 96 gigahertz and makes ultra-high-resolution observations of astronomical objects. For example, 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. Highlights include the first 3D view of a binary star-exoplanet system, movies of relativistic jets emitted from near supermassive black holes, and the first direct distance measurement of a magnetar.

NSF's Green Bank Observatory (GBO) is a federally funded research and development center located in Green Bank, West Virginia. The main instrument at GBO is the 100-meter Green Bank Telescope (GBT), the world's largest fully steerable single-dish radio telescope, operating at frequencies from 0.2 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. Recent highlights include results from sensitive spectral surveys that continue to uncover ever larger carbon-bearing molecules, shedding light on the growth of molecular complexity in space. The GBT is complementary and synergistic with interferometric arrays. It is a highly sensitive and thus critical element in very-long-baseline interferometry and, as such, has recently contributed to imaging a new, distant black hole. It also serves as a bistatic radar receiver for rapid and sensitive imaging of near-Earth objects and asteroids. Within the past two years, radar transmit capabilities have been demonstrated by means of a low-power prototype radar that yielded the sharpest images of the Moon captured from the surface of Earth. Motivated by these developments, designs of high-power radar systems for planetary and solar system astronomy are being explored.

Construction of the NSF's Daniel K. Inouye Solar Telescope (DKIST) continued through FY 2021 and was officially completed on November 20, 2021. Despite some minor delays due to the COVID-19 pandemic, the DKIST staff completed close-out and punch-list activities scheduled for January and early February of 2022. NSF's Daniel K. Inouye Solar Telescope conducted its first science observations on February 23, 2022, signaling the official start of the operations commissioning phase, which will last 12–18 months. The National Solar Observatory (NSO), which operates DKIST for the NSF, issued a press release marking the event.[1]

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1 *https://nso.edu/press-release/us-nsf-daniel-k-inouye-solar-telescope-begins-science-operations-commissioning-phase/*

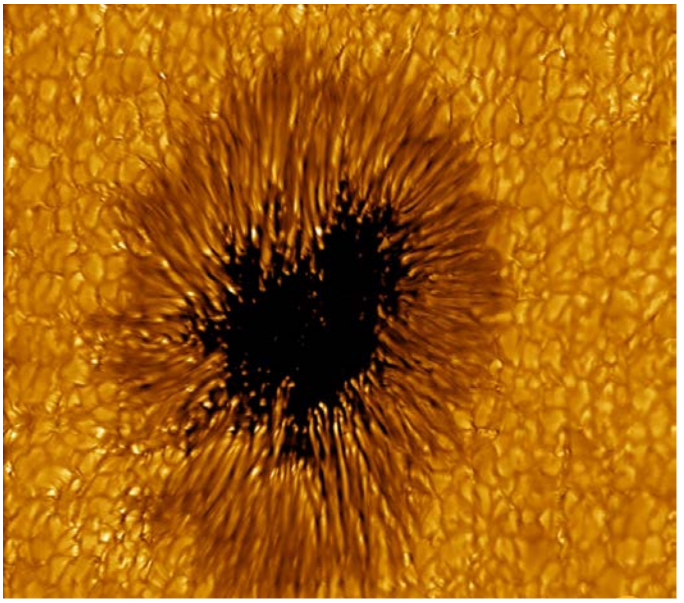

Image of a sunspot taken at 450 nm with the DKIST Visible Broadband Imager (VBI) instrument during the first science observations on February 23, 2022.

The first science observations included two of DKIST's four first-light instruments, including the Visible Spectro-Polarimeter and Visible Broadband Imager (VBI). Shown below is an image of a sunspot taken during these first science observations. The image was recorded with the VBI instrument observing at the blue end of the spectrum (450 nanometers). Details as small as 20 kilometers are visible in this image of the solar photosphere. Coincidentally, NASA's Parker Solar Probe was flying through the solar corona on one of its periodic close approaches during the DKIST observations.

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 it had previously earned the strong recommendation of the National Research Council of the National Academies of Sciences, Engineering, and Medicine. 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 Atmospheric and Geospace Sciences (AGS) participated in the National Science and Technology Council's (NSTC) Space Weather Operations, Research, and Mitigation (SWORM) Working Group under the Space Weather, Security, and

Hazards (SWSH) subcommittee. SWORM continues to implement their National Space Weather Strategy and Action Plan (NSW-SAP). NSO's Global Oscillations Network Group (GONG), supported by NSF and the National Oceanic and Atmospheric Administration (NOAA), continued their support for operational space weather forecasting. The NSF-NOAA agreement was renewed in FY 2021. GONG end-of-life is expected in the early 2030s, and SWORM has drafted a continuity of observations document. Concerns about a possible gap in critical data were raised within SWORM after the next-generation GONG (ngGONG) facility was first proposed unsuccessfully to NSF. An updated SWORM implementation plan will include follow-on actions, such as strengthening the partnership between NSF, NOAA, and the Department of the Air Force (DAF).

Construction of the Vera C. Rubin Observatory (formerly the Large Synoptic Survey Telescope) continued in FY 2021 and FY 2022, although delayed and slowed by the COVID-19 global pandemic. The project has been re-baselined with COVID-induced delays totaling nearly two years with completion now projected late in FY 2024, and NSF has authorized additional funding to cover the full costs of COVID-19 impacts. Construction of the 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 nearly complete, and the commissioning camera has been installed for the first time. 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, and the 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 2022.

In Rubin Observatory's planned ten-year prime mission, imaging the entire accessible sky nearly a thousand times, the multicolor survey 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 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). NSF and DOE expect this survey to generate about 20 terabytes of data every night, night after night, throughout its operational life.

AST's Mid-Scale Innovations Program (MSIP) did not run a planned competition in FY 2022, but continued several relevant projects, all of which were affected by COVID-19 to a variable extent. Operations support for the Event Horizon Telescope (EHT), a planet-sized very-long-baseline interferometer experiment, was joined by development funding for an expanded EHT, supported by the NSF-wide Mid-scale Research Infrastructure program. Extending EHT to even longer baselines will require space-based components. MSIP supports several Cosmic Microwave Background experiments, the Keck Planet Finder instrument, the interferometer of the Center for High Angular Resolution Astronomy, and several survey programs, which assist research from current and future space platforms.

Emergency clean-up at the Arecibo Observatory (AO) was completed in spring 2022, and a Salvage Survey Committee was established.[2] The Thornton Tomasetti Forensic Investigation into the collapse of the 305-meter telescope at the AO was made publicly available on 25 July 2022.[3] This report identified several issues relating to the suspension cable-attachment sockets, possibly exacerbated by natural disasters, rather than attributing the platform collapse to structural problems with the cables themselves.

In the first half of 2021 NSF organized a workshop to explore ideas for future scientific, educational, and cultural activities at AO. The NSF encouraged participants to continue to explore concepts and to submit proposals. One initiative, the Center for Advanced Radio Sciences and Engineering, was awarded in FY 2022

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2 Their report is available at *https://www.naic.edu/documents/AOSSC_REPORT_FINAL20220325.pdf.*

3 Available at *https://www.nsf.gov/news/special_reports/arecibo/Arecibo-Telescope-Collapse-Forensic-Investigation-508c.pdf.*

to the University of Puerto Rico at Mayagüez. This new center will develop tools for spectrum monitoring and radio frequency interference mitigation, to resolve spectrum sharing and coexistence issues, and to improve the performance of radio science observations.

The Ángel Ramos Foundation Science and Visitor's Center at AO reopened to the public, with appropriate COVID-19 restrictions, on March 10, 2022. Scientists and engineers at AO continue to analyze and publish research based on the large amount of archival data, along with existing instrumentation such as the 12-meter telescope, the optical facility, and the lidar facility.

NSF is partnering with NASA to fund an aerospace study of the existing capabilities for planetary defense. This study will begin in FY 2023, and its findings will help to inform future investments.

AST also hosts 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. ESMU engages in domestic and international spectrum management, including leading the U.S. delegation to the ITU-R Working Party 7D for Radio Astronomy, coordinating frequency assignments domestically with ground-based astronomy sites, chairing an NSF-wide ESM coordination group, and examining future astronomical facilities in cislunar space, especially on the far side of the Moon. The ESMU provides spectrum management support for the entire NSF.

The ESMU provided significant contributions to a comprehensive review of U.S. space-based operations and spectrum use issued in FY 2021 by the National Telecommunications and Information Administration.[4]

The cross-directorate SWIFT program (Spectrum and Wireless Innovation enabled by Future Technologies) invested $16 million in FY 2020 and $11.5 million in FY 2021 for research on effective spectrum utilization and coexistence techniques. The multi-disciplinary Spectrum Innovation Initiative (SII) began in

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4 *https://www.ntia.gov/blog/2021/ntia-releases-comprehensive-review-us-space-based-operations-and-spectrum-use*

FY 2020 to promote dynamic and agile spectrum utilization while ensuring innovation and security for all users. SII includes the National Radio Dynamic Zones program, to advance dynamic spectrum sharing, building toward a permanent national facility for innovative systems that use or manage spectrum. Early investigations supported in FY 2020 and FY 2021 paved the way to a full program solicitation in FY 2022. SII's National Center thrust seeks to establish the first national center for wireless spectrum research, to connect the academic research community with nationwide challenges, and to grow the spectrum workforce. Planning grants were made in FY 2020, and a single $25 million award in FY 2021 set up SpectrumX, an NSF Spectrum Innovation Center. The Integrative Activities part of SII promotes increased and more effective use of the spectrum for passive and active applications, especially of a cross-disciplinary nature. Finally, the Workforce Development thrust encourages developing a skilled and diverse workforce through education and training programs.

NSF's NOIRLab co-hosts the Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference (CPS) of the International Astronomical Union (IAU). The IAU CPS 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

MPS's Division of Physics (PHY) continued to operate its Laser Interferometer Gravitational-Wave Observatory (LIGO), completing its third observational run (O3). During the O3 10-month run, LIGO released 56 trigger alerts for gravitational-wave events, a rate of more than one per week. LIGO has now identified 90 events corresponding to mergers of black holes and neutron stars. In April 2020, LIGO started on the A+ upgrades, increasing sensitivity by about 70 percent and the detection rate five-fold. LIGO and its European and Japanese counterparts Virgo and KAGRA will resume observations in March 2023. This new run (O4) will include about half of the A+ upgrades, with the rest being completed for the O5 run to be carried out in 2025.

Complementing LIGO, PHY, in partnership with AST, continued its funding of the North American Nanohertz Observatory for Gravitational Waves (NANOGrav), which monitors a large number of pulsars for timing deviations caused by gravitational waves. NANOGrav earlier published the first evidence of a stochastic background detection, and confirmation is anticipated around the end of FY 2022 or the beginning of FY 2023.

For a description of the IceCube Neutrino Observatory, partially supported by PHY, see the Office of Polar Programs section below.

Division of Atmospheric and Geospace Sciences

The Division of Atmospheric and Geospace Sciences (AGS) within the NSF Directorate for Geosciences funded a wide variety of research and research infrastructure programs in space science and space weather in FY 2021 and FY 2022. Additionally, AGS funding supported several hundred faculty members and students in U.S. universities 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 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.

The GS funds a wide-ranging portfolio of basic research in space physics through the Space Weather Research, the Solar-Terrestrial Research, the Aeronomy, and the Magnetospheric Physics programs. In FY 2022, these GS programs collaboratively issued a solicitation, titled "Grand Challenges in Integrative Geospace Sciences: Advancing National Space Weather Expertise and Research toward Societal Resilience." The solicitation resulted in seven awards to U.S. universities totaling more than $11 million to advance space weather modeling, in collaboration with partners from government and the private sector. These new awards will broaden participation in space weather science and education through support of early career researchers and those traditionally underrepresented in STEM, including female scientists, students, and other researchers at minority-serving institutions, and those at universities in EPSCoR states.

The GS also continued to support a wide array of 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 (SuperDARN), ground-based optical and meteor radio instruments to study the neutral upper atmosphere as well as aurora and airglow phenomena, and partial support to ground-based solar telescopes and instruments. Three ISR facilities at Poker Flat, Alaska; Millstone Hill Observatory, Massachusetts; and near Jicamarca, Peru, are respectively in the polar cap, subauroral zone, and equatorial region, ideally situated to observe the properties of the ionosphere in the three distinct regions.

In FY 2021 and FY 2022, the GS continued funding 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 cover large areas in both hemispheres to monitor global magnetic perturbations. These projects play a crucial role in space research and are also great opportunities to train our future experimentalists. In addition, the GS supports SuperMAG in collecting and disseminating these vital magnetic measurements to researchers and space weather operators across the country. Another funded project, Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE-III), provides global and continuous measurements of the Birkeland currents using magnetic field data from the commercial satellites of the Iridium constellation. The GS also supported an NSF-NASA-NOAA sponsored Ideas Workshop on Geomagnetically Induced Currents (GIC) and the Power Grids in November 2022 to address research-to-operations challenges. This workshop brings together scientific researchers and power grid operators to develop new solutions for GIC effects on the power grid.

In FY 2021 and FY 2022, the GS continued its support of seven CubeSat missions, all selected in previous fiscal years. 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 National Center for Atmospheric Research (NCAR) is 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 continues to support Mauna Loa Solar Observatory's instrumentation and its related data-sharing website. HAO has 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 is conducting the COSMO Site and Design Advancement (COSADA) project, which in FY 2022 started site surveys with remote observing instrumentation to determine scientifically optimal locations for COSMO. This instrumentation is deployed to measure atmospheric conditions critical to the operation of coronagraph telescopes, such as aerosol content, sky brightness, cloud cover, and atmospheric stability. Another critical part of COSADA is to finalize the design of the proposed 1.5-meter Large Coronagraph.

In FY 2021, the AGS's Atmosphere Section (AS) continued to support the Data Analysis and Archive Center (CDAAC) 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 is now conducting 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 processes data for several other RO satellite missions, including South Korea's KOMPSAT-5 and Spain's Paz, which are used operationally. NSF also supports 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 includes 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 the National Space Program Office (NSPO) of Taiwan.

During FY 2021 and FY 2022, AGS and AST staff represented NSF on the Space Weather Operations, Research, and Mitigation (SWORM) Subcommittee within the Committee on Homeland and National Security of NSTC. AGS continued, including through the aforementioned programs, to implement the goals and objectives identified in the National Space Weather Strategy and Action Plan (NSW-SAP).[5] NSF focuses on the NSW-SAP objective to "improve observations and modeling for characterization and forecasting" of space weather. In FY 2022, AGS provided equal funding, along with NASA and NOAA, for the Space Weather Roundtable of the National Academy of Science, as mandated by the Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act signed into law in October 2020.

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.

Office of Polar Programs

In FY 2021 and FY 2022, the primary activities of the Office of Polar Programs in ground-based space science and astronomy included observations at the U.S. Amundsen-Scott South Pole Station with the 10-meter off-axis radio South Pole Telescope (SPT) and the battery of small-aperture telescopes called the Background Imaging of Cosmic Extragalactic Polarization (BICEP) Array. Recent scientific results from the SPT and BICEP Collaborations include deep multi-frequency sky

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5 *https://trumpwhitehouse.archives.gov/wp-content/uploads/2019/03/National-Space-Weather-Strategy-and-Action-Plan-2019.pdf*

maps of the cosmic microwave background (CMB)'s *B*-mode polarization that take into account gravitational lensing and foregrounds to unprecedented precision. The constraints that SPT and BICEP telescopes have produced on primordial gravitational waves continue to improve, leading the way in probing models of inflation that operate near grand unified theory (GUT) energy scales.

The IceCube Neutrino Observatory (ICNO), jointly operated at the South Pole by the NSF's Office of Polar Programs and Division of Physics, has now collected data for 12 full years of operation from a complete array of 86 strings of optical photodetectors deployed in the ice under the South Pole Station in Antarctica at depths between 1.4 and 2.4 kilometers. The existing detector can observe cosmogenic neutrinos with energies ranging from 100 gigaelectronvolts (GeV) to tens of petaelectronvolts (PeV). The PeV neutrinos observed by IceCube have a thousand times the energy of the highest-energy neutrinos produced by existing particle accelerators and a billion times the energy of the neutrinos detected from supernova SN1987A in the Large Magellanic Cloud, the only neutrinos that had been detected on Earth from outside the solar system prior to IceCube's breakthrough. In FY 2022, for the first time, the IceCube Collaboration found evidence of high-energy neutrino emission from the NGC-1068 (Messier 77) active galaxy in the constellation Cetus. First spotted in 1780, this galaxy is located 47 million light-years away from Earth, and it is one of the most familiar and well-studied galaxies. The new results, published in *Science*, show the excess of 79 neutrinos at the teraelectronvolt energies above the background flux which were interpreted as associated with the active galaxy core. This flux of high-energy neutrinos is more than an order of magnitude higher than the upper limit on emissions of teraelectronvolt gamma rays from this source.

The NSF's Office of Polar Programs also supports NASA's Long Duration Balloon (LDB) Program at the U.S. Antarctic Program's McMurdo Station, providing all necessary logistical support for the LDB astrophysical and space science payload 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 57 LDB science payloads have been successfully launched from McMurdo since the first interagency Memorandum of Understanding was signed in August 1988.

The Office of Polar Programs support for all LDB activities during two austral summer seasons, 2020/2021 and 2021/2022, was canceled because of the COVID-19 pandemic. The return of LDB is planned for the 2022/2023 austral summer.

Department of State

DOS

The Department of State (DOS) carries out diplomatic and public diplomacy efforts to strengthen American 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 through the negotiation of bilateral and multilateral agreements, through engagement with partner countries, and by leading U.S. participation in numerous international space and technological activities and international 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.

Bilateral Dialogues

Europe (European Union and European Commission)

OES/SA and AVC/ESC hosted the 11th U.S.-EU Space Dialogue on June 28–29, 2022, the first such dialogue in three years. The event brought together U.S. and European space officials and experts to discuss trans-Atlantic civilian and security issues, including space security challenges related to the Russian invasion of Ukraine. The civil space discussion for the U.S. side was led by OES Principal

Deputy Assistant Secretary Jennifer R. Littlejohn and the security track by AVC Acting Deputy Assistant Secretary Eric Desautels. The European delegation was led by European Commission Directorate General for Defense Industry and Space (DG-DEFIS) Acting Director for Space Paraskevi Papantoniou and European External Action Service (EEAS) Special Envoy for Space Dr. Carine Claeys. The meeting agenda included a broad spectrum of civil space issues of high priority for both sides of the Atlantic, including GPS-Galileo collaboration, continued joint work on Earth observation programs such as Landsat and Copernicus, space cyber security, space traffic coordination, space-related critical infrastructure security and resilience, SSA data sharing, collaboration in international fora such as the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS), Group on Earth Observations (GEO), Committee on Earth Observation Satellites (CEOS), International Committee on GNSS (ICG), and more. The meeting closed with concurrence on a list of action items that will guide this strategic, trans-Atlantic partnership until the next meeting to be held in Brussels in the summer of 2023.

Science Envoy Virtual Symposium

OES/SA organized a virtual roundtable on November 1, 2021, under the U.S. Science Envoy Program, entitled "Symposium on the Intersection of Earth Observation from Space and Climate Change: U.S. and European Opportunities and Challenges." The 90-minute event was co-organized with the Office of Science and Technology Cooperation (STC) and was hosted by the U.S. Space Envoy and former NASA Administrator, Mr. Charles Bolden. The Trans-Atlantic event successfully highlighted opportunities for U.S.-European space collaborations on satellite Earth observations to better address global environmental challenges, specifically those related to climate change.

The event included a roundtable discussion on a broad spectrum of topics, including U.S. international space cooperation, the U.S.-EU bilateral science relationship, climate change research, challenges and opportunities to open distribution and sharing of satellite data, and the role of international space agreements. All participants highlighted the importance of continued diplomatic and scientific collaborative arrangements that promote the leadership role of U.S. and European space agencies in multilateral partnerships with other countries around the globe, including groups such as the Group on Earth Observations (GEO), the Committee on Earth Observations (CEOS), the Consultative Group on Meteorological Satellites (CGMS), the Disaster Charter on Space and Major Disasters, the United Nations Office of Outer Space Affairs (UNOOSA), the World Meteorological Organization, and many others.

Japan

The usual cadence of in-person bilateral dialogues was interrupted by the travel restrictions and health measures instituted to mitigate the spread of COVID-19. DOS transitioned many bilateral exchanges from in-person to virtual in FY 2021. The number and range of in-person exchanges increased in FY 2022 as public health restrictions eased in many regions. On July 20–21, 2022, State led a U.S. delegation to a U.S.-Japan Space Security Dialogue in Tokyo. Building upon high-level commitments on the importance of space cooperation, participants exchanged views on their space security policies and discussed ways to deepen cooperation on space domain awareness, as well as joint responses to serious threats in the space domain.

The two sides also exchanged their views on cooperation in the international arena aimed at preserving and ensuring a safe, secure, stable, and sustainable space domain, establishing norms of responsible behaviors in space, and on strengthening cooperation with third countries. Both sides have concurred to steadily advance their cooperation in bilateral and multilateral contexts.

The participants to the space security dialogue included representatives of the Ministry of Foreign Affairs, Ministry of Defense, National Space Policy Secretariat of the Cabinet Office, and National Security Secretariat from the Japanese side, and the Department of State and Department of Defense from the U.S. side.

Philippines

The United States government conducted two virtual briefings with the Philippines. In May, NASA and DOS delivered the Artemis Accords to the government of the Philippines. In June, at the request from the newly formed Philippines' national space agency, the Office of Space Affairs conducted an information session on regional space cooperation.

Republic of Korea

The United States government organized and led a bilateral technical exchange with the Republic of Korea (ROK) in September 2021 to discuss coordination and cooperation related to GPS and the Korea Positioning System (KPS). The United States signed a Joint Statement of Cooperation on GPS and KPS following a Presidential Summit in May 2021, which was reaffirmed earlier this year with a commitment to hold the technical meeting. The KPS will be a regional system providing service over East Asia and the Pacific. Given the strategic importance of this region, the DOD is looking into the feasibility of enhanced cooperation with the ROK on KPS.

Singapore

Resulting from Vice President Harris's visit in the summer of 2021, in August of that year the United States held a virtual discussion on possible areas for bilateral cooperation on civil and commercial space activities in preparation for the upcoming first civil space bilateral dialogue for 2023.

Taiwan

The United States government conducted a three-day official visit from the Minister of Science and Technology and the head of Taiwan's national space organization in early June 2021. Assistant Secretary Monica Medina for the Bureau of Oceans, International Environmental, and Scientific Affairs raised priority areas of science and technology and space cooperation with Taiwan, including advanced semiconductor chip design and fabrication and collaboration with USGS on Landsat 9 on potential data sharing. The representatives from Taiwan also paid a courtesy visit with all the interagency space partners, including the Executive

Secretary of the National Space Council, NASA's Administrator, NOAA's Administrator, and the Director of the USGS.

Thailand

In April 2021, the United States government conducted a workshop on Space Laws and Policies with Thailand. Thailand provided an overview of its Draft National Space Master Plan, which includes Thailand's strategy for developing space policies and laws to advance their civil, commercial, and national security objectives.

In July 2021, the United States hosted a second virtual workshop with several Thai agencies to discuss opportunities for business growth and partnership in the burgeoning commercial space industry where the Director of Space Commerce gave an overview of U.S. efforts to support space commerce. The event drew several dozen attendees from the Thai government, industry, and academia.

Vietnam

At the request from the Vietnamese government, the United States conducted two separate events. First, a virtual workshop held in early February 2021 focused exclusively on the development of a national space policy. Second, a three-part civil space bilateral dialogue was held to discuss Vietnam's space strategy, development goals, and priorities. Participants from Vietnam included representatives from more than 50 ministries, government agencies, and national universities.

Multilateral Activities

Artemis Accords

Inspired by NASA's Artemis program, the Artemis Accords promote peaceful cooperation in space exploration and scientific endeavors in the 21st century and aim to increase the safety of operations, reduce uncertainty, and promote the sustainable and beneficial use of space for all of humanity. Since concluding negotiations on the Artemis Accords with Australia, Canada, Italy, Japan, Luxembourg, the United Arab Emirates, and the United Kingdom in October 2020, DOS and NASA welcomed 13 additional signatories by the end of FY 2022: Bahrain, Brazil, Colombia, France, Israel, the Republic of Korea, Mexico, New Zealand, Poland, Romania, Saudi Arabia, Singapore, and Ukraine. DOS continues to work with NASA to share the Accords with a range of prospective signatories.

As a high-level, whole-of-government political commitment, the Artemis Accords provide nonbinding guidance for the implementation of the Outer Space Treaty of 1967, also reinforcing obligations set out in the Agreement on the Rescue of Astronauts, Liability Convention, and Registration Convention. To affirm the benefits of coordination via multilateral forums such as the UNCOPUOS, in December 2020 the U.S. Mission to the United Nations submitted the text of the Artemis Accords to the UN Secretary General to be distributed to UN Member States as an official UN document. This undertaking promotes transparency and provides an opportunity for a constructive, multilateral exchange of views on the Artemis Accords and the development of an international regime for norms and rules for civil space activities.

Association of Southeast Asian Nations

In July 2022, the State Department and NASA held a virtual briefing with nine Association of Southeast Asian Nations (ASEAN) member states on the Artemis Accords. OES Assistant Secretary Medina opened the meeting by reaffirming the U.S. commitment to work with international community members such as the ASEAN nations "to uphold and strengthen a rules-based international order for space exploration and peaceful use." NASA emphasized that the Artemis Accords represent shared principles for responsible behavior to govern the use of outer space and that all countries, regardless of the extent of their space sector, are welcome to become signatories to the agreement. As a follow up, requested by the ASEAN Secretariat, on October 5, 2022, the State Department and NASA delivered a second briefing to the ASEAN Committee on Space Applications on programs to assess the contribution of deforestation to atmospheric CO_2 emissions, to determine how much carbon forests will absorb in the future, and to assess how habitat degradation will affect global biodiversity. The U.S. presentations focused on NASA's Global Ecosystem Dynamics Investigation (GEDI). The briefing generated strong interest among the ten ASEAN nations, with both Singapore and Indonesia expressing support for further bilateral cooperation with the United States on GEDI.

International Committee on GNSS

In October 2022, the State Department led the U.S. delegation to the 16th annual meeting of the International Committee on Global Navigation Satellite Systems (ICG-16), held in Abu Dhabi, United Arab Emirates. Among other things, State supported U.S. efforts to promote development of positioning, navigation, and timing capabilities extending into cislunar space in support of lunar exploration. State also supported efforts to expand the membership of the ICG to include the Republic of Korea (approved at ICG-16) and Pakistan (still pending).

United Nations Committee on the Peaceful Uses of Outer Space

2021 Sessions

Scientific and Technical Subcommittee: The United States continued to display its leadership in the exploration and peaceful use of outer space while promoting commercial space activity and responsible behavior during the 58th session of the UNCOPUOS Scientific and Technical Subcommittee (STSC), held in a largely virtual format in Vienna April 19–30, 2021. During plenary exchanges and a half-day symposium on human space exploration, the United States and many of its partners promoted the Artemis program's ambitious space exploration agenda and sought to expand international support and participation in the program. The United States used the STSC to highlight the different components of Artemis, ranging from the scientific importance of In-orbit Servicing, Assembly, and Manufacturing (ISAM) to the high-level goals of the Artemis program, following the principles of the Artemis Accords. The United States promoted and encouraged other countries to implement the 21 Long-Term Sustainability (LTS) guidelines of outer space activities. These guidelines, based on "bottom-up" best practices developed cooperatively with other space actors, support U.S. efforts to develop non–legally binding international norms or rules for responsible behavior consistent with the existing legal regime.

