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Statement of

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Overview

Mr. Chairman and Members of the Committee, I am pleased to have this opportunity to discuss NASA's FY 2020 budget request of $21 billion. This budget represents a significant step in pursuit of the ambitious, long-term goals set for the Agency in legislation and in Space Policy Directive-1.

NASA is going forward to the Moon. We are building a sustainable, open architecture that returns humanity to our nearest neighbor as the next step in our long-term drive to send humans to the Moon and on to Mars. We are moving fast; we are incentivizing speed, and we are going to start taking "shots on goal" almost immediately. We look to land humans on the Moon within a decade. We are completing development of Orion, the spacecraft that will carry humans to lunar orbit, and the Space Launch System (SLS), the rocket that will launch Orion. We are pressing forward toward an uncrewed test flight of Orion around the Moon in 2020 and we are working to launch the Power Propulsion Element (PPE) in 2022, the first element of the Lunar Gateway, a spacecraft that will orbit the Moon and support future landings. Once habitation capability is added, the Gateway will serve as a reusable command module, supporting human missions to the surface of the Moon and giving us access to the entire lunar surface. Working with commercial partners and international partners, we seek to land humans on the surface of the Moon. We look forward to receiving industry proposals this July and moving forward on an ambitious schedule.

We are building for the long term, and this time are going to the Moon to stay. A sustainable exploration plan requires that we build within realistically available resources. We are designing an open, durable, reusable architecture that will support exploration for decades to come. Sustainability requires reusable systems and an openness to partnerships from across the commercial sector and around the world.

We are actively seeking partner contributions and participation. NASA is working to identify partnership opportunities that widen the pool of resources, enhance sustainability, and advance our most important exploration objectives.

Sustainability requires that we remain focused on the next goal beyond the Moon. Systems we develop for lunar exploration will be designed to contribute to a human exploration mission to Mars where feasible. Beyond developing, testing, and demonstrating the technology we need for the journey, we need

to understand the destination. Humans have, in fact, been exploring Mars for decades. We have moved from landers to small solar-powered rovers, and on to large nuclear-powered rovers. At the same time, we have invested in critical infrastructure in orbit around the planet. With the FY 2020 request, NASA will go beyond current capabilities to begin developing a Mars Sample Return mission, a high priority of the scientific community as well as an important precursor to human exploration.

This Exploration Campaign relies on seamless collaboration across the Agency, including human exploration and operations in low-Earth orbit (LEO) and beyond, technology development, and elements of science, as well as the rapidly advancing capabilities of our commercial partners. It draws upon decades of experience and data from our continuing efforts in LEO. NASA has played a pivotal role in enabling the ongoing and rapid expansion of commercial activity in LEO. Our commercial partners are set to make history – sending humans into space on commercially-developed, -owned, and -operated systems this year. This has been a long process, beginning with regular commercial cargo deliveries to the International Space Station (ISS); it will soon bring human spaceflight launches back to American soil. NASA is working to extend this success with commercial partners to the Moon and beyond.

The FY 2020 budget request supports our continuing efforts to improve the performance and safety of aircraft, crewed and uncrewed, here on Earth. NASA's Aeronautics research is returning to the X-plane business; our Low Boom Flight Demonstration Project (LBFD) is working toward a first flight of the X-59 QueSST supersonic flight demonstrator in FY 2021. We will push the sound barrier once again, this time with the goal of making practical commercial supersonic travel a reality, while again helping to foster economic activity.

Much of NASA's current infrastructure was built to support the Apollo Program. Sustainability also includes the ability of our infrastructure, capabilities, and facilities to effectively and efficiently support our missions, while including sufficient flexibility to meet future needs as we continue to explore. This budget includes significant new investments in NASA's mission support activities, to ensure that exploration in space is not limited by our capabilities on the ground.

NASA remains focused on exploring worlds that humans may never visit. NASA robotic missions have visited all the planets of the solar system, and the Parker Solar Probe is preparing to touch the Sun's atmosphere. While the long-lived Opportunity Rover has finally ceased functioning, the even longer-lived Voyager spacecraft has left the solar system. The search for life beyond Earth takes its next step with our planned mission to Europa. The unparalleled James Webb Space Telescope will open a new chapter in humanity's ongoing quest to explore and understand our universe.

NASA's focus on exploration also extends to the one planet known to support life. Exploring the Earth as a system from space, NASA is our leading source of information on the how the planet works, how the climate is changing, and what the future holds. No planet is more important to explore than our own. With a fleet of spacecraft operating in orbit NASA will continue its world-leading role exploring the home planet.

With the James Webb Space Telescope poised to look out into the cosmos and back to the time when the first stars were forming, humans landing on the Moon, and constellations of spacecraft exploring the solar system, NASA's FY 2020 request supports what is truly a golden age of exploration.

Human Exploration and Operations

The FY 2020 budget request supports bold new steps in NASA's Exploration Campaign. The United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations. The request provides the FY 2020 resources NASA

needs to develop the SLS rocket and Orion crew vehicle, as well as the other critical technologies and research needed to support a robust exploration program. The budget supports NASA's plan to use a commercial rocket to deliver to cislunar orbit the Power and Propulsion Element (PPE) as the foundation of a Lunar Gateway no earlier than 2022.

