

NASA's FUTURE IN LOW EARTH ORBIT: CONSIDERATIONS FOR INTERNATIONAL SPACE STATION EXTENSION AND TRANSITION

HEARING BEFORE THE SUBCOMMITTEE ON SPACE AND AERONAUTICS OF THE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY OF THE HOUSE OF REPRESENTATIVES ONE HUNDRED SEVENTEENTH CONGRESS

FIRST SESSION

SEPTEMBER 21, 2021

Serial No. 117-29

Printed for the use of the Committee on Science, Space, and Technology



Available via the World Wide Web: <http://science.house.gov>

U.S. GOVERNMENT PUBLISHING OFFICE

45-537PDF

WASHINGTON : 2023

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**NASA'S FUTURE IN LOW EARTH ORBIT:
CONSIDERATIONS FOR INTERNATIONAL
SPACE STATION EXTENSION
AND TRANSITION**

TUESDAY, SEPTEMBER 21, 2021

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON SPACE AND AERONAUTICS,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to notice, at 11:01 a.m., via Zoom, Hon. Donald S. Beyer, Jr. [Chairman of the Subcommittee] presiding.

**SUBCOMMITTEE ON SPACE AND AERONAUTICS
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES**

HEARING CHARTER

**NASA's Future in Low Earth Orbit: Considerations for International Space Station
Extension and Transition**

September 21, 2021
11:00 a.m.
Zoom

PURPOSE

The purpose of the hearing is to examine the status of the International Space Station (ISS), NASA's requirements for future research and development in low Earth orbit, and plans for sustaining such activities once the ISS is no longer operating, among other issues.

WITNESSES

- **Ms. Robyn Gatens**, Director, International Space Station; National Aeronautics and Space Administration
- **Dr. Kathleen "Kate" Rubins**, Astronaut; National Aeronautics and Space Administration
- **Mr. Jeffrey Manber**, Chief Executive Officer; Nanoracks, LLC
- **Mr. Todd Harrison**, Senior Fellow and Director of the Aerospace Security Project; Center for Strategic and International Studies
- **Captain William Shepherd (USN, Retired)**, Former Astronaut, National Aeronautics and Space Administration

OVERARCHING QUESTIONS

- *What is the operational status of the ISS, and what is NASA's current evaluation of its structural integrity and lifetime?*
- *What is NASA's current ISS transition plan?*
- *What are NASA's requirements for low Earth orbit beyond ISS, and what is needed to meet those requirements?*
- *What are the interests and activities of international partners in low Earth orbit, and how might they relate to NASA's future activities?*
- *What are the capabilities and activities of private industry in low Earth orbit, and what are the implications for NASA's future activities there?*

BACKGROUND

In November 2020, the International Space Station (ISS) marked the milestone of twenty years of continuous human presence in space. In that time, ISS has served as a unique orbiting laboratory for a range of basic and applied scientific research and technology demonstrations and development. The ISS has contributed to a growing body of knowledge of operating a crewed space facility and the effects of the microgravity environment on humans and other living systems. The ISS also has been a significant achievement of international cooperation: it is operated by a partnership of five space agencies comprising fifteen countries and has hosted more than 240 crew from 18 countries and experiments from researchers in 108 countries.¹

The ISS has made a number of landmark advances in research and development (R&D) in the nearly twenty-three years since the first modules were launched. For example, in 2018, the ISS was host to the creation of the first Bose-Einstein condensate—a fifth state of matter first produced on Earth only twenty-five years prior—in Earth orbit.² The first-of-its-kind Twins Study provided new insights into the effects of spaceflight on the human mind and body by collecting data concurrently from identical twin astronauts while one lived nearly a year aboard ISS—setting the single-spaceflight stay in space record of 340 days—and the other stayed home on the ground.³ More than 250 cubesats have been launched from the ISS to conduct activities such as technology demonstrations, Earth imagery, or studies of the cosmos. The ISS life support systems recover and recycle 93% of the water astronauts use on board using NASA technology that now can be found in ground-based water filtration systems in communities on Earth.⁴

As of 2015, the U.S. had spent almost \$78 billion in developing and assembling the ISS.⁵ As of FY2020, NASA's operations costs for the ISS, including cargo and crew transportation and ground support services, total approximately \$4 billion annually.⁶ The ISS was designed to last 15 years. Continuous maintenance, replacements, and upgrades to many systems have extended its lifetime. While the facility has been operating safely for over twenty years, plans for the eventual end of ISS operations, and what follows it, must be in place to avoid a gap in NASA's activities in low Earth orbit (LEO).⁷ ISS operations are currently authorized through at least 2024, and in recent years, there have been legislative proposals to extend its operations again.

¹ NASA, "International Space Station Facts and Figures." Available at: <https://www.nasa.gov/feature/facts-and-figures>

² NASA, "NASA's Cold Atom Lab Takes One Giant Leap Forward for Quantum Science," June 12, 2020. Available at: <https://www.nasa.gov/feature/jpl/nasas-cold-atom-lab-takes-one-giant-leap-for-quantum-science>

³ NASA, "NASA's Twins Study Results Published in Science Journal," April 11, 2019. Available at:

<https://www.nasa.gov/feature/nasa-s-twins-study-results-published-in-science>

⁴ NASA, "Advanced NASA Technology Supports Water Purification Efforts Worldwide," October 9, 2019. Available at: https://www.nasa.gov/mission_pages/station/research/news/b4h-3rd/it-advanced-nasa-water-purification

⁵ NASA OIG, "Final Memorandum, Audit of NASA's Management of International Space Station Operations and Maintenance Contracts (IG-15-021; A-14-023-00)" July 15, 2015. Available at: <https://oig.nasa.gov/docs/IG-15-021.pdf>

⁶ NASA, FY 2022 Budget Request Congressional Justification, released May 28, 2021. Available at: https://www.nasa.gov/sites/default/files/atoms/files/fy2022_congressional_justification_nasa_budget_request.pdf

⁷ Low Earth orbit (LEO) is generally defined as the area of space within 1000 km, or approximately 620 miles, from the Earth's surface.

Current Partnerships and Operations of the ISS

The U.S. leads the ISS partnership of five space agencies: NASA, Roscosmos (Russia), the Japanese Aerospace Exploration Agency (JAXA), the Canadian Space Agency (CSA), and the European Space Agency (ESA). The partnership is governed by the Intergovernmental Agreement (IGA) between fifteen member countries⁸ and a series of bilateral agreements between NASA and the participating space agencies. In addition to power and support structures, the ISS is comprised of eight major U.S. modules, six major Russian modules, the Japanese *Kibo* module, and the European *Columbus* module. The ISS program and its international partnerships have laid the foundation for future international exploration. Many of the ISS partners have continued to work with NASA across its exploration and science portfolio and have also engaged on the lunar Gateway project.

NASA also has agreements with commercial industry as both users and providers of microgravity services, largely through the ISS National Laboratory, managed by the Center for the Advancement of Science in Space (CASIS).

ISS Hardware Lifetime and Structural Integrity

As NASA noted in a 2018 ISS Transition Report to Congress, as of 2018 a structural life assessment estimated that the structural margin of the ISS would be fully adequate to support ISS operations to 2028.⁹ During a 2019 hearing on NASA's ISS plans, the NASA Inspector General's office testified to this Subcommittee that Boeing (NASA's prime contractor for ISS operations and support services) had certified almost all major U.S. structural elements to 2028.¹⁰ ISS hardware continues to be upgraded, most recently with new lithium-ion batteries and the current deployment of the ISS Roll-out Solar Array (iROSA) system to augment ISS power. However, long-term hardware issues for the 20-year-old ISS continue, such as air leaks in the Russian segment of the ISS (the origin of those leaks is yet to be determined),¹¹ propellant resupply logistics, and battery power management challenges.¹²

In late July 2021, Roscosmos launched and integrated the first new ISS module in more than a decade, a research laboratory called *Nauka*. On July 29, 2021, an incident during the docking of *Nauka* caused the module's thrusters to inadvertently fire, leading to the ISS turning 540 degrees (one-and-a-half-revolutions, ending with the station upside-down) and NASA mission control

⁸ The IGA was signed by the United States, Russia, Japan, Canada, and participating countries of the European Space Agency (Belgium, Denmark, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom). Available at:

https://www.nasa.gov/mission_pages/station/structure/elements/partners_agreement.html

⁹ NASA, "International Space Station Transition Report," March 20, 2018.

¹⁰ Examining NASA's Plans for the International Space Station and Future Activities in Low Earth Orbit: *Hearing before the Subcommittee on Space and Aeronautics of the House Committee on Science, Space, and Technology*, 116th Cong. (2019) (testimony of Paul K. Martin).

¹¹ NASA, "NASA TV Broadcasts Spacewalk for Solar Array Mods on Friday" March 4, 2021. Available at:

<https://blogs.nasa.gov/spacestation/2021/03/04/nasa-tv-broadcasts-spacewalk-for-solar-array-mods-on-friday/>

¹² "Current and Future Operations and Challenges with the International Space Station," Presentation by Marybeth Edeen (NASA), Fall 2020 meeting of the Aeronautics and Space Engineering Board, National Academies of Science, October 15, 2020. Available at: <https://www.nationalacademies.org/event/10-14-2020/aeronautics-and-space-engineering-board-2020-fall>

having to declare a “spacecraft emergency,” which reportedly activated additional U.S. antennae for communications.¹³ The attitude and orientation of the ISS is now stable and routine operations have continued.¹⁴ NASA announced on August 12, 2021, that the agency has initiated an investigation focused on “analyzing available data, cooperating with [NASA’s] Russian colleagues for any information they require for their assessment, and coordinating with the other international partners.”¹⁵

ISS Authorization and Congressional Actions

Congress has directed several actions regarding the International Space Station. The NASA Authorization Act of 2005 established it as U.S. policy to achieve “diverse and growing utilization of, and benefits from, the ISS” and directed the NASA Administrator to assemble and operate the ISS “as long as the Administrator determines that the Shuttle can safely enable the United States to do so.”¹⁶ The NASA Authorization Act of 2008 directed NASA to prepare a plan for operating the ISS for a least five years beyond 2015,¹⁷ and then the NASA Authorization Act of 2010 authorized the extension of operations through at least 2020.¹⁸ Later, the Commercial Space Launch and Competitiveness Act of 2015¹⁹ authorized another extension of ISS operations through at least 2024.²⁰

The NASA Authorization Act of 2005²¹ also designated the U.S. segment of the ISS as a national laboratory, and authorized NASA to enter into an agreement with a nongovernmental entity to manage the ISS National Laboratory (ISSNL). The NASA Authorization Act of 2010²² then further directed that the ISSNL be guaranteed not less than 50 percent of the U.S. ISS research capacity allocation, which includes transportation, upmass, power, cold stowage, and crew time.