Legal Subcommittee: The 60th session of the UNCOPUOS Legal Subcommittee (LSC) was held virtually May 31–June 11, 2021. The U.S. delegation's efforts focused on promoting the Artemis Accords, engaging in the discussion of space resource use, and continued work on the Space2030 agenda. Artemis Accords partner Canada hosted a roundtable discussion featuring the U.S. delegation and other Artemis Accords signatories to discuss why they joined the Accords and the importance of multilateral agreement. The event was the most attended technical presentation at the LSC and presented an opportunity to showcase that the Accords are open to any country willing to abide by the principles. Under the agenda item on the potential legal models for activities in exploration, exploitation, and utilization of space resources, the U.S. delegation contributed to the discussion and promoted the establishment of a working group. Finally, consensus was reached on several outstanding items within the Space2030 Agenda. The goal of the Agenda is a greater promotion of space as a driver of sustainable development.

Full Committee: The United States, in coordination with like-minded government delegations, advanced its space policy objectives during the 64th session of the UNCOPUOS, held in Vienna, Austria, in a hybrid format August 25–September 3, 2021. The committee adopted the "Space2030 Agenda" and made progress on the work plan for the Space Resources Working Group and the organization of the Long-Term Sustainability for Outer Space Working Group. The meeting's hybrid format facilitated broad and high-level participation, including NASA Administrator Nelson's delivery of the U.S. statement, which highlighted U.S. priorities and welcomed the newest Artemis Accords signatories. The U.S. delegation delivered ten statements to highlight U.S. priorities on agenda items including climate change, nuclear power sources, and exploration and innovation in space. The United States amplified the principles of the Artemis Accords with a display in the Vienna International Center rotunda that received praise from partners.

2022 Sessions

Scientific and Technical Subcommittee: The 59th session of the UNCOPUOS STSC was held in Vienna February 7–18, 2022, and served as an opportunity to continue advancing U.S. priorities in outer space. The United States provided a forceful rebuke of Russia's November 2021 destructive anti-satellite missile test and was joined by several other delegations in highlighting Russia's continued irresponsible actions in outer space. The U.S. delegation also continued promoting the Artemis Accords and program and welcomed the adoption of the terms of reference, methods of work, and workplan for the recently revived LTS working group. The Committee also opened a new agenda item on "Dark and Quiet Skies" to discuss the effects of large satellite constellations on terrestrial-based astronomy, where the United States highlighted the efforts by U.S. commercial industry coordination with the astronomical community to proactively address these concerns.

Legal Subcommittee: The 61st session of the UNCOPUOS LSC was held in hybrid format March 28–April 8, 2022. Condemnation of Russia's invasion of Ukraine featured heavily but did not derail the proceedings or report. The United States displayed its leadership in the exploration and peaceful use of outer space while promoting commercial space activity and responsible behavior throughout the two-week meeting. During plenary exchanges, many members used their general statements to condemn Russia's invasion of Ukraine. The United States and like-minded partners called for Russia to immediately halt its military operations in and to withdraw its forces from Ukraine. Russian rights of reply prompted two in-person walkouts of the primary conference room with the U.S. delegation joining on both occasions.

The United States used the LSC to highlight the 2021 U.S. Space Priorities Framework's commitment to promote U.S. leadership in the international community and to uphold and strengthen a rules-based international order for space. The U.S. delegation explored ways to synchronize messaging among the Artemis Accords signatories in UNCOPUOS. The United States also actively participated in the Working Group on Legal Aspects of Space Resource Activities, which reached consensus on its methods of work and five-year work plan to implement the mandate and terms of reference endorsed by the full Committee in June 2021. Despite attempts to erase report language on the activities of a specific non-governmental organization (NGO) and change modalities for NGO participation in future LSC meetings by Turkey and Russia, the body adopted a consensus report that reflected U.S. and like-minded priorities.

Full Committee: The United States, in coordination with like-minded government delegations, advanced its space policy objectives during the 65th session of the UNCOPUOS meeting held in Vienna in a hybrid format June 1–10, 2022. The war against Ukraine prompted tense discussions throughout the session; 23 countries openly condemned Russia's further invasion of Ukraine. Additionally, eight nations rebuked Russia's November 2021 destructive direct-ascent anti-satellite (ASAT) missile test, which generated thousands of pieces of debris. In an apparent effort to distract from the broad criticism of their actions in Ukraine as well as their reckless generation of space debris in low-Earth orbit, Russia engaged in a series of unhelpful theatrics to sidetrack the Committee and peddle disinformation. Fortunately, the Committee was able to reach consensus on its final report and endorse a draft for the United Nations General Assembly titled "Space and Global Health Resolution" despite Russia's fervent opposition. Canada, Japan, the United Kingdom, and the United States submitted a conference room paper encouraging the UN Secretary General's Office to update UNOOSA and the Committee on planning for the "Summit of the Future" space-track event envisioned for late 2023. The key concepts of this paper garnered widespread support and were noted in the final UNCOPUOS report.

Space4Women/UNOOSA

The United States government joined the UN and ROK in co-sponsoring a Space4Women Experts Group in Daejeon, Korea, in mid-August 2022 to raise awareness of the significant gender disparity in the space sector, focusing specifically on the Asia Pacific region. This effort, which falls under the UN Capacity Building Initiative, seeks to create a policy road map to help countries encourage women and girls to pursue STEM education and address gender equality in the space sector. A total of 78 participants representing 32 nations attended the conference. UNOOSA and SA met to discuss the possibility of bringing the project to the United States in 2025. Canada is scheduled to host the project in 2023, followed by Israel in 2024.

Space Five

In September 2022, the State Department led the U.S. delegation to the Space Five meetings in London, United Kingdom. It was the first in-person meeting of the Space Five nations (Australia, Canada, United Kingdom, United States, and New Zealand) since the onset of the pandemic. The various delegations shared views and best practices on a number of topic areas, including space regulatory frameworks, cybersecurity for space systems, and space situational awareness.

Space Security

During the 75th and 76th sessions of the UN General Assembly, the United States worked in the First and Fourth Committees to advance U.S. policy principles and goals regarding space security and sustainability. These engagements highlighted the 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 the long-standing U.S. commitment 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.

The U.S. commitment to international leadership in promoting norms, rules, and principles of responsible behavior in outer space was highlighted in the Space Priorities Framework adopted by the National Space Council in December 2021. The priorities framework highlights the importance of international engagement to strengthen global governance and the rules-based international order for space.

To advance these efforts, Vice President Harris announced on April 18, 2022, that the United States commits not to conduct destructive, direct-ascent ASAT missile testing, and that the United States seeks to establish this as a new international norm for responsible behavior in space. The Vice President also called on other nations to make similar commitments and to work together in establishing this as a norm, making the case that such efforts benefit all nations.

At the Biden-Harris Administration's first National Space Council meeting in December 2021, Vice President Harris tasked the National Security Council staff to work with the Department of State, the Department of Defense, and other national security agencies to develop proposals for national security space norms that advance U.S. interests and preserve the security and sustainability of space. The commitment on destructive, direct-ascent missile testing is the first initiative under this effort. The United States is the first nation to make such a declaration and was subsequently joined by a number of allies. These allies also joined the United States in co-sponsoring a resolution for the 77th session of the UN General Assembly urging all nations to make a similar commitment. This resolution was endorsed in the General Assembly's First Committee on November 2, 2022.

Due to the COVID-19 pandemic, sessions of the Conference on Disarmament and the UN Disarmament Commission in 2021 were postponed. In response, State continued virtual consultations in virtual and hybrid formats with like-minded allies on space security to prepare for virtual space security discussions during the 75th and 76th sessions of the UN General Assembly's First Committee in October 2020 and 2021. This diplomatic outreach resulted in the adoption of U.S. co-sponsored resolutions on "Reducing space threats through norms, rules and principles of responsible behaviors" by the full General Assembly on December 7, 2020, and December 24, 2021. The 2021 resolution established an Open-Ended Working Group, which held meetings in Geneva in April and September 2022. At these meetings, the United States took a leadership role in efforts to encourage other nations to join in the U.S. commitment to refrain from destructive direct-ascent missile testing.

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 the 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.

1 See *https://science.osti.gov/lp/Strategic-Partnership-Projects* and *https://www.energy.gov/nnsa/strategic-partnership-projects-spp* for further information. Strategic Partnership Projects was previously known as Work for Others prior to December 2016.

Power the Exploration of Space

DOE, through its Office of Nuclear Energy (NE), supports NASA's planetary science and human exploration programs by maintaining capabilities needed to develop, produce, and deliver Radioisotope Power Systems (RPS) for space mission applications. RPS convert heat from the radioactive decay of plutonium (Pu)-238 into electricity and reliably operate for decades in the harsh conditions encountered in space or on the surfaces of other planets where solar energy or stored energy devices are impractical or impossible to use.

Radioisotope Power Systems Powered Missions

DOE continued to support close-out activities after the launch of the Mars 2020 mission, completing the post-launch activities 20 percent below the initial cost estimate. DOE also worked on National Security Presidential Memorandum (NSPM-20) implementation in support of NASA missions including environmental analysis and development of a standard Documented Safety Analysis for Light Weight Radioisotope Heater Units (LWRHUs) as well as General Purpose Heat Source (GPHS) modules. In FY 2021 and FY 2022, DOE did the following:

- Conducted accident analysis and programmatic environmental analysis for the Dragonfly mission.
- Supported Multi-mission Radioisotope Thermoelectric Generator (MMRTG) compatibility assessments with the Titan atmosphere and progressed towards fabrication of an electrically heated MMRTG flight unit with mission-unique features for Dragonfly.
- Supported the development of a GPHS Radioisotope Heater Unit (RHU) concept for future missions and developed an updated model and system requirements.

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 the following CRP activities in FY 2021 and FY 2022 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:

- Conceptual design, mockups, and irradiation of Neptunium (Np)-237 targets for irradiation in the South Flux Trap of the Advanced Test Reactor (ATR) were completed at the Idaho National Laboratory (INL) as part of the second target irradiation campaign in the ATR.
- Flight-quality fuel clads (FC) were manufactured and packaged at LANL and shipped to INL in support of the Dragonfly mission.
- Additional Np-237 targets were irradiated in the High Flux Isotope Reactor at the Oak Ridge National Laboratory (ORNL).
- Process refinements while reducing waste streams were performed by reducing the chemical processing and separation steps needed in the production of plutonium heat source material.
- The production of specialized components, including Carbon-bonded Carbon Fiber, iridium alloy blanks/foils, Clad Vent Sets, and LWRHU clad components, continued to be maintained at ORNL.
- Plans were developed at LANL to reduce manufacturing risks and risks from aging systems and equipment, such as replacing the Astro Furnaces and Limited Volume Chilled Circulating Water Systems and installing the Hot Press Furnace Line.

RPS Technology Development Activities

DOE in FY 2021 and FY 2022, through NE and the DOE national laboratories, 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. Both static and dynamic energy conversion projects are under way with the goal of providing higher conversion efficiency and improving mission performance over design lifetime. DOE launched three development efforts that encompass both static and dynamic conversion systems: the enhanced multi-mission radioisotope thermoelectric generator (eMMRTG), the next-generation radioisotope thermoelectric generator (NGRTG), and a dynamic radioisotope power system (DRPS).

The eMMRTG project was discontinued in FY 2021 based on performance of the eMMRTG technology testing and the start of the Skutterudite Technology Maturation effort to advance some of the technologies from the eMMRTG project.

The NGRTG project proceeded with the development of concepts and identification of risks of NGRTGs for phase 1 of the project, as well as issuance of a contract to develop NGRTG design with well-characterized thermoelectric material technologies to mitigate design risks (i.e., refurbish an existing GPHS-RTG unit as Mod-0 in design development).

The DRPS project focused on technology maturation of the conversion system and hardware testing, including controller architecture trade and design changes to improve convertor and electronic efficiencies.

Surface Fission System Development

DOE, through NE and the DOE national laboratories, provides technical support for fission surface system development. In FY 2021, DOE published a draft Request for Proposal (RFP) for industry comment. This draft RFP garnered responses from over a dozen companies, and the feedback was incorporated to support a revised, final RFP.

In FY 2022, DOE and NASA 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. DOE awarded 12-month design contracts valued at $5 million each to three teams for their design proposals.[2] The contracts were awarded in September 2022.

In addition, DOE published a Technology Maturation Plan (TMP) in July 2022; this document provided technical direction for government-funded technology

2 *https://inl.gov/article/battelle-energy-alliance-nasa-select-industry-partners-to-design-nuclear-power-system-for-lunar-applications/*

development efforts that support FSP. The TMP also provided budget and schedule estimates to NASA to support planning for six years of development efforts.

Nuclear Thermal Propulsion System Development

DOE, through NE and the DOE national laboratories, provides technical support for Nuclear Thermal Propulsion (NTP) system development. In FY 2021 and FY 2022, DOE focused on experimental activities and contract design.

Experimental Activities: DOE completed irradiation testing of the Sirius-2b and Sirius-3 fuel samples in the Transient Reactor Test (TREAT) facility at INL. The Sirius samples were made at NASA's Marshall Space Flight Center and machined at INL for testing. The tests involved heating the samples to simulate NTP operational conditions to determine the limits of fuel performance. The tests were successful, with no fuel failures due to rapid heating and high temperatures. DOE also completed fabrication and assembly of the Sirius-2c fuel sample.

Contract Design: DOE also worked with NASA on the RFP development and contract procurement for NTP reactor design activities. The design contracts were issued by INL to industry teams led by BWX Technologies, Inc.; General Atomics, Inc.; and Ultrasafe Nuclear Technologies, Inc. The contracts were fixed-price awards of $5 million each with a one-year performance period and included development of reactor designs, manufacturing and testing plans, and miscellaneous information associated with NTP reactor technology development.

Support the Secure and Peaceful Use of Space

In FY 2021 and FY 2022, 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 worked with NASA, the Department of Defense, 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 near-Earth object (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 2021 and FY 2022, 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 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 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.

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 2021 and FY 2022, DOE continued full-scale production and delivery 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.

Varied Extraterrestrial Off-Nominal Mission (VENOM) Preparedness

NNSA is engaged with NASA to develop and execute a facilitated discussion on a varied extraterrestrial off-nominal mission (VENOM) scenario. The discussion will address a U.S. government response to an off-nominal return of an adversary's space item within the United States. The scenario will include a space item from a foreign nation with an unknown payload, considered a mixed hazard threat containing one or more chemical, biological, radiological, or nuclear materials. The discussion will focus on the roles and responsibilities of U.S. government departments and agencies in the recovery and collection of the space item(s) and the related payload. This effort will continue into FY 2023.

Solve the Mysteries of Space

In FY 2021 and FY 2022, DOE 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.

During the first quarters of FY 2021 and FY 2022, the Science and Innovation Working Group (SIWG) met to discuss new opportunities for collaboration, receive updates on existing joint efforts, and discuss other agency activities of mutual interest. The SIWG was established in the October 2020 Memorandum of Understanding between DOE and NASA 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 SIWG is led by the Director of DOE's Office of Science and the Associate Administrator of NASA's Science Mission Directorate, with participation from senior leaders from both agencies' core science programs.

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 2021 and FY 2022, DOE continued to support plasma science research activities at the Large Plasma Device at the Basic Plasma Science Facility at the University of California, Los Angeles (controlled studies of Alfvén waves); the Big Red Plasma Ball and Madison Symmetric Torus experiments at the Wisconsin Plasma Physics Laboratory at the University of Wisconsin–Madison (high-fidelity measurements of magnetic reconnection, dynamo, turbulence, and particle-energization processes); and the Magnetorotational Instability (MRI) Experiment (accretion or accumulation processes involving star and planet formation) and Magnetic Reconnection (MRX) Experiment (magnetic reconnection and particle energization processes) devices at the Princeton Plasma Physics Laboratory (PPPL). NASA has 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 involving magnetic reconnection, through laboratory experiments using the MRX experiment and analyses of observation data from NASA's Magnetospheric Multiscale (MMS) mission. PPPL, which has been collaborating with the MMS mission since it was launched in 2015, is now installing the Facility for Laboratory Reconnection Experiment, a new and more powerful version of MRX.

In FY 2022, PPPL researchers, through laboratory experiments using the MRI, discovered an instability mechanism believed to be behind astrophysical disk accretion rates. New knowledge and data derived from these experiments and research activities not only contributed to DOE's mission to advance fusion energy and plasma science, but also contributed to greater understanding of complex space weather phenomena, enabling more accurate models and predictions of this behavior, and mitigating the risk to both humans and equipment operating in the space environment.

High Energy Physics (HEP) and Astrophysics

In FY 2021 and FY 2022, DOE, through its High Energy Physics (HEP) program, continued to support fundamental physics and high-priority national science objectives. Examples of these efforts included the Alpha Magnetic Spectrometer (AMS), located on the International Space Station, and the Fermi Gamma-ray Space Telescope (FGST), a "free flyer" in orbit approximately 565 km above Earth.

The AMS science goals include a search for evidence of dark matter and cosmic domains of antimatter, as well as the measurements of different types of cosmic nuclei as a function of location in Earth's atmosphere, which may be of interest for astronaut safety considerations. An extravehicular activity (EVA) was carried out by NASA in FY 2020 to replace the AMS cooling system, enabling it to operate beyond 2028. As of the end of FY 2022, observations of more than 210 billion cosmic-ray events have been collected.

The AMS can determine the types and locations of cosmic nuclei (e.g., finding differing amounts of lithium, carbon, and oxygen inside and outside the south Atlantic anomaly). At the February 2020 Space Weather Operations, Research, and Mitigation Interagency Working Group meeting, NASA and other agencies expressed a strong interest in the AMS measurements of space radiation as a function of location in Earth's atmosphere. In FY 2021, conversations between the AMS experiment, NASA, and HEP continued making AMS data publicly available.

During FY 2022, the DOE continued to work with NASA and the AMS Collaboration to ensure the AMS scientific data is stored in a publicly accessible archive to maximize scientific return to the greater science community. In December 2021, the scientific case for a potential upgrade to AMS was considered in a DOE review. The panel reviewed the proposal favorably assuming it would be constructed and installed in a timely manner. Installation of this upgrade would require an additional EVA orbital crew for installation, and DOE and NASA have initiated those discussions.

The Large Area Telescope (LAT), the primary instrument on FGST, entered its 15th year of successful operations and data analysis on such topics as searches for dark matter and high-energy particle acceleration mechanisms. 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 (SLAC).

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, and 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 searchers, and the inflationary era in the early universe. Scientists supported by all three agencies continue working together towards 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 late 2024).[3] 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 (PHA) with orbits having a high probability of crossing Earth's path someday.

During the second quarter of FY 2021, DOE and NASA jointly published a Request for Information (RFI) on collaborative activities that could further advances in high-energy physics and space-based astrophysics in support of shared science goals. The RFI focused on three major areas: potential lunar surface missions on the lunar far side; space-based probes of fundamental physics on the International Space Station; and synergies in the usage of data from the Rubin Observatory, Roman Space Telescope, and Euclid missions. While the responses to the RFI did not offer new science opportunities, it did reinforce the need for DOE and NASA to collaborate on planning novel science proposals and to increase interagency communication with regards to each agency's technology development activities.

In FY 2021, DOE and NASA began development of the Lunar Surface Electromagnetics Experiment at Night (LuSEE-Night) mission in partnership with Space Sciences Laboratory in Berkley, California. The mission 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. The LuSEE-Night mission will be sent to the Moon in 2025 via a Commercial Lunar Payload Services launch. 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).

In FY 2022, DOE and NASA continued development of the LuSEE-Night mission. DOE roles on LuSEE-Night, including the science antennae and associated

3 NASA was directed in 2005 to catalog 90 percent of potentially hazardous asteroids.

instrumentation, were approved and funded within the FY 2022 omnibus appropriations bill. The new instrument package will be developed through a partnership of two DOE laboratories.

Finally, NASA, through its Strategic Astrophysics Technology program, initiated funding in FY 2020 for a project at SLAC National Accelerator Laboratory 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 2021, SLAC developed and tested a Radio Frequency System on a Chip (RFSoC) with space-grade components. In FY 2022, testing and validation of the RFSoC was completed and preparation for radiation hardness testing was put in place to establish its viability through NASA's technology readiness level 6.

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 made significant contributions to science funded by NASA, conducted by NASA researchers and of direct relevance to NASA projects and missions. In FY 2021, NERSC hosted 24 researchers from NASA research centers, 23 projects that received NASA funding, and an additional 15 with relevance to NASA programs. In FY 2022, NERSC hosted 22 researchers from NASA research centers, 16 projects that received NASA funding, and an additional 13 with direct relevance to NASA programs. Among the projects: continued analysis of Planck Cosmic Microwave Background mission data, designing the next-generation Probe Class satellite mission, work on the Transiting Exoplanet Survey Satellite, Hubble data analysis, putting constraints on

Dark Energy, Earth Systems modeling, reactive subsurface geological fluid flows, magnetic reconnection and space weather, modeling atmospheric molecular line absorption, and simulating high redshift line intensity mapping as will be observed by the NASA SPHEREx (Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ice Explorer) mission set to launch in 2024. NERSC led a discussion at a workshop for the NASA Open-Source Science Initiative Data Computing Architecture Study in September 2022. 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. As part of the DOE Exascale Computing Project, the two Advanced Scientific Computing Research Leadership Computing Facilities—the Argonne Leadership Computing Facility and the Oak Ridge Leadership Computing Facility—made significant contributions to space science projects. Cumulatively at the two facilities, twenty-four and nineteen projects cited support from NASA in FY 2021 and FY 2022, respectively. These projects spanned a wide range of topics to help NASA's Nancy Grace Roman Space Telescope (formerly called WFIRST) and SPHEREx missions. For example, the Hardware/Hybrid Accelerated Cosmology Code general cosmology simulation software, which simulates cosmology data from an initial condition set in the early universe, continued to make use of the Summit supercomputer in FY 2021 and FY 2022 to produce simulations used by ground- and space-based surveys. Simulation-based extragalactic catalogs tailored to specific wavebands and filters were used to make synthetic datasets for these missions. Computer allocations for this work were made through the ASCR Argonne Leadership Computing Challenge program.

Atmospheric Science and Terrestrial Ecology

DOE, through the Biological and Environmental Research program, also engaged in many collaborative research efforts with NASA in the areas of atmospheric science and terrestrial ecology. During FY 2021 and FY 2022, DOE's Atmospheric Radiation Measurement (ARM) User Facility and Environmental System Science (ESS) activity (formerly known as Terrestrial Ecosystem Science) 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 (CO_2) concentrations. ARM provided support for ground-based measurements of CO_2 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 (JPSS) satellites.

ARM and NASA researchers collaborated on preparation and planning for the coordinated DOE-led Tracking Aerosol Convection Experiment (TRACER) and NASA-led TRACER–Air Quality field campaigns in Houston, Texas, to study atmospheric composition and aerosol impacts on convective storms. Although the official TRACER campaign start date was delayed until October 1, 2021, due to the COVID-19 pandemic, ARM supported deployment of ground-based lidar from the NASA Tropospheric Ozone Lidar Network system during FY 2021 and made preliminary data taken during the TRACER installation period available to NASA researchers. DOE's Atmospheric System Research activity also supported collaboration with NASA scientists at Goddard Space Flight Center, 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.

The ESS activity supported the Next Generation Ecosystem Experiments-Arctic, which continued to collaborate 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 (ECOSTRESS) mission by sharing flux tower measurements such as vegetation cover data and soil moisture data that are coupled with water flux/evapotranspiration measurements to serve as validation sites.

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 Office of Science's Nuclear Physics program leveraged electromagnetic radiation data from NASA's Neutron Star Interior Composition ExploreR (NICER) installed on the ISS to study the properties of such supranuclear systems.

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 2021, discussions began on how to address nuclear data needs for human spaceflight safety and electronics protection from radiation, including from cosmic ray interactions with spacecraft. Nuclear data needs were also identified for space-based nuclear reactors, which have some overlaps with Earth-based systems. In FY 2022, discussions progressed, and initial planning began on a potential data collection activity to address these needs. Nuclear data needs 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 (NSRL) 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.[4] The work advances the understanding of the link between ionizing radiation and cell damage. NASA continued to provide funding in FY 2021 and FY 2022 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 2021 and FY 2022. Representative techniques and their applications used in FY 2021 included the first neutron diffraction experiment in the High Flux Isotope Reactor at ORNL to characterize neptunium dioxide (NpO_2) and the use of infrared spectroscopy and single-shot and time-resolved synchrotron x-ray diffraction at the Advanced Photon Source at Argonne National Laboratory to discover that an iron-rich Earth rock sample contained stored water, with possible implications for water content of related rocks on Mars.[5]

Representative techniques and their applications used in FY 2022 included nanoscale infrared (IR) spectroscopy and imaging techniques at the Advanced Light Source at Lawrence Berkeley National Laboratory to reveal the chemical history of a carbonaceous chondrite meteorite, as well as in situ x-ray diffraction at the Advanced Photon Source at Argonne National Laboratory to study the phase behavior of iron-iron (II) sulfide (Fe-FeS) under pressures and temperatures expected to exist in the cores of rocky planets.[6]

Isotope Program

DOE, through the Isotope Program (IP), supplied critical isotopes for NASA space-related research, development, and applications in FY 2021 and FY 2022,

4 A recent paper highlighting research at *https://doi.org/10.1016/j.lssr.2022.09.001* describes the development of a galactic cosmic ray simulator for modeling space missions.

5 More information is available at *https://www.aps.anl.gov/APS-Science-Highlight/2021-08-04/earthly-rocks-point-way-to-water-hidden-on-mars*.

6 Investigators found that water played a key role in the meteorite's evolution, laying groundwork for further work on asteroid samples to be returned to Earth by NASA in 2023. *https://als.lbl.gov/nanoscale-infrared-study-of-meteorite-mineralogy/*. The investigators identified Fe_2S and a novel $Fe_{12}S_7$ phase at these conditions, revealing that a wide variety of core structures are possible with minor changes in sulfur content for S-rich planetary cores. *https://www.aps.anl.gov/APS-Science-Highlight/2022-08-15/fe-fes-phase-equilibria-and-eutectic-melting-relations-in*.

such as Helium-3 for use in cryogenics and Rubidium-87 for navigation satellite systems. The DOE IP advanced the availability of long-lived isotopes for nuclear batteries and power sources that may be of interest to NASA in the future, including Americium-241, Strontium-90, and Promethium-147. DOE also monitored the Helium-4 supply chain to ensure adequate supplies for the production of rocket fuel.

Enable the Development of Space

In FY 2021 and FY 2022, DOE, through the Office of Technology Transitions, conducted significant industry outreach to identify gaps and opportunities to connect its labs and capabilities with space industry counterparts. DOE also focused on ensuring that the transfer and commercialization of its technologies were specifically highlighted and supported in policy documents, setting the stage for further engagement on space-related activities.

DOE evaluated opportunities for quantum networking in free space, which included space applications and leveraging artificial intelligence. In FY 2021, DOE continued its collaboration with the space and quantum communities and the national labs through workshops on quantum entanglement and quantum networks in space, helping to facilitate public-private partnerships. AI applications and deployments in space are part of these discussions, and specific use cases are under development.