The FY 2020 request includes $5,021.7 million for Deep Space Exploration Systems, and $4,285.7 million for Low-Earth Orbit and Spaceflight Operations, including the ISS and Space Transportation – both commercial crew system development and ongoing crew and cargo transportation services that resupply the ISS.

NASA will continue its mission in LEO with the ISS to enable exploration, while continuing to perform research that benefits humanity, supporting National Laboratory research by private industry and other organizations, and working towards reducing operations and maintenance costs. NASA will create new opportunities for collaboration with industry on the ISS and develop public-private partnerships for exploration systems that will extend human presence into the solar system. NASA is working to transition our work in LEO, including our international partnerships, to be based on commercially-provided space station services that help enable deep space exploration and private sector expansion in LEO. To support this transition, the ISS will focus near-term activities on supporting commercial industry as well as meeting government requirements in LEO. In parallel, NASA is creating a focused effort aimed at long-term American operations in LEO independent of the ISS.

Under the auspices of the ISS National Laboratory, managed by the Center for the Advancement of Science In Space (CASIS), NASA and CASIS continue to expand research on the ISS sponsored by pharmaceutical, technology, consumer product, and other industries, as well as by other government agencies, such as the National Institutes of Health and the National Science Foundation. Through the joint efforts of NASA and CASIS, the ISS National Lab has reached full capacity for allocated crew time and upmass and downmass.

Space life and physical science research will continue to follow the guidance of the National Academies' decadal studies. NASA-sponsored researchers will be a major user of the ISS and an early user of new commercial platforms as they: enable exploration with research in fluid physics, combustion, microbiology, food production, and animal models; and produce knowledge for use on Earth in materials science, complex fluids, and fundamental cold atom physics. Space life and physical science research expertise will be shared with new Governmental, commercial, and academic researchers to accelerate their productive use of LEO for research and technology development and increase demand for LEO capability.

NASA's Human Research Program (HRP) will continue to conduct cutting-edge research on the effects of spaceflight on the human body, including experiments that require the microgravity environment of the ISS. HRP will support the development of deep space exploration habitat concepts to ensure crew health and performance risks are adequately addressed.

Maintaining the ISS requires service providers to sustain a regular supply line of both crew and cargo. Under the original Commercial Resupply Services (CRS) contracts, our two commercial cargo partners, Space Exploration Technologies (SpaceX) and Northrop Grumman, have provided cargo deliveries to the ISS. Using the launch vehicles developed in partnership with NASA, SpaceX has helped to bring some of the commercial satellite launch market back to the United States and has contributed to a reduction of launch costs. Northrop Grumman has begun to explore commercial markets by offering LEO missions for up to a year after their ISS cargo mission is completed. Under new CRS-2 contracts, SpaceX, Northrop Grumman, and Sierra Nevada Corporation will deliver critical science, research, and technology demonstrations to the ISS over five years from 2020 through 2024. The addition of Sierra Nevada will

add the unique capability to return cargo to various runways, enabling quicker return of cargo for ISS users.

NASA and its commercial partners, Boeing and SpaceX, will soon make history as they prepare to launch humans to the ISS. Before the companies can begin regularly flying long-duration missions to the orbiting laboratory, they first need to demonstrate their systems' capabilities through a series of flight tests. SpaceX's uncrewed Demo-1 launched on March 2, 2019, successfully docked to the ISS, re-enterd Earth's atmosphere, and was recovered after splashing down in the Atlantic Ocean. Boeing is planning for an uncrewed launch in April. Through NASA's Commercial Crew Program, American astronauts will soon launch to orbit from American soil for the first time since the Space Shuttle retired in 2011. Further, for the first time in history, humans will travel to space on systems owned, built, tested, and operated by private companies. The recent flight of the Crew Dragon and upcoming flight of the CST-100 Starliner will demonstrate the enormous potential of commercial partnerships for the human exploration and development of space.

Through the Commercial LEO Development program, NASA will continue to leverage its resources and capabilities to enable the development of a commercial market in LEO. The program's first solicitation activity, which will go out in the next few months, will support the development of new commercial LEO platforms and capabilities. These partnerships will further accelerate the transisition of human spaceflight operations in low-Earth orbit to commercial partners for NASA and non-NASA needs.

NASA is building a deep space launch and crew system – the Orion spacecraft, the heavy-lift SLS launch vehicle, and the supporting Exploration Ground Systems (EGS) – to support the Exploration Campaign. The SLS Block 1 cargo variant will be capable of delivering Orion to cislunar space in the early 2020s, While more powerful SLS configurations remain an important future capability, recent delays in SLS core stage manufacturing require that NASA concentrate in the near term on the successful completion of EM-1 and EM-2 rather than split attention between EM-1, EM-2, and developing an upgraded upper stage. As a result, SLS Block 1B final development efforts will be deferred. The Orion crew vehicle will carry up to four humans to the lunar vicinity for up to 21 days, and when combined with additional habitation can support longer-duration missions. The Orion will also be able to provide key initial life-support and abort capabilities to Gateway.