In the NASA Transition Authorization Act of 2017, Congress directed NASA to develop and transmit an ISS transition plan, to “transition in a step-wise approach from the current regime that relies heavily on NASA sponsorship to a regime where NASA could be one of many customers of a low-Earth orbit non-governmental human space flight enterprise.” The Act required a number of elements of the plan, including: a description of progress achieving deep

¹³ Chang, Kenneth, “It Was His Day Off. Then, the Space Station Went for a Spin” August 2, 2021. Available at: <https://www.nytimes.com/2021/08/02/science/nasa-space-station-zebulon-scoville.html>

¹⁴ NASA, “Space Station Stable After Earlier Unplanned MLM Thruster Firing,” July 29, 2021. Available at: <https://blogs.nasa.gov/spacestation/page/5/>

¹⁵ NASA, “Cygnus Arrival and Hatch Open Complete,” August 12, 2021. Available at: <https://blogs.nasa.gov/spacestation/2021/08/12/cygnus-arrival-and-hatch-open-complete/>

¹⁶ Public Law 109-155, “National Aeronautics and Space Administration Authorization Act of 2005,” December 30, 2005. Available at: <https://www.congress.gov/109/plaws/publ155/PLAW-109publ155.pdf>

¹⁷ Public Law 110-422, “National Aeronautics and Space Administration Authorization Act of 2008,” October 15, 2008. Available at: <https://www.congress.gov/110/plaws/publ422/PLAW-110publ422.pdf>

¹⁸ Public Law 111-267, “National Aeronautics and Space Administration Authorization Act of 2010,” October 11, 2010. Available at: <https://www.congress.gov/111/plaws/publ267/PLAW-111publ267.pdf>

¹⁹ Public Law 114-90, “U.S. Commercial Space Launch Competitiveness Act,” November 25, 2015. Available at: <https://www.govinfo.gov/content/pkg/PLAW-114publ90/pdf/PLAW-114publ90.pdf>

²⁰ See sections 18351 and 18353 of title 42, U.S. code, and section 70907 of title 51, U.S. Code.

²¹ Public Law 109-55, “National Aeronautics and Space Administration Authorization Act of 2005,” December 30, 2005. Available at: <https://www.congress.gov/109/plaws/publ155/PLAW-109publ155.pdf>

²² Public Law 111-267, “National Aeronautics and Space Administration Authorization Act of 2010,” October 11, 2010. Available at: <https://www.congress.gov/111/plaws/publ267/PLAW-111publ267.pdf>

space human exploration objectives on ISS and prospects for achieving future exploration and other research objectives on future commercial LEO or cislunar platforms; the cost estimates for further extensions of ISS and the eventual deorbit; steps NASA will take to stimulate and facilitate commercial demand and supply of products and services in LEO; identification of barriers preventing the commercialization of LEO; the criteria for defining the ISS as a research success; and an evaluation of the feasible and preferred service life of the ISS beyond 2024.

NASA's ISS Transition Planning

In 2018, NASA submitted an ISS Transition Report to Congress, pursuant to the NASA Transition Authorization Act of 2017.²³ As stated in the report, “NASA intends to begin shifting responsibility for meeting its needs and requirements in LEO by leveraging private industry capacity, innovation, and competitiveness that would offer the prospect of lower cost to the Government to enable NASA to apply more personnel and budget resources on expanding human spaceflight beyond LEO and enhancing U.S. leadership in human spaceflight around the world.” NASA further stated in the report that it will seek continuity in LEO following the eventual end of ISS operations, including in the areas of U.S. human spaceflight leadership, relationships with international partners, government-sponsored access to LEO research facilities, conducting basic and applied on-orbit research, and maintaining critical human spaceflight knowledge and expertise within the government. In the plan, NASA stated it would proceed with a stepwise approach that includes soliciting information from industry on development and operations of private on-orbit modules, platforms, or other capabilities and then funding multiple awards toward enabling commercial LEO development.

Commercial Market Studies

In 2018, NASA contracted with twelve companies to complete studies about the commercialization of low Earth orbit, and the agency released top-level summaries of those studies in June 2019.²⁴ While the twelve studies varied widely in projections of the future commercial LEO market's size and estimated relative success of potential applications, nearly all relied on an expectation that NASA would be a significant initial investor and primary customer (“anchor tenant”) for any commercial destination in the near- to mid-future. This finding echoes some of the conclusions of a 2017 Science and Technology Policy Institute (STPI) market analysis of a privately owned and operated space station.²⁵ STPI found that “it is unlikely that a commercially owned and operated space station will be economically viable by 2025,” due to lack of sufficient revenue and significant uncertainties around a potential market. The study also found that such a station would find it difficult to find initial investors outside of the government; in particular, that “Venture capitalists whom [STPI] interviewed noted that the projections of revenues and costs are so uncertain that they would have no interest in financing a space station until projected revenues from these activities show signs of materializing.”

²³ NASA, “International Space Station Transition Report” March 20, 2018. Available at:

https://www.nasa.gov/sites/default/files/atoms/files/iss_transition_report_180330.pdf

²⁴ NASA LEO Commercialization Study Results. Available at:

https://www.nasa.gov/sites/default/files/atoms/files/leo_commercialization_study_results.pdf

²⁵ STPI, “Market Analysis of a Privately Owned and Operated Space Station,” March 2017. Available at:

<https://www.ida.org/-/media/feature/publications/m/ma/market-analysis-of-a-privately-owned-and-operated-space-station/p-8247.ashx>

Commercial Low Earth Orbit Program

NASA established a Commercial LEO Program office and released the “NASA Plan for Commercial LEO Development” in 2019.²⁶ NASA has stated that the Commercial LEO Development Program objectives include supporting the development of both the “supply” side—such as future privately-owned and -operated on-orbit platforms—and the “demand” side—new users and markets for on-orbit services—for a future LEO economy.

On the supply side, NASA is sponsoring commercial development of new LEO destinations for potential future utilization by NASA and other customers. In early 2020, NASA awarded a contract to Axiom Space to build a commercial module attached to the ISS.²⁷ In spring 2021, NASA released a solicitation²⁸ for free-flying Commercial LEO Destinations (CLDs)—i.e., privately-owned and -operated platforms orbiting independently and not attached to the ISS—and is currently reviewing proposals. The CLD solicitation directs proposers to expect a transition from the ISS to a CLD in the fiscal year 2029-2030 timeframe.²⁹

To mature and stimulate demand for new markets in a future LEO economy, NASA has released new policies it intends to use to enable and encourage commercial use of the ISS.³⁰ NASA has reserved five percent of its share of ISS resources—such as crew time, power, and cargo delivery and return space—for non-R&D, commercial and marketing activities and developed pricing policies for such activities, including private astronaut missions (PAMs).³¹ PAMs are to be privately-funded, fully commercial spaceflights bringing non-government passengers to the ISS for short-duration visits. NASA has stated that it will enable up to two PAMs per year. According to NASA, in a spring 2021 update, the pricing policy for PAMs and other commercial and marketing activities “reflects full reimbursement for the value of NASA resources that are above the space station baseline capability.”³² NASA and Axiom announced the first PAM agreement in May 2021 for an eight-day stay involving four private astronauts on ISS no earlier than January 2022. NASA is currently reviewing proposals in response to a summer 2021 solicitation for two new PAMs, to occur between fall 2022 and late 2023.³³

²⁶ NASA, “NASA Plan for Commercial LEO Development: Summary and Near-Term Implementation Plans,” June 7, 2019. Available at: https://www.nasa.gov/sites/default/files/atoms/files/commleodevt_plan_6-7-19_final-links-new.pdf

²⁷ NASA, “NASA Selects First Commercial Destination Module for International Space Station” January 27, 2020. Available at: <https://www.nasa.gov/press-release/nasa-selects-first-commercial-destination-module-for-international-space-station>

²⁸ Commercial LEO Development Program Office, “Commercial LEO Destinations Announcement 80JSC021CLD FINAL Amendment 3” NASA. August 5, 2021. Available at: <https://sam.gov/opp/6ab6a554434f469f9f7f95783489e821/view>

²⁹ *Ibid.*

³⁰ As part of the President’s Budget Request for NASA for FY 2022, NASA proposed moving these “demand stimulation” activities into the ISS research account and out of the Commercial LEO Development program, where they are currently managed and bookkept.

³¹ NASA, “Commercial and Marketing Pricing Policy” April 29, 2021. Available at: <https://www.nasa.gov/leo-economy/commercial-use/pricing-policy>

³² *Ibid.*

³³ NASA, “NASA seeks Proposals for Next 2 Private Astronaut Missions to Space Station,” June 11, 2021. Available at: <https://www.nasa.gov/leo-economy/NASA-seeks-proposals-next2-private-astronaut-missions-ISS>

Scientific Research and Technology Development in LEO

The ISS provides continuous exposure to a microgravity environment at an altitude of approximately 400km and has hosted almost 3,000 research investigations from researchers in 108 countries.³⁴ NASA supports research investigations that are enabled by the unique microgravity environment aboard the ISS for one of two broad purposes: to improve the understanding of living and working in space in support of future human exploration missions, or to support space-based basic and applied research.³⁵ The ISS is also a platform for development, testing, validating, and demonstrating technologies that will be necessary for long-distance human exploration missions beyond LEO or that could have societal or commercial applications back on Earth. These R&D activities are primarily managed through the Human Research Program and the ISS National Laboratory via NASA's Human Exploration and Operations Mission Directorate (HEOMD) and the Biological and Physical Sciences Division of the Science Mission Directorate (SMD).

Human Research Program

NASA's Human Research Program (HRP) is an applied and operational research and technology development effort aimed at understanding and mitigating the highest risks to human health and performance in space exploration. The ISS is the primary platform for HRP activities and critical to achieving its objectives, although the program does also use ground-based analogs and other platforms, such as suborbital flights. HRP is managed under the Human Spaceflight Capabilities Division within HEOMD. HRP activities are conducted across five elements: Human Factors and Behavioral Performance, Exploration Medical Capability, Human Health Countermeasures, Research Operations and Integration, and Space Radiation. HRP also funds a cooperative agreement with a consortium led by Baylor College of Medicine, the Translational Research Institute for Space Health (TRISH), to lead an effort to translate terrestrial biomedical research and technology development into applications for human spaceflight risk mitigation.

NASA uses an evidence-based risk management approach to assess and mitigate specific human health and performance risks for human spaceflight,³⁶ which stem from five threats: radiation, altered gravity fields, hostile and closed environments, distance from Earth, and isolation and confinement.³⁷ According to the HRP Integrated Research Plan (IRP), the program uses the ISS to study human physiological and behavioral responses to the microgravity environment, test

³⁴ [International Space Station Facts and Figures | NASA](#)

³⁵ NASA, FY 2022 Budget Request Congressional Justification, released May 28, 2021. Available at: https://www.nasa.gov/sites/default/files/atoms/files/fy2022_congressional_justification_nasa_budget_request.pdf

³⁶ Elkin Romero, David Francisco, "The NASA human system risk mitigation process for space exploration," *Acta Astronautica*, Volume 175, 2020, Pages 606-615, ISSN 0094-5765. Available at: <https://doi.org/10.1016/j.actaastro.2020.04.046>.

³⁷ Patel, Z.S., Brunstetter, T.J., Tarver, W.J. *et al.* Red risks for a journey to the red planet: The highest priority human health risks for a mission to Mars. *npj Microgravity* 6, 33 (2020). Available at: <https://doi.org/10.1038/s41526-020-00124-6>.

countermeasures and mitigations, serve as an analog for longer-duration missions, and provide baseline measurements (“space normal”) of the space environment.³⁸

ISS National Laboratory

The ISS National Laboratory (ISSNL), managed by the non-profit Center for the Advancement of Science in Space (CASIS) for NASA, manages and coordinates U.S. research and development activities on the ISS that are funded by other organizations, including other federal agencies, universities, educational or research organization, or commercial entities.