In FY 2021 and FY 2022, 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 2021, the National Renewable Energy Laboratory (NREL) completed the development of a Dynamic Hydride Vapor Phase Epitaxy (D-HVPE) procedure for high throughput and high materials utilization epitaxial growth of III-V layers. In FY 2022, NREL focused on supporting substrate reuse research, reducing cell costs, and optimizing III-V multijunction cell efficiency for terrestrial applications. SETO continued to serve as vice 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 contribute to national aerospace goals in FY 2021 and FY 2022. The Smithsonian Astrophysical Observatory (SAO) is a partner of the Center for Astrophysics | Harvard & Smithsonian (CfA) in Cambridge, Massachusetts, and represents the largest component of the Smithsonian's space contributors. The organization has more than 300 scientists engaged in a broad program of research in astronomy, astrophysics, Earth and space sciences, and science education. The Smithsonian's National Air and Space Museum and National Museum of Natural History (NMNH) in Washington, DC, contributed to reaching national aerospace goals through their research and education activities.

Five widely reported news stories in FY 2021 and 2022 featured Smithsonian scientists and space historians. SAO astronomers used NASA's Transiting Exoplanet Survey Satellite (TESS) and the IRAC camera on the Spitzer Space Telescope to detect and characterize a giant planet, about the size of Jupiter, tightly orbiting a white dwarf star every 1.4 days. The widely reported discovery, published in *Nature*, is remarkable because all the thousands of other known exoplanets orbit stars that are not in advanced old age. A white dwarf marks the final phase of life for a Sun-like star and follows aging processes that destroy most orbiting planets. The unexpected discovery of this planet so close to its white dwarf star

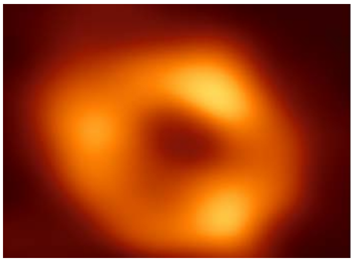
An artist's conception of the white dwarf star WD1856+534 (left) and the giant Jupiter-size planet (right) that orbits it every 1.4 days. (Credit: NASA)

An image of the galaxy Centaurus A showing the dark dust lane crossing the galaxy and dramatic, bright jets streaming out from its supermassive black hole nucleus. (Credit: X-ray: NASA/CXC/SAO; Optical: Rolf Olsen; Infrared: NASA/JPL-Caltech)

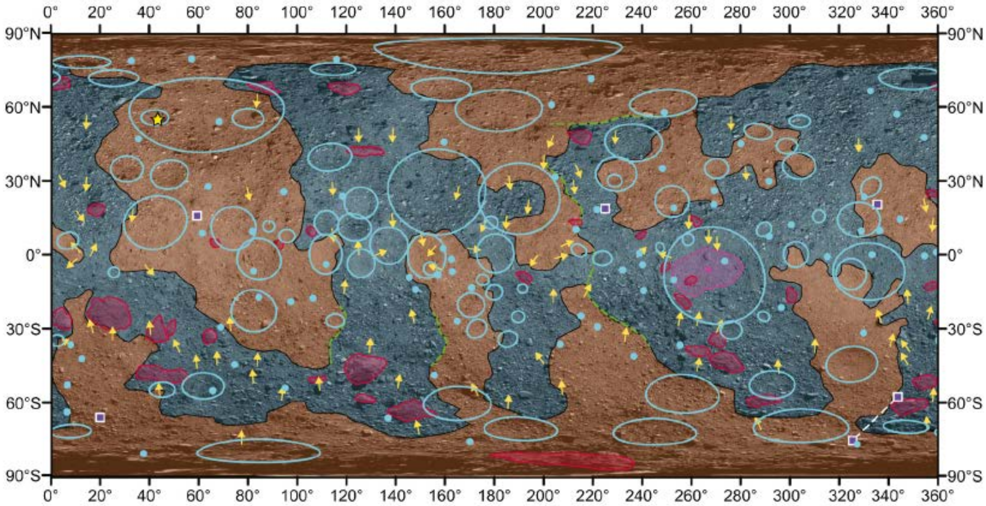
implies some unusual mechanism may have captured the planet from much farther away and may more broadly play a role in the development of planetary systems like our own.

SAO controls the science and operations of the Chandra X-ray Observatory for NASA. In FY 2021 and 2022 SAO astronomers, following up on Chandra observations of the galaxy Centaurus A, used radio data to obtain a unified description of the gas and dust that are accreting onto the vicinity of its supermassive black hole and the hot gas that is ejected from the nucleus in the form of powerful bipolar jets.

SAO astronomers have been conducting coordinated monitoring of flare activity from the four million solar-mass black hole (SMBH) at the center of our Milky Way galaxy, located about 25,000 light-years away, with NASA's Spitzer Space Telescope and Chandra X-ray Observatory. In FY 2021 and 2022 they published their results and models of the physical mechanisms present. Images of this black hole were also published for the first time in this period: SAO astronomers leading the Event Horizon Telescope consortium, and its dozens of collaborating institutions, used the global



The supermassive black hole at the center of our Milky Way galaxy as imaged with the Event Horizon Telescope. The black hole itself is invisible, but radiation from the hot gas around it is bent and distorted, creating a "shadow" of the object. (Credit: The Event Horizon Telescope consortium)



A geologic map of the asteroid Bennu. Smooth areas are shown in pink, rugged areas in blue, and craters are outlined in blue. (Credit: NASA, NMNH, Jawin, McCoy, et al.)

array of radio telescopes to image the SMBH. The dramatic picture revealed the "shadow" of the Milky Way's supermassive black hole, and in spring 2022, it was reproduced in newspapers around the world.

NMNH scientists using NASA's OSIRIS-REx mission produced the first geologic map of the 490-meter-diameter "rubble pile" asteroid Bennu, made of fragments held together by gravity. The mission will return samples to Earth, and this map will provide context for the sample studies, as well as offer a blueprint for future asteroid mapping. There are more small rubble pile asteroids in the solar system than planets, moons, and larger asteroids combined.

During FY 2021 and FY 2022, the National Air and Space Museum focused on the revitalization and transformation of its National Mall building, including the development of new exhibit galleries at one of the most visited museums in the world.

The Smithsonian continued to play a leadership role in space research during FY 2021 and FY 2022. SAO scientists have been active participants in the research of NASA's James Webb Space Telescope, launched in December 2021, and have published more than 100 journal articles so far on their discoveries, including the first definitive measurement of the carbon dioxide level in an exoplanet atmosphere and studies of atmospheres around other exoplanets. Scientists imaged distant galaxies in the very young universe with JWST and reported finding many more bright galaxies than had been expected, prompting a reevaluation of how the

The new Kenneth C. Griffin Exploring the Planets gallery in the National Air and Space Museum.

early cosmos evolved. Other SAO discoveries with JWST uncovered new details about nearby star-forming regions and bright nebulae. NASA's Chandra X-ray Observatory, operated for NASA by the SAO, observes critical targets proposed by scientists around the world. Chandra continues to operate with high (about 70 percent) efficiency and a spatial resolution unmatched by any other X-ray telescope either currently in operation or planned for the future. Chandra's results appear in an average of 480 highly cited refereed papers each year. In FY 2021 and FY 2022, Chandra enabled astronomers from around the world to observe X-rays emitted by a wide range of cosmic objects to tackle important astrophysical questions ranging from the first detection of X-rays from Uranus to the discovery of a huge jet from a black hole almost 13 billion light-years from Earth. Scientists used Chandra to study the effects of host stars on planets that orbit them and gained a deeper understanding of the process that drives the explosions of massive stars. They learned more about the center of the Milky Way galaxy and the supermassive black hole that resides there, and about how some of the largest structures in the universe—galaxy clusters—grow and evolve. SAO is a key participant in the Extreme-ultraviolet Stellar Characterization for Atmospheric Physics and Evolution (ESCAPE) mission, a NASA Small Explorer concept employing ultraviolet spectroscopy to explore the high-energy radiation environment in the habitable zones around nearby stars, to provide the first comprehensive study of the stellar extreme ultraviolet (EUV) environments that directly affect the habitability of rocky exoplanets. During FY 2021 and 2022, SAO participated in the ESCAPE Phase A study. SAO completed mirror coating test samples and measurements, as well as mirror alignment tests. SAO also supported the production of the Phase A Report in both scientific and technical sections and supported and participated in the site visit that formed part of the Phase A review.

The Parker Solar Probe continues to orbit the Sun and to set records as the fastest human-made object and the closest a spacecraft has ever approached the Sun. SAO built and operates the Solar Probe Faraday Cup instrument and leads the "SWEAP" suite of instruments that measures the Sun's thermal plasma. These instruments endure an extremely harsh environment while making groundbreaking scientific measurements about the fundamental processes taking place in the solar corona and interplanetary space. During FY 2021 and FY 2022, the mission completed 7 solar encounters and 2 Venus flybys that brought the probe to within just 13.3 solar radii, more than 4 times closer than any previous spacecraft. In April of 2021, the spacecraft entered an extended region of sub-Alfvénic plasma (a region dominated by the Sun's magnetic field) and thus made the first measurements from within the solar corona. This was the first in situ observation of the solar plasma that eventually becomes the solar wind.

The Solar Dynamics Observatory spacecraft provides better-than-high-definition-quality images of the Sun's surface and outer atmosphere, measuring physical conditions that help scientists model the stellar wind and its influence on the "space weather" around Earth. SAO is a major partner for one of its instruments, the Atmospheric Imaging Assembly. In FY 2021 and FY 2022 its four telescopes continued to photograph the Sun in ten different wavelength bands once every 12 seconds, continuing to produce the most spectacular images ever recorded of the active surface of the Sun. NASA's Interface Region Imaging Spectrograph (IRIS) satellite offers a unique view of the Sun's mysterious chromosphere and transition regions. SAO built the telescope feed, and in FY 2021 and FY 2022 continued its active role in IRIS operations, calibration, and science to provide information on particle acceleration in hot coronal loops and a better understanding of the physical processes powering solar flares. During FY 2021 and FY 2022, SAO scientists also continued their involvement in other solar satellites, including Hinode and the Deep Space Climate Observer.

FY 2021 and FY 2022 marked continued progress for the Giant Magellan Telescope (GMT), for which SAO is a team leader. The GMT is a facility in development for optical and infrared observations that combines seven huge mirrors to create one of the world's largest telescopes to address key questions in cosmology, astrophysics, and the study of planets outside our solar system. The sixth of the seven 8.4-meter-diameter mirror segments began fabrication in early 2021; the other fabricated mirrors are in various stages of preparation for shipment to the site in Chile.

SAO leads NASA's first Earth Venture Instrument, Tropospheric Emissions: Monitoring of Pollution (TEMPO) satellite mission as the Principal Investigator (PI) institution and heads the retrieval algorithm and calibration effort of the MethaneSAT satellite mission. TEMPO and MethaneSAT will provide revolutionary measurements of greenhouse gases and aerosols that are important for understanding air quality and climate change, allowing us to better fight against air pollution and global warming. During FY 2021 and 2022 the TEMPO mission made excellent progress. The instrument has been fully integrated into its satellite host and has finished spacecraft thermal vacuum testing. Launch-ready science algorithms have been completed, and ground systems, including the Instrument Operation Center and Science Data Processing Center, hosted at SAO, are to be completed soon for the Operation Readiness Review. TEMPO is scheduled to launch on a SpaceX Falcon 9 on March 1, 2023, providing the first-ever hourly daytime observations of atmospheric pollution from a geostationary orbit over North America. MethaneSAT is an Environmental Defense Fund mission funded by philanthropic donors to address climate change. The mission objective is to measure the methane emissions of more than 80 percent of the global oil and gas sector and produce actionable data to reduce oil and gas methane emissions by 45 percent by 2025. The instrument has been mostly built and is waiting for integration with the spacecraft bus working toward a launch by SpaceX in October 2023. SAO has been involved in the MethaneSAT project since its inception in 2015, including feasibility studies, and led the building of its airborne precursor instrument called MethaneAIR. SAO is leading the MethaneSAT/MethaneAIR retrieval algorithm development and instrument validation of the MethaneSAT mission. MethaneAIR will continue to fly on a dedicated plane routinely for 40–60 hours per month to complement MethaneSAT and double methane observations.

SAO is responsible for orchestrating the follow-up observations needed to confirm and characterize the planet candidates identified by NASA's TESS, now in its fifth year of operation. This effort continued in FY 2021 and FY 2022 with the TESS Follow-up Observing Program Working Group, which has more than 600 members based at observatories all around the world. SAO's telescopes at the Whipple Observatory on Mount Hopkins in Arizona play a major role in this work. A recent milestone passed in FY 2022 by the TESS mission was paper number 1000 published in a refereed journal. SAO is a member of the NASA MIDEX SPHEREx mission team and, during FY 2021 and FY 2022, continued to develop plans for this space-based telescope to conduct four all-sky infrared spectral surveys.

SAO continued to pursue a wide variety of nationwide STEM education and outreach initiatives in FY 2021 and FY 2022, many of which are aimed at broadening public participation in and maximizing the societal benefits of the astrophysics research efforts of the institution. The Chandra X-ray Observatory continues to lead in engaging the public. One example is the "sonification" of astronomical data—translating visual images into sequences of musical tones, making the images accessible to those with visual impairment. Chandra sonifications, including of the black hole in the Perseus cluster, appeared across social and traditional media in 2022. Stories about this Chandra-led project appeared in hundreds of outlets around the globe, including *The New York Times*, CNN, and NBC. The MicroObservatory is a robotic network of telescopes operated by the CfA for research and public outreach purposes. In the last 5 years, YouthAstroNet has reached nearly 4,500 youth in more than 20 states. Participating locations include museums, libraries, and community centers. Activities include digital image analysis to enhance and take measurements of astronomical images. Educational research studies investigate the impact of pre-college in-school and out-of-school activities on interest in pursuit of STEM careers and adequacy of preparation for success in college STEM courses, particularly for groups historically underrepresented in the sciences. Nationwide classroom studies examine teacher subject-matter knowledge and their decisions to utilize differing pedagogies for their effect on student learning.

During FY 2021 and FY 2022, the National Air and Space Museum, one of the most visited museums in the world, focused on the revitalization and transformation of its National Mall building (NMB), including the development of new exhibit galleries. The NMB has been closed for construction since March 28, 2022. The west end of the building is now complete, and eight exhibits opened to the public on October 14, 2022:

- The Wright Brothers and the Invention of the Aerial Age
- Early Flight
- America by Air
- Thomas W. Haas We All Fly
- Nation of Speed
- One World Connected
- Destination Moon
- Kenneth C. Griffin Exploring the Planets

The east end of the NMB will remain closed for construction until 2025. Information about this project can be found at *https://airandspace.si.edu/about-transformation*.

Meanwhile, the Museum began planning the Bezos Learning Center that will be added to the east end of the NMB, thanks to a generous donation of $200 million from Amazon founder and executive chairman Jeff Bezos. This is the largest donation to the Smithsonian since its founding in 1846 and includes $130 million for the Bezos Learning Center and $70 million for the NMB.

The Museum's Steven F. Udvar-Hazy Center in Chantilly, Virginia, remained open to the public during 2022, showcasing the Space Shuttle Discovery, Lockheed SR-71 Blackbird, Grumman F-14D(R) Tomcat, and numerous other aircraft and spacecraft.

While these projects progressed, the Museum's curators and scientists continued their groundbreaking research in aeronautics history, space history, and planetary geology. This expertise informs new exhibit galleries, scholarly publications, collections, and public outreach.

Aeronautics Department curator Dr. John Anderson won the 2021 American Institute of Aeronautics and Astronautics Summerfield Book Award for his book, *Hypersonic and High Temperature Gas Dynamics*, 3rd ed. Curator Dr. Michael

Hankins published his book, *Flying Camelot: The F-15, the F-16, and the Weaponization of Fighter Pilot Nostalgia*. The Museum collected a Wild-Leitz Kern DRS-15 Analytic Stereoplotter (dual head) and Bausch & Lomb Stereo Zoom Transfer System, late 20th- and early 21st-century tools that were used to analyze aerial and satellite photography. "Pride of the West" muslin fabric that covered the 1903 Wright Flyer when flown at Kitty Hawk on December 17, 1903, was also collected. Dr. Alex Spencer acquired a collection of artifacts and archival materials related to James E. Purton's service as a B-17 waist gunner in the 91st Bombardment Group and prisoner of war during World War II.

The Museum collaborated with the Consulate of Mexico and Brownsville Museum of Fine Arts in Brownsville, Texas, to mount the temporary exhibit "Women in Aviation and Space History" at the South Padre Island/Brownsville International Airport. This exhibit features 32 women from the Museum's Women in Aviation and Space History webpage, plus additional female pioneers.

The American Astronautical Society selected Department of Space History curator Dr. Teasel Muir-Harmony's book *Operation Moonglow* as the winner of the Eugene M. Emme Astronautical Literature Award for 2020. Curator Dr. Martin Collins's book, *A Telephone for the World: Iridium, Motorola, and the Making of a Global Age*, won the 2021 William and Joyce Middleton Electrical Engineering History Award from the Institute of Electrical and Electronics Engineers. Two new curators joined the Department of Space History. Dr. Colleen Anderson is the curator of Post-1945 Rocketry. Her research focuses on how science and technology have shaped Germany's roles in the wider world. Dr. Andrew Meade McGee joined the department as the curator of the History of Computing, including guidance and navigation artifacts. He is a historian of the politics, culture, and technology of 20th-century United States.

The Museum's Center for Earth and Planetary Studies (CEPS) hired two new geologists in FY 2022. Dr. Sharon Purdy received a NASA Early Career Award and was selected as a participating scientist on NASA's Curiosity rover mission to Mars. Dr. Emily Martin received a $515,000 NASA grant to map Saturn's moon Dione and participated in the "Ocean World and Dwarf Planet" panel on the Planetary Science and Astrobiology Decadal Survey.

CEPS scientists participated on 11 NASA and international mission teams to Venus, the Moon, Mars, Jupiter, and the asteroid Bennu. Dr. Bruce Campbell is a radar system co-lead on the VERITAS mission to Venus, now in development. His precise measurement of the rotation of Venus earned him a Smithsonian Secretary's Research Prize in 2021. Dr. Thomas Watters led the investigation of very young faults on the Moon by the Lunar Reconnaissance Orbiter, including their possible seismic hazards. On Mars, Dr. John Grant constrained erosion of the InSight landing site, helped to guide the Curiosity rover's exploration of rocks that may record the ancient drying of Mars, and led the Mars Reconnaissance Orbiter HiRISE camera imaging of landscape evolution and landing sites. Dr. Erica Jawin published a global geologic map of the rubble-pile asteroid Bennu and serves as a Science Team member on the OSIRIS-REx extended mission to asteroid Apophis, OSIRIS-APEX. Working with an international team, Dr. Bob Craddock helped to develop some of the first models that matched the early climate of Mars to geologic features on the surface, where an ancient ocean supported occasional rainfall.

Each June, the Museum marks the anniversary of Dr. Sally K. Ride's first look back at Earth from space by organizing virtual and in-person events to mark Sally's Night. This year, "Sally's Night" began with a celebration at Nationals Park during the Nationals afternoon game against the Milwaukee Brewers. Sally's sister, Rev. Dr. Bear Ride, threw out the first pitch. The impetus for Sally's Night came from Dr. Emily Margolis, the American Women's History Initiative curator who works with both the Aeronautics and Space History departments at the Museum as well as the Smithsonian Astrophysical Observatory.

Leveraging one-of-a-kind collections and research, learning at the National Air and Space Museum sparks curiosity and empowers learners to imagine the possibilities of the future. Throughout 2021 and 2022, the Education team connected with learners virtually while reintroducing onsite programming at the Udvar-Hazy Center and throughout the DC area while the NMB was closed for construction.

Soar Together @ Air and Space, the Museum's content-themed, monthly family-focused program, invited families to imagine their own futures by exploring stories of innovators and explorers from diverse backgrounds who challenged conventions and changed the world. The Museum's lecture programming launched a new hybrid format beginning in 2022 with the popular four-part Exploring Space series, which saw more than 375 onsite attendees and 20,000 online viewers between the live presentation and views post-presentation. In 2022, the Museum's lectures reached nine times the number of pre-pandemic individuals as a result of this hybrid model.

The NMB closure gave the Education team an opportunity to take the Museum's learning "on the road." The Museum's Explainers, college and high school students who facilitate hands-on learning with visitors, facilitated nearly 6,800 interactions with the Museum's Spacesuit at the Smithsonian Visitors Center in "the Castle." Reserved online programming provided unique opportunities for students located outside the national capital region to engage with the Museum's content. During the 2021–2022 school year, the Museum engaged 3,367 groups serving 17,098 participants, from 48 states, Puerto Rico, and nine countries.

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, where 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. In FY 2021 the Museum was closed to the public for the first 8.5 months due to the coronavirus pandemic. As a result, digital outreach was greatly increased, including the award-winning "Science How" broadcasts, NMNH social media takeovers, and numerous web postings. The staff of the National Museum of Natural History did not return to regular work at the Museum until late April 2022, an absence of 25 months.

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 27,000 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. Unfortunately, the 2021–2022 and 2022–2023 field seasons were cancelled due to the pandemic and higher-priority science activities on the continent, respectively, but meteorites from previous years continue to be classified.

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 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. In the first month of FY 2021, OSIRIS-REx completed sample acquisition at the Nightingale site on asteroid Bennu, departing Bennu in May 2021 for the return journey to Earth with its precious sample. NMNH is slated to be one of the first sites to display a sample from Bennu to the public as part of the ongoing education and outreach efforts. The Psyche mission, which was scheduled for an FY 2022 launch, has been delayed to sometime in the 2023–2024 timeframe. It will visit the 200-kilometer-diameter asteroid of the same name, which is 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.

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

Calendar Year	Earth Orbit[a]		Earth Escape[b]	
	Success	Failure	Success	Failure
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
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
TOTAL	**2,007**	**171**	**125**	**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				
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				

Appendix A-2 (cont.)

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
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
TOTAL	**1,762**	**3,162**	**10**	**8**	**117**	**477**	**1**	**1**	**301**	**77**	**9**	**5**	**2**	**1**	**29**

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 on U.S. Vehicles

October 1, 2020–September 30, 2021 (FY 2021)

Launch Date Spacecraft Name COSPAR[a] Designation Launch Vehicle	Mission Objectives	Remarks
October 3, 2020		
Cygnus CRS-14	ISS Resupply	Cargo resupply. Docked with ISS for 115 days. Carried seven CubeSats that were subsequently deployed on November 5, 2020.
Bobcat 1	Technology Demonstration	
DESCENT	Technology Demonstration	
Lemur-2 (Baxter-Oliver)	Earth Observation	
Lemur-2 (Djara)	Technology Demonstration	
NEUTRON 1	Technology Demonstration	
SATLLA 1	Education	
SPOC	Technology Demonstration	
2020-069		
Antares 230+		
October 6, 2020		
Starlink v1.0 L12-1 to -60	Communications	12th launch of 60 Starlink Block v1.0 satellites.
2020-070		
Falcon 9 v1.2		
October 18, 2020		
Starlink v1.0 L13-1 to -60	Communications	13th launch of 60 Starlink Block v1.0 satellites.
2020-073		
Falcon 9 v1.2		
October 24, 2020		
Starlink v1.0 L14-1 to -60	Communications	14th launch of 60 Starlink Block v1.0 satellites.
2020-074		
Falcon 9 v1.2		
October 28, 2020		
CE-SAT 2B	Earth Observation	Group of ten CubeSats launched from Mahia, New Zealand.
Flock-4e' 1 to 9	Earth Observation	
2020-077		
Electron KS		
November 5, 2020		
GPS-III 4	Navigation	Medium Earth orbit satellite operated by the U.S. Space Force.
2020-078		
Falcon 9 v1.2		
November 13, 2020		
USA 310 (NROL 101)	Reconnaissance	National Reconnaissance Office satellite in Molniya orbit.
2020-083		
Atlas-5(531)		
November 16, 2020		
Crew Dragon 1	ISS Crew Rotation	See Appendix C for details.
2020-084		
Falcon 9 Block 5		
November 20, 2020		
Dragracer A and B	Technology Demonstration	Group of 31 SmallSats launched from Mahia, New Zealand.
BRO 2 and 3	Signals Intelligence	
Mandrake 1	Technology Demonstration	
SpaceBEE 22 to 39	Communications	
SpaceBEE NZ 1 to 6	Communications	
APSS 1	Ionospheric Research	
Gnome Chompski	Mass Simulator	
2020-085		
Electron KS		
November 21, 2020		
Jason-CS A (Sentinel 6A)	Oceanography	Ocean surface topography satellite operated in partnership between NOAA, NASA, EUMETSAT, ESA, CNES, and industry.
2020-086		
Falcon-9 v1.2		

a. U.N. Committee on Space Research.

Appendix B-1 (cont.)

Successful Launches to Orbit on U.S. Vehicles

October 1, 2020–September 30, 2021 (FY 2021)

Launch Date Spacecraft Name COSPAR[a] Designation Launch Vehicle	Mission Objectives	Remarks
November 24, 2020 Starlink v1.0 L15-1 to -60 2020-088 *Falcon 9 v1.2*	Communications	15th launch of 60 Starlink Block v1.0 satellites.
December 6, 2020 Dragon CRS-21 2020-093 *Falcon 9 v1.2*	ISS Resupply	Cargo resupply. This first flight of the cargo version of Dragon 2 docked with ISS for 38 days and landed on January 14, 2021. Onboard was the Bishop commercial airlock module, installed on the ISS on December 20, 2020.
December 10, 2020 Orion 10 2020-095 *Delta-4H*	Reconnaissance	Signals intelligence satellite in geosynchronous orbit.
December 13, 2020 SXM-7 2020-096 *Falcon 9 v1.2*	Communications	Spacecraft failure occurred during in-orbit testing.
December 15, 2020 StriX-α 2020-098 *Electron KS*	Earth Observation	Japanese satellite launched from Mahia, New Zealand.
December 19, 2020 USA 312 and USA 313 2020-101 *Falcon 9 v1.2*	Reconnaissance	NROL-108 mission.
January 1, 2021 Türksat 5A 2021-001 *Falcon 9 v1.2*	Communications	Turkish satellite in geosynchronous orbit.
January 17, 2021 CACTUS 1 CAPE 3 ExoCube 2 MiTEE PICS 1 and 2 PolarCube Prometheus 2.8 Prometheus 2.11 Q-PACE RadFxSat 2 TechEdSat 7 2021-002 *LauncherOne*	 Technology Demonstration Technology Demonstration Atmospheric Research Technology Demonstration Technology Demonstration Technology Demonstration Technology Demonstration Technology Demonstration Microgravity Research Technology Demonstration Technology Demonstration	Test of LauncherOne rocket carrying ten CubeSats as part of NASA's ELaNa 20 mission.
January 20, 2021 GMS-T 2021-004 *Electron KS*	Communications	Prototype LEO broadband communications satellite launched from Mahia, New Zealand.
January 20, 2021 Starlink v1.0 L16-1 to -60 2021-005 *Falcon 9 v1.2*	Communications	16th launch of 60 Starlink Block v1.0 satellites.

Appendix B-1 (cont.)