The budget request supports a planned SLS/Orion mission, Exploration Mission-1 (EM-1) that would send an uncrewed Orion spacecraft around the Moon. This would be followed by the first crewed SLS/Orion mission, Exploration Mission-2 (EM-2) and an annual launch cadence thereafter. The EM-1 and EM-2 launch dates are under review pending completion of independent assessments of core stage production and the integrated mission schedule. NASA is also assessing alternative architectures for EM-1 that could include the use of commercial launch vehicles. Our goal is to maintain our planned EM-1 schedule. NASA will keep the committee apprised of our findings as we analyze these options. NASA remains focused on the major risk areas associated with first-time production and testing of the SLS core stage, integrated assembly and test of the Orion crew and service module, and integrated operations at the Kennedy Space Center. The FY 2020 budget fully funds the Agency baseline commitment schedule for EM-2 and the Orion spacecraft and enables NASA to begin work on post-EM-2 missions. SLS, Orion, and EGS are critical capabilities for maintaining and extending U.S. human spaceflight leadership beyond LEO to the Moon, Mars, and beyond.

As a key part of the Exploration Campaign, NASA will establish the Lunar Gateway, a small way station that will orbit the Moon and enable human and robotic missions to the lunar surface. The Lunar Gateway will support exploration on and around the Moon, and sustainable human lunar surface exploration missions by supporting reusable human lunar landers. It will be a temporary home for astronauts and will foster growing domestic and international economic opportunities for commercial logistics and refueling

services, as well as providing robust communications with spacecraft in cislunar space and on the lunar surface.

The PPE is the first element of the Lunar Gateway which will be launched on a commercial rocket in 2022 and placed in orbit around the Moon. The PPE will demonstrate advanced high-power solar-electric propulsion (SEP) bus systems that will support both future NASA and commercial applications. The PPE will supply power and propulsion for elements and systems on the Lunar Gateway as well as communication to and from Earth, other spacecraft, and missions to the lunar surface. The Lunar Gateway is intended to be capable of supporting human-class lander deployments and operations. Once the PPE and mimimal habitation capabilities have been delivered to cislunar space, a crew of four - launched on Orion - will be able to visit the Lunar Gateway on their way to the lunar surface.

The Lunar Gateway will be launched on competitively procured commercial launch vehicles and assembled in orbit around the Moon where it will be used immediately as a staging point for missions to the lunar surface. It can evolve depending on mission needs, and will support human-class reusable landers, landing a crew of up to four astronauts on the lunar surface and ultimately developing sustaining lunar operations on the Moon. This budget integrates the NASA Docking System (NDS) into the modules of the Lunar Gateway, reducing development cost and allowing NASA, international and commercial partners to easily dock with Lunar Gateway to support lunar landers (including reusable human), the Lunar Gateway itself and science objectives. Further, the early development of commercial docking and delivery capabilities will be essential for developing a sustainable and scalable lunar program. Delivery of Lunar Gateway and lunar lander elements, including refueling of these elements, will create a reusable hub for sustainable lunar activity and feed forward to Mars. The Gateway and lunar surface campaign will benefit from components being provided by International partners. The Gateway will be functional for lunar surface support with the addition of a utilization module planned as the next element after the PPE element.

NASA is supporting the development of commercial lunar exploration capabilities leading to a human lunar landing. NASA is focused on engaging U.S. industry partners using innovative approaches to combine lunar robotics, a cislunar presence, and lunar landing capabilities building up to a human-rated lander. NASA's lunar efforts will incorporate results from the following.

- The Lunar Cargo Transportation and Landing by Soft Touchdown (CATALYST) initiative, established in 2014, is encouraging the development of U.S. private-sector robotic lunar landers capable of successfully delivering payloads to the lunar surface using U.S. commercial launch capabilities.

- Through Commercial Lunar Payload Services (CLPS), NASA selected nine U.S. companies to bid on delivery services to the lunar surface. Lunar payloads from a variety of customers, including NASA, will fly on contracted missions starting in 2020, enabling critical technology demonstrations and scientific observations.

- The budget request supports commercial development of a large lunar lander that can initially carry cargo and later astronauts to the surface of the Moon. NASA issued a solicitation on February 7, 2019 to seek proposals from industry for human lander system studies, risk reduction, development, and spaceflight demonstrations. These Next Space Technologies for Exploration Partnerships (NextSTEP) will enable rapid development and flight demonstrations of human lunar landers by supporting critical studies and risk reduction activities, maturing requirements, tailoring applicable standards, and creating technology maturation plans.

- NASA and its industrial partners are also working on NextSTEP habitation systems to develop concepts for cislunar habitats and to conduct ground-based testing of prototype habitats to evaluate human factors, validate subsystem integration, and test standard interfaces. The knowledge gained from testing the NextSTEP habitats will reduce risk in the design of the Gateway.

Missions to the Moon and cislunar space will also serve as a stepping-stone, a training ground, and a platform to strengthen commercial and international partnerships and prepare for future human missions to Mars and other destinations.