According to CASIS in its ISSNL annual report for 2020, from 2011 through 2020, ISSNL sent 449 payloads to the ISS in support of more than 500 investigations.³⁹ Over the five-year period spanning fiscal years 2016 through 2020, 70% of the ISSNL payloads were provided by non-government (academic, nonprofit, and/or commercial) entities. ISSNL investigations may be scientific experiments in physical or life sciences, remote sensing of Earth or other targets, technology development, or education initiatives. In 2020, an Independent Review Team (IRT) commissioned by NASA to evaluate the operations and management of the ISSNL found that “the underlying set of expectations and predicted futures have evolved dramatically in the intervening fifteen years” between the establishment of the ISSNL in 2005 and 2020.⁴⁰ The report issued a number of recommendations on NASA’s management and oversight of the ISSNL and CASIS, the business structure and organization of CASIS, and the approach to developing priorities and soliciting and selecting R&D payloads. In response, NASA identified six changes it, together with CASIS, is making, which include establishing an ISSNL User Advisory Committee, creating transparent project and program evaluation and prioritization processes, consolidating NASA-CASIS communication and management functions and responsibilities to a single Program Executive at NASA, and managing prioritization and allocation of ISSNL resources to meet strategic priorities.⁴¹

Biological and Physical Sciences

NASA’s Biological and Physical Sciences (BPS) division, part of SMD, uses spaceflight environments to study biological and physical systems. BPS activities span basic to applied research and development to execute a dual mission of pioneering scientific discovery and enabling human spaceflight exploration in and beyond LEO.⁴² Within the Space Biology program, BPS supports research in animal biology; cell and molecular biology; microbiology; plant biology; and developmental, reproductive, and evolutionary biology. Within the Physical

³⁸ NASA, Human Research Program Integrated Research Plan, Revision M, July 2021. Available at:

https://humanresearchroadmap.nasa.gov/Documents/IRP_Rev-Current.pdf

³⁹ CASIS, “International Space Station U.S. National Laboratory annual Report for Fiscal Year 2020,” January 14, 2021. Available at: <https://www.issnationallab.org/ar2020/>

⁴⁰ NASA, “NASA Shares Findings, Recommendations, and Response to Review of International Space Station Lab,” April 6, 2020. Available at: <https://www.nasa.gov/feature/nasa-shares-findings-recommendations-and-response-to-review-of-international-space-station>

⁴¹ NASA, “A Strategy for the Future of the International Space Station (ISS) National Laboratory (ISSNL) and Commercial Low Earth Orbit (LEO) Development.” Available at:

https://www.nasa.gov/sites/default/files/atoms/files/iss_cooperative_agreement_irt_final_report.pdf

⁴² <https://science.nasa.gov/biological-physical>

Sciences program, the division supports research in biophysics, combustion science, complex fluids, fluid physics, fundamental physics, and materials science.

The ISS is the primary host to more than 20 experiment and observing platforms managed by BPS or led by international partners that are critical to advancing BPS investigations. For example, the Wetlab-2 platform, led by the NASA Ames Research Center, provides tools for conducting polymerase chain reaction (PCR) techniques to conduct real-time gene expression analysis on board ISS. An example in physical sciences is the Phase II Real-time Protein Crystal Growth (RTPCG-2), which uses the microgravity environment of the ISS to grow unique, high-quality protein crystals that may have application to drug treatments on Earth.

NASA commissioned the first decadal survey dedicated to the biological and physical sciences in space in 2011, with a midterm assessment released in 2018.⁴³ A new decadal survey is underway, with an expected release date of 2023.

International Developments and Future Plans

In April 2021, China launched the first module of its new space station *Tiangong*. In early summer 2021, two taikonauts (Chinese astronauts) conducted the first spacewalk from the new module. While smaller than the ISS, China plans for *Tiangong* to have two modules for science research, in addition to the current *Tianhe* module.⁴⁴ China has opened solicitations to host experiments on the station from any United Nations member state. Accepted projects involve institutions from ESA member states, Mexico, Kenya, Russia, and India,⁴⁵ in addition to the more than 1,000 tentatively approved experiments led by Chinese principal investigators, some of which have already launched.⁴⁴ ESA astronauts have trained with taikonauts, with the eventual goal of ESA astronauts flying to *Tiangong*.⁴⁶ Pursuant to direction in a provision of annual appropriations legislation,⁴⁷ NASA is prohibited from bilateral activities with China or any Chinese-owned company without Congressional approval.

⁴³ National Academies of Sciences, Engineering, and Medicine. 2018. *A Midterm Assessment of Implementation of the Decadal Survey on Life and Physical Sciences Research at NASA*. Washington, DC: The National Academies Press. Available at: <https://doi.org/10.17226/24966>.

⁴⁴ Mallapaty, Smriti, "China's Space Station is Preparing to Host 1,000 Scientific Experiments," July 23, 2021. Available at: <https://www.nature.com/articles/d41586-021-02018-3>.

⁴⁵ United Nations Office for Outer Space Affairs, United Nations/China Cooperation on the Utilization of the China Space Station (CSS), Selected Experiment Projects to be executed on board the CSS for the 1st Cycle, June 12, 2019. Available at: https://www.unoosa.org/documents/doc/psa/hsti/CSS_1stAO/1stAO_FinSelResults.pdf.

⁴⁶ ESA, "ESA and Chinese Astronauts Train Together," August 24, 2017. Available at: https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Astronauts/ESA_and_Chinese_astronauts_train_together.

⁴⁷ Public Law 116-260, "Consolidated Appropriations Act, 2021," Section 526, Division B. December 27, 2020. Available at: <https://www.congress.gov/116/bills/hr133/BILLS-116hr133enr.pdf>.

Chairman BEYER. Good morning and welcome to our distinguished witnesses. We're very pleased to have you with us today as we discuss "NASA's Future in Low Earth Orbit: Considerations for International Space Station Extension and Transition."

The International Space Station, ISS, has been an important component of America's post-Apollo human spaceflight program for decades. Beginning in 1984 with President Reagan's resurrecting the idea of developing a crewed orbiting station that would include our allies and our partners, followed by President Clinton's decision to include the Russians in a redesigned station, it has continued through multiple Congresses and Administrations with development, assembly, and now full utilization. In many ways, the ISS epitomizes the long-term continuity of purpose is that essential for our human spaceflight program.

During its more than two decades of operation, the ISS has cemented our international partnerships, enabled knowledge of large structural assembly in space, supported extensive basic and applied research, maintained U.S. expertise in human spaceflight operations, enabled the development of public-private partnerships for cargo and crew transportation to the ISS, and opened space to multiple users, including commercial entities, academia, and other Federal Government agencies.

And it allowed me to just recite the longest sentence I've ever seen.

Perhaps most importantly, it continues to inspire our youth as they are born into an era that has never been without an American living and working in low Earth orbit (LEO).

This Committee and multiple Congresses have shaped U.S. policy related to the ISS. Today, we must continue to exercise our responsibilities as we face important decisions on the future of NASA's (National Aeronautics and Space Administration's) role in low Earth orbit, the duration of ISS operations, what should follow, and ensuring a U.S. presence in LEO.

By the way, the nice part about this being remote for many of you is you don't have to listen to this "expletive deleted" bell.

Anyway, has the ISS fulfilled its purpose? If not, what additional objectives need to be achieved during the ISS's lifetime? How much time is needed? And is the ISS, as a facility, structurally fit to support the duration required to achieve those objectives?

And if we're going to consider extending the ISS, we'll need assurances of its structural integrity, because, whether due to routine use, aging, or otherwise, the ISS structure is not problem-free. A debris hit to the Canadian arm, air leaks in the Russian segment, and the incident of the newly attached Russian module firing its thrusters, causing the ISS to flip until attitude control was regained, are recent examples.

The 2020 annual report of the Aerospace Safety Advisory Panel, the ASAP, recommended that NASA document the ISS life-limiting systems and components through and beyond 2028 which are considered to be of highest risk to ISS lifetime and that NASA assess the engineering lead time required to develop and fly solutions to the highest-risk failures if they were to occur before 2028.

So I look forward to hearing from our witnesses on this matter. Whatever decision is made on the lifetime of ISS operations, we

need a strong plan in place to ensure research and related activities can be transitioned seamlessly to alternative capabilities without a gap.

And as we look to ISS transition, there's no getting around the fact that we'll need to consider the plan for deorbiting the facility and the cost and responsibilities for that action.

The 2017 *NASA Authorization Act* directed NASA to develop a plan to transition in a step-wise approach from the current regime that relies heavily on NASA's sponsorship to a regime where NASA could be one of many customers of an LEO nongovernmental human spaceflight enterprise.

NASA's current post-ISS plans are to use commercial LEO platforms, or destinations, to support its future activities in low Earth orbit and to purchase services from commercial LEO providers. While commercial activities in LEO are developing, multiple market studies have shown that commercial demand is not yet sufficient to support a commercial LEO platform or platforms and that NASA will need to be an anchor tenant for the foreseeable future.

To that end, we'll need to understand NASA's costs and related commitments once ISS operations cease and what NASA support a private LEO platform will need, at what level, and for how long. We also need to understand the demand for a National Laboratory in low Earth orbit following the end of ISS.

Because all of these decisions, while consequential from a U.S. policy perspective, they also come with costs and resource implications, we need to go in with our eyes wide open. There's \$3 billion to \$4 billion in annual costs of operating the station for whatever duration is decided, in addition to any NASA investment in commercial platform development and the future costs associated with purchasing commercial LEO services.

And who's to pay for the sustainment of commercial LEO platforms, including repairs, supplies, and ground-based mission operations? Will commercial providers be prepared to bear all of these costs? And what level of savings is NASA anticipating to accrue from being a customer?

Well, we have a lot to discuss today, and I look forward to our witness testimonies.

In closing, our decisions about the ISS and what follows are not only essential to sustaining our research in LEO, they also concern our Nation's strategic presence in space. How we'll continue to engage with our international partners in LEO in a post-ISS era and the implications of other activities, including China's space station, must be considered.

The ISS partnership is a beacon of, and a vehicle for, peaceful international cooperation in outer space that has built the foundation for our collaborative next steps in human exploration—Moon to Mars. Maintaining the fabric of this peaceful coalition must guide us as this Subcommittee and Committee continues to shape our Nation's policy for civil space in low Earth orbit and outer space.

[The prepared statement of Chairman Beyer follows:]

Good morning, and welcome to our distinguished witnesses. We are very pleased to have you with us today as we discuss "NASA's Future in Low Earth Orbit: Considerations for International Space Station Extension and Transition."

The International Space Station—the ISS—has been an important component of America’s post-Apollo human spaceflight program for decades. Beginning in 1984 with President Reagan’s resurrecting the idea of developing a crewed orbiting space station that would include our allies and partners, followed by President Clinton’s decision to include the Russians in a redesigned station, it has continued through multiple Congresses and Administrations with development, assembly, and now full utilization. In many ways, the ISS epitomizes the long-term continuity of purpose that is essential to our human spaceflight program.

During its more than two decades of operation, the ISS has cemented our international partnerships, enabled knowledge of large structural assembly in space, supported extensive basic and applied research, maintained US expertise in human spaceflight operations, enabled the development of public private partnerships for cargo and crew transportation to the ISS, and opened space to multiple users, including commercial entities, academia, and other Federal government agencies. Perhaps, most importantly, it continues to inspire our youth as they are born into an era that has never been without an American living and working in low Earth orbit.

This Committee and multiple Congresses have shaped U.S. policy related to the ISS, and today we must continue to exercise our responsibilities as we face important decisions on the future of NASA’s role in low Earth orbit, the duration of ISS operations, what should follow, and ensuring a U.S. presence in LEO.

Has the ISS fulfilled its purpose? If not, what additional objectives need to be achieved during the ISS lifetime, how much additional time is needed, and is the ISS, as a facility, structurally fit to support the duration required to achieve those objectives?

If we’re going to consider extending the ISS, we will need assurances of its structural integrity and safety.