Successful Launches to Orbit on U.S. Vehicles

October 1, 2020–September 30, 2021 (FY 2021)

Launch Date Spacecraft Name COSPAR[a] Designation Launch Vehicle	Mission Objectives	Remarks
January 24, 2021		
Starlink v1.0 R1-1 to -10	Communications	Rideshare launch with 143 SmallSats in total.
QPS-SAR 2	Earth Observation	
Capella 3 and 4	Earth Observation	
ICEYE X8 and X9	Earth Observation	
XR 1	Earth Observation	
GHGSat C2	Earth Observation	
Hawk 2A, 2B, and 2C	Technology Demonstration	
Astrocast 0101 to 0105	Communications	
PTD 1	Technology Demonstration	
Prometheus 2.10	Technology Demonstration	
ARCE 1A, 1B, and 1C	Technology Demonstration	
SpaceBEE 40 to 75	Communications	
Charlie	RF Sensing	
Hiber 4	Remote Sensing	
ASELSAT	Earth Observation	
PIXL 1	Technology Demonstration	
SOMP 2b	Technology Demonstration	
IDEASSat	Technology Demonstration	
YUSAT 1	Technology Demonstration	
UVSQ-SAT	Technology Demonstration	
V-R3x 1, 2, and 3	Communications	
Flock-4s 1 to 48	Earth Observation	
Kepler 8 to 15	Communications	
Lemur-2 130 to 137	Earth Observation	
2021-006		
Falcon 9 v1.2		
February 4, 2021		
Starlink v1.0 L18-1 to -60	Communications	17th launch of 60 Starlink Block v1.0 satellites.
2021-009		
Falcon 9 v1.2		
February 16, 2021		
Starlink v1.0 L19-1 to -60	Communications	18th launch of 60 Starlink Block v1.0 satellites.
2021-012		
Falcon 9 v1.2		
February 20, 2021		
Cygnus CRS-15	ISS Cargo Resupply	Cargo resupply docked with ISS for 131 days. The 23 SmallSats on board the Cygnus spacecraft were deployed from the ISS subsequent to docking.
MMSATS-1	Earth Observation	
ThinSat-2 x9	Technology Demonstration	
GuaraniSat 1	Technology Demonstration	
Gunsmoke J2	Technology Demonstration	
Hirogari	Technology Demonstration	
IT-SPINS	Ionospheric Research	
Maya 2	Technology Demonstration	
MYSat 2	Technology Demonstration	
ORCA 6 and 7	Technology Demonstration	
RSP 01	Technology Demonstration	
STARS EC	Technology Demonstration	
TAU-SAT 1TSURU	Education	
WARP 01	Technology Demonstration	
2021-013		
Antares 230+		
March 4, 2021		
Starlink v1.0 L17	Communications	19th launch of 60 Starlink Block v1.0 satellites.
2021-017		
Falcon 9 v1.2		
March 11, 2021		
Starlink v1.0 L20	Communications	20th launch of 60 Starlink Block v1.0 satellites.
2021-018		
Falcon 9 v1.2		

Successful Launches to Orbit on U.S. Vehicles

October 1, 2020–September 30, 2021 (FY 2021)

Launch Date Spacecraft Name COSPAR[a] Designation Launch Vehicle	Mission Objectives	Remarks
March 14, 2021 Starlink v1.0 L21 2021-021 *Falcon 9 v1.2*	Communications	21st launch of 60 Starlink Block v1.0 satellites.
March 22, 2021 BlackSky 7 Centauri 3 Myriota 7 RAAF-M2 A and B Gunsmoke-J 3 Veery RL-1 Pathstone 2021-023 *Electron Photon-LEO*	 Earth Observation Internet of Things Internet of Things Technology Demonstration Reconnaissance Earth Observation	
March 24, 2021 Starlink v1.0 L22 2021-024 *Falcon 9 v1.2*	Communications	22nd launch of 60 Starlink Block v1.0 satellites.
April 7, 2021 Starlink v1.0 L23 2021-027 *Falcon 9 v1.2*	Communications	23rd launch of 60 Starlink Block v1.0 satellites.
April 23, 2021 Crew Dragon 2 2021-030 *Falcon 9 v1.2*	International Space Station Crew Rotation	Second operational Crew Dragon mission (see Appendix C).
April 26, 2021 KH-11 18 2021-032 *Delta 4H (upg)*	Reconnaissance	National Reconnaissance Office satellite.
April 29, 2021 Starlink v1.0 L24 2021-036 *Falcon 9 v1.2*	Communications	24th launch of 60 Starlink Block v1.0 satellites.
May 4, 2021 Starlink v1.0 L25 2021-038 *Falcon 9 v1.2*	Communications	25th launch of 60 Starlink Block v1.0 satellites.
May 9, 2021 Starlink v1.0 L27 2021-040 *Falcon 9 v1.2*	Communications	26th launch of 60 Starlink Block v1.0 satellites.
May 15, 2021 Starlink v1.0 L26 Capella 6 GeoStare 2 2021-041 *Falcon 9 v1.2*	 Communications Earth Observation Astronomy	 27th launch of 52 Starlink Block v1.0 satellites. Capella 6 is part of a constellation of synthetic-aperture radar Earth observation satellites. GeoStare 2 is a 6U CubeSat that carries a miniature space telescope.
May 18, 2021 SBIRS-GEO 5 TDO 3 and 4 2021-042 *Atlas 5(420)*	 Early Warning Technology Demonstration	 SBIRS-GEO is a geosynchronous satellite operated by the U.S. Space Force.

Appendix B-1 (cont.)

Successful Launches to Orbit on U.S. Vehicles

October 1, 2020–September 30, 2021 (FY 2021)

Launch Date **Spacecraft Name** **COSPAR[a] Designation** **Launch Vehicle**	**Mission Objectives**	**Remarks**
May 26, 2021 Starlink v1.0 L28 2021-044 *Falcon 9 v1.2*	Communications	28th launch of 52 Starlink Block v1.0 satellites.
June 3, 2021 Dragon CRS-22 G-Satellite 2 MIR-SAT1 RamSat SOAR 2021-048 *Falcon 9 v1.2*	ISS Resupply Space Advertising Technology Demonstration Education Technology Demonstration	Cargo resupply. Docked with ISS for 36 days. Landed July 10, 2021. The four CubeSats were deployed from the ISS later in June 2021.
June 6, 2021 SXM-8 2021-049 *Falcon 9 v1.2*	Communications	Sirius XM satellite in geosynchronous orbit.
June 13, 2021 Odyssey (TacRL 2) 2021-051 *Pegasus-XL*	Space Domain Awareness	Technology demonstration satellite for the U.S. Space Force's tactically responsive launch program (TacRL).
June 15, 2021 USA 316, 317, 318 2021-052 *Minotaur-1*	Reconnaissance	National Reconnaissance Office satellites.
June 17, 2021 GPS-3 5 2021-054 *Falcon 9 v1.2*	Navigation	GPS satellite in Medium Earth Orbit.
June 30, 2021 HALO-Net FFS Gunsmoke-J 4 CNCE 1 and 3 Brik 2 STORK 4 and 5 2021-058 *LauncherOne*	Technology Demonstration Technology Demonstration Technology Demonstration Technology Demonstration Earth Observation	Payload consisted of seven CubeSats.
June 30, 2021 ION-SCV 003 Sherpa-FX 2 Sherpa-LTE 1 Starlink v1.5 R1-1 to -3 Aurora (Shasta) Capella 5 (Whitney 3) GNOMES 2 Hawk 3A, 3B, 3C Umbra-SAR 2001 YAM 2 and 3 ÑuSat 19 to 22 ICEYE X11 to X15 TUBIN (Tubsat 27) Mandrake 2A and 2B LINCS 1 and 2 PACE 1 TROPICS 01 D2/AtlaCom 1 EG 3 (Tyvak 0173) Centauri 4 (Tyvak 0210)	CubeSat Deployer CubeSat Deployer Space Tug Communications Earth Observation Earth Observation Radio Occultation Technology Demonstration Technology Demonstration Technology Demonstration Earth Observation Earth Observation Technology Demonstration Laser Communications Laser Communications Technology Demonstration Technology Demonstration Technology Demonstration Technology Demonstration Internet of Things	Dedicated SmallSat Rideshare mission.

(continued)

SUCCESSFUL LAUNCHES TO ORBIT ON U.S. VEHICLES

October 1, 2020–September 30, 2021 (FY 2021)

Launch Date Spacecraft Name COSPAR[a] Designation Launch Vehicle	Mission Objectives	Remarks
Lynk 06 (Shannon) Astrocast 0201 to 0205 Lemur-2 140 to 145 Painani 2 SpaceBEE 88 to 111 SpaceBEENZ 7 to 10 Tenzing (Tanker 001) ARTHUR 1 Faraday Phoenix KSM 1A, 1B, 1C, 1D Tiger 2 (Ayan-21) NAPA 2 (RTAF-SAT 2) Spartan Neptuno (NEPT 1) W-Cube Ghalib QMR-KWT 2021-059 *Falcon 9 v1.2*	Technology Demonstration Communications Earth Observation Technology Demonstration Communications Communications Technology Demonstration Technology Demonstration Earth Observation Navigation Technology Demonstration Earth Observation Technology Demonstration Technology Demonstration Technology Demonstration Technology Demonstration Education	
July 29, 2021 Monolith 2021-068 *Electron KS*	Technology Demonstration	USAF Research Laboratory (AFRL) microsatellite technology demonstration launched from New Zealand.
August 10, 2021 Cygnus CRS-16 PIRPL 2021-072 *Antares 230+*	ISS Resupply Technology Demonstration	Cargo resupply docked with ISS for 100 days. PIRPL was a multispectral camera initially mounted on the outside of the Cygnus spacecraft.
August 29, 2021 Dragon CRS-23 CAPSat PR_CuNaR 2 SPACE-HAUC CUAVA 1 Binar 1 Maya 3 and 4 2021-078 *Falcon 9 v1.2*	ISS Resupply Quantum Annealing Education Technology Demonstration Technology Demonstration Technology Demonstration Technology Demonstration	Cargo resupply that landed on October 1, 2021. The seven CubeSats on board were launched from the ISS in October 2021.
September 14, 2021 Starlink v1.5 G2-1 2021-082 *Falcon 9 v1.2*	Communications	First launch of 51 Starlink Block v1.5 satellites featuring laser inter-satellite links.
September 16, 2021 Crew Dragon Inspiration4 2021-084 *Falcon 9 v1.2*	Space Tourism	Four civilian passengers (see Appendix C).
September 27, 2021 Landsat 9 CuPID CUTE Cesium Satellite 1 and 2 2021-088 *Atlas 5(401)*	Earth Observation Space Weather Astronomy Technology Demonstration	USGS-operated Earth observation satellite launched with four CubeSats.

Appendix B-2

Successful Launches to Orbit on U.S. Vehicles

October 1, 2021–September 30, 2022 (FY 2022)

Launch Date Spacecraft Name COSPAR[a] Designation Launch Vehicle	Mission Objectives	Remarks
October 16, 2021 Lucy 2021-093 *Atlas-5(401)*	Asteroid Observation	NASA Discovery Program mission to observe main belt asteroids and Jupiter Trojan asteroids.
November 11, 2021 Crew Dragon 3 2021-103 *Falcon 9 v1.2*	International Space Station Crew Rotation	Third operational Crew Dragon mission (see Appendix C).
November 13, 2021 Starlink v1.5 G4-1-1 to -53 2021-104 *Falcon 9 v1.2*	Communications	Second launch of 53 Starlink Block v1.5 satellites.
November 18, 2021 BlackSky 10 and 11 2021-106 *Electron KS (R)*	Earth Observation	Launched from Mahia, New Zealand.
November 20, 2021 STP 27AD2 2021-108 *Astra Rocket 3.3*	Flight Test	First Rocket 3 launch to successfully reach orbit. STP-27AD2 collected data on the rocket's performance during launch.
November 24, 2021 DART LICIACube 2021-110 *Falcon 9 v1.2*	Asteroid Redirect Test Asteroid Flyby	Mission to impact Dimorphos, a small asteroid orbiting Didymos. LICIACube is a CubeSat launched on board DART to image the effects of DART's impact.
December 2, 2021 Starlink v1.5 G4-3-1 to -48 BlackSky 12 and 13 2021-115 *Falcon 9 v1.2*	Communications Earth Observation	Third launch of 48 Starlink Block v1.5 satellites. Two Earth observation microsatellites that make up part of the BlackSky constellation were also launched.
December 7, 2021 STPSat 6 LDPE 1 (ROOSTER 1) Ascent 2021-118 *Atlas 5(551)*	Technology Demonstration Technology Demonstration Technology Demonstration	Two U.S. Space Force satellites launched to geosynchronous orbit. STPSat 6 hosts NASA's Laser Communications Relay Demonstration payload, and the Ascent CubeSat was deployed from LDPE-1 in January 2022.
December 9, 2021 BlackSky 14 and 15 2021-120 *Electron KS*	Earth Observation	Launched from Mahia, New Zealand.
December 9, 2021 IXPE (SMEX 14, Explorer 97) 2021-121 *Falcon 9 v1.2*	X-ray Astronomy	X-ray observatory led by NASA's Marshall Space Flight Center.
December 18, 2021 Starlink v1.5 G4-4-1 to -52 2021-125 *Falcon 9 v1.2*	Communications	Fourth launch of 52 Starlink Block v1.5 satellites.
December 19, 2021 Türksat 5B 2021-126 *Falcon 9 v1.2*	Communications	Geosynchronous Turkish communications satellite.

Appendix B-2 (cont.)

Successful Launches to Orbit on U.S. Vehicles

October 1, 2021–September 30, 2022 (FY 2022)

Launch Date Spacecraft Name COSPAR[a] Designation Launch Vehicle	Mission Objectives	Remarks
December 21, 2021		
Dragon CRS-24	ISS Resupply	Cargo resupply docked with ISS for 32 days. Landed January 24, 2022.
DAILI	Ionospheric Research	The seven CubeSats on board were deployed from the ISS in early 2022.
FEES 2	Technology Demonstration	
GASPACS	Technology Demonstration	
GT 1	Technology Demonstration	
Light 1	Earth Observation	
PATCOOL	Technology Demonstration	
TARGIT	Technology Demonstration	
2021-127		
Falcon 9 v1.2		
January 6, 2022		
Starlink v1.5 G4-5-1 to -49	Communications	Fifth launch of 49 Starlink Block v1.5 satellites.
2022-001		
Falcon 9 v1.2		
January 13, 2022		
Umbra 02	Earth Observation	Dedicated SmallSat Rideshare mission.
Capella 7 and 8	Earth Observation	
ICEYE X14 and X16	Earth Observation	
Sich 2-1	Earth Observation	
ION-SCV 004	CubeSat Deployer	
Dodona (La Jument 2)	Technology Demonstration	
STORK 1 and 2	Earth Observation	
LabSat	Technology Demonstration	
SW1FT	Earth Observation	
VZLUSAT 2	Technology Demonstration	
ETV A1	Earth Observation	
BRO 5	Signals Intelligence	
HYPSO 1	Earth Observation	
Kepler 16 to 19	Communications	
Flock-4x 1 to 44	Earth Observation	
Lemur-2 146 to 150	Earth Observation	
DEWA-Sat 1	Technology Demonstration	
NuX 1	Internet of Things	
IRIS A	Technology Demonstration	
MDASat 1a, 1b, and 1c	AIS Tracking	
Gossamer Piccolomini	Technology Demonstration	
Tevel 1 to 8	Amateur Radio	
Challenger	Earth Observation	
Delfi-PQ 1	Technology Demonstration	
Unicorn 2A, 2D, and 2E	Earth Observation	
FossaSat 2E1 to 2E6	Internet of Things	
MDQube-SAT 1	Technology Demonstration	
SATLLA 2A and 2B	Education	
Unicorn 1	Technology demonstration	
EASAT 2	Amateur Radio	
HADES	Amateur Radio	
Grizu-263a	Education	
PION-BR 1	Technology Demonstration	
SanoSat 1	Amateur Radio	
Tartan-Artibeus 1	Technology Demonstration	
USA 320 to 323	Unknown	
2022-002		
Falcon 9 v1.2		
January 13, 2022		
PAN A and B	Technology Demonstration	Launch of seven CubeSats.
GEARRS 3	Technology Demonstration	
TechEdSat 13	Technology Demonstration	
ADLER 1 (Lemur-2)	Space Debris Measurement	
STORK 3	Earth Observation	
SteamSat 2	Technology Demonstration	
2022-003		
LauncherOne		

Appendix B-2 (cont.)

Successful Launches to Orbit on U.S. Vehicles

October 1, 2021–September 30, 2022 (FY 2022)

Launch Date Spacecraft Name COSPAR[a] Designation Launch Vehicle	Mission Objectives	Remarks
January 19, 2022 Starlink v1.5 G4-6-1 to -49 2022-005 *Falcon 9 v1.2*	Communications	Sixth launch of 49 Starlink Block v1.5 satellites.
January 21, 2022 GSSAP 5 and 6 2022-006 *Atlas 5(511)*	Space Surveillance	Two space surveillance satellites operated by the U.S. Space Force in geosynchronous orbit.
January 31, 2022 CSG 2 2022-008 *Falcon 9 v1.2*	Earth Observation	COSMO-SkyMed second-generation (CSG) satellite part of the Italian Space Agency's Earth observation constellation.
February 2, 2022 USA 326 (NROL 87) 2022-009 *Falcon 9 v1.2*	Reconnaissance	National Reconnaissance Office payload.
February 3, 2022 Starlink v1.5 G4-7-1 to -49 2022-016 *Falcon 9 v1.2*	Communications	Seventh launch of 49 Starlink Block v1.5 satellites. The majority of satellites were lost due to a geomagnetic storm.
February 19, 2022 Cygnus CRS-17 KITSUNE NACHOS IHI-Sat 2022-015 *Antares 230+*	ISS Resupply Technology Demonstration Technology Demonstration Technology Demonstration	Cargo resupply docked with the ISS for 127 days. Three CubeSats onboard were deployed at a later date.
February 21, 2022 Starlink v1.5 G4-8-1 to -46 2022-016 *Falcon 9 v1.2*	Communications	Eighth launch of 46 Starlink Block v1.5 satellites.
February 25, 2022 Starlink v1.5 G4-11-1 to 50 2022-017 *Falcon 9 v1.2*	Communications	Ninth launch of 50 Starlink Block v1.5 satellites.
February 28, 2022 StriX β *Electron KS*	Earth Observation	Japanese synthetic aperture radar satellite launched from Mahia, New Zealand.
March 1, 2022 GOES 18 (GOES T) 2022-021 *Atlas-5(541)*	Meteorology	NOAA satellite for meteorological forecasting in geosynchronous orbit.
March 3, 2022 Starlink v1.5 G4-9-1 to -47 2022-022 *Falcon 9 v1.2*	Communications	Tenth launch of 47 Starlink Block v1.5 satellites.
March 9, 2022 Starlink v1.5 G4-10-1 to -48 2022-025 *Falcon 9 v1.2*	Communications	11th launch of 48 Starlink Block v1.5 satellites.

Successful Launches to Orbit on U.S. Vehicles

October 1, 2021–September 30, 2022 (FY 2022)

Launch Date **Spacecraft Name** **COSPAR[a] Designation** **Launch Vehicle**	**Mission Objectives**	**Remarks**
March 14, 2022		
S4 Crossover	Technology Demonstration	22 payloads launched from the Pacific Spaceport Complex in Alaska.
OreSat 0	Technology Demonstration	
SpaceBEE 112 to 127	Communications	
SpaceBEENZ 11 to 14	Communications	
2022-026		
Astra Rocket 3.3		
March 19, 2022		
Starlink v1.5 G4-12-1 to -53	Communications	12th launch of 53 Starlink Block v1.5 satellites.
2022-029		
Falcon 9 v1.2		
April 1, 2022		
EnMAP	Earth Observation	Dedicated SmallSat Rideshare mission.
ÑuSat 23 to 27	Earth Observation	
GNOMES 3	Radio Occultation	
Hawk 4A, 4B, and 4C	Signals Intelligence	
Lynk 05	Communications	
ION-SCV 005	CubeSat Deployer	
KSF 2A to 2D	Navigation	
PlantSat	Biological Research	
SUCHAI 2 and 3	Ionospheric Research	
MP42	Internet of Things	
ARCSAT	Technology Demonstration	
Spark 1	Internet of Things	
Pixxel-TD 2	Earth Observation	
BRO 7	Signals Intelligence	
AlfaCrux	Communications	
BDSAT (CZE-BDSAT)	Technology Demonstration	
SpaceBEE 128 to 139	Communications	
2022-033		
Falcon 9 v1.2		
April 2, 2022		
BlackSky 16 and 17	Earth Observation	Launched from Mahia, New Zealand.
2022-034		
Electron KS		
April 8, 2022		
Crew Dragon Ax1	Private Spaceflight	Axiom Mission 1 (see Appendix C).
2022-037		
Falcon 9 v1.2		
April 17, 2022		
Intruder 13A and 13B	Electronic Signals Intelligence	Launch of two National Reconnaissance Office satellites.
2022-040		
Falcon 9 v1.2		
April 21, 2022		
Starlink v1.5 G4-14-1 to -53	Communications	13th launch of 53 Starlink Block v1.5 satellites.
2022-041		
Falcon 9 v1.2		
April 27, 2022		
Crew Dragon 4	International Space Station Crew Rotation	Fourth operational Crew Dragon mission (see Appendix C for details).
2022-042		
Falcon-9 v1.2		
April 29, 2022		
Starlink v1.5 G4-16-1 to -53	Communications	14th launch of 53 Starlink Block v1.5 satellites.
2022-045		
Falcon 9 v1.2		

Appendix B-2 (cont.)

Successful Launches to Orbit on U.S. Vehicles

October 1, 2021–September 30, 2022 (FY 2022)

Launch Date **Spacecraft Name** **COSPAR[a] Designation** **Launch Vehicle**	**Mission Objectives**	**Remarks**
May 2, 2022		
E-Space Demo 1 to 3	Technology Demonstration	SmallSat Rideshare mission.
BRO 6	Signals Intelligence	
AuroraSat 1	Technology Demonstration	
SpaceBEE 140 to 155	Communications	
SpaceBEENZ 15 to 22	Communications	
Unicorn 2	Earth Observation	
MyRadar 1	Technology Demonstration	
TRSI 2 and 3	Amateur Radio	
Copia	Technology Demonstration	
2022-047		
Electron KS		
May 6, 2022		
Starlink v1.5 G4-17-1 to -53	Communications	15th launch of 53 Starlink Block v1.5 satellites.
2022-049		
Falcon 9 v1.2		
May 13, 2022		
Starlink v1.5 G4-13-1 to -53	Communications	16th launch of 53 Starlink Block v1.5 satellites.
2022-051		
Falcon 9 v1.2		
May 14, 2022		
Starlink v1.5 G4-15-1 to -53	Communications	17th launch of 53 Starlink Block v1.5 satellites.
2022-052		
Falcon 9 v1.2		
May 18, 2022		
Starlink v1.5 G4-18-1 to -53	Communications	18th launch of 53 Starlink Block v1.5 satellites.
2022-053		
Falcon 9 v1.2		
May 19, 2022		
Starliner OFT-2	Orbital Flight Test	Uncrewed orbital flight test of Starliner spacecraft. Successfully docked with the ISS on May 21 and landed on May 25, 2022.
2022-055		
Atlas 5(N22)		
May 25, 2022		
Umbra 03	Earth Observation	Dedicated SmallSat Rideshare mission with 59 small satellites and hosted payloads.
ICEYE 17 to 20, 24	Earth Observation	
ÑuSat 28 to 31	Earth Observation	
GHGSat C3, C4, and C5	Earth Observation	
Hawk 5A, 5B, 5C	Signals Intelligence	
CICERO-2 1 and 2	Radio Occultation	
Sherpa-AC 1	CubeSat Deployer	
ION-SCV 006	CubeSat Deployer	
Guardian 1	Earth Observation	
SBUDNIC	Earth Observation	
Vigoride 3	Space Tug	
SelfieSat	Education	
FossaSat 2E7 to 2E13	Internet of Things	
Veery FS-1	Technology Demonstration	
Urdaneta-Armsat 1	Earth Observation	
Spark 2	Internet of Things	
AMS	Technology Demonstration	
CNCE 4 and 5	Technology Demonstration	
Platform 1	Technology Demonstration	
BroncoSat 1	Technology Demonstration	
Foresail 1	Technology Demonstration	
Planetum 1	Education	
SPiN 1 (MA61C)	Technology Demonstration	
Connecta T1.1	Internet of Things	

(continued)

Launch Date Spacecraft Name COSPAR[a] Designation Launch Vehicle	Mission Objectives	Remarks
Centauri 5 Lemur-2 152 to 156 VariSat 1C PTD 3 CPOD A and B OMD 1 2022-057 *Falcon 9 v1.2*	Internet of Things Earth Observation Technology Demonstration Technology Demonstration Technology Demonstration Technology Demonstration	
June 8, 2022 Nilesat 301 2022-061 *Falcon 9 v1.2*	Communications	Egyptian communications satellite launched to geosynchronous orbit.
June 17, 2022 Starlink v1.5 G4-19-1 to -53 2022-062 *Falcon 9 v1.2*	Communications	19th launch of 53 Starlink Block v1.5 satellites.
June 18, 2022 SARah 1 2022-063 *Falcon 9 v1.2*	Reconnaissance	German reconnaissance satellite.
June 19, 2022 USA 328 to 331 Globalstar M087 2022-064 *Falcon 9 v1.2*	Military Communications	Launch of four undisclosed military satellites and a Globalstar communications satellite.
June 28, 2022 CAPSTONE Lunar Photon 2022-070 *Electron Photon-IP*	Technology Demonstration Space Tug	NASA CubeSat launched to lunar orbit from Mahia, New Zealand, with Lunar Photon acting as an upper stage for deploying the CAPSTONE payload.
June 29, 2022 SES 22 2022-071 *Falcon 9 v1.2*	Communications	Satellite owned by Luxembourgish satellite telecommunications network provider SES.
July 1, 2022 WFOV-T USSF-12 Ring USA 337 2022-073 *Atlas 5(541)*	Early Warning Technology Demonstration Technology Demonstration	Three satellites launched to geosynchronous orbit.
July 2, 2022 Recurve Slingshot 1 Gunsmoke-L 1 NACHOS 2 MISR-B 1 CTIM-FD GPX 2 2022-074 *LauncherOne*	Technology Demonstration Technology Demonstration Technology Demonstration Earth Observation Technology Demonstration Technology Demonstration Technology Demonstration	Launch of seven SmallSats.
July 7, 2022 Starlink v1.5 G4-21-1 to -53 2022-076 *Falcon 9 v1.2*	Communications	20th launch of 53 Starlink Block v1.5 satellites.

Appendix B-2 (cont.)

Successful Launches to Orbit on U.S. Vehicles

October 1, 2021–September 30, 2022 (FY 2022)

Launch Date **Spacecraft Name** **COSPAR[a] Designation** **Launch Vehicle**	**Mission Objectives**	**Remarks**
July 11, 2022 Starlink v1.5 G3-1-1 to -46 2022-077 *Falcon 9 v1.2*	Communications	21st launch of 46 Starlink Block v1.5 satellites.
July 13, 2022 USA 334 2022-079 *Electron KS*	Reconnaissance	National Reconnaissance Office payload launched from Mahia, New Zealand.
July 15, 2022 Dragon CRS-25 BeaverCube CapSat 1 CLICK A D3 FUTABA HSU-SAT 1 JAGSAT 1 TUMnanoSAT 2022-081 *Falcon 9 v1.2*	 ISS Resupply Technology Demonstration Education Technology Demonstration Technology Demonstration Education Technology Demonstration Technology Demonstration Technology Demonstration	 Cargo resupply docked with ISS for nearly 33 days. Landed August 20, 2022. The eight CubeSats on board were deployed from the ISS in August and September of 2022.
July 17, 2022 Starlink v1.5 G4-22-1 to -53 2022-083 *Falcon 9 v1.2*	Communications	22nd launch of 53 Starlink Block v1.5 satellites.
July 22, 2022 Starlink v1.5 G3-2-1 to -46 2022-084 *Falcon 9 v1.2*	Communications	23rd launch of 46 Starlink Block v1.5 satellites.
July 24, 2022 Starlink v1.5 G4-25-1 to -53 2022-086 *Falcon 9 v1.2*	Communications	24th launch of 53 Starlink Block v1.5 satellites.
August 4, 2022 USA 335 2022-091 *Electron KS*	Reconnaissance	National Reconnaissance Office payload launched from Mahia, New Zealand.
August 4, 2022 SBIRS-GEO 6 2022-092 *Atlas 5(421)*	Early Warning	Geosynchronous satellite operated by the U.S. Space Force.
August 4, 2022 KPLO (Danuri) 2022-094 *Falcon 9 v1.2*	Lunar Orbiter	Korea Pathfinder Lunar Orbiter (KPLO) or Danuri is South Korea's first lunar orbiter.
August 10, 2022 Starlink v1.5 G4-26-1 to -52 2022-097 *Falcon 9 v1.2*	Communications	25th launch of 52 Starlink Block v1.5 satellites.
August 12, 2022 Starlink v1.5 G3-3-1 to -46 2022-099 *Falcon 9 v1.2*	Communications	26th launch of 46 Starlink Block v1.5 satellites.