The FY 2020 budget request provides for critical infrastructure indispensable to the Nation's access to and use of space, including those provided under the Space Communications and Navigation (SCaN) Program, the Communication Services Program, the Launch Services Program, Rocket Propulsion Testing, and Human Space Flight Operations.

Human missions to the Moon and Mars will require advanced space communications and navigation capabilities. SCaN's technology development effort invests in leading-edge communications technologies to enable, improve, and mature spacecraft communication and navigation technologies. NASA is conducting studies to identify future technologies under development that can be infused to support NASA exploration missions in the 2022-and-beyond timeframe. These studies include Requests for Information and funded Broad Area Announcements to leverage the creativity of industry partners through mechanisms such as public-private partnerships that will be central to NASA's future communications architecture. NASA is also initiating a Communications Services Program, based on our successful Launch Services Program, which will begin work towards matching future NASA missions with communications services furnished by commercial providers.

Exploration Technology

NASA's FY 2020 request includes $1,014.3 million for Exploration Technology to accelerate technology development to enable human and robotic exploration of the Moon and Mars and foster commercial expansion in LEO and beyond. Technology drives exploration with investments spanning the Technology Readiness Level (TRL) spectrum, advancing early-stage concepts and maturing key technologies and systems that enable demonstrations in relevant environments.

Within Exploration Technology, NASA will accelerate development of lunar surface technologies through the Lunar Surface Innovation Initiative, driving new essential technologies required for humans to successfully operate on the lunar surface. Utilizing the five-year horizon, NASA will transition key technologies through the ground demonstration phase toward flight demonstrations. The Lunar Surface Innovation Initiative will include the technology areas highlighted below.

- NASA is developing the technologies to make use of resources available on the Moon, on Mars, and on other planetary bodies (*in situ* resources). This technology holds the potential to produce consumables, including oxygen, water, and hydrogen on the Moon, thus drastically reducing mission mass, cost, and risk for human exploration.

- In order to address power requirements for long-duration human missions to the lunar surface, NASA is continuing work on its Kilopower technology project to demonstrate a small, lightweight fission power system. The Kilopower project will transition into a demonstration mission in FY 2020 that would permit long-duration crewed missions on the surface of the Moon.

The Lunar Surface Innovation Initiative will bring together the full range of stakeholders, including entrepreneurs, academia, small businesses, industry, and the NASA workforce to catalyze technology and systems development.

Additionally, computer systems for spaceflight are exposed to a hostile radiation environment that can impact performance and reliability. NASA will address this challenge in FY 2020 by testing a powerful, radiation-hardened computer processor that will enable advanced precision landing, hazard avoidance, and autonomous operations.

NASA plans to launch two Exploration Technology demonstration missions in 2019: the Green Propellant Infusion Mission spacecraft, and the Deep Space Atomic Clock instrument will both be delivered to orbit as part of the U.S. Air Force Space Test Program-2 mission. The Green Propellant Infusion Mission demonstrates a propulsion system that could reduce spacecraft processing costs by replacing hydrazine propellant with a propellant that is less toxic and has approximately 40 percent higher performance by volume. The Deep Space Atomic Clock will demonstrate the potential of a 50-fold increase in clock accuracy for improved deep space navigation and improved gravity science measurements.

NASA is working to an August 2020 launch readiness date for its Laser Communications Relay Demonstration project. The project will demonstrate optical communications technology in an operational setting, providing data rates up to 100 times faster than today's radio-frequency-based communication systems.

In 2020, the Solar Electric Propulsion project will complete the Critical Design Review for the electric propulsion subsystem, and build qualification units to conduct qualification testing of the Solar Electric Propulsion engineering development units for the high-power electric propulsion string. The first demonstration of this system will be the 50-kilowatt-class PPE for NASA's Lunar Gateway spacecraft.

Other technology development that Exploration Technology supports includes critical technology for the Mars 2020 mission to be delivered this year; inflatable aerodynamic decelerator technology which could enable high mass Entry, Descent, and Landing on Mars; and In-Space Robotic Manufacturing and Assembly, with the potential to revolutionize exploration. These and many more technology efforts are enabling NASA's most challenging missions.

Science

NASA's Science Mission Directorate leverages space-, air-, and ground-based assets to answer fundamental questions about the Earth, the solar system and the universe, and our place in the cosmos. Our scientists, engineers, and technologists work with a global community of researchers to provide the scientific discoveries that advance critical understanding and inform decision-making. Whether through disaster response, natural resource management, planetary defense, or space weather monitoring, NASA provides tangible benefits that help protect and improve life on Earth. At the same time, NASA is leading the quest to answer some of most pressing human questions, among them how Earth and the universe evolved, how life emerged, and whether we are alone in the universe.

The FY 2020 budget requests $6,303.7 million for NASA Science, including $2,622.1 million for Planetary Science, $844.8 million for Astrophysics, $352.5 million for JWST $704.5 million for Heliophysics, and $1,779.8 million for Earth Science. The budget enables NASA to continue advancing national science and exploration goals while maintaining its global leadership position through a balanced and integrated science program. This year's budget request reflects a concerted effort to seek and execute new partnerships that will allow the Agency to leverage the innovation, resources, and know-how of the

full breadth of the global science enterprise, including other U.S. and foreign agencies, as well as commercial, academic, and other non-Governmental partners.