Because, whether due to routine use, aging, or otherwise, the ISS structure is not problem-free. A debris hit to the Canadian arm, air leaks in the Russian segment, and the incident of the newly attached Russian module firing its thrusters—causing the ISS to flip over until attitude control was regained—are recent examples.

The 2020 Annual Report of the Aerospace Safety Advisory Panel—the ASAP—recommended “that NASA document the ISS life-limiting systems and components—through and beyond 2028—which are considered . . . to be of highest risk to ISS lifetime” and that “NASA assess the engineering lead time required to develop and fly solutions to the highest risk failures if they were to occur before 2028.”

I look forward to hearing from our witnesses on this matter.

Whatever decision is made on the lifetime of ISS operations, we’ll need a strong plan in place to ensure research and related activities can be transitioned seamlessly to alternative capabilities without a gap.

And, as we look to ISS transition, there is no getting around the fact that we’ll need to consider the plan for deorbiting the facility, and the cost and responsibilities for that action.

The 2017 *NASA Authorization Act* directed NASA “to develop a plan to transition in a step-wise approach from the current regime that relies heavily on NASA sponsorship to a regime where NASA could be one of many customers of a low-Earth orbit non-governmental human space flight enterprise.”

NASA’s current post-ISS plans are to use commercial LEO platforms or “destinations” to support its future activities in low Earth orbit and to purchase services from a commercial LEO providers.

While commercial activities in LEO are developing, multiple market studies have shown that commercial demand is not yet sufficient to support a commercial LEO platform or platforms and that NASA will need to be an anchor tenant for the foreseeable future.

To that end we’ll need to understand NASA’s costs and related commitments, once ISS operations cease, and what NASA support a private LEO platform will need, at what level, and for how long. We’ll also need to understand the demand for a National Laboratory in low Earth orbit following the end of the ISS.

Because all of these decisions, while consequential from a U.S. policy perspective, also come with costs and resource implications. We need to go in with our eyes wide open.

There’s the \$3-4 billion annual costs of operating the Station for whatever duration is decided, in addition to any NASA investment in commercial platform development, and the future costs associated with purchasing commercial LEO services.

And who is to pay for the sustainment of commercial LEO platforms, including repairs, supplies and ground-based mission operations? Will commercial providers be prepared to bear all of these costs, and what level of “savings” is NASA anticipating to accrue from being a customer?

Well, we have a lot to discuss today and I look forward to our witnesses testimony.

In closing, our decisions about the ISS and what follows are not only essential to sustaining our research in LEO, they also concern our nation's strategic presence in space. How we'll continue to engage with our international partners in LEO in a post-ISS era, and the implications of other activities, including China's Space Station, must be considered.

The ISS partnership is a beacon of, and vehicle for, peaceful, international cooperation in outer space that has built the foundation for our collaborative next steps in human exploration-Moon to Mars. Maintaining the fabric of this peaceful coalition must guide us as this Subcommittee and Committee continues to shape our nation's policy for civil space in low Earth orbit and outer space.

Chairman BEYER. Now let me recognize my good friend, the Ranking Member of the Space Subcommittee, Dr. Brian Babin from Texas.

Mr. BABIN. Thank you, Mr. Chairman. I really appreciate it.

We are at an inflection point for our Nation's space program. Last year, NASA once again launched American astronauts on American rockets from American soil. Earlier this summer, we witnessed two suborbital commercial human launches. Just last week, the first spaceflight participant mission achieved orbit. The Space Launch System will launch within a few months. And the Artemis program will return to the Moon, and that is underway.

We also celebrated the 20th anniversary of continuous occupation of the International Space Station, the ISS, last November, recognizing Expedition 1 when Bill Shepherd ushered in the current era of space exploration. We're privileged to have Bill testify before us today as one of our expert witnesses.

A lot has happened since then. We suffered the tragic loss of Columbia in 2003, grounded the shuttle fleet for over 2 years as part of the Return to Flight effort, and completed space shuttle assembly of the ISS in 2011, canceled the shuttle program as we developed new spacecraft, and relied on the Russian Soyuz launches for crew transfer for far too long.

Throughout all of this, the ISS and the international partnerships that enabled it remained resilient. After over 20 years of continuous operations, however, the ISS is beginning to show its age. Cracks and leaks are popping up. Solar arrays were recently upgraded. And the space suits necessary for space walks need to be replaced. The first segments of ISS have a design life of roughly 15 years with a safety factor of 2, meaning that, with the appropriate life-extension measures, the segments can reasonably be expected to last until 2028.

While no law prevents NASA from operating the ISS as long as it deems necessary, it is time to have a conversation about the future of the ISS and our presence in low Earth orbit. Section 303 of the 2017 *NASA Authorization Act* calls for NASA to develop an ISS transition plan and to update it biannually. And while this is a good start, no significant decisions have been made about the future of the ISS and our presence in low Earth orbit. While Administrator Nelson expressed support for continuing operations past 2024 at one of our hearings this summer and many of the international partners have expressed similar support, a formal agreement has not been solidified.

Other issues include how to prioritize upgrades to the existing ISS space suits used for space walks and the development of future

space suits for the lunar surface, engineering analysis of the lifetime of the ISS, whether we will reciprocate seat swaps with the Russians, and the development of future free-flyers and other efforts to offset the operational costs of the ISS. We also need to understand the impacts of the recent incident involving the docking of the Russian Nauka module.

I proudly represent Johnson Space Center, home of the historic mission control and the ISS program. Many of my constituents have a vested and a personal interest in the success of the ISS. I want to see NASA not only fulfill the expectations of the ISS but also to carry on its legacy in other programs so that we do not retreat from space.

Abandoning the ISS without a clear transition plan in place would only serve the interests of the Communist Chinese. Like in other domains, the CCP (Chinese Communist Party) seeks to exploit vacuums left by the great nations. If they are the only game in town, other nations will seek to partner with them to gain access to space. This would erode America's strategic leadership and, unfortunately for those other nations, result in the exploitation of their own scientific, technical, and strategic standing.

The ISS is not only a bridge to space but also a bridge to the other nations. It binds us under the common cause of discovery. I am sure that all of us share the same goal of ensuring that the ISS and follow-on endeavors continue this special tradition.

And I yield back, Mr. Chairman.

[The prepared statement of Mr. Babin follows:]

We are at an inflection point for our nation's space program. Last year, NASA once again launched American astronauts on American rockets from American soil. Earlier this summer we witnessed two suborbital commercial human launches. Just last week, the first orbital spaceflight participant mission launched and safely returned to Earth after 3 days in space. The Space Launch System will launch within a few months, and the Artemis program to return to the Moon and venture to Mars is underway. We also celebrated the 20th anniversary of continuous occupation of the International Space Station (ISS) last November, recognizing Expedition 1 when Bill Shepherd ushered in the current era of space exploration.

A lot has happened since then. We suffered the tragic loss of Columbia in 2003, grounded the Shuttle fleet for over two years as part of the Return to Flight effort, completed Space Shuttle assembly of the ISS in 2011, cancelled the Shuttle program as we developed new spacecraft, and relied on Russian Soyuz launches for crew transfer for far too long. Throughout all of this, the ISS, and the international partnerships that enable it, remained resilient.

Now, after more than 20 years of continuous operations, the ISS is beginning to show its age. Cracks and leaks are popping up, solar arrays were recently upgraded, and the space suits necessary for space walks need to be replaced. The first segments of the ISS have a design life of roughly 15 years with a safety factor of two, meaning that with appropriate life extension measures the segments can reasonably be expected to last to 2028. While no law prevents NASA from operating the ISS as long as it deems necessary, it is past time to have a conversation about the future of the ISS and our presence in low Earth orbit.

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Chairman BEYER. Mr. Babin, thank you very much. We appreciate that.

I would now like to recognize the distinguished Chair of the entire Space—or Science, Space, and—Science, Technology, and Space Committee—you see I’ve got my priorities correct—Chairwoman Johnson.

Chairwoman JOHNSON. Well, thank you, and good morning. And, Chairman Beyer, I am so pleased that you set this important hearing on the International Space Station and NASA’s future in low Earth orbit.

I want to welcome our distinguished witnesses today and thank you for participating. I also want to thank you for your service. We wouldn’t be discussing the International Space Station, its accomplishments, and the plans for its future without your important contributions and those of so many others.

And important work remains to be done, including research on human health and performance in space, fundamental microgravity science, life-support systems for deep space exploration, and next-generation space suit development and testing.

I certainly hope that these activities, as well as other research, are NASA’s priorities. Because part of our congressional role is to consider how long the Space Station should operate. And while novelties such as private space tourist missions or movie-making on the International Space Station may grab media attention, they do not establish the case for extending this unique and one-of-a-kind orbiting laboratory. And as we look forward to the International Space Station, we need NASA to provide a clear accounting of what its specific requirements will be.

I am really proud of what NASA and our partners have accomplished with the Space Station. It has supported humans on orbit for two decades, which is a considerable achievement. It also continues to enable an array of research and technology development that advances basic science and our preparations for sending humans to the Moon and Mars.

I also want to say that I echo Chairman Beyer’s comments on the importance of the Space Station to our U.S. leadership and bringing nations together in pursuit of the peaceful use and exploration of outer space. The enduring mission of peaceful space cooperation is more important now than ever. While planning for a future beyond the Space Station is important, the reality is that the International Space Station is still operating.

In addition, as we look ahead to NASA's future in low Earth orbit, I hope we also continue to maintain a focus on STEM (science, technology, engineering, and mathematics) engagement and inspiring youth. America's future depends on a 21st-century work force that can continue our science and innovation capabilities, including space.

Mr. Chairman, there is so much to discuss at today's hearing, including the structural health of the Space Station, NASA's plans and cost estimates for what follows, and the need for a clear understanding of what NASA's requirements for the low Earth orbit activities will be once the International Space Station has retired.

And, finally, given the important geopolitical role that the International Space Station has played, we need to examine how best we can ensure that the U.S. can continue to maintain the international partnerships that the Space Station has fostered.

So, with that, I look forward to the witnesses' testimony, and I yield back. Thank you.

[The prepared statement of Chairwoman Johnson follows:]

Good morning, and thank you Chairman Beyer for holding this important hearing on the International Space Station and NASA's future in low Earth orbit.

I want to welcome our distinguished witnesses today, and thank you for participating. I also want to thank you for your service. We wouldn't be discussing the International Space Station, its accomplishments, and the plans for its future without your important contributions and those of so many others.

I am proud of what NASA and our partners have accomplished with the International Space Station. It has supported humans on orbit for two decades—a considerable achievement. It also continues to enable an array of research and technology development that advances basic science and our preparations for sending humans the Moon and Mars.

I also want to echo Chairman Beyer's comments on the importance of the Space Station to our U.S. leadership in bringing nations together in pursuit of the peaceful use and exploration of outer space. The enduring mission of peaceful space cooperation is more important now than ever.

While planning for a future beyond the Space Station is important, the reality is that the International Space Station is still operating.

And important work remains to be done, including research on human health and performance in space, fundamental microgravity science, life support systems for deep space exploration, and next generation space suit development and testing.

I certainly hope that these activities, as well as other research, are NASA's priorities. Because part of our congressional role is to consider how long the Space Station should operate.

And while novelties such as private space tourist missions or movie-making on the International Space Station may grab media attention, they don't establish the case for extending this unique, one-of-a-kind orbiting laboratory.

And as we look beyond the International Space Station, we need NASA to provide a clear accounting of what its specific requirements will be for low Earth orbit human spaceflight activities, so that NASA can focus its limited resources on ensuring those requirements are met.