Successful Launches to Orbit on U.S. Vehicles

October 1, 2021–September 30, 2022 (FY 2022)

Launch Date Spacecraft Name COSPAR[a] Designation Launch Vehicle	Mission Objectives	Remarks
August 19, 2022 Starlink v1.5 G4-27-1 to -53 2022-101 *Falcon 9 v1.2*	Communications	27th launch of 53 Starlink Block v1.5 satellites.
August 28, 2022 Starlink v1.5 G4-23-1 to -54 2022-104 *Falcon 9 v1.2*	Communications	28th launch of 54 Starlink Block v1.5 satellites.
August 31, 2022 Starlink v1.5 G3-4-1 to -46 2022-105 *Falcon 9 v1.2*	Communications	29th launch of 46 Starlink Block v1.5 satellites.
September 5, 2022 Starlink v1.5 G4-20-1 to -51 Sherpa-LTC 2 2022-107 *Falcon 9 v1.2*	Communications Space Tug	30th launch of 51 Starlink Block v1.5 satellites.
September 11, 2022 Starlink v1.5 G4-20-1 to -34 BlueWalker 3 2022-111 *Falcon 9 v1.2*	Communications Communications	31st launch of 34 Starlink Block v1.5 satellites. BlueWalker 3 is a prototype for a mobile communications constellation.
September 19, 2022 Starlink v1.5 G4-34-1 to -54 2022-114 *Falcon 9 v1.2*	Communications	32nd launch of 54 Starlink Block v1.5 satellites.
September 24, 2022 KH-11 19 2022-117 *Delta 4H (Upg.)*	Reconnaissance	National Reconnaissance Office satellite.
September 24, 2022 Starlink v1.5 G4-35-1 to -52 2022-119 *Falcon 9 v1.2*	Communications	33rd launch of 52 Starlink Block v1.5 satellites.

Appendix C-1

Human Spaceflights

October 1, 2020–September 30, 2021 (FY 2021)

Spacecraft/Mission	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Soyuz MS-17 Expedition 63, 64	October 14, 2020	Sergei Kud-Sverchkov Kathleen Rubins Sergei Ryzhikov	184:23:10	Quickest crewed trip to the ISS, docking just over three hours—or two orbits—after launch.
Crew Dragon C207 "Resilience" SpaceX Crew-1 Expedition 64, 65	November 16, 2020	Victor Glover Michael Hopkins Soichi Noguchi Shannon Walker	167:6:29	First operational commercial crew flight.
Soyuz MS-18 Expedition 64, 65, 66	April 9, 2021	Oleg Novitsky Pyotr Dubrov Mark Vande Hei	190:20:53	Russian film director Klim Shipenko and actress Yulia Peresild returned on Soyuz MS-18 with Oleg Novitsky.
Crew Dragon C206 "Endeavour" SpaceX Crew-2 Expedition 65, 66	April 23, 2021	Akihiko Hoshide Shane Kimbrough Megan McArthur Thomas Pesquet	199:17:43	The longest spaceflight by a U.S. crewed spacecraft. Due to launch delays for Crew-3, Crew-2 returned to Earth before the arrival of Crew-3 at the ISS.
Shenzhou 12	June 17, 2021	Liu Boming Nie Haisheng Tang Hongbo	92:4:11	First crewed flight to the Tianhe core module of the Tiangong space station.
Crew Dragon "Resilience" Inspiration4	September 16, 2021	Hayley Arceneaux Jared Isaacman Sian Proctor Christopher Sembroski	2:23:3	The first orbital spaceflight with only private citizens aboard.

Note: Suborbital human spaceflights are not included.

Appendix C-2
HUMAN SPACEFLIGHTS

October 1, 2021–September 30, 2022 (FY 2022)

Spacecraft/Mission	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Soyuz MS-19 Expeditions 65, 66	October 5, 2021	Yulia Peresild (returned in Soyuz-MS 18) Klim Shipenko (returned in Soyuz-MS 18) Anton Shkaplerov	176:02:33	Departing crew included one cosmonaut and two Russian travelers who filmed a movie in space and returned on Soyuz-MS-18. Pyotr Dubrov and Mark Vande Hei returned to Earth on Soyuz MS-19 with Shkaplerov.
Shenzhou 13	October 15, 2021	Ye Guangfu Wang Yaping Zhai Zhigang	182:09:32	Second flight to the first module of the Tiangong space station. This mission included the first spacewalk by a female Chinese astronaut.
Crew Dragon 3 "Endurance" Expeditions 66, 67	November 11, 2021	Kayla Barron Raja Chari Thomas Marshburn Matthias Maurer	176:02:39	Maiden flight of the Endurance spacecraft. It was commanded by Raja Chari on his first trip to space.
Soyuz MS-20	December 8, 2021	Yozo Hirano Yusaku Maezawa Aleksandr Misurkin	11:19:34	Crew included one Russian cosmonaut and two Japanese space tourists.
Soyuz MS-21 Expeditions 66, 67	March 18, 2022	Oleg Artemyev Sergey Korsakov Denis Matveev	194:19:02	First time three Russian cosmonauts flew together to the ISS.
Crew Dragon Axiom Mission 1 (Ax1) "Endeavour"	April 8, 2022	Larry Connor Michael Lopez-Alegria Mark Pathy Eytan Stibbe	017:01:48	Delivered one astronaut and three space tourists to the ISS.
Crew Dragon 4 "Freedom" Expeditions 67, 68	April 27, 2022	Samantha Cristoforetti Bob Hines Kjell Lindgren Jessica Watkins	170:13:03	Maiden flight for the Freedom spacecraft.
Shenzhou 14	June 5, 2022	Chen Dong Cai Xuzhe Liu Yang	181:17:19	Third crewed mission to the Tiangong Space Station with a focus on station construction. Included three spacewalks.
Soyuz-MS 22 Expeditions 67, 68	September 21, 2022	Dmitri Petelin Sergei Prokopyev Francisco Rubio	187:21:52	The Soyuz capsule suffered a leak due to a micrometeoroid strike while docked to the ISS and returned to Earth uncrewed. Soyuz MS-23 was launched uncrewed to replace it.

Note: Suborbital human spaceflights are not included.

Appendix D-1A

Space Activities of the U.S. Government

HISTORICAL TABLE OF BUDGET AUTHORITY

(in millions of real-year dollars)

FY	NASA Total	NASA Space	DOD[a]	Other[b]	DOE[c]	DOC	DOI	USDA	NSF[d]	DOT	Total Space
1959	331	261	490	34	34						785
1960	524	462	561	43	43						1,066
1961	964	926	814	68	68						1,808
1962	1,825	1,797	1,298	199	148	51					3,294
1963	3,673	3,626	1,550	257	214	43					5,433
1964	5,100	5,016	1,599	213	210	3					6,828
1965	5,250	5,138	1,574	241	229	12					6,953
1966	5,175	5,065	1,689	214	187	27					6,968
1967	4,966	4,830	1,664	213	184	29					6,707
1968	4,587	4,430	1,922	174	145	28	0.2	1			6,526
1969	3,991	3,822	2,013	170	118	20	0.2	1	31		6,005
1970	3,746	3,547	1,678	141	103	8	1	1	28		5,366
1971	3,311	3,101	1,512	162	95	27	2	1	37		4,775
1972	3,307	3,071	1,407	133	55	31	6	2	39		4,611
1973	3,406	3,093	1,623	147	54	40	10	2	41		4,863
1974	3,037	2,759	1,766	158	42	60	9	3	44		4,683
1975	3,229	2,915	1,892	158	30	64	8	2	54		4,965
1976	3,550	3,225	1,983	168	23	72	10	4	59		5,376
TQ*	932	849	460	43	5	22	3	1	12		1,352
1977	3,818	3,440	2,412	194	22	91	10	6	65		6,046
1978	4,060	3,623	2,738	226	34	103	10	8	71		6,587
1979	4,596	4,030	3,036	248	59	98	10	8	73		7,314
1980	5,240	4,680	3,848	231	40	93	12	14	72		8,759
1981	5,518	4,992	4,828	234	41	87	12	16	78		10,054
1982	6,044	5,528	6,679	313	61	145	12	15	80		12,520
1983	6,875	6,328	9,019	327	39	178	5	20	85		15,674
1984	7,458	6,858	10,195	395	34	236	3	19	103		17,448
1985	7,573	6,925	12,768	584	34	423	2	15	110		20,277
1986	7,807	7,165	14,126	477	35	309	2	23	108		21,768
1987	10,923	9,809	16,287	466	48	278	8	19	112	1	26,562
1988	9,062	8,322	17,679	741	241	352	14	18	115	1	26,742
1989	10,969	10,097	17,906	560	97	301	17	21	121	3	28,563

a. DOD reported that improvements to the estimating methodology resulted in a change in estimated budget authority and outlays starting in FY 2013.

b. The Other column is the total of the non-NASA and non-DOD budget authority figures that appear in the succeeding columns. The total is sometimes different from the sum of the individual figures because of rounding. The Total Space column does not include the NASA Total column because the latter includes budget authority for aeronautics as well as space. For the years 1989–97, this Other column also includes small figures for the Environmental Protection Agency (EPA), as well as $2.1 billion for the replacement of Space Shuttle Challenger in 1987.

c. DOE has recalculated its space expenditures since 1998.

d. The NSF has recalculated its space expenditures since 1980, making them significantly higher than reported in previous years.

e. Budget Authority amounts do not include supplemental or emergency-designated funding.

* Transition Quarter

Appendix D-1A (cont.)

Space Activities of the U.S. Government

HISTORICAL TABLE OF BUDGET AUTHORITY

(in millions of real-year dollars)

FY	NASA Total	NASA Space	DOD[a]	Other[b]	DOE[c]	DOC	DOI	USDA	NSF[d]	DOT	Total Space
1990	12,324	11,460	15,616	506	79	243	31	25	124	4	27,582
1991	14,016	13,046	14,181	772	251	251	29	26	211	4	27,999
1992	14,317	13,199	15,023	798	223	327	34	29	181	4	29,020
1993	14,310	13,064	14,106	731	165	324	33	25	180	4	27,901
1994	14,570	13,022	13,166	632	74	312	31	31	179	5	26,820
1995	13,854	12,543	10,644	759	60	352	31	32	278	6	23,946
1996	13,884	12,569	11,514	828	46	472	36	37	231	6	24,911
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	2,528	236	1,596	85	20	547	45	41,188

Appendix D-1B

Space Activities of the U.S. Government

HISTORICAL TABLE OF BUDGET AUTHORITY

(in millions of inflation-adjusted FY 2021 dollars)

FY	Inflation Factors	NASA Total	NASA Space	DOD[a]	Other[b]	DOE[c]	DOC	DOI	USDA	NSF[d]	DOT	Total Space
1959	7.172	2,374	1,872	3,514	244	244						5,630
1960	7.077	3,708	3,270	3,970	304	304						7,544
1961	6.980	6,729	6,464	5,682	475	475						12,621
1962	6.911	12,612	12,418	8,970	1,375	1,023	352					22,763
1963	6.830	25,087	24,766	10,587	1,755	1,462	294					37,108
1964	6.744	34,394	33,827	10,783	1,436	1,416	20					46,047
1965	6.630	34,805	34,063	10,435	1,598	1,518	80					46,096
1966	6.490	33,587	32,874	10,962	1,389	1,214	175					45,225
1967	6.299	31,280	30,423	10,481	1,342	1,159	183					42,246
1968	6.087	27,919	26,964	11,698	1,060	883	170	1	6			39,722
1969	5.821	23,232	22,248	11,718	992	687	116	1	6	181		34,957
1970	5.525	20,697	19,598	9,271	779	569	44	6	6	155		29,648
1971	5.258	17,409	16,305	7,950	851	500	142	11	5	194		25,106
1972	5.020	16,600	15,415	7,063	670	276	156	30	10	198		23,148
1973	4.812	16,389	14,883	7,810	709	260	192	48	10	199		23,402
1974	4.492	13,641	12,392	7,932	710	189	269	40	13	198		21,034
1975	4.071	13,146	11,867	7,702	642	122	261	33	8	219		20,212
1976	3.806	13,511	12,274	7,547	641	88	274	38	15	226		20,461
TQ*	3.696	3,444	3,138	1,700	159	18	81	11	4	44		4,996
1977	3.549	13,551	12,210	8,561	687	78	323	35	21	229		21,457
1978	3.325	13,500	12,047	9,104	751	113	342	33	27	236		21,903
1979	3.077	14,141	12,399	9,341	763	182	302	31	25	225		22,504
1980	2.830	14,828	13,244	10,889	654	113	263	34	40	204		24,787
1981	2.577	14,220	12,865	12,442	604	106	224	31	41	202		25,910
1982	2.410	14,565	13,322	16,096	754	147	349	29	36	192		30,171
1983	2.309	15,874	14,611	20,824	755	90	411	12	46	196		36,191
1984	2.229	16,625	15,288	22,726	880	76	526	7	42	229		38,894
1985	2.157	16,336	14,938	27,542	1,259	73	912	4	32	237		43,738
1986	2.109	16,468	15,114	29,798	1,006	74	652	4	49	227		45,917
1987	2.063	22,539	20,240	33,607	961	99	574	17	39	231	2	54,809
1988	1.999	18,113	16,634	35,337	1,481	482	704	28	36	230	2	53,452
1989	1.921	21,071	19,396	34,397	1,076	186	578	33	40	233	6	54,869

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.

* 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-1B (cont.)

Space Activities of the U.S. Government

HISTORICAL TABLE OF BUDGET AUTHORITY

(in millions of inflation-adjusted FY 2021 dollars)

FY	Inflation Factors	NASA Total	NASA Space	DOD[a]	Other[b]	DOE[c]	DOC	DOI	USDA	NSF[d]	DOT	Total Space
1990	1.853	22,837	21,236	28,937	937	146	450	57	46	229	7	51,111
1991	1.789	25,078	23,342	25,373	1,382	449	449	52	47	378	7	50,097
1992	1.746	24,992	23,040	26,224	1,392	389	571	59	51	315	7	50,657
1993	1.706	24,406	22,281	24,058	1,247	281	553	56	43	307	7	47,586
1994	1.669	24,320	21,736	21,976	1,056	124	521	52	52	300	8	44,768
1995	1.635	22,645	20,502	17,398	1,240	98	575	51	52	454	10	39,141
1996	1.604	22,275	20,166	18,473	1,328	74	757	58	59	370	10	39,967
1997	1.576	21,611	19,637	18,486	1,244	55	706	66	61	346	9	39,368
1998	1.557	21,249	19,183	19,242	1,307	160	677	67	61	332	9	39,733
1999	1.538	20,995	19,159	20,303	1,510	161	884	91	57	308	9	40,973
2000	1.506	20,489	18,862	19,495	1,590	247	866	90	66	311	9	39,947
2001	1.471	20,929	19,567	21,070	1,562	213	849	88	53	341	18	42,199
2002	1.448	21,527	20,084	22,790	1,709	240	932	93	41	385	17	44,582
2003	1.421	21,828	20,402	27,545	1,854	271	922	105	60	479	17	49,801
2004	1.387	21,328	19,862	26,509	2,030	290	1,033	98	85	508	17	48,402
2005	1.346	21,802	20,505	26,502	2,088	308	1,086	94	98	485	16	49,095
2006	1.304	21,669	20,550	28,827	2,147	319	1,121	107	109	474	16	51,524
2007	1.269	20,662	19,752	28,443	2,131	254	1,157	110	82	513	15	50,326
2008	1.243	21,273	20,509	30,816	2,110	242	1,071	112	73	595	16	53,435
2009	1.230	21,869	21,254	32,638	2,298	246	1,326	79	33	597	17	56,190
2010	1.220	22,839	22,233	32,277	2,508	248	1,538	82	32	590	18	57,019
2011	1.196	22,038	21,399	32,562	2,613	274	1,726	79	23	493	18	56,574
2012	1.174	20,867	20,198	31,321	3,029	234	2,203	89	8	477	19	54,548
2013	1.153	20,056	19,445	12,473	2,972	213	2,150	97	23	472	17	34,891
2014	1.131	19,961	19,321	11,764	3,211	197	2,361	93	21	521	18	34,295
2015	1.118	20,141	19,413	11,546	3,366	204	2,486	93	21	542	20	34,325
2016	1.109	21,389	20,679	7,727	3,504	197	2,602	96	21	563	24	31,910
2017	1.090	21,415	20,696	11,241	3,264	187	2,412	93	22	523	26	35,201
2018	1.065	22,081	21,271	8,371	3,145	186	2,235	84	17	592	31	32,787
2019	1.044	22,456	21,699	10,413	2,719	227	1,741	88	19	607	38	34,832
2020	1.031	23,324	22,516	12,266	2,476	201	1,553	87	21	560	54	37,257
2021	1.000	23,271	22,443	15,100	2,459	211	1,516	84	27	576	44	40,002

Appendix D-1C

Space Activities of the U.S. Government

HISTORICAL TABLE OF BUDGET AUTHORITY

(in millions of inflation-adjusted FY 2022 dollars)

FY	Inflation Factors	NASA Total	NASA Space	DOD[a]	Other[b]	DOE[c]	DOC	DOI	USDA	NSF[d]	DOT	Total Space
1959	7.693	2,546	2,008	3,769	262	262						6,039
1960	7.591	3,978	3,507	4,258	326	326						8,092
1961	7.487	7,217	6,933	6,094	509	509						13,536
1962	7.412	13,527	13,319	9,621	1,475	1,097	378					24,415
1963	7.326	26,908	26,563	11,355	1,883	1,568	315					39,801
1964	7.233	36,889	36,282	11,566	1,541	1,519	22					49,388
1965	7.111	37,331	36,535	11,192	1,714	1,628	85					49,441
1966	6.961	36,025	35,259	11,758	1,490	1,302	188					48,506
1967	6.756	33,550	32,631	11,242	1,439	1,243	196					45,312
1968	6.528	29,945	28,920	12,547	1,137	947	183	1	7			42,605
1969	6.243	24,918	23,862	12,568	1,064	737	125	1	6	195		37,494
1970	5.926	22,199	21,020	9,944	836	610	47	6	6	166		31,800
1971	5.639	18,672	17,488	8,527	913	536	152	11	6	208		26,928
1972	5.384	17,805	16,534	7,575	718	296	167	32	11	212		24,827
1973	5.161	17,579	15,963	8,376	761	279	206	52	10	213		25,100
1974	4.818	14,631	13,292	8,508	761	202	289	43	14	212		22,561
1975	4.367	14,099	12,728	8,261	689	131	279	35	9	235		21,679
1976	4.082	14,491	13,164	8,095	687	94	294	41	16	242		21,946
TQ*	3.964	3,694	3,365	1,823	170	20	87	12	4	48		5,359
1977	3.807	14,534	13,096	9,182	737	84	346	38	23	246		23,014
1978	3.566	14,480	12,921	9,765	806	121	367	36	29	253		23,492
1979	3.300	15,167	13,299	10,019	818	195	323	33	26	241		24,137
1980	3.035	15,904	14,205	11,679	701	121	282	36	42	219		26,585
1981	2.764	15,252	13,798	13,345	648	113	240	33	44	216		27,791
1982	2.585	15,622	14,289	17,264	808	158	375	31	39	206		32,361
1983	2.476	17,026	15,671	22,336	810	97	441	12	50	211		38,817
1984	2.391	17,832	16,397	24,375	944	81	564	7	45	246		41,716
1985	2.314	17,521	16,022	29,540	1,350	79	979	5	35	254		46,912
1986	2.262	17,663	16,211	31,960	1,079	79	699	5	52	244		49,249
1987	2.213	24,175	21,709	36,046	1,031	106	615	18	42	248	2	58,786
1988	2.144	19,428	17,841	37,901	1,589	517	755	30	39	247	2	57,331
1989	2.060	22,600	20,804	36,893	1,154	200	620	35	43	249	6	58,851

a. DOD reported that improvements to the estimating methodology resulted in a change in estimated budget authority and outlays starting in FY 2013.

b. The Other column is the total of the non-NASA and non-DOD budget authority figures that appear in the succeeding columns. The total is sometimes different from the sum of the individual figures because of rounding. The Total Space column does not include the NASA Total column because the latter includes budget authority for aeronautics as well as space. For the years 1989–97, this Other column also includes small figures for the Environmental Protection Agency (EPA), as well as $2.1 billion for the replacement of Space Shuttle Challenger in 1987.

c. DOE has recalculated its space expenditures since 1998.

d. The NSF has recalculated its space expenditures since 1980, making them significantly higher than reported in previous years.

e. Budget Authority amounts do not include supplemental or emergency-designated funding.

* Transition Quarter

Note: Inflation factors calculated using data from Table 10.1—Gross Domestic Product and Deflators Used in the Historical Tables: 1940–2028 available at *https://www.whitehouse.gov/omb/budget/historical-tables/*

Appendix D-1C (cont.)

SPACE ACTIVITIES OF THE U.S. GOVERNMENT

HISTORICAL TABLE OF BUDGET AUTHORITY

(in millions of inflation-adjusted FY 2022 dollars)

FY	Inflation Factors	NASA Total	NASA Space	DOD[a]	Other[b]	DOE[c]	DOC	DOI	USDA	NSF[d]	DOT	Total Space
1990	1.988	24,494	22,777	31,037	1,005	157	483	62	50	246	8	54,819
1991	1.919	26,898	25,036	27,214	1,482	482	482	56	50	405	8	53,733
1992	1.872	26,806	24,712	28,127	1,494	418	612	64	54	338	7	54,333
1993	1.829	26,177	23,898	25,804	1,337	302	593	60	46	329	7	51,039
1994	1.790	26,085	23,313	23,571	1,132	132	559	55	55	321	9	48,017
1995	1.753	24,288	21,990	18,661	1,330	105	617	54	56	487	11	41,981
1996	1.721	23,892	21,629	19,814	1,424	79	812	62	64	397	10	42,867
1997	1.691	23,179	21,062	19,828	1,335	59	757	71	66	371	10	42,225
1998	1.670	22,791	20,575	20,639	1,402	172	726	72	65	357	10	42,616
1999	1.649	22,519	20,550	21,777	1,620	173	948	97	61	330	10	43,946
2000	1.616	21,976	20,231	20,909	1,706	265	929	97	71	334	10	42,845
2001	1.577	22,447	20,987	22,599	1,675	229	910	95	57	366	19	45,261
2002	1.553	23,089	21,541	24,444	1,832	258	1,000	99	43	413	19	47,817
2003	1.524	23,412	21,882	29,544	1,989	291	989	113	64	514	18	53,415
2004	1.487	22,876	21,304	28,433	2,178	311	1,108	106	91	544	18	51,915
2005	1.444	23,384	21,993	28,426	2,239	331	1,165	101	105	520	17	52,657
2006	1.398	23,241	22,042	30,918	2,303	343	1,202	115	117	509	17	55,263
2007	1.361	22,161	21,185	30,507	2,286	272	1,241	118	88	550	16	53,978
2008	1.333	22,817	21,997	33,052	2,263	260	1,149	120	79	639	17	57,313
2009	1.320	23,456	22,796	35,007	2,465	264	1,423	84	35	640	18	60,267
2010	1.308	24,497	23,846	34,620	2,691	266	1,650	88	35	633	20	61,157
2011	1.282	23,637	22,952	34,924	2,803	294	1,852	85	25	528	19	60,679
2012	1.259	22,382	21,664	33,594	3,249	251	2,362	96	8	511	20	58,507
2013	1.237	21,512	20,856	13,378	3,188	229	2,306	104	25	506	19	37,423
2014	1.213	21,409	20,723	12,617	3,444	211	2,532	99	23	559	19	36,784
2015	1.199	21,602	20,821	12,384	3,610	218	2,666	100	23	582	22	36,816
2016	1.190	22,941	22,180	8,288	3,758	212	2,791	103	23	604	26	34,226
2017	1.169	22,969	22,198	12,057	3,501	201	2,588	99	23	561	28	37,755
2018	1.142	23,679	22,811	8,977	3,372	200	2,397	90	18	634	33	35,160
2019	1.120	24,079	23,267	11,166	2,916	243	1,867	94	21	651	41	37,350
2020	1.105	25,010	24,144	13,152	2,655	216	1,666	93	23	601	57	39,951
2021	1.069	24,884	23,998	16,146	2,629	226	1,621	90	29	615	47	42,773
2022[e]	1.000	24,041	23,161	15,500	2,528	236	1,596	85	20	547	45	41,188

Appendix D-2
Federal Space Activities Budget

(in millions of dollars by fiscal year)[1]

	Budget Authority				Budget Outlays			
Federal Agencies	**2020 actual**	**2021 actual**	**2022 actual**[2]	**2023 est.**	**2020 actual**	**2021 actual**	**2022 actual**	**2023 est.**
NASA[3]	21,845	22,443	23,887	25,039	20,698	21,486	22,588	23,575
DOD[4]	11,900	15,100	15,500	21,700	11,900	15,500	16,700	21,700
DOE	195	211	236	225	198	207	240	246
DOC	1,507	1,516	1,596	1,753	1,605	1,438	1,582	1,753
DOI[5]	84	84	85	92	84	84	85	92
USDA	20	27	20	20	15	27	20	20
DOT	52	44	45	48	52	44	45	48
NSF	544	576	547	528	550	544	540	527

1 Amounts rounded to the nearest million.

2 Budget Authority amounts do not include supplemental or emergency-designated funding.

3 FY 2021 Budget Authority based on enacted appropriation language in P.L. 116-260, FY 2022 Budget Authority based on enacted appropriation language in P.L. 117-103, and FY 2023 Budget Authority based on enacted appropriation language in P.L. 117-328.

4 DOD submitted estimates in billions of dollars, so the figures are rounded to the nearest hundred million.

5 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).

Appendix D-3

Federal Aeronautics Activities Budget

(in millions of dollars by fiscal year)[1]

	Budget Authority				Budget Outlays			
Federal Agencies	**2020 actual**	**2021 actual**	**2022 actual**[2]	**2023 est.**	**2020 actual**	**2021 actual**	**2022 actual**	**2023 est.**
NASA[3]	784	829	881	935	826	763	808	804
USDA	65	69	74	65	69	75	76	65
DOD[4]	57,700	60,600	56,200	56,500	56,900	56,900	52,400	56,500
DOE	1	2	3	6	1	1	2	4
DOI[5]	36	36	40	43	36	36	40	43
DOT	3,220	3,193	3,121	3,179	2,943	2,907	3,232	3,179

1 Amounts rounded to the nearest million.

2 Budget Authority amounts do not include supplemental or emergency-designated funding.

3 FY 2021 Budget Authority based on enacted appropriation language in P.L. 116-260, FY 2022 Budget Authority based on enacted appropriation language in P.L. 117-103, and FY 2023 Budget Authority based on enacted appropriation language in P.L. 117-328.