Science remains critical to the exploration goals of the Agency, contributing both capabilities and knowledge needed to advance human and robotic exploration of the Moon, Mars, and beyond. The Lunar Discovery and Exploration program advances an integrated strategy for exploration, not only through improved collaboration across the Agency but also by leveraging interagency, international, and commercial partnerships. In November 2018, NASA selected nine U.S. companies to bid on delivery services to the lunar surface through Commercial Lunar Payload Services (CLPS) contracts. Lunar payloads from a variety of customers, including NASA, will fly on contracted missions starting in 2020, enabling critical technology demonstrations and scientific observations; most recently, NASA selected 10 proposals for the Development and Advancement of Lunar Instrumentation (DALI) program, which will support instruments that will fly on future lunar missions. NASA's Lunar Reconnaissance Orbiter (LRO), which marks its tenth anniversary in 2019, continues to help scientists characterize the lunar surface, providing insights into lunar resource analysis that could support future human exploration.

NASA's Planetary Science Division develops and operates increasingly sophisticated missions to reveal new knowledge of our Solar System's content, origin, evolution, and the potential for life elsewhere. With spacecraft in place from the innermost planet to the very edge of the Sun's influence, this year's budget request reinvigorates robotic exploration of our Solar System, supporting the long-term scientific study of the Moon, Mars, and beyond.

NASA's robust Mars Exploration Program continues to achieve great things. In November 2018, the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) lander reached the Martian surface, marking the Agency's eighth successful soft landing on the Red Planet. A robot geologist, InSight will yield new discoveries about the Martian interior, providing an unprecedented look at its core structure and heat flow. Cruising behind InSight were two experimental, briefcase-sized spacecraft named Mars Cube One (MarCO) – the first ever planetary CubeSats – which successfully relayed data back to Earth from the InSight lander during its descent to the Martian surface.

The budget request also supports continued progress of the Mars 2020 rover, which – after an intensive effort to identify the most promising landing site – will head to the Jezero Crater following a July 2020 launch. A precursor to human missions to Mars, Mars 2020 will continue to search for evidence of life on the Red Planet and collect a cache of core samples.

In 2020, NASA will commence studies and development of a Mars Sample Return mission – the highest priority strategic mission identified by the scientific community in the most recent planetary science decadal survey and endorsed in the 2018 midterm assessment – that would allow for the return of the Mars 2020 rover samples. Leveraging commercial and international partnerships, such as with the European Space Agency, this mission may launch as early as 2026.

Beyond Mars, NASA will continue development of the next Discovery missions, Lucy and Psyche, as well as the cutting-edge Europa Clipper strategic mission to fly by Jupiter's moon – a first step in exploring ocean worlds and their potential habitability. And just this year, NASA celebrated the first flyby of a Kuiper Belt object (MU69/Ultima Thule) with our New Horizons mission. The data collected from over four billion miles away from Earth will help answer basic questions about the surface properties, geology, and atmospheres of these primitive bodies.

In December 2018, NASA's first asteroid sampling mission, the Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer (OSIRIS-REx), entered orbit around Bennu, the smallest object a spacecraft has ever orbited. In 2020, OSIRIS-REx will have completed its mapping of

Bennu, informing selection of the most promising sample collection site. Its measurements of this potentially hazardous object (Bennu's orbit could bring it relatively close to Earth at the end of the next century), will not only shed light on the early history of our Solar System, but will also inform the design of future missions to mitigate possible asteroid impacts on Earth.

Built as a cohesive, international program for Near-Earth Object (NEO) detection and mitigation technology development, NASA's Planetary Defense Program will continue to fund the NEO Observations project and development of a space-based infrared instrument for detecting NEOs with this year's budget request. Meanwhile, the Double Asteroid Redirection Test (DART) to demonstrate the kinetic impact technique for asteroid deflection will continue to make progress towards its planned 2021 launch.

NASA's Astrophysics Division seeks to understand the universe and our place in it, probing how it works and peering into the origin and evolution of galaxies and stars. Through a coordinated program of research, space-based missions, and technology development, it also explores the formation of planetary systems and seeks to understand how habitable environments develop, a key aspect of the search for life in the universe.

In 2018, NASA bid farewell to the Kepler mission, after nine years of searching for planets outside our Solar System. Kepler discovered almost 2,700 new exoplanets, bringing the total from all sources to over 3,900 known exoplanets. Kepler's legacy serves as the foundation for NASA's next planet-hunting mission, the Transiting Exoplanet Survey Satellite (TESS), launched in April 2018. TESS has already found 12 new exoplanets, including four new multi-planet systems. During its two-year primary mission, TESS will observe nearly the whole sky, providing a rich catalog of worlds around nearby stars, including valuable targets for the James Webb Space Telescope to explore. The 2020 budget accommodates the funds needed to support the revised March 2021 launch date of the James Webb Space Telescope, the largest and most powerful space telescope to be developed to date. Webb will join NASA's family of observatories to examine the first stars and galaxies that formed, viewing the atmospheres of nearby planets outside our solar system and informing our understanding of the evolution of our own solar system.