In addition, as we look ahead to NASA's future in low Earth orbit, I hope that we also continue to maintain a focus on STEM engagement and inspiring our youth. America's future depends on a 21st-century workforce that can continue our science and innovation capabilities, including in space.

Mr. Chairman, there's much to discuss at today's hearing, including the structural health of the Space Station, NASA's plans and cost estimates for what follows, and the need for a clear understanding of what NASA's requirements for low Earth orbit activities will be once the International Space Station has been retired.

Finally, given the important geopolitical role that the International Space Station has played, we need to examine how best we can ensure that the U.S. can continue to maintain the international partnerships that the ISS has fostered.

With that, I look forward to our witness's testimonies, and I yield back.

Thank you.

Chairman BEYER. Madam Chairman, thank you very, very much.

And now let me recognize the Ranking Member of the entire Committee, the gentleman from Oklahoma, Mr. Lucas.

Mr. LUCAS. Thank you, Mr. Chairman.

I simply want to reflect on the wise and wisdom-filled words of my three colleagues, and I look forward to our witnesses and a lively discussion today.

And, with that, I yield back, and let's proceed.

Chairman BEYER. Thank you, Mr. Lucas, very much.

Let me make a couple of the housekeeping things I should've done at the very beginning, which is that, without objection, the Chair is authorized to declare a recess at any time.

We are meeting virtually. A couple of reminders. Please keep your video feed on as long as you are present in the hearing. Members are responsible for their own microphones, so please keep the microphones muted unless you're speaking.

And, finally, if Members have documents they wish to submit for the record, please email them to the Committee Clerk, whose email address was circulated prior to our hearing.

And now let me introduce, at least, our witnesses, in the best way that I can. Let's see.

Our first witness is Ms. Robyn Gatens. Ms. Gatens is the Director of the International Space Station at NASA Headquarters. As ISS Director, Gatens leads strategy, policy, integration, and stakeholder engagement for the Space Station program at the agency.

In her 35 years at NASA, Ms. Gatens has led the development and management of life-support and habitation systems for human spaceflight missions. She's also led agency strategic and budget planning to mature these technologies needed for future deep space explorations, using the ISS as a demonstration testbed.

Ms. Gatens holds a bachelor of chemical engineering degree from Georgia Institute of Technology.

Our second witness is Dr. Kate Rubins. Dr. Rubins was selected by NASA as an astronaut in 2009, and Dr. Rubins completed her first spaceflight on Exploration 48/49, where she became the first person to sequence DNA in space.

Prior to joining NASA, she worked as a fellow/principal investigator at the Whitehead Institute for Biomedical Research, studying viral diseases that primarily affect Central and West Africa.

Dr. Rubins has most recently served aboard the International Space Station as flight engineer for Expedition 63/64. Across the two flights, she has spent a total of 300 days in space and conducted four space walks.

She holds a Bachelor of Science in molecular biology from the University of California and a Ph.D. in cancer biology from Stanford University.

Our third witness is Mr. Jeffrey Manber. Mr. Manber has served as the CEO (Chief Executive Officer) of Nanoracks since 2009. Today, Nanoracks has customers in over 30 countries, ranging from governmental agencies to universities and companies and, most recently, the Bishop Airlock, permanently docked to the International Space Station to provide deployment services.

Previously, as CEO of MirCorp, which leased the Russian space station Mir, Mr. Manber oversaw the first commercially funded crewed mission to the Mir Space Station. He currently serves on

the NASA National Advisory Committee on Commercialization and is the Chairperson of the CASIS (Center for the Advancement of Science in Space)-ISS National Lab Users Advisory Subcommittee on Commercial Uses of ISS.

Our fourth witness is Mr. Todd Harrison. He's the Director of the Aerospace Security Project at the Center for Strategic and International Studies. As a senior fellow in the International Security Program, he leads the Center's efforts to provide in-depth, non-partisan research and analysis of defense funding, space security, and air power issues.

He previously worked at Booz Allen Hamilton, across the aerospace industry, and served as a captain in the U.S. Air Force Reserves. He's a graduate of the Massachusetts Institute of Technology, MIT, with both a B.S. And an M.S. In aeronautics and astronautics. And our fifth and final witness is Captain William Shepherd. Captain Shepherd served as a Navy SEAL, NASA astronaut, program manager and senior government official with the Department of Defense.

He started his military in 1971 as an underwater demolition Frogman and Navy SEAL. In 1984, he was selected as a NASA astronaut. Captain Shepherd flew as a mission specialist on three space shuttle flights. In 1993, he was selected to serve as Program Manager for the new International Space Station. In 2000, he served as Commander of Expedition 1, the first crew of the International Space Station. And then Captain Shepherd returned to the Navy in 2001 and later was the first science advisor for the U.S. Special Operations Command.

Captain Shepherd consults with government and industry organizations and is a member of Stevens Institute Systems Engineering Research Center. He received a bachelor's degree in aerospace engineering from the U.S. Naval Academy and Master of Engineering degrees in mechanical and ocean engineering from MIT.

Wow.

Well, as the witnesses should know, you each have 5 minutes for your spoken testimony. Your written testimony, which can be much longer, will be included in the record for the hearing. And when all of you have completed your spoken statements, we will begin asking you our questions. Each Member will have 5 minutes to question the panel.

And let's start with Ms. Robyn Gatens.

Ms. Gatens, the floor is yours.

**TESTIMONY OF MS. ROBYN GATENS,
DIRECTOR, INTERNATIONAL SPACE STATION,
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION**

Ms. GATENS. Thank you.

Chairwoman Johnson, Ranking Member Lucas, Chairman Beyer, Ranking Member Babin, and Members of the Subcommittee, I'm honored to appear before you to discuss the International Space Station, the world's preeminent orbital microgravity platform for research and development.

For more than 20 years, the ISS has supported cutting-edge research that benefits humanity, including in-space manufacturing of novel materials and lifesaving medical products. It has helped us

to understand the Earth's climate and provided an unparalleled platform for science, technology, engineering, and mathematics engagement. The ISS continues to be a positive example of international partnerships, and the research conducted on the ISS has helped to advance science and improve life on Earth.

Today, with commercial crew and cargo transportation systems online, the ISS is busier than ever and provides the United States and our partners with unmatched capabilities in space. The ISS National Laboratory hosts hundreds of experiments from other government agencies, academia, and commercial users. Meanwhile, NASA's research and development onboard is advancing the technologies and procedures that will be necessary to send the first woman and the first person of color to the Moon and the first humans to Mars.

The ISS is now entering its third and most productive decade of utilization, including research advancement, commercial value, and global partnership. The first decade of ISS was dedicated to assembly, and the second was devoted to research and technology development and learning how to most effectively conduct these activities in space. The third decade is one of results, where research capacity will be maximized. Deep space exploration technologies will be verified to support human exploration of the solar system, and medical and environmental benefits will continue to be returned to humanity.

This decade is also when the groundwork is laid for a commercial future in space. NASA is already laying the foundation of this future, which includes careful planning to ensure there is no gap in U.S. human spaceflight capability in low Earth orbit, or LEO.

The ISS is certified technically to continue to operate until at least 2028, and there are no engineering issues that NASA is aware of that would preclude safely and productively operating the ISS through 2030. Extending the operation of the ISS could give U.S. private industry time to develop the capabilities and experience to operate in LEO and to deploy the platforms that will meet the needs of NASA and other users there.

With the introduction of Commercial LEO Destinations (CLD), NASA expects to realize efficiencies from the use of innovative, efficient, and cost-effective platforms using a more commercial approach to meeting the agency's needs in LEO. This will allow NASA to shift significant financial and personnel resources toward exploration objectives.

As Commercial LEO Destinations become available, NASA intends to implement an orderly transition from current ISS operations to these destinations. NASA envisions a transition period of roughly 2 years, during which both ISS and Commercial LEO Destinations are operational, allowing gradual transfer of NASA activities from ISS to commercial platforms.

NASA intends to purchase services on these commercial platforms for accommodating U.S. astronauts, technology testing, human research, and science. A continuously crewed LEO platform is a more cost-effective place than deep space to test technologies and practice protocols to prepare us for a Mars mission.

NASA also plans to continue to provide support for research in LEO based on the successes and lessons learned of the ISS Na-

tional Laboratory. We hope that our other U.S. Government partner agencies will join us in doing so. This will provide continuity for research institutions, U.S. Government agencies, and developing industries to continue their work using the unique environment of low Earth orbit.

Finally, it is imperative that the United States maintain and expand its international partnerships during and after the transition to Commercial LEO Destinations. NASA operates the ISS in partnerships with 5 other space agencies, representing 15 countries, offering high-profile opportunities for U.S. leadership in civil and robotic spaceflight.

At a time when other nations are seeking to expand their abilities to operate in space, the ISS remains the premier example of how an international team can productively and successfully cooperate in space over the course of decades.

Further details of NASA's plans for ISS transition are contained in our update to the "ISS Transition Report," which we will deliver to Congress in the coming weeks.

Thank you again, and I look forward to your questions.

[The prepared statement of Ms. Gatens follows:]



National Aeronautics and
Space Administration

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Presented by Witness

Sept. 21, 2021

Committee on Science, Space, and Technology Subcommittee on Space and Aeronautics

U.S. House of Representatives

Statement of:
Ms. Robyn Gatens
Director, International Space Station Division
Human Exploration and Operations Mission Directorate
National Aeronautics and Space Administration

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BY WITNESS
September 21, 2021

**Statement of
Ms. Robyn Gatens
Director, International Space Station Division
Human Exploration and Operations Mission Directorate
National Aeronautics and Space Administration**

before the

**Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology
U.S. House of Representatives**

Chairman Beyer, Ranking Member Babin, and Members of the Subcommittee, I am honored to appear before you to discuss the International Space Station (ISS), the world's preeminent orbital microgravity platform for research and development. For more than 20 years, the ISS has supported cutting-edge research that benefits humanity, including in-space manufacturing of novel materials and life-saving medical products; helped to understand the Earth's climate; and provided an unparalleled platform for Science, Technology, Engineering, and Mathematics (STEM) engagement. The ISS has been and continues to be a positive example of international partnerships.

The research conducted on ISS has helped to advance science and improve life on Earth. Technology demonstrations and development on board have progressed the state-of-the-art for applications both on Earth and in deep space. Climate sensors deployed on ISS have validated climate models and contributed a host of new information about Earth's changing climate environment, while space science instruments on board have advanced our knowledge of everything from neutron stars to dark matter. The Station's crew itself has been a critical part of the experiment as well, using their own bodies as test subjects for research into human adaptation to living and working in microgravity. Without these long-duration demonstrations and experiments into the human and vehicle joint system, human exploration of the solar system will not be possible.

The ISS is now entering its third and most productive decade of utilization, including research advancement, commercial value, and global partnership. The first decade of ISS was dedicated to assembly, and the second was devoted to research and technology development, and learning how to most effectively conduct these activities in space. The third decade is one of results, where research capacity will be maximized due to the commercial crew and cargo programs, deep space exploration technologies will be verified to support human exploration of the solar system, medical and environmental benefits will continue to be returned to humanity, and the groundwork is laid for a commercial future in space.

Today, with commercial crew and cargo transportation systems online, the ISS is busier than ever. The ISS National Laboratory, responsible for utilizing 50 percent of NASA's resources on board the ISS, hosts hundreds of experiments from other Government agencies, academia, and commercial users to return benefits to people and industry on the ground. Meanwhile, NASA's research and development on board is advancing the technologies and procedures that will be necessary to send the first woman and first person of color to the Moon and the first humans to Mars.