4 DOD submitted estimates in billions of dollars, so the figures are rounded to the nearest hundred million.

5 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).

Appendix E-1

Memorandum on Space Policy Directive-6

National Strategy for Space Nuclear Power and Propulsion

Issued on December 16, 2020

MEMORANDUM FOR THE VICE PRESIDENT

THE SECRETARY OF STATE
THE SECRETARY OF DEFENSE
THE SECRETARY OF COMMERCE
THE SECRETARY OF TRANSPORTATION
THE SECRETARY OF ENERGY
THE DIRECTOR OF THE OFFICE OF MANAGEMENT AND BUDGET
THE ASSISTANT TO THE PRESIDENT FOR NATIONAL SECURITY AFFAIRS
THE ADMINISTRATOR OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
THE CHAIRMAN OF THE NUCLEAR REGULATORY COMMISSION
THE DIRECTOR OF THE OFFICE OF SCIENCE AND TECHNOLOGY POLICY

SUBJECT: National Strategy for Space Nuclear Power and Propulsion

Section 1. Policy. The ability to use space nuclear power and propulsion (SNPP) systems safely, securely, and sustainably is vital to maintaining and advancing United States dominance and strategic leadership in space. SNPP systems include radioisotope power systems (RPSs) and fission reactors used for power or propulsion in spacecraft, rovers, and other surface elements. SNPP systems can allow operation of such elements in environments in which solar and chemical power are inadequate. They can produce more power at lower mass and volume compared to other energy sources, thereby enabling persistent presence and operations. SNPP systems also can shorten transit times for crewed and robotic spacecraft, thereby reducing radiation exposure in harsh space environments.

National Security Presidential Memorandum-20 (NSPM-20) of August 20, 2019 (Launch of Spacecraft Containing Space Nuclear Systems), updated the process for launches of spacecraft containing space nuclear systems. It established it as the policy of the United States to "develop and use space nuclear systems when such systems safely enable or enhance space exploration or operational capabilities."

Cooperation with commercial and international partners is critical to achieving America's objectives for space exploration. Presidential Policy Directive 4 of June 28, 2010 (National Space Policy), as amended by the Presidential Memorandum of December 11, 2017 (Reinvigorating America's Human Space Exploration Program), established it as the policy of the United States to "[l]ead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities."

This memorandum establishes a national strategy to ensure the development and use of SNPP systems when appropriate to enable and achieve the scientific, exploration, national security, and commercial objectives of the United States. In the context of this strategy only, the term "development" includes the full development process from design through testing and production, and the term "use" includes launch, operation, and disposition. This memorandum outlines high-level policy goals and a supporting roadmap that will advance the ability of the United States to use SNPP systems safely, securely, and sustainably.

The execution of this strategy will be subject to relevant budgetary and regulatory processes and to the availability of appropriations.

Sec. 2. Goals. The United States will pursue goals for SNPP development and use that are both mission-enabling and ambitious in their substance and their timeline. These goals will enable a range of existing and future space missions, with the aim of accelerating achievement of key milestones, including in-space demonstration and use of new SNPP capabilities. This memorandum establishes the following such goals for the Nation:

(a) Develop uranium fuel processing capabilities that enable production of fuel that is suitable to lunar and planetary surface and in-space power, nuclear electric propulsion (NEP), and nuclear thermal propulsion (NTP) applications, as needed. These capabilities should support the ability to produce different uranium fuel forms to meet the nearest-term mission needs and, to the extent feasible, should maximize commonality — meaning use of the same or similar materials, processes, designs, or infrastructure — across these fuel forms. To maximize private-sector engagement and cost savings, these capabilities should be developed to enable a range of terrestrial as well as space applications, including future commercial applications;

(b) Demonstrate a fission power system on the surface of the Moon that is scalable to a power range of 40 kilowatt-electric (kWe) and higher to support a sustained lunar presence and exploration of Mars. To the extent feasible, this power system should align with mission needs for, and potential future government and commercial applications of, in-space power, NEP, and terrestrial nuclear power;

(c) Establish the technical foundations and capabilities — including through identification and resolution of the key technical challenges — that will enable options for NTP to meet future Department of Defense (DoD) and National Aeronautics and Space Administration (NASA) mission requirements; and

(d) Develop advanced RPS capabilities that provide higher fuel efficiency, higher specific energy, and longer operational lifetime than existing RPS capabilities, thus enabling survivable surface elements to support robotic and human exploration of the Moon and Mars and extending robotic exploration of the solar system.

Sec. 3. Principles. The United States will adhere to principles of safety, security, and sustainability in its development and use of SNPP systems, in accordance with all applicable Federal laws and consistent with international obligations and commitments.

(a) Safety. All executive departments and agencies (agencies) involved in the development and use of SNPP systems shall take appropriate measures to ensure, within their respective roles and responsibilities, the safe development, testing, launch, operation, and disposition of SNPP systems. For United States Government SNPP programs, the sponsoring agency holds primary responsibility for safety. For programs involving multiple agencies, the terms of cooperation shall designate a lead agency with primary responsibility for safety in each stage of development and use.

(i) Ground development. Activities associated with ground development, including ground testing, of SNPP systems shall be conducted in accordance with applicable Federal, State, and local laws and existing authorities of regulatory agencies.

(ii) Launch. NSPM-20 established safety guidelines and safety analysis and review processes for Federal Government launches of spacecraft containing space nuclear systems, including SNPP systems, and for launches for which the Department of Transportation has statutory authority to license as commercial space launch activities (commercial launches). These guidelines and processes address launch and any subsequent stages during which accidents may result in radiological effects on the public or the environment — for instance, in an unplanned reentry from Earth orbit or during an Earth flyby. Launch activities shall be conducted in accordance with these guidelines and processes.

(iii) Operation and disposition. The operation and disposition of SNPP systems shall be planned and conducted in a manner that protect human and environmental safety and national security assets. Fission reactor SNPP systems may be operated on interplanetary missions, in sufficiently high orbits, and in low-Earth orbits if they are stored in sufficiently high orbits after the operational part of their mission. In this context, a sufficiently high orbit is one in which the orbital lifetime of the spacecraft is long enough for the fission products to decay to a level of radioactivity comparable to that of uranium-235 by the time it reenters the Earth's atmosphere, and the risks to existing and future space missions and of collision with objects in space are minimized. Spacecraft operating fission reactors in low-Earth orbits shall incorporate a highly reliable operational system to ensure effective and controlled disposition of the reactor.

(b) Security. All agencies involved in the development and use of SNPP systems shall take appropriate measures to protect nuclear and radiological materials and sensitive information, consistent with sound nuclear nonproliferation principles. For United States Government SNPP programs, the sponsoring agency holds primary responsibility for security. For programs involving multiple agencies, the terms of cooperation shall designate a lead agency with primary responsibility for security in each stage of development and use. The use of highly enriched uranium (HEU) in SNPP systems should be limited to applications for which the mission would not be viable with other nuclear fuels or nonnuclear power sources. Before selecting HEU or, for fission reactor systems, any nuclear fuel other than lowenriched uranium (LEU), for any given SNPP design or mission, the sponsoring agency shall conduct a thorough technical review to assess the viability of alternative nuclear fuels. The sponsoring agency shall provide to the respective staffs of the National Security Council, the National Space Council, the Office of Science and Technology Policy, and the Office of Management and Budget a briefing that provides justification for why the use of HEU or other non-LEU fuel is required, and any steps the agency has taken to address nuclear safety, security, and proliferation-related risks. The Director of the Office of Science and Technology Policy shall ensure, through the National Science and Technology Council, that other relevant agencies are invited to participate in these briefings.

(c) Sustainability. All agencies involved in the development and use of SNPP systems shall take appropriate measures to conduct these activities in a manner that is suitable for the long-term sustainment of United States space capabilities and leadership in SNPP.

(i) Coordination and Collaboration. To maximize efficiency and return on taxpayer investment, the heads of relevant agencies shall seek and pursue opportunities to coordinate among existing and future SNPP development and use programs. Connecting current efforts with likely future applications will help ensure that such programs can contribute to long-term United States SNPP capabilities and leadership. Agencies also shall seek opportunities to partner with the private sector, including academic institutions, in order to facilitate contributions to United States SNPP capabilities and leadership. To help identify opportunities for collaboration, the heads of relevant agencies should conduct regular technical exchanges among SNPP programs, to the extent that such exchanges are consistent with the principle of security and comply with applicable Federal, State, and local laws. Agencies shall coordinate with the Department of State when seeking opportunities for international partnerships.

(ii) Commonality. The heads of relevant agencies shall seek to identify and use opportunities for commonality among SNPP systems, and between SNPP and terrestrial nuclear systems, whenever doing so could advance program and policy objectives without unduly inhibiting innovation or market development, or hampering system suitability to specific mission applications. For example, opportunities for commonality may exist in goals (e.g., demonstration timeline), reactor design, nuclear fuels (e.g., fuel type and form, and enrichment level), supplementary systems (e.g., power conversion, moderator, reflector, shielding, and system vessel), methods (e.g., additive manufacturing of fuel or reactor elements), and infrastructure (e.g., fuel supply, testing facilities, launch facilities, and workforce).

(iii) Cost-effectiveness. The heads of relevant agencies should pursue SNPP development and use solutions that are cost-effective while also consistent with the principles of safety and security. For any program or system, the heads of such agencies should seek to identify the combination of in-space and ground-based testing and certification that will best qualify the system for a given mission while ensuring public safety.

Sec. 4. Roles and Responsibilities. (a) The Vice President, on behalf of the President and acting through the National Space Council, shall coordinate United States policy related to use of SNPP systems.

(b) The Secretary of State shall, under the direction of the President, coordinate United States activities related to international obligations and commitments and international cooperation involving SNPP.

(c) The Secretary of Defense shall conduct and support activities associated with development and use of SNPP systems to enable and achieve United States national security objectives. When appropriate, the Secretary of Defense shall facilitate private-sector engagement in DoD SNPP activities.

(d) The Secretary of Commerce shall promote responsible United States commercial SNPP investment, innovation, and use, and shall, when consistent with the authorities of the Secretary, ensure the publication of clear, flexible, performance-based rules that are applicable to use of SNPP and are easily navigated. Under the direction of the Secretary of Commerce, the Department of Commerce (DOC) shall ascertain and communicate the views of private-sector partners and potential private-sector partners to relevant agency partners in order to facilitate public-private collaboration in SNPP development and use.

(e) The Secretary of Transportation's statutory authority includes licensing commercial launches and reentries, including vehicles containing SNPP systems. Within this capacity, the Secretary of Transportation shall, when appropriate, facilitate private-sector engagement in the launch or reentry aspect of SNPP development and use activities, in support of United States science, exploration, national security, and commercial objectives. To help ensure the launch safety of an SNPP payload, and consistent with 51 U.S.C. 50904, a payload review may be conducted as part of a license application review or may be requested by a payload owner or operator in advance of or apart from a license application.

(f) The Secretary of Energy shall, in coordination with sponsoring agencies and other agencies, as appropriate, support development and use of SNPP systems to enable and achieve United States scientific, exploration, and national security objectives. When appropriate, the Secretary of Energy shall work with sponsoring agencies and DOC to facilitate United States private-sector engagement in Department of Energy (DOE) SNPP activities. Under the direction of the Secretary of Energy and consistent with the authorities granted to DOE, including authorities under the Atomic Energy Act of 1954 (AEA), as amended, 42 U.S.C. 2011, et seq., DOE may authorize ground-based SNPP development activities, including DOE activities conducted in coordination with sponsoring agencies and private-sector entities. As directed in NSPM-20, the Secretary of Energy shall maintain, on a full-cost recovery basis, the capability and infrastructure to develop, furnish, and conduct safety analyses for space nuclear systems for use in United States Government space systems.

(g) The Administrator of NASA shall conduct and support activities associated with development and use of SNPP systems to enable and achieve United States space science and exploration objectives. The Administrator of NASA shall establish the performance requirements for SNPP capabilities necessary to achieve those objectives. When appropriate, the Administrator of NASA shall facilitate private-sector engagement in NASA SNPP activities, and shall coordinate with the Secretary of Commerce and, as appropriate, the Secretary of State and the Secretary of Energy, to help facilitate private-sector SNPP activities.

(h) The Nuclear Regulatory Commission (NRC) has statutory authority under the AEA for licensing and regulatory safety and security oversight of commercial nuclear activities taking place within the United States. The NRC should, as appropriate and particularly in circumstances within NRC authority where DOE regulatory authorities cannot be applied, enable private-sector engagement in SNPP development and use activities in support of United States science, exploration, national security, and commercial objectives.

(i) The Director of the Office and Science and Technology Policy shall coordinate United States policy related to research and development of SNPP systems.

Sec. 5. Roadmap. The United States will pursue a coordinated roadmap for federally-supported SNPP activities to achieve the goals and uphold the principles established in this memorandum. This roadmap comprises the following elements, which the relevant agencies should pursue consistent with the following objective timeline, subject to relevant budgetary and regulatory processes and to the availability of appropriations:

(a) By the mid-2020s, develop uranium fuel processing capabilities that enable production of fuel that is suitable for lunar and planetary surface and in-space power, NEP, and NTP applications, as needed.

(i) Identify relevant mission needs. DoD and NASA should provide to DOE any mission needs (e.g., power density, environment, and timelines) relevant to the identification of fuels suitable for planetary surface and in-space power, NEP, and NTP applications.

(ii) Identify candidate fuel or fuels. DoD and NASA, in cooperation with DOE and private-sector partners, as appropriate, should identify candidate fuel or fuels to meet the identified mission requirements. This review and assessment should account for current and expected United States capabilities to produce and qualify for use candidate fuels, and for potential commonality of fuels or fuel variants across multiple planetary surface and in-space power, in-space propulsion, and terrestrial applications.

(iii) Qualify at least one candidate fuel. DoD and NASA, in cooperation with DOE and private-sector partners, as appropriate, should qualify a fuel or fuels for demonstrations of a planetary surface power reactor and an in-space propulsion system. While seeking opportunities to use private-sector-partner capabilities, agencies should ensure that the Federal Government retains an ability for screening and qualification of candidate fuels.

(iv) Supply fuel for demonstrations. DOE, in cooperation with NASA and DoD, and with private-sector partners, as appropriate, should identify feedstock and uranium that can be made available for planetary surface power and in-space propulsion demonstrations. DOE shall ensure that any provision of nuclear material for SNPP will not disrupt enriched uranium supplies for the United States nuclear weapons program and the naval propulsion program, and that SNPP needs are included among broader considerations of nuclear fuel supply provisioning and management.

(b) By the mid- to late-2020s, demonstrate a fission power system on the surface of the Moon that is scalable to a power range of 40 kWe and higher to support sustained lunar presence and exploration of Mars.

(i) Initiate a surface power project. NASA should initiate a fission surface power project for lunar surface demonstration by 2027, with scalability to Mars exploration. NASA should consult with DoD and other agencies, and with the private sector, as appropriate, when developing project requirements.

(ii) Conduct technology and requirements assessment. NASA, in coordination with DoD and other agencies, and with private-sector partners, as appropriate, should evaluate technology options for a surface power system including reactor designs, power conversion, shielding, and thermal management. NASA should work with other agencies, and private-sector partners, as appropriate, to evaluate opportunities for commonality among other SNPP needs, including in-space power and terrestrial power needs, possible NEP technology needs, and reactor demonstrations planned by NASA, other agencies, or the private sector.

(iii) Engage the private sector. DOE and NASA should determine a mechanism or mechanisms for engaging with the private sector to meet NASA's SNPP surface power needs in an effective manner consistent with the guiding principles set forth in this memorandum. In evaluating mechanisms, DOE and NASA should consider the possibility of NASA issuing a request for proposal for the development and construction of the surface power reactor system or demonstration.

(iv) System development. NASA should work with DOE, and with other agencies and private-sector partners, as appropriate, to develop the lunar surface power demonstration project.

(v) Conduct demonstration mission. NASA, in coordination with other agencies and with private-sector partners, as appropriate, should launch and conduct the lunar surface power demonstration project.

(c) By the late-2020s, establish the technical foundations and capabilities — including through identification and resolution of the key technical challenges — that will enable NTP options to meet future DoD and NASA mission needs.

(i) Conduct requirements assessment. DoD and NASA, in cooperation with DOE, and with other agencies and private-sector partners, as appropriate, should assess the ability of NTP capabilities to enable and advance existing and potential future DoD and NASA mission requirements.

(ii) Conduct technology assessment. DoD and NASA, in cooperation with DOE, and with other agencies and private-sector partners, as appropriate, should evaluate technology options and associated key technical challenges for an NTP system, including reactor designs, power conversion, and thermal management. DoD and NASA should work with their partners to evaluate and use opportunities for commonality with other SNPP needs, terrestrial power needs, and reactor demonstration projects planned by agencies and the private sector.

(iii) Technology development. DoD, in coordination with DOE and other agencies, and with private-sector partners, as appropriate, should develop reactor and propulsion system technologies that will resolve the key technical challenges in areas such as reactor design and production, propulsion system and spacecraft design, and SNPP system integration.

(d) By 2030, develop advanced RPS capabilities that provide higher fuel efficiency, higher specific energy, and longer operational lifetime than existing RPS capabilities, thus enabling survivable surface elements to support robotic and human exploration of the Moon and Mars and extending robotic exploration of the solar system.

(i) Maintain RPS capability. Mission sponsoring agencies should assess their needs for radioisotope heat source material to meet emerging mission requirements, and should work with DOE to jointly identify the means to produce or acquire the necessary material on a timeline that meets mission requirements.

(ii) Engage the private sector. NASA, in coordination with DOE and DOC, should conduct an assessment of opportunities for engaging the private sector to meet RPS needs in an effective manner consistent with the guiding principles established in this memorandum.

(iii) Conduct technology and requirements assessment. NASA, in coordination with DOE and DoD, and with other agencies and private-sector partners, as appropriate, should assess requirements for next-generation RPS systems and evaluate technology options for meeting those requirements.

(iv) System development. DOE, in coordination with NASA and DoD, and with other agencies and private-sector partners, as appropriate, should develop one or more next-generation RPS system or systems to meet the goals of higher fuel efficiency, higher specific energy, and longer operational lifetime for the required range of power.

Sec. 6. Implementation. The Vice President, through the National Space Council, shall coordinate implementation of this memorandum.

Sec. 7. General Provisions. (a) Nothing in this memorandum shall be construed to impair or otherwise affect:

(i) the authority granted by law to an executive department or agency, or the head thereof; or

(ii) the functions of the Director of the Office of Management and Budget relating to budgetary, administrative, or legislative proposals.

(b) This memorandum shall be implemented consistent with applicable law and subject to the availability of appropriations.

(c) This memorandum is not intended to, and does not, create any right or benefit, substantive or procedural, enforceable at law or in equity by any party against the United States, its departments, agencies, or entities, its officers, employees, or agents, or any other person.

(d) The Secretary of Energy is authorized and directed to publish this memorandum in the Federal Register.

Donald J. Trump

Appendix E-2

Memorandum on Space Policy Directive-7

The United States Space-Based Positioning, Navigation, and Timing Policy

Issued on January 15, 2021

MEMORANDUM FOR THE VICE PRESIDENT

THE SECRETARY OF STATE
THE SECRETARY OF DEFENSE
THE ATTORNEY GENERAL
THE SECRETARY OF THE INTERIOR
THE SECRETARY OF COMMERCE
THE SECRETARY OF TRANSPORTATION
THE SECRETARY OF ENERGY
THE SECRETARY OF HOMELAND SECURITY
THE DIRECTOR OF THE OFFICE OF MANAGEMENT AND BUDGET
THE DIRECTOR OF NATIONAL INTELLIGENCE
THE ASSISTANT TO THE PRESIDENT FOR NATIONAL SECURITY AFFAIRS
THE ADMINISTRATOR OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
THE CHAIRMAN OF THE JOINT CHIEFS OF STAFF
THE CHAIRMAN OF THE FEDERAL COMMUNICATIONS COMMISSION

SUBJECT: Space Policy Directive 7, The United States Space-Based Positioning, Navigation, and Timing Policy

This Space Policy Directive establishes implementation actions and guidance for United States space-based positioning, navigation, and timing (PNT) programs and activities for United States national and homeland security, civil, commercial, and scientific purposes. This policy complements the guidance set forth in Executive Order 13905 of February 12, 2020 (Strengthening National Resilience through Responsible Use of Positioning, Navigation, and Timing Services), and the intersector guidance for Global Navigation Satellite Systems (GNSS) included in the December 9, 2020, National Space Policy. This policy supersedes National Security Presidential Directive-39 (NSPD-39) of December 15, 2004 (United States Space-Based Positioning, Navigation, and Timing Policy).

Section 1. Scope. This policy directive provides guidance for:

(a) sustainment and modernization of the Global Positioning System (GPS) and federally developed, owned, and operated systems used to augment or otherwise improve GPS;

(b) implementation and operation of capabilities to protect United States and allied access to and use of GPS for national, homeland, and economic security, and to deny adversaries hostile applications use of United States space-based PNT services; and

(c) United States participation in international cooperative initiatives regarding foreign space-based PNT services and foreign use of GPS and its augmentations.

Sec. 2. Definitions. For purposes of this document:

(a) "PNT service" refers to any system, network, or capability that provides a reference to calculate or augment the calculation of longitude, latitude, altitude, or transmission of time or frequency data, or any combination thereof.

(b) "Primary PNT Service" refers to an independent PNT service chosen by a user or system operator as the preferred source of PNT information. A primary PNT service is expected to provide sufficient accuracy, availability, integrity, or other characteristics important to the user.

(c) "Augmentation" refers to any system that provides users of PNT signals with additional information that enables users to obtain enhanced performance when compared to the un-augmented signals from a primary PNT service alone. These improvements include improved accuracy, availability, integrity, and reliability, and independent integrity monitoring and alerting capabilities for critical applications. Augmentation systems inherently rely on a primary PNT service to operate.

(d) "Alternative PNT Service" refers to a PNT service that has the capability to operate completely independent of, or in conjunction with, other PNT services. Multiple, varied PNT services used in combination may provide enhanced security, resilience, assurance, accuracy, availability, and integrity. An alternative PNT service allows a user to transition from the primary source of PNT signals in the event of a disruption or manipulation.

(e) "Interoperable" refers to the ability of multiple, independent PNT services and their augmentations to be used together to provide better capabilities at the user level than would be achieved by relying solely on a single service or signal.

(f) "Compatible" refers to the ability of multiple, independent PNT services and their augmentations to be used separately or in combination with each other without interfering with any individual service, and without adversely affecting the United States and allied military employment of PNT, commonly referred to as Navigation Warfare.

(g) "Navigation Warfare" or "NAVWAR" refers to the deliberate defensive and offensive action to assure and prevent positioning, navigation, and timing information through coordinated employment of space, cyberspace, and electronic warfare. Desired effects are generated through the coordinated employment of components within information operations, space operations, and cyberspace operations, including electronic warfare, offensive and defensive space operations, and computer network operations.

Sec. 3. Background. The multi-use services provided by GPS are integral to United States national security, economic growth, transportation safety, and homeland security. These services are essential but largely invisible elements of worldwide economic infrastructures.

(a) Responsible use of Space–Based PNT.

(i) GPS is a key component of multiple sectors of United States critical infrastructure, as identified in Presidential Policy Directive-21 (PPD-21) of February 12, 2013 (Critical Infrastructure Security and Resilience) and stated in EO 13905. Cascading effects from extended PNT service disruption or denial can adversely affect all sectors. Autonomous vehicles on land, sea, and air have begun to rely on GPS for navigation, positional awareness, and other vehicle capabilities. Additionally, many information systems rely on the GPS timing signal to enable both fixed and mobile communications. An extended outage of GPS, or extended period of spoofed or manipulated GPS signals, could cause severe economic losses and put lives at risk.

(ii) GPS remains critical to United States national security. Its applications are integrated into virtually every facet of United States military operations. United States and allied military forces will continue to equip and train for the responsible use of GPS and alternative PNT services to support mission operations.

(iii) The widespread and growing dependence on GPS by military, civil, and commercial applications, systems, and infrastructure make the performance of many of these systems inherently vulnerable if disruption or manipulation of GPS signals were to occur. GPS users must plan for potential signal loss and take reasonable steps to verify or authenticate the integrity of the received GPS data and ranging signal, especially in applications where even small degradations can result in loss of life. In addition, whether designed for military capabilities or not, signals from PNT services and their augmentations provide inherent capabilities that may be used by adversaries, including enemy military forces and terrorist groups.

(b) Space Applications. Applications for GPS now extend beyond Earth. The Terrestrial Service Volume of GPS, defined as the volume from the ground to an altitude of 3,000 kilometers, has become an integral component for space launch operations. Use of GPS is expanding into the Space Service Volume (SSV), which extends from 3,000 km to geosynchronous Earth orbit (GEO), despite reduced line-of-sight visibility and lower received signal power. Satellites rely on GPS for navigation, attitude control, space situational awareness, and new space science applications such as radio occultation. Consistent with Space Policy Directive-1 (SPD-1) of December 11, 2017 (Reinvigorating American's Human Space Exploration Program) and Space Policy Directive-3 (SPD-3) of June 18, 2018 (National Space Traffic Management Policy) PNT services will also play an important role in space traffic management and future applications in the Cislunar Service Volume, which extends from GEO out to and including the Moon's orbit. For requirements necessary to support these emerging applications, agencies should coordinate through standard GPS requirements processes.

(c) Foreign Space-Based PNT. Emerging foreign space-based PNT services could enhance or undermine the future utility of GPS. The United States will continue to encourage the development of foreign space-based PNT services based on GPS and their responsible use in non-military applications with allied and likeminded nations. Use of multiple, varied PNT services can result in better performance in terms of user accuracy, availability, and resilience. However, the United States Government does not assure the reliability or authenticity of foreign PNT services. Although foreign space-based PNT services may be used to complement civil GPS service, receiver manufacturers should continue to improve security, integrity, and resilience in the face of growing cyber threats. Thus, incorporation of foreign PNT in multi-constellation devices should be designed in a manner that precludes potential degradation of essential user capabilities resulting from possible foreign global navigation satellite system (GNSS) origins. The United States will maintain awareness of the risks and potential benefits associated with the use of foreign space-based PNT services and continue to promote and support the responsible use of GPS as the pre-eminent space-based PNT service.

(d) United States Policy and Management Framework.

(i) The United States continues to improve and maintain GPS and its augmentations to meet growing national, homeland, and economic security requirements as well as other civil requirements, and to enable diverse commercial and scientific applications. In parallel, the United States continues to improve capabilities to deny adversary access to space-based PNT services, particularly including services that are openly available and can be readily used by adversaries or terrorists, to threaten the security of the United States. The United States is addressing risks associated with dependence on space-based PNT and fostering responsible use approaches to PNT service acquisition, integration, and deployment across critical infrastructures. The United States is also encouraging the development of alternative approaches to PNT services and security that can incorporate new technologies and services as they are developed, such as quantum sensing, relative navigation and private or publicly owned and operated alternative PNT services.

(ii) The diverse requirements for and multiple applications of space-based PNT services require stable yet adaptable policies and management mechanisms. Therefore, the United States Government will continue to support a policy and management framework governing GPS and its augmentations that meets increasing and varied domestic and global requirements.