The budget request also supports operations for the airborne Stratospheric Observatory for Infrared Astronomy (SOFIA), a partnership with the German Aerospace Center; SOFIA will complete its five-year prime mission in 2019. Flying into the stratosphere above 99 percent of Earth's infrared-blocking atmosphere, SOFIA allows astronomers to study the solar system and beyond in ways that are not possible with ground-based telescopes, from almost anywhere in the world.

In order to maintain a balanced science program that optimizes overall scientific return, the FY 2020 budget request again proposes termination of the Wide Field Infrared Survey Telescope (WFIRST), given its significant cost and higher priorities within NASA, including completing the delayed James Webb Space Telescope.

The budget also enables NASA to fully support competed Astrophysics missions and research, and follow the decadal- survey-recommended cadence of new Astrophysics Explorers missions. By the end of FY 2019, NASA plans to release Announcements of Opportunity for the next Astrophysics Small Explorer and Mission of Opportunity missions for an initial selection in 2020.

NASA's Heliophysics Division studies the nature of the Sun, how it affects Earth and other objects in the solar system, and the very nature of space itself. Understanding the Sun and its interactions with the space environment, including near-Earth space, helps scientists identify the causes and impacts of space

weather phenomena, which can threaten spacecraft and astronauts, and affect human technological infrastructure and activities, both on and around Earth, and beyond.

The Heliophysics Division adopts a holistic approach to the study of the Sun and its connection to Earth and other planets – venturing to the very edge of the Sun's influence and beyond. In December 2018, Voyager 2 exited the heliosphere, the protective bubble of particles and magnetic fields created by the Sun, a milestone only achieved once before – by Voyager 1 in 2012. In over 40 years in space, Voyager 2 has traveled a staggering 18.5 billion miles and is NASA's longest-running mission.

In 2018, several successful launches also expanded the Heliophysics System Observatory, including the January 2018 launch of the Global-scale Observations of the Limb and Disk (GOLD) instrument, and the August 2018 launch of the Parker Solar Probe, which completed its first of 24 planned orbits around the Sun in January 2019. Together with GOLD, the Ionospheric Connection Explorer (ICON) instrument launching in 2019 will provide the most comprehensive observations of the ionosphere – a region of charged particles in Earth's upper atmosphere. In July 2018, NASA selected the Interstellar Mapping and Acceleration Probe (IMAP), identified as a priority in the most recent solar and space physics decadal survey, to launch in 2024 to study the boundary of the outer solar system where the solar wind ends. Also, in 2020, NASA will launch Solar Orbiter, a joint collaboration led by the European Space Agency, into orbit around the Sun in order to better understand the dynamics of the heliosphere.

NASA continues to work with its agency partners to reduce gaps between space weather research and operations. The budget initiates the Heliophysics Space Weather Science and Applications project to further strengthen the feedback between fundamental research and operational forecasting needs by improving the transition of science results into operational products. The budget also provides for a potential new Small Explorer-class space weather mission. This will lay the groundwork for a future Space Weather Mission line to focus on resolving fundamental science problems required to improve space weather prediction, and serve as a pathfinder for observation technology for the National Oceanic and Atmospheric Administration's (NOAA's) operational space weather missions.

NASA's Earth Science Division develops and operates space-based and airborne missions that obtain revolutionary observations of our planet. NASA Earth Science works with the scientific community to coordinate and integrate measurements to improve quantitative understanding of our planet and accurately model Earth's complex system of interacting processes. The program also teams with government and commercial partners in the U.S. and internationally to use the measurements and understanding to develop and demonstrate applications that will provide direct benefit to our Nation, and indeed all of humanity.

In 2018, NASA launched two strategic missions recommended by the 2007 Earth Science decadal survey: Gravity Recovery and Climate Experiment Follow-On (GRACE-FO); and Ice, Cloud and land Elevation Satellite-2 (ICESat-2). The twin satellites of GRACE-FO are continuing the original GRACE mission's 15-year legacy (2002-2017) of measuring the changing mass of ice sheets and glaciers and tracking Earth's water movement across the planet. ICESat-2, the follow-on to NASA's ICESat mission (2003-2009), is providing unprecedented data on the topography of ice, forests, and oceans. In November 2018, the Operation IceBridge 2018 Antarctic Field Campaign concluded successfully after flying under ICESat-2 orbits to validate and verify the new satellite's measurements.

In addition, NASA Earth Science is collaborating with the Human Exploration and Operations Mission Directorate to utilize the ISS for Earth observations. NASA Earth Science launched two low-cost, competitively selected missions to the ISS in 2018. The ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) instrument is measuring agricultural water use, vegetation stress, and drought warning conditions. In December 2018, the similarly low-cost, competitively selected

Global Ecosystem Dynamics Investigation (GEDI) vegetation canopy lidar instrument was launched to the ISS and is now embarked on its science mission to make 3D maps of the world's forests.