The ISS is also now entering an era of robust commercial use, taking advantage of the utilities provided by the ISS to develop the capabilities industry needs to move from being dependent on NASA for access to space to providing the access NASA will need to continue its mission in low-Earth orbit (LEO) after the lifetime of the ISS. Commercial crew and cargo transportation are well known examples, and today provide the vital lifeline from the Earth to the ISS. Perhaps less known are over 20 commercial facilities operating on board ISS today, including a 3-D printer, a bioprinter, external Earth observation and materials platforms, and an airlock, that are available for use by both NASA and other paying customers.

The ISS provides the United States and our partners with unmatched capabilities in space. NASA operates ISS in partnership with four other space agencies, representing 15 countries, offering high-profile opportunities for U.S. leadership in civil and robotic spaceflight. At a time when other nations are seeking to expand their abilities to operate in space, the ISS remains the premier example of how an international team can productively and successfully cooperate in space over the course of decades. The United States will maintain and expand its international partnerships during and after the transition to commercial low-Earth orbit destinations (CLDs).

That said, the ISS is now more than 20 years old and is relatively expensive to operate. NASA is currently exploring, with its international partners, the extension of ISS operations to 2030, by which time we hope to have cost-effective commercial alternatives that will allow retirement of the Station. This approach would continue to return these benefits to the United States and to humanity as a whole, while preparing for a seamless transition of these missions to commercially-owned and -operated LEO destinations that will follow. The ISS is certified technically to continue to operate until at least 2028, and there are no engineering issues that NASA is aware of that would preclude safely and productively operating the ISS through 2030. Indeed, the ISS itself has been recently upgraded with a new commercial airlock, a new Russian research and docking module, and several power system upgrades that will operate for the life of the vehicle.

A number of research investigations and technology development activities that are necessary to extend human presence into the solar system require capabilities that at this time can only be provided by the ISS. NASA maintains roadmaps for these activities, including the ISS Technology Demonstration Fly-Off Plan and the Human Research Program Plan for Risk Reduction. These roadmaps show the plan for using the remaining life of ISS to accomplish what must be accomplished there, before moving any remaining and future work to CLDs. The ISS and future CLD platforms are more cost-effective locations than deep space to practice protocols to prepare humans for Mars missions. Long-duration crew stays in a microgravity environment followed by landing on Earth can to some degree replicate the conditions that astronauts will need to perform on a trip to Mars.

NASA envisions a bright future for the LEO economy. By the early 2030s, NASA plans to purchase crew time for at least two – and possibly more – NASA crewmembers per year aboard commercial CLDs to continue basic microgravity research, applied biomedical research, and ongoing exploration technology development and human research, informed by the first several Artemis lunar landings. These activities could be supplemented by crew time purchased by NASA from a commercial provider using the provider's own private astronauts. The CLDs would be visited on a rotating basis by other private astronauts unaffiliated with the CLD provider, seeking either research time for their own experiments, or tourists looking to visit and experience space.

After the end of the ISS, NASA plans to continue to provide support for research in LEO based on the successes and lessons learned of the ISS National Laboratory. We hope that our other U.S. Government partner agencies will join us in doing so. This will provide continuity for academia, research institutions,

U.S. Government Agencies (including NASA), and developing industries to continue their work using the unique environment of LEO.

NASA is already laying the foundation of this future. Extending the operation of ISS could give U.S. private industry time to develop the capabilities and experience to operate in LEO, and to deploy the platforms that will meet the needs of NASA and other users there. In January 2020, NASA competitively awarded a contract to Axiom Space for the use of the forward Node 2 port on ISS, on which they will deploy a commercial module in the 2024 timeframe. This module will support private activities in LEO that could otherwise not be accomplished on the Government-owned ISS, proving out a business plan for commercial platform operations. Axiom plans to add more modules to this complex with the eventual aim of departing ISS and becoming a free-flying destination in LEO.

In order to maintain competition for safe, reliable, and cost-effective CLDs, NASA recently released a solicitation to stimulate U.S. private industry development of free-flying orbital destination capabilities and create a market environment in which those services are available to both Government and private-sector customers. NASA's hope is to make two to four awards for commercial free-flyers, provided that sufficient funding is available to do so. These awards, combined with the Axiom port segment, will ensure that private industry is ready to provide CLD services prior to ISS retirement so that there is no gap in U.S. presence in LEO.

After Axiom and the other CLD partners have matured their designs over the next three to four years, NASA intends have a second phase of activity whereby NASA first contracts with industry to certify their designs as safe for NASA personnel and then goes on to purchase services from the CLD providers. This second phase is similar to the Commercial Crew transportation Capabilities (CCtCap) contracts that NASA awarded to SpaceX and Boeing for the Commercial Crew Program. Thus, NASA is building on the successful legacy of our commercial crew and cargo programs that are currently delivering important research, supplies, and NASA astronauts to the ISS.

These activities will enable the development of commercially-owned and -operated LEO destinations that are safe, reliable, and cost-effective, and will allow NASA to be one of many customers in LEO. With the introduction of CLDs, NASA expects to realize efficiencies from the use of innovative, efficient, and cost-effective platforms using a more commercial approach to meeting the Agency's needs in LEO. As commercial LEO destinations become available, NASA intends to implement an orderly transition from current ISS operations to these new commercial LEO destinations. Transition of LEO operations to the private sector will yield efficiencies in the long term, enabling NASA to shift significant financial and personnel resources towards exploration objectives. NASA envisions a transition period, during which both ISS and CLDs are operational, of roughly two years. This would allow a gradual transfer of NASA activities from ISS to commercial platforms, while allowing NASA and its commercial partners to incorporate lessons learned from the first round of activities on CLDs into subsequent activities.

To give future commercial providers a business model to work towards, NASA is refining its "Forecasting Future NASA Demand in Low-Earth Orbit: Quantifying Demand"¹ white paper, and will define NASA's anticipated service requirements for future CLD providers. These forecasts will include not only the anticipated NASA demand for crew accommodation, technology testing, human research, and science, but also capture the expected future needs of other U.S. Government, private, and international users. The intent of this activity is to allow future CLD and launch providers to scale their

¹ https://www.nasa.gov/sites/default/files/atoms/files/forecasting_future_nasa_demand_in_low-earth_orbit_revision_two_-_quantifying_demand.pdf

activities to meet the future needs of the U.S. Government, while also allowing them to design private use of the capabilities. Given the unique barriers of access to space, NASA and the ISS National Laboratory are partnering to support and incubate promising commercial in-space manufacturing applications such as advanced materials, regenerative medicine, and tissue engineering through the ISS National Lab, with the goal of creating sustained, self-sufficient demand for future CLD services. Other demand-enabling initiatives include allocating a portion of ISS resources for commercial use activities and private astronaut missions on a reimbursable basis.

It is in the interests of the United States that a seamless transition be effected from ISS to a future CLD such that no gap in U.S. human spaceflight capability is experienced. A gap could jeopardize the strong network of U.S. Government, international, and commercial research and technology partnerships that have developed over the last two decades. Operating ISS beyond 2025 gives NASA and U.S. commercial industry the time necessary to bring one or more CLDs online, concurrent in the late 2020s with ISS operations, to ensure that these new capabilities can meet the needs of NASA, its partners, and the Nation.

Thank you for the opportunity to discuss the International Space Station; I would be pleased to respond to any questions you might have.

Robyn Gatens
Director, International Space Station
NASA HQ

Ms. Robyn Gatens is the director of the International Space Station (ISS) in the Human Exploration and Operations mission directorate at NASA Headquarters. She is also an agency senior expert for environmental control and life support (ECLSS) and crew health and performance systems.



As ISS director, Gatens leads strategy, policy, integration, and stakeholder engagement for the space station program at the agency level, including use of the station for research and technology demonstrations including to support NASA's Artemis missions, and activities to secure an ongoing U.S. presence in low-Earth orbit (LEO) by enabling a successful, long-term private sector commercial LEO space economy.

In her 35 years at NASA, Gatens has led the development and management of life support and habitation systems for human spaceflight missions. She has also led agency strategic and budget planning to mature these habitation system technologies needed for future deep space exploration missions, using the ISS as a demonstration testbed.

She began her NASA career in 1985 at the Marshall Space Flight Center in Huntsville, Alabama. She held various leadership positions at Marshall, including manager for the Orion spacecraft crew support and thermal systems before transferring to NASA Headquarters in 2012.

Gatens is the recipient of NASA's Outstanding Leadership and Exceptional Achievement Medals and holds a Bachelor of Chemical Engineering degree from the Georgia Institute of Technology.

Chairman BEYER. Ms. Gatens, thank you very much.
 Now we'll hear from Dr. Rubins.
 Dr. Rubins, the floor is yours.

**TESTIMONY OF DR. KATHLEEN "KATE" RUBINS, ASTRONAUT,
 NATIONAL AERONAUTICS AND SPACE ADMINISTRATION**

Dr. RUBINS. Thank you.

Good morning, Chairwoman Johnson, Ranking Member Lucas, Chairman Beyer, Ranking Member Babin, and Members of the Subcommittee. I'm Kate Rubins, a NASA astronaut, veteran of two long-duration missions aboard the International Space Station, and a molecular biologist.

Thank you for the opportunity to share details of the cutting-edge science we're doing on the ISS and to highlight the tremendous value in having a spaceborne laboratory, where we can do research that is not possible on Earth.

I've spent 300 days combined on two long-duration missions living and working aboard the ISS. As a researcher and sometimes simultaneously as a test subject providing biological samples for further study, I can share firsthand the importance and the unique opportunity for scientific advancements in research made possible by having a research laboratory outside the bonds and limitations of gravity.

The ISS is the only place we can currently conduct long-duration research on how living in microgravity affects the human body, and it's the only place we can test technologies that will take us further into deep space. The ISS has offered over two decades of human research opportunities in a way that no other platform has been able to accomplish.

The things we've learned so far provide a great foundation for us as we reach even further away from our home planet. For future exploration of the Moon and Mars, we need the capability to autonomously monitor the microbial health of spacecraft and planetary habitats and to potentially identify life via DNA and RNA signatures as well. The ISS gives researchers an environment in which they can test sequencing in microgravity and refine the sequencing processes.

During my first mission to the Space Station in 2016, I had the honor of being the first person to ever sequence DNA in microgravity. Eventually, we sequenced more than 2 billion base pairs of DNA in collaboration with a world-class team of researchers on the ground.

During my most recent expedition to space this past year, I was able to build on the past work, conducting new DNA sequencing activities. With the ability to sequence DNA in space, astronauts could diagnose an illness or identify microbes growing in the ISS or another habitable spacecraft and determine if they represent a health concern.

I also spent many hours during my mission with my arms in the Life Sciences Glovebox. We conducted the Cardinal Heart experiment there. My breath was taken away by the sight of beating heart cells in microgravity for the first time.

Cardinal Heart studies how changes in gravity affect cardiovascular cells at the cellular and tissue levels. Not only will this

research contribute to our success in future space exploration, but it could also impact how we develop treatments for heart disease on Earth. Results could provide new understanding of heart problems on Earth, help identify treatments, and support development of screening measures to predict cardiovascular risk prior to spaceflight or on the ground.

As a third example, I took hundreds of microbial samples for the three-dimensional Microbial Monitoring study. This experiment provides sequencing and analysis on samples collected from over a thousand different locations within the Space Station. By advancing our understanding of the Space Station microbiome, this work helps identify potential risks and supports developing countermeasures to mitigate those risks.