Sec. 4. Policy Goals and Guidance. The goal of this policy is to maintain United States leadership in the service provision, and responsible use of global navigation satellite systems, including GPS and foreign systems. To this end, the United States Government shall:

(a) Provide continuous worldwide access to United States space-based GPS services and government-provided augmentations, free of direct user fees, and provide open, free access to information necessary to develop and build equipment to use these services;

(b) Operate and maintain the Global Positioning System in accordance with United States law to satisfy civil, homeland security, and national security needs, consistent with published performance standards and interface specifications;

(c) Improve NAVWAR capabilities to deny hostile use of United States Government space-based PNT services, without unduly disrupting civil and commercial access to civil PNT services outside an area of military or homeland security operations;

(d) Improve the performance of United States space-based PNT services, including developing more robust signals that are more resistant to disruptions and manipulations consistent with United States and allied national security, homeland security, and civil purposes;

(e) Improve the cybersecurity of GPS, its augmentations, and United States Government owned GPS-enabled devices, and foster private sector adoption of cyber-secure GPS enabled systems through system upgrades and incorporation of cybersecurity principles for space systems, interface specifications, and other guidance that prescribes cybersecurity for user equipment;

(f) Protect the spectrum environment that is currently used by GPS and its augmentations, and work with United States industry to investigate additional areas of the radio spectrum which could increase GPS and PNT resilience;

(g) Invest in domestic capabilities and support international activities to detect, mitigate, and increase resilience to harmful disruption or manipulation of GPS, and identify and implement, as appropriate, alternative sources of PNT for critical infrastructure, key resources, and mission-essential functions;

(h) Maintain GPS and its augmentations for use by United States critical infrastructure to enhance safety of life functions and operational efficiency, consistent with PPD-21;

(i) Engage with international GNSS providers to ensure compatibility, encourage interoperability with likeminded nations, promote transparency in civil service provision, and enable market access for United States industry. Encourage foreign development of PNT services and systems based on GPS and the inclusion of GPS as an essential element in systems that integrate multiple PNT services. At a minimum, seek to ensure that all foreign systems are compatible with GPS and its augmentations, that they do not interfere with GPS military and civil signals, and that mutual security concerns are addressed to prevent hostile use of United States space-based PNT services;

(j) Promote the responsible use of United States space-based PNT services and capabilities for applications at the Federal, State, and local level, consistent with Executive Order 13905; and

(k) Promote United States technological leadership in the provision of space-based PNT services and in the development of secure and resilient end user equipment.

Sec. 5. Management of Space-Based PNT Services.

(a) The National Space-Based Positioning, Navigation, and Timing Executive Committee (Executive Committee) is the interagency body responsible for guiding and preserving whole-of-government interests in the provision of space-based PNT services, augmentations, and space-based alternatives. The Deputy Secretaries of the Department of Defense and the Department of Transportation, or their designated representatives, shall co-chair the Executive Committee.

(b) In addition to the Co-Chairs, the members of the Executive Committee shall be at the deputy secretary level or equivalent from the Department of State, the Department of the Treasury, the Department of Justice, the Department of the Interior, the Department of Agriculture, the Department of Commerce, the Department of Energy, the Department of Homeland Security, the Office of the Director of National Intelligence, the Joint Chiefs of Staff, the National Aeronautics and Space Administration, or their designated representatives, and the heads of other executive departments and agencies (agencies) invited by the Co-Chairs. The Administrator of the National Telecommunications and Information Administration shall serve as an ex officio member consistent with the Administrator's duties to advise the President on telecommunications and information policy issues.

(c) Components of the Executive Office of the President, including the Office of Management and Budget, the National Space Council staff, the National Security Council staff, the Office of Science and Technology Policy, and the National Economic Council staff, may participate by invitation of the Co-Chairs as observers and advise the Executive Committee on Presidential policy implications. The Chairman of the National Space-Based Positioning, Navigation, and Timing Advisory Board (or designated representative) shall be invited in an advisory role representing non-governmental considerations. The Co-Chairs may also invite the Chairman of the Federal Communications Commission to participate on the Executive Committee as appropriate. The Executive Committee shall convene at least once each year and as required on the advice of the Executive Steering Group, as described in Section 5(e).

(d) The Executive Committee shall make recommendations on sustainment, modernization, and policy matters regarding United States space-based PNT services to its member agencies, and to the President, through the Assistant to the President for National Security Affairs, or the Executive Secretary of the National Space Council, as appropriate. In addition, the Executive Committee will advise and coordinate with and among the agencies responsible for the strategic decisions regarding policies to maintain and improve United States leadership in the provision of space-based PNT infrastructures and services, including GPS, its augmentations and United States Government owned and operated space-based PNT systems and applications, security for these services, and their relationships with foreign space-based PNT services. Specifically, the Executive Committee shall:

(i) Ensure that national security, homeland security, and civil requirements receive full and appropriate consideration in the decision-making process and facilitate the integration and deconfliction of these requirements for space-based PNT capabilities, as required;

(ii) Coordinate individual Departments' and Agencies' space-based PNT program plans, requirements, budget considerations and policies;

(iii) Every four years provide the Executive Secretary of the National Space Council a report assessing current and planned civil space-based PNT services and whether they are projected to remain competitive with foreign space-based PNT services;

(iv) Promote, review, and implement plans to modernize United States space-based PNT infrastructure and services, including development, deployment, and operation of new or improved, or both, national security and public safety services;

(v) In coordination with the Office of Science and Technology Policy, promote research and development on next-generation technologies and on workforce development to ensure continued United States leadership in space-based PNT technologies;

(vi) Review proposals from and provide recommendations to agencies for international cooperation in coordination with the Department of State, as well as PNT spectrum management and protection issues in coordination with the Department of Commerce; and

(vii) Maintain and receive advice from the National Space-Based Positioning, Navigation, and Timing Advisory Board (Advisory Board). The Advisory Board shall be composed of experts from outside the United States Government, and shall be chartered as a Federal Advisory Committee. The Advisory Board shall seek input from state and local governments, industry, and academia on developments in the application of space-based PNT technologies and advise the Executive Committee on policy and service impacts.

(e) The Executive Committee shall maintain an Executive Steering Group composed of officials designated by the agencies that constitute the Executive Committee. The Executive Steering Group shall meet as needed to determine tasks and topics that require consideration of the Executive Committee. The agenda for Executive Steering Group meetings shall be approved by steering group members or their designees in advance. The Executive Steering Group, operating on a consensus basis, shall build consensus and work to resolve issues on behalf of the Executive Committee while establishing priorities and deconflicting tasks across the interagency members and the National Space-Based Positioning, Navigation, and Timing Coordination Office. When the Executive Steering group members cannot achieve consensus on proposals, budget recommendations, or policy, or in the event of critical events affecting United States space-based PNT architecture or services, the group shall recommend supplemental meetings of the Executive Committee to address relevant issues.

(f) The National Space-Based Positioning, Navigation, and Timing Coordination Office (NCO) shall support the meetings and functions of the Executive Committee and Executive Steering Group. It shall be led by a full-time Director assigned from the Senior Executive Service from an agency other than the Department of Defense, and include a Deputy Director assigned from the Department of Defense. Agencies represented on the Executive Committee shall assign staff to the NCO, as appropriate and consistent with applicable law, on a defined duration as required for task completion with appropriate technical expertise. The Executive Committee shall determine the resources for the NCO, including funding, location, staffing, and composition, consistent with this directive.

(g) The NCO shall serve as the Secretariat for the Executive Committee and shall perform functions delegated by the Executive Committee and Executive Steering Group. Agencies shall provide appropriate information to the NCO to ensure interagency transparency about space-based PNT programs, plans, policies, budget allocations, and activities affecting mutual interests or interagency dependencies. The NCO will coordinate the development and dissemination of strategic messaging and educational materials to support trust and adoption of United States space-based PNT services.

(h) The Executive Committee shall advise on and coordinate the interdepartmental resource allocation for GPS and its augmentations. The Secretary of Defense shall have primary responsibility for providing resources for development, acquisition, operation, sustainment, and modernization of GPS. The Secretary of Transportation shall continue to provide resources to the Secretary of Defense for assessment, development, acquisition, implementation, operation, and sustainment of GPS civil signal performance monitoring and any additional designated GPS civil capabilities that have exclusively civil (non-military) application consistent with interagency agreements. GPS augmentations and other unique PNT capabilities shall be funded by any agency requiring those services or capabilities, including out-year procurement and operations costs. Any new technical features proposed and funded by the civil agencies shall not unduly degrade or displace existing or planned national security functions of GPS. Resource issues will be resolved through the regular budget process.

(i) Within 120 days of publication of this directive, the Executive Committee shall publish an implementation plan to enact over a five-year period all provisions of this directive. Further, the Executive Committee will update the charter of both the Executive Committee, Executive Steering Group, and NCO consistent with the provisions within this Directive.

Sec. 6. Foreign Access to United States Space-based PNT Capabilities.

(a) Exports of any United States PNT capabilities included on the United States Munitions List or the Commerce Control List will continue to be licensed pursuant to the International Traffic in Arms Regulations or the Export Administration Regulations, as appropriate, and in accordance with all existing laws and regulations. Export controls shall be updated to ensure that unnecessary controls that undermine or restrict the resilience and global use of civil GPS are reduced or eliminated without compromising United States navigation warfare, national security, or homeland security.

(b) As a general guideline, most exports of civil, mass-market space-based PNT capabilities that are currently available or are planned to be available in the global marketplace will continue to be considered favorably. Exports of sensitive dual-use or advanced PNT information, systems, technologies, and components will be considered on a case-by-case basis in accordance with existing laws and regulations, as well as relevant national security and foreign policy goals and considerations.

Sec. 7. Agency Roles and Responsibilities. Agencies shall allocate the resources required to fulfill the objectives of this policy, subject to the availability of funds appropriated for that purpose.

(a) The Secretary of State shall:

(i) In cooperation with the Secretary of Defense, the Secretary of Transportation and the heads of other appropriate agencies, promote the use of GPS and its augmentation services and standards with foreign governments and other international organizations, and encourage the development of foreign civil PNT services and systems based on GPS;

(ii) Take the lead for negotiating with foreign governments and international organizations regarding civil and, as appropriate and in coordination with the Secretary of Defense, military PNT matters, including coordinating interagency review of:

(A) Instructions to United States delegations for bilateral and multilateral consultations relating to the planning, management, and use of GPS, other global and regional navigation satellite systems, and their augmentation systems;

(B) International agreements, arrangements, and public statements with foreign governments and international organizations regarding the planning, operation, management, or use of GPS, other global and regional navigation satellite systems, and their augmentation systems; and

(iii) Participate with the Secretary of Defense in PNT dialog with allies, especially NATO relations.

(b) The Secretary of Defense shall:

(i) Have responsibility for the development, acquisition, operation, security, and continued modernization of GPS, while facilitating appropriate civil and homeland security representation and participation in these activities and any decisions that affect civil and homeland security equities;

(ii) Develop, acquire, operate, realistically test, evaluate, and maintain NAVWAR capabilities and other capabilities required to:

(A) Effectively utilize GPS services in the event of an adversary or other jamming, disruption, or manipulation;

(B) Develop effective measures to counter adversary efforts to deny, disrupt, or manipulate PNT services;

(C) Identify, locate, and mitigate, in coordination with other agencies, as appropriate, any intentional disruption or manipulation that adversely affects use of GPS for military operations;

(iii) Ensure the earliest operational availability for modernized military and NAVWAR capabilities;

(iv) Train, equip, test, and exercise United States military forces and national security capabilities in operationally realistic conditions that include denial or degradation of GPS. In cooperation with the Secretary of Transportation and the Secretary of Homeland Security, and as appropriate, with the Secretary of State, develop guidelines that facilitate these activities and NAVWAR training, testing, demonstrations, and exercises without unduly disrupting or degrading homeland security and civil services and operations, either internationally or domestically;

(v) Encourage use of GPS national security services by allied military forces to facilitate interoperability between United States and allied forces and capabilities, and to maintain their use as the pre-eminent military space-based PNT capability;

(A) Consistent with the guidance in Section 6 of this directive, make GPS national security services, user equipment, information, and technology available for use by allied military forces; and

(B) Work with allies to monitor access to national security services and user equipment to limit the potential for adversaries to use these capabilities against United States and allied military forces;

(vi) Maintain the commitment to discontinue the use of the feature known as Selective Availability;

(vii) In coordination with the Department of Transportation, maintain safety-of-life backwards compatibility commitments to enable continued international acceptance of civil and military GPS PNT services in civil airspace;

(viii) Facilitate access to appropriate levels of national security services and user equipment at the Federal level to meet critical requirements for emergency response and other homeland security purposes, and, on an exceptional basis, for civil purposes, including State or local emergency response in accordance with established memorandums of understanding;

(ix) Develop improved and dedicated national security PNT capabilities, including more diverse, flexible, and capable signals and services;

(x) In coordination with the Secretary of Transportation, provide estimates of GPS program costs based on the Department of Transportation's strategy and future requirements to implement GPS data and signal authentication and reflect strategy consistent with the Federal Radio Navigation Plan or its successor;

(xi) Maintain lead responsibility for negotiating with foreign defense organizations for any cooperation regarding access to or information about GPS military services;

(xii) In cooperation with other agencies, as appropriate, assess the utility and feasibility of hosting secondary payloads on GPS satellites, including those intended to enhance global search and rescue capabilities for all users. No secondary payload may adversely affect the performance, schedule, or cost of GPS, or its signals or services. Resources required for the assessment, development, acquisition, integration, and operation of secondary payloads shall be the responsibility of the sponsoring agency or agencies; and

(xiii) In coordination with the Secretary of State and the Secretary of Commerce, and with all agencies who are members of the Executive Committee having been notified, maintain the Department of Defense's lead responsibility for Radio Frequency compatibility coordination with other Radio Navigation Satellite Services (RNSS) who operate or intend to operate in the RNSS radio frequency bands utilized by GPS.

(c) The Secretary of Commerce shall:

(i) Promote United States industry access to foreign markets for space-based PNT goods and services while adopting a risk management approach to United States national security concerns;

(ii) Invest in research and development on next-generation technologies that could enhance GPS applications for commercial use;

(iii) Represent United States commercial interests with other agencies in the requirements review of GPS and its related augmentations;

(iv) In coordination with the Secretary of State, the Secretary of Defense, the Secretary of Transportation, and the Administrator of the National Aeronautics and Space Administration, seek to protect the radio frequency spectrum used by GPS and its augmentations through appropriate domestic and international spectrum management and regulatory practices;

(v) In coordination with the Secretary of Defense, the Secretary of Transportation, the Secretary of Homeland Security, and the Administrator of the National Aeronautics and Space Administration, facilitate cooperation between the United States Government and the United States private sector as appropriate to identify mutually acceptable solutions that will preserve existing and evolving uses of space-based PNT services, while allowing for the development of other non-interfering technologies and services that depend on use of the radio frequency spectrum;

(vi) In cooperation with the Administrator of the National Aeronautics and Space Administration, develop, and provide to the Secretary of Transportation, requirements for use of GPS and its augmentations to support civil space systems; and

(vii) In cooperation with the heads of other agencies, as appropriate, develop guidelines to improve the cybersecurity of PNT devices, including their capability to detect and reject manipulated or counterfeit signals, and promote the responsible use of space-based PNT services and capabilities for applications that support national security, economic growth, transportation safety, and homeland security as directed in Executive Order 13905.

(d) The Secretary of Transportation shall:

(i) Have lead responsibility for the development of requirements for civil applications from all United States Government civil agencies;

(ii) Ensure, in coordination with the Secretary of Defense and the Secretary of Homeland Security, the performance monitoring of United States civil space-based PNT services;

(iii) Consistent with the guidance in section 6 of this directive, and in coordination with the Secretary of State, facilitate international participation in the development of civil transportation applications using United States space-based PNT services;

(iv) Consistent with the background provided in section 3 of this directive, and in coordination with the Secretary of State and the Secretary of Defense, ensure that international transportation initiatives consider the dual-use nature of space-based PNT services, particularly including services that are openly available and can be readily used by adversaries or terrorists to threaten the security of the United States;

(v) Ensure, in coordination with the Secretary of Defense, that public safety service applications based on United States space-based PNT services meet or exceed internationally recognized standards as required to meet mission requirements, including those used for aviation, maritime, and surface transportation applications;

(vi) In cooperation with the heads of other agencies, as appropriate, promote the responsible use of United States and foreign civil space-based PNT services and capabilities for transportation safety as directed in EO 13905;

(vii) Represent the civil agencies in the development, acquisition, management, and operations of GPS and its augmentations;

(viii) In coordination with the Secretary of Defense and the Secretary of Homeland Security and the heads of other agencies, as appropriate, implement Federal and facilitate State, local and commercial capabilities to monitor, identify, locate, and attribute space-based PNT service disruption and manipulations within the United States that adversely affect use of space-based PNT for transportation safety, homeland security, civil, commercial, and scientific purposes;

(ix) Ensure the earliest operational availability for modernized civil signals and services on GPS and its augmentations, in coordination with the Secretary of Defense;

(x) In coordination with the Secretary of Defense, assess and assist, as appropriate, in the international acceptance of using the military PNT services of GPS for operations in civil airspace;

(xi) Facilitate international coordination for the development of monitoring standards for space-based PNT services;

(xii) Maintain awareness of the risks and potential benefits associated with the use of foreign space-based PNT services, and

(xiii) In coordination with the Secretary of Defense and the Secretary of Homeland Security, develop and validate requirements and a funding strategy to implement data and signal authentication of civil GPS and wide area augmentations for homeland security and public safety purposes consistent with the Federal Radionavigation Plan or its successor plan.

(e) The Secretary of Homeland Security shall:

(i) Identify space-based PNT requirements for homeland security purposes to the Secretary of Transportation;

(ii) In coordination with the Secretary of Transportation, and with the heads of other agencies, as appropriate, promote the responsible use of GPS and other PNT services, consistent with EO 13905;

(iii) In coordination with the Secretary of Defense and the Secretary of Transportation, and in cooperation with the Secretary of Commerce:

(A) Ensure that mechanisms are in place to monitor, identify, locate, and attribute space-based PNT service disruptions and manipulations within the United States that can cause significant disruption to United States critical infrastructure and scientific purposes; and

(B) Develop procedures to notify the civil sectors and Federal, State, local, territorial and tribal agencies when space-based services have anticipated disruptions or are deemed to be no longer reliable.

(iv) In coordination with the Secretary of Defense, the Secretary of Commerce, and the Secretary of Transportation, develop and maintain capabilities, procedures, and techniques for, and routinely exercise, civil contingency responses to ensure continuity of operations in the event that access to GPS services are disrupted or manipulated;

(v) In coordination with the Secretary of Defense and the Secretary of Transportation, and in cooperation with the heads of other agencies, as appropriate, coordinate the use of existing and planned capabilities to identify, locate, and attribute any disruption or manipulation of GPS and its augmentations within the United States that significantly affects homeland security or critical infrastructure;

(vi) In coordination with the Secretary of Transportation, provide to the Executive Committee resourcing recommendations based on the Department of Transportation's strategy and future requirements to implement data and signal authentication and reflect that strategy consistent with the Federal Radionavigation Plan or its successor plan;

(vii) In coordination with the Secretary of Defense, the Secretary of Transportation, and the Director of National Intelligence, promptly notify the Secretary of Defense, the Administrator of the National Telecommunications and Information Administration, the Chairman of the Federal Communications Commission, the Director of National Intelligence, and the heads of other relevant agencies in cases of significant domestic or international disruption to or manipulation of United States space-based PNT services to enable appropriate investigation, notification, or enforcement action.

(f) The Director of National Intelligence shall identify, monitor, and assess the development of foreign threats to the use of GPS PNT architectures and related services, and provide information to assist the Secretary of Defense in development of countermeasures.

(g) The Administrator of the National Aeronautics and Space Administration shall:

(i) In cooperation with the Secretary of Commerce, develop and provide to the Secretary of Transportation technical requirements for the use of GPS and its augmentations to support civil and commercial space systems;

(ii) In cooperation with the Secretary of Defense, the Secretary of Commerce, and the Secretary of Transportation, develop requirements for GPS support of space operations and science in higher orbits within the SSV and beyond to cislunar space; and

(iii) In cooperation with the Secretary of State, the Secretary of Defense, the Secretary of Commerce, and the Secretary of Homeland Security, sustain and modernize search and rescue and distress alert and location capabilities and programs that operate as secondary payloads on GPS satellites.

Sec. 8. Notification of Harmful Disruption or Manipulation. Agencies detecting or receiving domestic or international reports of harmful disruption or manipulation of United States space-based PNT services shall provide timely reports to the Secretary of Homeland Security, the Secretary of Defense, the Secretary of Transportation, and the Director of National Intelligence. Upon notification:

(a) The Secretary of Commerce, and the Chairman of the Federal Communications Commission in cooperation with the heads of other agencies as appropriate, shall take appropriate and legally permissible actions required to mitigate harmful disruption or manipulation of United States space-based PNT services within the United States.

(b) The Secretary of State shall, as appropriate, notify or coordinate the notification of foreign governments and international organizations in the event of harmful disruption or manipulation of United States space-based PNT services caused by foreign government or commercial activities.

(c) The Secretary of Homeland Security, when appropriate, shall notify the civil sectors and United States Government agencies of the disruption.

Sec. 9. General Provisions. (a) Nothing in this directive shall be construed to impair or otherwise affect:

(i) the authority granted by law to an executive department or agency, or the head thereof; or

(ii) the functions of the Director of the Office of Management and Budget relating to budgetary, administrative, or legislative proposals.

(b) This directive shall be implemented consistent with applicable law and subject to the availability of appropriations.

(c) This directive is not intended to, and does not, create any right or benefit, substantive or procedural, enforceable as law or in equity by any party against the United States, its departments, agencies, or entities, its officers, employees, or agents, or any other person.

Donald J. Trump

ACRONYMS

3DEP	3D Elevation Program

A

AAM	Advanced Air Mobility
ABC	Agency Baseline Commitment
ACCESS	Advanced Communications Capabilities for Exploration and Science Systems
ACCESS	Advanced Computational Center for Entry System Simulation
ACD	Artemis Campaign Development
ACEP-ALE	Agricultural Conservation Easement Program–Agricultural Land Easements
ACEP-WRE	Agricultural Conservation Easement Program–Wetland Reserve Easements
ACO	Announcement of Collaboration Opportunity
ACS3	Advanced Composite Solar Sail System
ADO	Architecture Development Office
AEA	Albers Equal Area
AEHF	Advanced Extremely High Frequency
AEOIP	Applied Earth Observations Innovation Partnership
AES	Advanced Exploration Systems
AF	acre-feet
AFPP	Announcements for Partnership Proposals
AFRL	Air Force Research Laboratory
AFSPC	Air Force Space Command
AGS	Atmospheric and Geospace Sciences
AHE	Advanced Hawkeye
AI&T	assembly, integration, and test
AIM	Assessment, Inventory, and Monitoring
Air-LUSI	Airborne LUnar Spectral Irradiance
AIS	Automated Information System
AIT	American Institute in Taiwan
ALE	Air Launched Effects
ALIGNS	Airborne Location Integrating Geospatial Navigation System
ALMA	Atacama Large Millimeter/Submillimeter Array
AM	additive manufacturing
AM Bench	Additive Manufacturing Benchmark
AMAPPS	Atlantic Marine Assessment Program for Protected Species
AMEC	Alaska Mapping Executive Committee
AMOS	Advanced Maui Optical and Space Surveillance Technologies
AMPERE	Active Magnetosphere and Planetary Electrodynamics Response Experiment
AMS	Alpha Magnetic Spectrometer
AMS	Automated Modular Sensor
AMSR	Advanced Microwave Scanning Radiometer
ANE	Airborne Network Extension
AO	Arecibo Observatory
AOR	Area of Responsibility
APM	Airborne Particulate Monitor
ARC	Aviation Rulemaking Committee
ARCN	Arctic Inventory and Monitoring Network
ARD	Analysis Ready Data

ARM	Atmospheric Radiation Measurement
ARMD	Aeronautics Research Mission Directorate
ARS	Agricultural Research Service
AS	Atmospheric Section
ASA	Australian Space Agency
ASAT	anti-satellite
ASB	Agricultural Statistics Board
ASCENT	Advanced Spacecraft Energetic Non-Toxic
ASCR	Advanced Scientific Computing Research
ASE	Aviation Survivability Equipment
ASEAN	Association of Southeast Asian Nations
ASI	Agenzia Spaziale Italiana
ASIC	Application Specific Integrated Circuit
AST	Division of Astronomical Sciences
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASU	Aircraft Sector Understanding
ASuW	Anti-Surface Warfare
ATF	Armstrong Test Facility
ATIRCM	Advanced Threat Infrared Countermeasures
ATLAS	Advanced Tracking and Launch Analysis System
ATMS	Advanced Technology Microwave Sounder
ATR	Advanced Test Reactor
AVC/ESC	Office of Emerging Security Challenges Bureau of Arms Control, Verification and Compliance
AVSED	Aviation and Space Education

B

BAER	Burned Area Emergency Response
BCR	bird conservation region
BIA	Bureau of Indian Affairs
BICEP	Background Imaging of Cosmic Extragalactic Polarization
BIG	Breakthrough, Innovative, and Game-changing
BIL	Bipartisan Infrastructure Law
BIS	Bureau of Industry and Security
BLM	Bureau of Land Management
BLOS	beyond line-of-sight
BLT	ballistic lunar transfer
BMC3	Battle Management, Command, Control, and Communications
BNL	Brookhaven National Laboratory
BoD	Board of Directors
BOEM	Bureau of Ocean Energy Management
BOR	Bureau of Reclamation
BPA	Brine Processor Assembly
BPSD	Biological and Physical Sciences Division
BPTF	Blossom Point Test Facility
BVLOS	beyond visual line-of-sight

C

C2	Command and Control
C&N	communication and navigation
CAL	Cold Atom Lab
CAPS	Control and Planning Segment
CAPSTONE	Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment

CASIS	Center for the Advancement of Science in Space
CASSA	Cross-Artemis Site Selection Analysis Team
CCMD	Combatant Command
CCOR	Compact Coronagraph
CCP	Commercial Crew Program
CCS	Counter Communications System
CCSDS	Consultative Committee for Space Data Systems
CCSFS	Cape Canaveral Space Force Station
CDL	Cropland Data Layer
CDO	Contested Degraded and Operationally Limited
CDP	Commercial Data Program
CDR	Critical Design Review
CEOS	Committee on Earth Observations
CEPS	Center for Earth and Planetary Studies
CESD	Common Exploration Systems Development
CfA	Center for Astrophysics | Harvard & Smithsonian
CFM	Cryogenic Fluid Management
CFT	Crew Flight Test
CGMS	Consultative Group on Meteorological Satellites
CHAPEA	Crew Health and Performance Exploration Analog
CHM	canopy height model
CIF	Center Innovation Fund
CIRCM	Common Infrared Countermeasure
CLD	Commercial LEO Destinations
CLEEN	Continuous Lower Energy, Emissions, and Noise
CLICK	CubeSat Laser Infrared CrosslinK
CLPS	Commercial Lunar Payload Services
CLTV	cislunar transit vehicle
CM	countermeasures
CMB	cosmic microwave background
CMS	Carbon Monitoring System
CMWS	Common Missile Warning System
CNES	Centre National d'Études Spatiales
CO_2	carbon dioxide
COCOM	Combatant Command
COFFIES	Consequences Of Fields and Flows in the Interior and Exterior of the Sun
COMSATCOM	Commercial SATCOM
CONUS	continental United States or conterminous United States
COSADA	COSMO Site and Design Advancement
COSAS	Commercial SAR and Scatterometry
COSI	Compton Spectrometer and Imager
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
COSMIC-2	Constellation Observing System for Meteorology, Ionosphere and Climate 2
COSMO	Coronal Solar Magnetism Observatory
COVID-19	coronavirus disease 2019
COWVR	Compact Ocean Wind Vector Radiometer
CP2MRS	Compact Passive Polarimetric Microwave Radiometer and Sounder
CPOD	CubeSat Proximity Operations Demonstration
CPS	Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference
CPT	Command Post Terminals
CrIS	Cross-track Infrared Sounder
CRP	Constant Rate Production
CRS	Commercial Resupply Services
CSA	Canadian Space Agency
CSF	Cybersecurity Framework

CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSLI	CubeSat Launch Initiative
CTIM	Compact Total Irradiance Monitor
CVN	aircraft carriers with nuclear propulsion
CVW	Carrier Air Wing
CWDP	Commercial Weather Data Pilot

D

D-RATS	Desert Research and Technology Studies
DAF	Department of the Air Force
DARC	Deep Space Advanced Radar Capability
DARPA	Defense Advanced Research Projects Agency
DART	Double Asteroid Redirection Test
DCCS	Dream Chaser Cargo System
DCS	Data Collection and location System
DEM	digital elevation model
DESI	Detect Early Season Invasives
DevSecOps	development security and operations
DG-DEFIS	European Commission Directorate General for Defense Industry and Space
DKIST	Daniel K. Inouye Solar Telescope
DLR	German Aerospace Center
DLRW	dynamic launch and reentry windows
DMO	Distributed Maritime Operations
DMO-S	Distributed Mission Operations–Space
DMSP	Defense Meteorological Satellite Program
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOGAMI	Department of Geology and Mineral Industries
DOI	Department of the Interior
DOS	Department of State
DRB	Delaware River Basin
DRIVE	Diversify, Realize, Integrate, Venture, Educate
DSAC	Deep Space Atomic Clock
DSN	Deep Space Network
DSOC	Deep Space Optical Communications
DSSC	Delta System/Software Configuration
DSWE	Dynamic Surface Water Extent
DT&E	Development, Test and Evaluation
DTE	Direct to Earth
DVT	Design Verification and Testing or Design Verification Test

E

EABO	Expeditionary Advanced Base Operations
EAG	exotic annual grass
EAR	Export Administration Regulations
ECI	Early Career Initiative
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
ECU	End-Crypto Unit
EDGE	Experimental Demonstration Gateway Event
EEAS	European External Action Service
EGS	Exploration Ground Systems
EHP	EVA and HSM Program

EHT	Event Horizon Telescope
EL3	European Large Logistics Lander
EM&C	Enterprise Management and Control
EMIT	Earth Surface Mineral Dust Source Investigation
eMMRTG	enhanced multi-mission radioisotope thermoelectric generator
eMODIS	expedited Moderate Resolution Imaging Spectroradiometer
EO	Earth observation
EO	Executive Order
EOC	Early Operational Capability
EO/IR	Electro-Optical/Infrared
EoR	Established on Required Navigation Performance
EOS	Earth Observing System
EPFD	Electrified Powertrain Flight Demonstration
EPS	Enhanced Polar System
EPS-R	Enhanced Polar System-Recapitalization
EPS-SG	EUMETSAT Polar System-Second Generation
EROS	Earth Resources Observation and Science
EROS-ISP	Earth Resources Observation and Science Center–Imaging Spectroscopy Project
ERSA	European Radiation Sensors Array
ESA	Electronically Scanned Array
ESA	European Space Agency
ESCAPE	Extreme-ultraviolet Stellar Characterization for Atmospheric Physics and Evolution
ESD	Exploration Systems Development
ESDMD	Exploration Systems Development Mission Directorate
ESMU	Electromagnetic Spectrum Management Unit
ESI	early season invasives
ESM	European Service Module
ESO	Earth System Observatory
ESP	Environmental Studies Program
ESP	Efficient Space Procurement
ESPA	EROS Center Science Processing Architecture
ESR	Emergency Stabilization and Rehabilitation
ESS	Environmental System Science
ESS	Evolved Strategic SATCOM
ESSIO	Exploration Science Strategy and Integration Office
ET	evapotranspiration
ETa	actual evapotranspiration
ETM	Enhanced Thematic Mapper
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUS	Exploration Upper Stage
EUV	extreme ultraviolet
EVA	Extravehicular Activity
eVIIRS	expedited Visible Infrared Imaging Radiometer Suite
EWPP-FPE	Emergency Watershed Protection Program–Floodplain Easements
EWS	Electro-optical/infrared Weather System
EWS-G	Electro-optical/infrared Weather System-Geostationary
EWX	Early Warning eXplorer
EXIS	Extreme Ultraviolet and X-ray Irradiance Sensors

F

FAA	Federal Aviation Administration
FAB-T	Family of Advanced Beyond-Line-of-Sight Terminals
FACE	Future Airborne Compliance Environment

FARA	Future Attack Reconnaissance Aircraft
FAS	Foreign Agricultural Service
FC	fuel clads
FCC	Federal Communications Commission
FEMA	Federal Emergency Management Agency
FEN	Future Vertical Lift Ecosystem Network
FGDC	Federal Geographic Data Committee
FGST	Fermi Gamma-ray Space Telescope
FHP	Forest Health Protection
FIA	Forest Inventory and Analysis
FLRAA	Future Long Range Assault Aircraft
FORE-SCE	Forecasting Scenarios of land use
FORGE	Future Operationally Resilient Ground Evolution
FRB	Fast Radio Burst
FRP	Full Rate Production
FRPP	Farm and Ranchland Protection Program
FSA	Farm Service Agency
FSOC	Free-Space Optical Communication
FSP	Fission surface power
FSS	Farside Seismic Suite
FSS	Fixed Satellite Service
FTUAS	Future Tactical Unmanned Aerial Systems
FVL	Future Vertical Lift
FVL(MS)	Future Vertical Lift Maritime Strike
FWS	U.S. Fish and Wildlife Service
FY	fiscal year
FYDP	Future Years Defense Program

G

G-LiHT	Goddard's LiDAR, Hyperspectral and Thermal Imager
G-REALM	Global Reservoir and Lake Monitor
GADAS	Global Agricultural and Disaster Assessment System
GAO	Government Accountability Office
GBD	Global Burst Detector
GBO	Green Bank Observatory
GBT	Green Bank Telescope
GCOM-W	Global Change Observation Mission–Water Satellite
GCS	Ground Control Station
GDMS	General Dynamics Mission Systems
GEDI	Global Ecosystem Dynamics Investigation
GEO	Geosynchronous Earth Orbit
GEO	Group on Earth Observations
GEODSS	Ground-Based Electro-Optical Deep Space Surveillance
GeoXO	Geostationary Extended Observations
GeV	gigaelectronvolts
GIC	Geomagnetically Induced Currents
GIMMS	Global Inventory Modeling and Mapping Studies
GIS	Geographic Information Systems
GLAM	Global Agricultural Monitoring
GMA	Global Market Analysis
GMR	geometric mean regression
GMT	Giant Magellan Telescope
GNSS	Global Navigation Satellite System
GOCO	Government-owned and Contractor-operated

GOES	Geostationary Operational Environmental Satellites
GONG	Global Oscillations Network Group
GOSAT-GW	Global Observing SATellite for Greenhouse gases and Water cycle
GPHS	General Purpose Heat Source
GPIM	Green Propellant Infusion Mission
GPS	Global Positioning System
GPS IIIF	GPS III Follow-on
GS	Geospace Section
GSFC	Goddard Space Flight Center
GSSAP	Geosynchronous Space Situational Awareness Program
GUT	grand unified theory

H

HALO	Habitation and Logistics Outpost
HAO	High-Altitude Observatory
HAWC+	High-resolution Airborne Wideband Camera Plus
HEOMD	Human Exploration and Operations Mission Directorate
HEP	High Energy Physics
HERA	Human Exploration Research Analog
HERA	Hybrid Electronic Radiation Assessor
HERMES	Heliophysics Environmental and Radiation Measurement Experiment Suite
HERO	Human Exploration Research Opportunity
HFRP	Healthy Forest Reserve Program
HLCS	HALO Lunar Communication System
HLS	Harmonized Landsat Sentinel
HLS	Human Landing System
HRP	Human Research Program
HSM	Human Surface Mobility
HSN	Hybrid Satellite Networks
HST	Hubble Space Telescope

I

I-HAB	International Habitation Module or International Habitat
IAC	International Astronautical Congress
IAU	International Astronomical Union
IBS-L	Integrated Broadcast Service–LEO
IC	Intelligence Community
ICAO	International Civil Aviation Organization
ICG	International Committee on GNSS
ICNO	IceCube Neutrino Observatory
ICON	Ionospheric Connection Explorer
ICPS	Interim Cryogenic Propulsion Stage
IDA	Internal Dosimeter Array
IfSAR	Interferometric Synthetic Aperture Radar
INCUS	Investigation of Convective Updrafts
INL	Idaho National Laboratory
InSAR	Interferometric Synthetic Aperture Radar
InSight	Interior Exploration using Seismic Investigations, Geodesy and Heat Transport
IOAG	Interagency Operations Advisory Group
IOC	Initial Operational Capability
IOT&E	Initial Operational Test and Evaluation
IP	Isotope Program
IPAD	International Production Assessment Division

IR	infrared
IRIS	Interface Region Imaging Spectrograph
iROSA	ISS Roll-Out Solar Array
IRT	Independent Review Team
ISAAC	Integrated System for Autonomous and Adaptive Caretaking
ISAM	In-space Servicing, Assembly and Manufacturing
ISAR	inverse synthetic aperture radar
ISO	International Organization of Standardization
ISPF	In-Space Propulsion Facility
ISR	Incoherent Scattering Radars
ISR	Intelligence, Surveillance, and Reconnaissance
ISR&T	Intelligence, Surveillance, Reconnaissance, and Targeting
ISRO	Indian Space Research Organization
ISRU	In-Situ Resource Utilization
ISS	International Space Station
ISSNL	ISS National Laboratory
ITA	International Trade Administration
ITAC 1	Industry Trade Advisory Committee
ITAR	International Trafficking in Arms Regulations
ITDS	Improved Threat Detection System
IXPE	Imaging X-ray Polarimetry Explorer

J

JADC2	Joint All Domain Command and Control
JAGM	Joint Air-to-Ground Missile
JANUS	Joint Advanced Propulsion Institute
JAXA	Japan Aerospace Exploration Agency
JCTD	Joint Capability Technology Demonstration
JHU/APL	John Hopkins University Applied Physics Laboratory
JMUA	Joint Military Utility Assessment
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JSC	Johnson Space Center
JWST	James Webb Space Telescope

K

KPLO	Korea Pathfinder Lunar Orbiter
KPS	Korea Positioning System
KSC	Kennedy Space Center

L

L5	Lagrange point 5
LAANC	Low Altitude Authorization and Notification Capability
LandCART	Landscape Cover Analysis and Reporting Tools
LANL	Los Alamos National Laboratory
LASP	Laboratory for Atmospheric and Space Physics
LAT	Large Area Telescope
LCMAP	Land Change Monitoring, Assessment, and Projection
LCMS	Landscape Change Monitoring System
LCRD	Laser Communication Relay Demonstration
LDB	Long Duration Balloon
LDEP	Lunar Discovery and Exploration Program

LDS	Laser Detection System
LEAN	Lidar Elevation Adjustment using NDVI
LEIA	Lunar Explorer Instrument for space biology Applications
LEO	low-Earth orbit
LH2	liquid hydrogen
LIBOR	London Interbank Offered Rate
LIGO	Laser Interferometer Gravitational-Wave Observatory
LIMWS	Limited Interim Missile Warning System
LITMS	Lunar Interior Temperature and Materials Suite
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
LRIP	Low Rate Initial Production
LSA	Launch Service Agreement
LSIC	Lunar Surface Innovation Consortium
LSII	Lunar Surface Innovation Initiative
LSC	UNCOPUOS Legal Subcommittee
LSM	Lunar Spectrum Manager
LSP	Launch Services Program
LTS	Long-Term Sustainability
LTV	Lunar Terrain Vehicle
LuGRE	Lunar GNSS Receiver Experiment
Lunar-VISE	Lunar Vulkan Imaging and Spectroscopy Explorer
LuSEE-Night	Lunar Surface Electromagnetics Experiment at Night
LUSI	Lunar Spectral Irradiance
LuSTR	Lunar Surface Technology Research
LVSA	Launch Vehicle Stage Adapter
LWRHU	Light Weight Radioisotope Heater Unit

M

M&S	Modeling and Simulation
M-STAR	MUREP Space Technology Artemis Research
MAF	Michoud Assembly Facility
MAGTF	Marine Air Ground Task Force
MALE	Medium Altitude Long Endurance
MDA	milestone decision authority
MEDA	Mars Environmental Dynamics Analyzer
MEDLI	Mars Entry, Descent, and Landing Instrumentation
MEO	medium Earth orbit
MEP	Manufacturing Extension Partnership
MFOV	medium field of view
MGUE	Military GPS User Equipment
MILSATCOM	military satellite communications
MLO	Mauna Loa
MMPACT	Moon to Mars Planetary Autonomous Construction Technology
MMRTG	multi-mission radioisotope thermoelectric generator
MMS	Magnetospheric Multiscale
MOA	Memorandum of Agreement
MODIS	Moderate Resolution Imaging Spectroradiometer
MOSA	Modular Open System Approach
MOSSAIC	Maintenance of Space Situational Awareness Integrated Capabilities
MOU	memorandum of understanding
MOXIE	Mars Oxygen In-Situ Resource Utilization Experiment

MPRF	Maritime Patrol and Reconnaissance Force
MPS	Directorate for Mathematical and Physical Sciences
MRI	Magnetorotational Instability
MRP	Mineral Resources Program
MRX	Magnetic Reconnection
MSFC	Marshall Space Flight Center
MSI	Miniature Serialized Interface
MSIP	Mid-Scale Innovations Program
MSR	Mars Sample Return
MTA	Middle Tier of Acquisition
MTBS	Monitoring Trends in Burn Severity
MTVI2	modified triangular vegetation index 2
Multi-Int	multiple intelligence
MUOS	Mobile User Objective System
MUREP	Minority University Research and Education Project
MUSE	Multi-slit Solar Explorer
MUX	MAGTF UAS Expeditionary

N

NAICS	North American Industry Classification System
NAIP	National Agriculture Imagery Program
NANOGrav	North American Nanohertz Observatory for Gravitational Waves
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASS	National Agricultural Statistics Service
NBR	Normalized Burn Ratio
NCAR	National Center for Atmospheric Research
NDOP	National Digital Orthoimagery Program
NDSA	National Defense Space Architecture
NDSI	Normalized Difference Snow Index
NDVI	Normalized Difference Vegetation Index
NE	Office of Nuclear Energy
NEA	Near-Earth Asteroid
NEN	Near Earth Network
NEO	near-Earth object
NEPA	National Environmental Policy Act
NERSC	National Energy Research Scientific Computing Center
NetET	irrigation water use
NExT	National Defense Space Architecture (NDSA) Experimental Testbed
Next-Gen OPIR	Next Generation Overhead Persistent Infrared
NextSTEP	Next Space Technology Exploration Partnerships
NFS	National Forest System
NGA	National Geospatial-Intelligence Agency
NGO	non-governmental organization
NGRTG	next-generation radioisotope thermoelectric generator
NIAC	NASA Innovative Advanced Concepts
NICER	Neutron Star Interior Composition ExploreR
NIR	near-infrared
NISAR	NASA–Indian Space Research Organization Synthetic Aperture Radar
NIST	National Institute of Standards and Technology
NLOS	Non-Line of Sight
NLS	NASA Launch Services
NMB	National Mall building
NMNH	National Museum of Natural History

NNSA	National Nuclear Security Administration
NOAA	National Oceanic and Atmospheric Administration
NOC	National Operations Center
NOIRLab	National Optical-Infrared Astronomy Research Laboratory
NORAD	North American Aerospace Defense Command
NORTHCOM	U.S. Northern Command
NP	Nuclear Physics
NPS	National Park Service
NPV	Non-photosynthetic vegetation
NRCS	Natural Resources Conservation Service
NREL	National Renewable Energy Laboratory
NRL	Naval Research Laboratory
NRO	National Reconnaissance Office
NSF	National Science Foundation
NSN	Near Space Network
NSO	National Solar Observatory
NSPM	National Security Presidential Memorandum
NSPO	National Space Program Office
NSRL	NASA Space Radiation Laboratory
NSSL	National Security Space Launch
NSTC	National Science and Technology Council
NSW-SAP	National Space Weather Strategy and Action Plan
NTIA	National Telecommunications and Information Administration
NTP	Nuclear Thermal Propulsion
NWC	National Water Census
NWR	National Wildlife Refuge
NWS	National Weather Service

O

O&I	Operations and Integration
OADR	open architecture data repository
OC	Operations Center
OCO	Orbiting Carbon Observatory
OCT	optical communication terminal
OCX	Operational Control System
ODA	organization designation authorization
OECD	Organization for Economic Cooperation and Development
OES/SA	Bureau of Oceans and International Environmental and Scientific Affairs Office of Space Affairs
off-SEL	off the Sun-Earth Line
OFT	Orbital Flight Test
OGT	Optical Ground Terminal
OISL	Optical Intersatellite Links
OLI	Operational Land Imager
ORNL	Oak Ridge National Laboratory
OSA	Orion Stage Adapter
OSAM	On-Orbit Servicing, Assembly and Manufacturing
OSC	Office of Space Commerce
OSIRIS-REx	Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer
OSMRE	Office of Surface Mining Reclamation and Enforcement
OT	operational test
OT	Other Transaction
OTA	Other Transaction Authority
OTM	Office of Transportation and Machinery

P

PACE	Payload Accelerator for CubeSat Endeavors
PBN	Performance Based Navigation
PCC	Prizes, Challenges, and Crowdsourcing
PCDL	Predictive Cropland Data Layer
PCM	Post Certification Mission
PDR	Preliminary Design Review
PEO	Program Executive Office
PeV	petaelectronvolts
PGS	Pressure Garment System
PHA	potentially hazardous asteroid
PHM	prognostics and health management
PHY	Division of Physics
PI	Principal Investigator
PIRPL	Prototype Infrared Payload
PIV	particle image velocimetry
pLEO	proliferated low-Earth orbit
PNT	Positioning, Navigation, and Timing
PNTAB	PNT Advisory Board
POES	Polar Operational Environmental Satellites
POET	Prototype On-orbit Experimental Testbed
PPE	power and propulsion element
PPPL	Princeton Plasma Physics Laboratory
PRIME-1	Polar Resources Ice Mining Experiment-1
PRISM	Payloads and Research Investigations on the Surface of the Moon
PROSWIFT	Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow
PRR	Production Readiness Review
PSD	production, supply, and distribution
PTCL	Primary Thermal Control Loop
PTD	Pathfinder Technology Demonstrator
PTES	Protected Tactical Enterprise Service
PTS	Protected Tactical SATCOM
PTW	Protected Tactical Waveform
Pu	plutonium
PUNCH	Polarimeter to Unify the Corona and Heliosphere

R

R2O2R	Research-to-Operations-to-Research
RASC-AL	Revolutionary Aerospace Systems Concept–Academic Linkage
RCMAP	Rangeland Condition Monitoring Assessment and Projection
RCO	Rapid Capabilities Office
RCPP	Regional Conservation Partnership Program
RF	radio frequency
RF	Random Forest
RFI	request for information
RFP	Request for Proposal
RFSoC	Radio Frequency System on a Chip
rHEALTH	reusable Handheld Electrolyte and Lab Technology for Humans
RHU	Radioisotope Heater Unit
RMA	Risk Management Agency
RME	Remote Maui Experiment
RMSE	root mean square error

RO	radio occultation
ROK	Republic of Korea
ROSA	Roll-Out Solar Array
ROSES	Research Opportunities in Space and Earth Sciences
ROTF	Range of the Future
RPOD	rendezvous, proximity operations, and docking
RPS	Radioisotope Power Systems
RSLP	Rocket Systems Launch Program
RST	Roman Space Telescope
RSTA	Reconnaissance, Surveillance, and Target Acquisition
RT	regression tree
RTCA	Radio Technical Commission for Aeronautics
RWR	Radar Warning Receivers

S

S&TU	Science and Technology Utilization
SABRS	Space and Atmospheric Burst Reporting System
SAF	sustainable aviation fuels
SANS	Spaceflight Associated Neuro-ocular Syndrome
SAO	Smithsonian Astrophysical Observatory
SAR	Search and Rescue
SAR	synthetic aperture radar
SATCOM	satellite communications
SBEM	Space Based Environmental Monitoring
SBIR	Small Business Innovative Research
SBIRS	Space Based Infrared System
SCaN	Space Communications and Navigation
SCAT	San Carlos Apache Tribe
SCN	Satellite Control Network
SCOPE	Strategic Campaign Operations Plan for Exploration
SDA	Space Development Agency
SDA	Space Domain Awareness
SDB II	Small Diameter Bomb II
SDI	space data integrator
SDM	species distribution models
SE&I	Systems Engineering and Integration
SEACS	suitably equipped air-capable ships
SEM	Space Environment Monitor
SEMP	Systems Engineering Management Plan
SEP	solar electric propulsion
SERFE	Spacesuit Evaporation Rejection Flight Experiment
SETO	Solar Energy Technologies Office
SFCG	Space Frequency Coordination Group
SFCSCO	Space Force Commercial SATCOM Office
SFD	Sustainable Flight Demonstrator
SFNP	Sustainable Flight National Partnership
SGSS	Space Network Ground Segment Sustainment
SII	Spectrum Innovation Initiative
SIIRTD	Space Innovation, Integration, and Rapid Technology Development
SIPRNet	Secure Internet Protocol Router Network
SIWG	Science and Innovation Working Group
SLE	Service Life Extension
SLS	Space Launch System
SMAP	Soil Moisture Active Passive

SMBH	supermassive black hole
SMD	Science Mission Directorate
SN	Space Network
SNL	Sandia National Laboratories
SNSPD	superconducting nanowire single photon detector
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOMD	Space Operations Mission Directorate
SOST	Start of Season Time
SpaceX	Space Exploration Technologies
SPD	Space Policy Directive
SPHEREx	Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer
SPLICE	Safe and Precise Landing Integrated Capabilities Evolution
SPT	South Pole Telescope
SR	surface reflectance
SRM	Standard Reference Material
SRR	Systems Requirement Review
SSA	space situational awareness
SSAEM	Space Situational Awareness Environmental Monitoring
SSAU	State Space Agency of Ukraine
SSC	Space Systems Command
SSC	Stennis Space Center
SSEBop	Operational Simplified Surface Energy Balance
SSG	Senior Steering Group
SSMIS	Special Sensor Microwave Imager/Sounder
SSN	Space Situational Awareness Network
SST	Space Surveillance Telescope
SST	Standard Space Trainer
STARS	Standard Terminal Automation Replacement System
STC	Office of Science and Technology Cooperation
STEM	science, technology, engineering, and mathematics
STEReO	Scalable Traffic Management for Emergency Response Operations
STM	Space Traffic Management
STMD	Space Technology Mission Directorate
STRG	Space Technology Research Grants
STP-H8	Space Test Program–Houston 8
STPSat	Space Test Program Satellite
STSC	UNCOPUOS Scientific and Technical Subcommittee
STTR	Small Business Technology Transfer
sUAS	Small Unmanned Aircraft Systems or Small Uncrewed Aircraft Systems
Suomi NPP	Suomi National Polar-orbiting Partnership
SuperDARN	Super Dual Auroral Radar Network
SURF III	Synchrotron Ultraviolet Radiation Facility
SUW	Surface Warfare
SWFO	Space Weather Follow On
SWIFT	Spectrum and Wireless Innovation enabled by Future Technologies
SWIR	shortwave infrared
SW Next	Space Weather Next
SWO	Space Weather Observations
SWORM	Space Weather Operations, Research, and Mitigation
SWSH	Space Weather, Security, and Hazards

T

T0TL	T0 Transport Layer
T1DES	Tranche 1 Demonstration and Experimentation System

T2	Technology Transfer
TACSATCOM	Tactical Satellite Communication
TACTOM	Tactical Tomahawk
TBIRD	TeraByte InfraRed Delivery
TBLP	time-based launch/reentry procedures
TDRS	Tracking and Data Relay Satellite
TECRO	Taipei Economic and Cultural Representative Office
TEMPO	Tropospheric Emissions: Monitoring of Pollution
TESS	Transiting Exoplanet Survey Satellite
TIM	Technical Interchange Meeting
TIO	Technical Integration Office
TM	Thematic Mapper
TMP	Technology Maturation Plan
TRACE	Target Recognition and Acquisition in Complex Environments
TRACER	Tracking Aerosol Convection Experiment
TREAT	Transient Reactor Test
TRISH	Translational Research Institute for Space Health
TROPICS	Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of SmallSats
TRR	Test Readiness Review
TSIS-2	Total and Spectral Solar Irradiance Sensor 2
TWINS	Temperature and Wind sensors for InSight

U

UAE	United Arab Emirates
UAF ASF	University of Alaska-Fairbanks' Alaska Satellite Facility
UAG	User's Advisory Group
UAS	Unmanned Aircraft Systems or Uncrewed Aircraft Systems
UASSC	UAS Standards Collaborative
UCAD	Unmanned Carrier Aviation Demonstration
UEWR	Upgraded Early Warning Radar
UFO	UHF Follow-On
UHF	Ultra-High Frequency
UHI	urban heat island
ULA	United Launch Alliance
ULI	University Leadership Initiative
ULLYSES	Ultraviolet Legacy Library of Young Stars as Essential Standards
UN	United Nations
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
UNOOSA	United Nations Office of Outer Space Affairs
USAF	U.S. Air Force
USAID FEWS NET	U.S. Agency for International Development Famine Early Warning Systems Network
USASMDC	U.S. Army Space and Missile Defense Command
USCENTCOM	U.S. Central Command
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USGEO	U.S. Group on Earth Observations
USGS	U.S. Geological Survey
USINDOPACOM	U.S. Indo-Pacific Command
USMC	U.S. Marine Corps
USNDS	U.S. Nuclear Detonation Detection System
USSF	United States Space Force
USTR	U.S. Trade Representative
UWMS	Universal Waste Management System

V

VAB	Vehicle Assembly Building
VADR	Venture-Class Acquisitions of Dedicated and Rideshare
VBI	Visible Broadband Imager
VCLS	Venture Class Launch Services
VegDRI	Vegetation Drought Response Index
VegET	vegetation evapotranspiration
VENOM	varied extraterrestrial off-nominal mission
VHR	very-high-resolution
VI	vegetation index
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
VSAT	Vertical Solar Array Technology
VSFB	Vandenberg Space Force Base
VSRP	voluntary safety reporting program

W

WASDE	World Agricultural Supply and Demand Estimates
WAUSP	Water Availability and Use Science Program
WCDMA	Wideband Code Division Multiple Access
WERC	Western Ecological Research Center
WFC	Warfighter Council
WFOV	wide field of view
WGS	Wideband Global Satellite Communications
WIN	Written Impact Narratives
WRC	World Radiocommunication Conference
WSBW	World Satellite Business Week
WSF	Weather System Follow-on
WSF-M	WSF–Microwave
WSTF	White Sands Test Facility
WTO	World Trade Organization
WxDaaS	Weather Data as a Service

X

xEMU	Exploration Extravehicular Mobility Unit
xEVA	Exploration Extravehicular Activity
xEVAS	Exploration Extravehicular Activity Services
xPLSS	Exploration Portable Life Support Subsystem
XROOTS	eXposed Root On-Orbit Test System

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