Launching to the ISS in spring 2019, the Orbiting Carbon Observatory-3 (OCO-3) instrument will continue measurements of the complex dynamics of Earth's carbon cycle, increasing understanding of the regional sources and sinks of carbon dioxide. The FY 2020 budget request also funds continued progress of Landsat 9 for a launch as early as FY 2021. As part of the Sustained Land Imaging program architecture, Landsat 9 will enable continuity of the critical, long-term land imaging data record begun in 1972 with NASA's joint agency partner, the U.S. Geological Survey. Consistent with the FY 2019 budget request, the FY 2020 request proposes termination of the Plankton Aerosol Cloud ocean Ecosystem (PACE), and Climate Absolute Radiance and Refractivity Observatory Pathfinder (CLARREO-PF) missions.

NASA Earth Science continues to explore innovative partnerships and new approaches, including the acquisition of commercial data products from small satellite constellations. In September 2018, the Earth Science Division awarded contracts to three commercial data products providers. Through this pilot program, NASA-funded researchers will examine the scientific value of the data to help determine the utility of the private sector's constellation-based products for advancing NASA's science and applications development goals. The 2020 budget request continues support for the integration of NASA Earth Science efforts with non-Governmental partners through these and other activities, such as commercial hosting and new partnerships (such as the NASA-Conservation International collaboration announced in February 2018).

NASA Science leads the Nation on a journey of discovery through its nearly 100 missions. In every step, we share the adventure with the public and partner with others to substantially improve science, technology, engineering, and mathematics (STEM) literacy and understanding nationwide. In 2019, the National Academies will conduct an assessment of our Science Activation program, which since its establishment in 2016 has competitively selected over 25 awardees, enabling more than 200 partnerships that connect NASA science experts and content to learners of all ages in communities across the land.

Aeronautics

Aviation moves the world, and an efficient and safe air transportation system is fundamental to the future of the U.S. economy. NASA's cutting-edge aeronautics research is delivering new concepts and technologies which will change the face of aviation as we know it, boosting U.S. technological and economic leadership in this global industry and creating high quality American jobs. The FY 2020 budget requests $667 million for NASA aeronautics research.

NASA is enabling quiet commercial supersonic flight through construction of the X-59 supersonic flight demonstrator, with a first flight planned for FY 2021. NASA will then conduct a first-of-its kind, multi-year flight research campaign over populated areas to gather data about community response to quiet supersonic flights, enabling domestic and international regulators to establish a new supersonic noise standard. This capability will position the U.S. aviation industry to supply global customers with future supersonic aircraft products.

NASA is collaborating with industry to investigate innovative technology for subsonic aircraft, including advanced wing design, transformative structures, propulsion-airframe integration, and small-core turbine engines. NASA also is leading research into new components, technologies, and powertrain architectures for electric or hybrid electric systems that can bring about revolutionary improvements in small and large transport aircraft. NASA's work on the X-57 Maxwell aircraft – an all-electric, general-aviation-size plane – is already delivering important lessons to the community about designing, building, and operating

an all-electric system. Ground tests this year and flight tests next year will provide valuable insights into the challenges and opportunities of electric aircraft.

Building on these activities, NASA has begun a multi-year effort to solve the technical challenges associated with a 1-Megawatt (MW) power electric aircraft propulsion system – enough energy to power 165 homes. NASA will refine concepts and technologies and validate new electric systems through ground and flight tests. Realizing a practical 1-MW electric aircraft propulsion system has never been accomplished and is an area of notable international competition. To support this work, NASA has commissioned the world-leading NASA Electric Aircraft Test Facility (NEAT) capable of conducting full-scale ground tests of high-power electric propulsion systems.

In addition to developing new vehicle technologies, NASA is conducting research to make design and manufacturing processes more efficient and reduce the time and cost to build aircraft. Next year, NASA will complete the Advanced Composites Project, a six-year focused effort in partnership with industry to significantly reduce the time needed to develop and certify new composite structures for aerospace applications.

In 2020, NASA will complete demonstrations of technologies to integrate operations of larger Unmanned Aircraft Systems (UAS) into the existing National Air Space (NAS) as well as manage smaller vehicles safely at lower altitudes. Those efforts are providing the foundation for another major transformation of the aviation sector being led by NASA – creation of an urban air mobility (UAM) system that is safe, economical, and environmentally friendly to move people and packages in population centers.

NASA will begin a new Advanced Air Mobility project in FY 2020 to enable the emergence of UAM. NASA is preparing a series of “Grand Challenges” that will provide a means to assess the maturity of key systems for UAM. Through these Grand Challenges, NASA will serve as a catalyst for companies to rapidly develop and demonstrate their capabilities, while setting the course for needed research and investment. Initial community response to NASA’s leadership in UAM has been strongly supportive.

NASA research is enabling a transformed airspace system that supports efficient operations of all vehicles across these different market segments, and gives citizens the confidence that every flight is safe and secure. NASA will complete a series of Airspace Technology Demonstrations (ATDs) with the Federal Aviation Administration (FAA), airlines, and airport operators to demonstrate new capabilities for managing efficient airline operations. A final high-fidelity demonstration of all integrated system capabilities will support delivery of the research and development results the FAA needs to advance NextGen capabilities and improvements to meet the FAA's air traffic management needs. NASA then will turn its attention to new research to address the safety and efficiency challenges of a more complex airspace supporting a broad range of new users.