The ISS is a world-class research laboratory where we, as astronauts, are able to perform research developed by scientists across the world. It is also the most powerful example of collaboration that I've ever witnessed and, I believe, one of the most powerful examples of this world-class collaboration. The world needs this example of nations coming together for the greater good and to see how many amazing things can be accomplished when we work together, doing science and exploration in harmony.

For more than 20 years, NASA has maintained a continuous human presence in Earth orbit, developing technology, skills, and knowledge needed for the human exploration of the Moon, Mars, and our solar system. The ISS is an active, vibrant laboratory where we are making the next steps of space exploration possible.

As we set our sights on the Moon and beyond, it is the knowledge and the practical experience we've gained from more than 20 years of continuous human presence and research on the Space Station that will pave a successful path forward. What we learn also has great impacts on Earth and human health, technology development, and even commercial growth.

I hope the foregoing information regarding scientific research operations on the International Space Station has helped shed some light on the value and the importance of having a space-based research platform for scientists and astronauts like me to push the boundaries of the known world, to inspire children, and to learn how we as a species adapt as we reach further into the universe.

I appreciate the opportunity to appear before the Subcommittee, and I look forward to answering any questions you may have.

[The prepared statement of Dr. Rubins follows:]



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before the
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Good morning Chairman Byer, Ranking Member Babin, and Members of the Subcommittee. I am Kate Rubins, a NASA Astronaut, veteran of two long-duration missions aboard the International Space Station (ISS), and a molecular biologist.

Thank you for the opportunity to share details of the cutting-edge science we are doing on the ISS, and to highlight the tremendous value in having a spaceborne laboratory, where we can do research not possible on Earth.

I have spent 300 days, combined on two six-month missions, living and working aboard the ISS. As a researcher, and sometimes simultaneously as the test subject providing biological samples for further study on the ground, I can share first hand the importance and the unique opportunity for scientific advancements and research made possible by having a research laboratory outside the bonds and limitations of gravity.

The ISS is the only place we can currently conduct long-duration research on how living in microgravity affects the human body, and test technologies that will take us farther into deep space. The ISS has offered over two decades of human research opportunities in a way that no other platform has been able to accomplish.

The things we have learned so far provide a great foundation for us as we reach even further away from our home planet. For the future exploration of the Moon and Mars, we need the capability to autonomously monitor the microbial health of spacecraft and planetary habitats, and to potentially identify DNA-based life as well. The ISS gives researchers an environment in which they can test DNA sequencing in microgravity and refine the sequencing processes.

During my first mission to the Space Station in 2016, I had the honor of being the first person to ever sequence DNA in microgravity, eventually sequencing more than two billion base pairs of DNA in collaboration with a world-class team of researchers on the ground. During my most recent expedition to space this past year, I was able to build on my past work conducting new DNA sequencing activities. With the ability to sequence DNA in space, astronauts could diagnose an illness, or identify microbes growing in the ISS or another habitable spacecraft and determine whether they represent a health concern.

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As a third example, I took hundreds of microbial samples for the Three-Dimensional Microbial Monitoring (3DMM) study. This experiment provides sequencing and analyses on samples collected from 1,000 different locations within the Space Station. By advancing our understanding of the Space Station microbiome, this work helps identify potential risks and supports developing countermeasures to mitigate those risks.

The ISS is a world-class research laboratory where we as astronauts are able to perform research developed by scientists across the world. It is also the most powerful example of collaboration that I have ever witnessed, and I believe one of the most (if not the most) powerful examples that exists. The world needs this example of nations coming together for the greater good and to see how many amazing things can be accomplished when we work together in harmony.

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I hope the foregoing information regarding scientific research operations on the International Space Station has helped shed some light on the value and importance of having a space-based research platform for scientists like me to push the boundaries of the known world, and to learn how we as a species will adapt as we reach further into the universe. I appreciate the opportunity to appear before this Subcommittee. I look forward to answering any questions you may have.

**Summary:**

Kathleen Rubins was selected by NASA in 2009. Rubins completed her first spaceflight on Expedition 48/49, where she became the first person to sequence DNA in space. She holds a Bachelor of Science in Molecular Biology from the University of California and a Ph.D. in Cancer Biology from Stanford University Medical School Biochemistry Department and Microbiology and Immunology Department. Dr. Rubins conducted her undergraduate research on HIV-1 integration in the Infectious Diseases Laboratory at the Salk Institute for Biological Studies. She worked as a Fellow/Principal Investigator at the Whitehead Institute for Biomedical Research and headed 14 researchers studying viral diseases that primarily affect Central and West Africa. Rubins most recently served aboard the International Space Station as flight engineer for Expedition 63/64. Across her two flights, she has spent a total of 300 days in space, the fourth most days in space by a U.S. female astronaut.

Personal Data:

Born in 1978 in Farmington, Connecticut, and raised in Napa, California, where her father, Jim, still resides. Her mother, Ann Hallisey resides in Davis, California. She enjoys running, cycling, swimming, flying, scuba diving and reading.

Education:

Graduated from Vintage High School in 1996, received a Bachelor of Science degree in Molecular Biology from the University of California, San Diego, in 1999 and a Ph.D. in Cancer Biology in 2005 from Stanford University Medical School Biochemistry Department and Microbiology and Immunology Department.

Experience:

Dr. Rubins conducted her undergraduate research on HIV-1 integration in the Infectious Diseases Laboratory at the Salk Institute for Biological Studies. She analyzed the mechanism of HIV integration, including several studies of HIV-1 Integrase inhibitors and genome-wide analyses of HIV integration patterns into host genomic DNA. She obtained her Ph.D. from Stanford University and, with the U.S. Army Medical Research Institute of Infectious Diseases and the Centers for Disease Control and Prevention, Dr. Rubins and colleagues developed the first model of smallpox infection. She also developed a complete map of the poxvirus transcriptome and studied virus-host interactions using both invitro and animal model systems.

Dr. Rubins then accepted a Fellow/Principal Investigator position at the Whitehead Institute for Biomedical Research (MIT/Cambridge, Massachusetts) and headed a lab of 14 researchers studying viral diseases that primarily affect Central and West Africa. She traveled to the Democratic Republic of Congo to conduct research and supervise study sites. Work in the Rubins Lab focused on poxviruses and host-pathogen interaction as well as viral mechanisms for regulating host cell mRNA transcription, translation and decay. In addition, she conducted research on transcriptome and genome sequencing of filoviruses (Ebola and Marburg) and Arenaviruses (Lassa Fever) and collaborative projects with the U.S.

<https://www.nasa.gov/astronauts/biographies/kathleen-rubins>



Army to develop therapies for Ebola and Lassa viruses. Dr. Rubins has published and presented her work in numerous papers at international scientific conferences and in scientific journals.

NASA Experience:

Rubins was selected in July 2009 as one of 9 members of the 20th NASA astronaut class. Her training included scientific and technical briefings, intensive instruction in International Space Station systems, spacewalks, robotics, physiological training, T 38 flight training and water and wilderness survival training.

Spaceflight Experience:

Expeditions 48 and 49 (July 2016 through October 2016) On July 7th, 2016, Dr. Rubins launched from the Baikonur Cosmodrome in Kazakhstan to the International Space Station aboard the first test flight of the new Soyuz MS spacecraft. Together the international crew of Expeditions 48 and 49 conducted or participated in more than 275 different scientific experiments including research in molecular and cellular biology, human physiology, fluid and combustion physics, Earth and space science and technology development. Dr. Rubins was the first person to sequence DNA in space, eventually sequencing over 2 billion base pairs of DNA during a series of experiments to analyze sequencing in microgravity. Dr. Rubins also grew heart cells (cardiomyocytes) in cell culture, and performed quantitative, real-time PCR and microbiome experiments in orbit.

Dr. Rubins conducted two spacewalks totaling 12 hours, 46 minutes. During her first spacewalk, Rubins and Jeff Williams installed the first International Docking Adapter, a new docking port for U.S. commercial crew spacecraft. During the second, they performed maintenance of the station external thermal control system and installed high-definition cameras, enabling never-before seen images of the planet and space station. Jeff Williams and Rubins successfully captured SpaceX Dragon commercial resupply spacecraft and then returned science experiment samples to earth. During Expedition 49, Rubins and crewmate Takuya Onishi grappled Orbital ATK's Cygnus resupply spacecraft, providing several tons of supplies and research experiments for future work on the orbital outpost.

Expeditions 63 and 64 (October 2020 through April 2021) On October 14, 2020, Dr. Rubins launched from the Baikonur Cosmodrome in Kazakhstan to the International Space Station aboard the Soyuz spacecraft. Dr. Rubins spent hundreds of hours working on new space station experiments, building on investigations she conducted during her first mission, including heart research and multiple microbiology studies. She also advanced her work in DNA sequencing, which could allow astronauts to diagnose an illness in space or identify microbes growing at the space station. Rubins worked on the Cardinal Heart experiment, which studies how changes in gravity affect cardiovascular cells at the cellular and tissue levels. Results could provide new understanding of heart problems on Earth, help identify new treatments, and support development of screening measure to predict cardiovascular risk prior to spaceflight. She returned safely to Earth on April 17, 2021 spending 185 days in space and conducted two spacewalks.

During Dr. Rubins two spaceflight missions, she has logged in a total of 300 days in space and conducted four spacewalks.

Awards/Honors:

Popular Science's Brilliant Ten (2009), National Science Foundation Predoctoral Fellowship (2000), Stanford Graduate Fellowship - Gabilan Fellow (2000), UCSD Emerging Leader of the Year (1998), Order of Omega Honor Society Scholarship Award (1998).

**Organizations:**

American Association for the Advancement of Science (AAAS), American Society of Tropical Medicine and Hygiene (ASTMH), American Society for Virology (ASV), RNA Society, Chi Omega, American Institute of Aeronautics and Astronautics (AIAA).

Pronunciation:

KATH-lean ROO-bens

Chairman BEYER. Thank you, Dr. Rubins, very much. Fascinating stuff.

Now I recognize Mr. Jeffrey Manber for his testimony.

**TESTIMONY OF MR. JEFFREY MANBER,
CHIEF EXECUTIVE OFFICER, NANORACKS, LLC**

Mr. MANBER. Thank you.

Chairwoman Johnson, Ranking Member Lucas, Chairman Beyer, Ranking Member Babin, and other Members of the Subcommittee, as well as my friends and fellow finalists—panelists—thank you for this opportunity.

My insights are informed by my three decades pursuing a stronger commercial space marketplace, as well as being the CEO of Nanoracks, which conducts commercial services on the ISS for organizations and governments as well as thousands of students engaged in space research.

I first testified before this panel and then-Chairman Bill Nelson in 1991. As I reviewed that testimony, it is heartening to realize the extraordinary progress that has been made.

Our largest utilization challenge in the 1990's was NASA's space shuttle program. It is remarkable to see how far we have progressed, from a single-point dependence with the space shuttle to a robust commercial launch industry with names like "SpaceX" and "Rocket Lab" that are the envy of the world.

And that is one of the key considerations as we seek the next steps for the International Space Station. We've been here before, haven't we? And that was, how and when to transition from the aging shuttle program.

So many strong arguments were made to keep the program operational, but, finally, Congress made the bold and correct decision that opened the new era of the launch vehicle industry that is, indeed, the envy of the world. And now we must do the same and have that dialog with another beloved program, the ISS.

The common thread in the recent extraordinary renaissance of space services is not advances in technology alone but also the repeated direction by Congress to support commercial participation in NASA activities. For ISS, this has been successfully demonstrated with the commercial cargo program through the use of the multiple vehicles, and so too and soon enough with commercial crew.