NASA continues its investment in unique specialized facilities and experts who conduct fundamental research to address key challenges in hypersonic flight. NASA coordinates closely with partners in the Department of Defense (DOD) to leverage DOD investment in ground and flight activities to develop and validate advanced physics-based computational models as building blocks towards a long-term vision for hypersonic flight. At the same time, the DOD benefits from NASA hypersonics expertise, analyses, testing capabilities and computational models.

NASA aeronautics research is conducted in partnership with the aviation community to transform aviation as we know it, and find solutions to aviation system needs that will provide benefits in mobility, environmental sustainability, and safety, while ensuring continued long-term U.S. aviation technology leadership in this rapidly expanding global industry. NASA investments are enabling the early stages of the future airspace system that will enable all users – from UAS to UAM to traditional airlines – to

seamlessly access the airspace and safely and efficiently, with great benefit to U.S. industry and passengers alike.

STEM Engagement

NASA's FY 2020 budget proposes the termination of NASA's Office of STEM Engagement and its portfolio of domestic assistance awards (grants and cooperative agreements), and instead prioritizes funding toward an innovative and inspirational program of exploration. While the FY 2020 budget no longer supports these programs, a common vision, mission and focus areas will drive NASA's future endeavors in science, technology, engineering, and mathematics (STEM) engagement. Through its mission directorates, NASA will focus on: creating unique opportunities for students to contribute to NASA's work in exploration and discovery; building a diverse future STEM workforce by engaging students in authentic learning experiences with NASA's people, content and facilities; and strengthening understanding by enabling powerful connections to NASA's mission and work. A small, focused functional office at NASA headquarters will be accountable for the strategic direction and coordination of the Agency's STEM engagement efforts.

NASA's mission successes will continue to inspire the next generation to pursue science, technology, engineering, and mathematics studies, join us on our journey of discovery, and become the diverse workforce we will need for tomorrow's critical aerospace careers. We will use every opportunity to engage learners in our work and to encourage educators, students, and the public to continue making their own discoveries.

Mission Support

In this budget, NASA will simultaneously implement multiple large development programs in order to return to the surface of the Moon by 2028. To be successful, NASA must have the institutional capabilities and facilities necessary to efficiently and effectively support these programs, which is why this budget proposes important new investment in Mission Support. NASA's mission support programs directly enable the Agency's portfolio of missions. The FY 2020 request prioritizes the capabilities, operations and equipment to safely operate and maintain NASA Centers and facilities, along with the independent technical authority required to reduce risk to life and program objectives for all NASA missions. With installations in 14 states, NASA collectively manages $39 billion in assets with an inventory of over 5,000 buildings and structures. Over the past 60 years, NASA has leveraged unique test facilities to develop new and innovative vehicles and technology for space exploration. Now, commercial companies are also leveraging this unique infrastructure. Over 80 percent of NASA facilities are beyond their constructed design life, and NASA faces the challenge of a deferred maintenance backlog of ~$2.3B. The 2020 budget includes additional funding critical to renewing our infrastructure while we continue to divest of unneeded, costly facilities.

In the area of information technology (IT) services, NASA continues to improve management and strengthen NASA's cybersecurity capabilities in order to safeguard critical systems and data. We have made significant progress over the past several years, raising NASA's score on the Federal IT Acquisition Reform Act (FITARA) from an "F" in 2015 to a B+ this past year. The 2020 budget provides critical resources to continue strengthening cyber security protections and funding to help modernize NASA's IT systems in support of future mission objectives. In FY20, the Agency will continue its efforts to implement and develop optimal solutions. Examples include IT consolidation, automated segmentation architecture and end user cloud migration. NASA continues to transition its IT to an enterprise governance and operating model.

Conclusion

NASA's FY 2020 budget request provides for the foundation of a national exploration campaign that will create an architecture that is open, sustainable and agile. The Space Launch System and Orion, critical components of our exploration architecture, will reach important milestones in construction and testing this year as the program works through significant development challenges, and our new lunar command module, the Gateway, will see international and commercial partnerships solidified and construction begin. We have called on American companies to help design and develop human lunar landers and reusable systems for surface activities. In LEO, our Commercial Crew program remains strong and will soon be delivering American astronauts, on American rockets, from American soil to the ISS for the first time since 2011.

With the FY 2020 request NASA will initiate the first round-trip mission to the Red Planet with a Mars sample return mission, and many of the technological advancements we achieve moving forward to the Moon will provide critical data and capabilities for future robotic and crewed Mars missions. We will continue to pursue transformative aeronautics technology as we develop the next generation of aircraft and make air travel safer and more efficient. We will increase our understanding of our home planet and move out on ambitious programs to study the far reaches of our solar system and beyond.

Mr. Chairman, I would be pleased to respond to your questions and those of other Members of the Committee.