The challenge to assure a seamless transition is more urgent today than with the shuttle time, as our reliance on space assets is far greater today, and others seek to fill even the perception of any voids. There is no room for error, least we cede leadership to other nations. The Chinese space station is a challenge. As part of my written testimony, I have submitted a list of our allies participating on the Tiangong.

There is no dispute that, in space, when America participates, America leads. So I don't fear cooperation and competition with China. But we cannot allow even the perception that we will cede our 20-plus years of humans working in LEO to others.

Like the debate over transitioning from the shuttle program, these are difficult issues. I personally witnessed the declined of the Mir Space Station from a productive habitat to a fixer-upper. The

change was slow, and, soon, the Mir was less productive as a research platform.

Today, there are technical issues with the ISS. Some make the headlines; some do not. But it is clear that, no matter the congressional funding, no one can predict how long the ISS will remain efficient.

So our national choice is clear: Either push the ISS hardware far beyond the anticipated lifespan, or open the door to a new chapter of American leadership that will realize smaller, truly commercial space stations dedicated to research and in-space manufacturing.

I choose the latter, because recent history has shown that multiplicity in space assets is the safest and most cost-efficient pathway. And recent history has also shown that the private sector, working with NASA, produces cost-efficient and reliable results.

I'm less worried about losing a generation of space station personnel, as we are seeing companies like Sierra, Axiom, and Nanoracks hiring, and hiring big, from the ISS community.

Members of the Subcommittee, I ask you to support the NASA Commercial LEO Destination, CLD, free-flyer program to ensure there is no Space Station gap and that tomorrow's stations will, like today's launch vehicles, be the envy of the world.

Our parent company, Voyager Space, is investing significant capital in a private Nanoracks-led station dedicated to innovative space research. And we are not alone. Industry is ready to lead.

I consider the CLD program the pathway to assuring continuation of American leadership in LEO and, indeed, of the ISS program itself, with a new generation of cost-efficient, free-flying platforms which will continue the ISS tradition of STEM outreach as well.

We lack the luxury of our previous challenges. The space domain is today interwoven into the fabric of our society, and its continued health is every American's continued well-being. The lessons learned are clear. We must do all to prevent yet another gap in our basic space capabilities. I will say, this is what I fear the most, is that gap.

Thank you, Madam Chairwoman and Mr. Ranking Member, and to all Members for beginning today this necessary but difficult dialog.

Thank you.

[The prepared statement of Mr. Manber follows:]

*NASA's Future in Low Earth Orbit:
Considerations for International Space Station Extension and Transition.*

Testimony

Mr. Jeffrey Manber

Chief Executive Officer, Nanoracks, LLC

Introduction

Chairwoman Johnson, Ranking Member Lucas, Chairman Beyer, Ranking Member Babin, and members of the subcommittee, thank you for the opportunity to testify before you today. I have been asked to share my thoughts on our country's future in low-Earth orbit, the extension and transition of the International Space Station, and what lessons I have learned over 30 years in the space business that others could apply as our nation seeks to build out a new era in commercializing space. My opinions and insights are informed both by my work on the Mir Space Station and its transition and ultimate deorbit, as well as being the CEO of Nanoracks, which does business on the ISS with customers in over 40 states and 30 countries.

I first testified before this panel and then Chairman Bill Nelson, in 1991 as the Executive Director of the Space Business Roundtables. As I reviewed that testimony, it is heartening to observe the extraordinary progress that has been made in the past three decades. Our main utilization challenge in the early 1990s was NASA's *Space Shuttle* program. How far we have progressed from a single point dependence on space access with the government-owned *Space Shuttle*, to a robust commercial launch industry with names like SpaceX and Rocket Lab that is the envy of the world.

We have transitioned from programs that were routinely funded solely by the government to programs funded by private capital where the government is one of many customers. At Nanoracks, we privately funded our Bishop Airlock in a robust partnership with NASA which is now a permanent addition to the International Space Station.

The common thread in this wonderful renaissance of space services is not advances in technology alone, but also the repeated direction by Congress to support greater commercial participation in NASA's operational space activities. This was first successfully demonstrated with the Commercial Cargo program, through the use of multiple carriers that have assured extraordinary stability for ISS operations, and in the Commercial Crew program supported by SpaceX and, soon, Boeing, which provides crew transportation for LEO activities.

Today the key challenge confronting this Subcommittee is once again when and how to transition a beloved core NASA program. Yes, we have been here before, have we not? This time it is not the *Space Shuttle* but the International Space Station. So many strong arguments were made to keep the *Space Shuttle* program operational. But finally, Congress and the Administration

together made the bold and correct decision that opened the door to the current launch vehicle industry that is indeed the envy of the world.

But the stakes are higher today. The space domain is fully integrated into our society and it a vital component of the strategic defense of this nation. More than any other factor, my greatest concern is assuring that we do not confront a gap in the United States having full productive use of a domestic space station. Should we not have a seamless transition from ISS to a new generation of space stations the entire LEO ecosystem of space transportation services, Earth observation satellites and strong private capital investments in space services, will be in jeopardy.

Fortunately, the lessons learned since the 1990s can serve as a policy guide to this Subcommittee and the Administration. Ironically, this includes not only examining lessons learned from the transition from *Space Shuttle* to the current launch vehicle market, and from our increasing commercialization of the International Space station itself, but also from the late 1990s efforts by American entrepreneurs, including myself, to commercialize the then-aging Russian space station, Mir.

Lessons of Mir and MirCorp

One of the first examples of private capital and American entrepreneurs supporting a core government space program in a robust public private partnership took place not with NASA but within the Russian space community after the fall of the Soviet Union.

During the 1990s the Russian Federation confronted the need to commercialize the core assets of their space program, including the Federal launch vehicle programs and the Mir Space Station. Just as today, the satellite deployment market was far further developed and soon enough U.S. industry stepped up to commercialize the launch vehicles. Lockheed Aerospace participated in the creation of International Launch Services (ILS) which commercially marketed the Russian workhorse launch vehicle, the Proton. And Boeing Aerospace successfully participated in the novel Sea Launch program, which utilized the Russian-Ukrainian Zenit from a mobile platform.

These two efforts showed the international community that private companies and government programs could work together to provide efficiencies and funding. But the space station Mir represented a more uncertain marketplace. No one had ever marketed a human-occupied space station. The Russian government allowed the prime government contractor, RSC Energia, to seek commercial non-Federal markets to maintain the crewed space station. Significant revenue came from the Europeans in the form of guest ESA astronauts, and from NASA from the Shuttle-Mir program as well as smaller levels of income from an increasingly vibrant commercial program of advertising and tourism.

In 1999 Prime Minister Yevgeny Primakov issued a decree formally privatizing the Mir space station, turning ownership from the Russian Federation over to the recently privatized Energia, Russia's oldest and most respected space organization. Energia turned to international capital, signing a landmark leasing agreement with MirCorp for operating the Mir space station. MirCorp was a company established in Holland, of which I served as the Chief Executive Officer. The

Company was funded by several American investors seeking to transform the station into a fully commercial platform.

In many respects, MirCorp was the industry's first New Space company, funded solely with private capital and ultimately sponsoring the world's first privately funded crew mission of seventy-five days by S.V. Zaletin and A.Yu. Kaleria, during which the Mir was upgraded and cutting edge pharmaceutical drug and materials research was conducted.

Though the company was in the end unsuccessful, I'm proud how the effort to commercially operate the Mir became a critical data point in the evolution of the industry. When MirCorp closed its doors about 2002, it had over \$179 million in backlog. Customers in the pipeline included Mark Burnett of the game show *Survivor* and NBC for a game show in space, as well Dennis Tito, the space tourist who later flew to the ISS. Smaller customers included an international government agency and a handful of respects biopharma researchers.

MirCorp was a success in showing that entrepreneurial companies could work with space agencies, both foreign and domestic. Also that private capital could be raised for space station platforms and perhaps most importantly of all, that public excitement could be turned into marketable assets that serve both commercial markets and national policy objectives. MirCorp represented one of the first examples in space exploration of a private company contributing to upkeep and improve a core space program of a national space agency.

It is also important to note that one of the great concerns of all public officials, the loss of key specialized jobs in a given community, never materialized as the Russian space industrial base transferred over to the ISS program.

I witnessed the decline of the Mir station from a productive habitat to a fixer upper. I take away the sobering view that no matter the ability to keep an aging space station in orbit, there comes a time when a vibrant space faring nation like the United States, one not suffering catastrophic budget shortfalls like the post-Soviet Russian Federation, must seek to invest in a new generation of platforms. Over time the laboratory that was the Mir became known more for the repair missions than for the research and exploration. That must never happen to us.

Additionally, as repairs became more numerous, there arose in the Russian space community an entire subset of contractor expertise skilled on repairing an aging station. This may well be wonderful knowledge as we consider voyages to Mars and living on the Lunar surface. But if that will be the role of the ISS a decade from now, then it is even more urgent to establish a new generation of in-space research and manufacturing centers to advance our knowledge base to help us here on Earth before the ISS becomes a repair test bed.

I have no doubt we can keep the ISS functioning for another decade, even longer. But at what price to its core functions? At what price to American leadership as newer stations, from China and Russia and the commercial sector, both domestic and foreign, become centers for cutting edge research, manufacturing and global leadership.

Policy Guidance

Members of this Subcommittee are fortunate that there is far more policy to guide their decisions on when and how to transition from the ISS than two decades ago, when Congress struggled over how to transition from Space Station Freedom to the ISS, next from the *Space Shuttle* program to a commercial marketplace for launch vehicle services and finally, most recently, on how to handle commercial customers onboard the ISS. Those earlier great debates for two great programs ultimately centered on whether continued reliance on NASA and its trusted contractor base could be balanced against a new reliance on entrepreneurial space companies.

Today the answer is known. Programs entrusted to entrepreneurial companies have fared very well. NASA enjoys a well-balanced cargo vehicle program that has moved beyond NASA as the only customer and stimulated the birth of dozens of launch companies backed by private capital where both government agencies and commercial customers are the customers. And the legacy contractors are shifting as well, putting more of their own capital at risk and supporting the smaller, more agile companies in new projects.

NASA deserves praise for taking the first steps towards behaving more as a customer than an operator via the 2008 multi-billion dollar awards to two companies, Orbital Sciences and SpaceX to supply cargo to and from the International Space Station. Many doubted the wisdom of relying on unproven companies to produce unproven launch vehicles. SpaceX was able to transform NASA from a core customer to one customer of many, as proponents hoped. The current valuation of SpaceX, the jobs created and the capital interest is key to the vitality of NASA programs today.

The new public private partnerships have not been limited to human spaceflight programs. For decades, our Earth observation programs utilized expensive large satellites that suffered from key data policy issues. Today, companies like Planet, Spire Global and Maxar offer commercial capabilities to monitor key environmental resources, track maritime traffic and often provide transparency to opaque international activities.

Consider Spire Global. Launched nine years ago, it is now listed on the New York Stock Exchange with a market cap of about \$1.37B (as of market close on 9/17/21) operating out of six offices in four countries, serving a global base of government and commercial customers.

At Nanoracks, we are very proud that we deployed from the ISS, using our own privately financed hardware, the first satellites of both Spire and Planet thus paving the way for their own commercial success and that of the launch vehicle community based on the Cubesat revolution.

Congressional legislation and Administration policies have matured to sufficient degree that Spire is by no means a unique example. The entrepreneurial space industry has the legal, regulatory, technical and capital assuring capability to partner with NASA on smaller commercial space stations dedicated to a variety of commercial needs. Industry requires NASA as a customer, one of many; and NASA needs the new platforms for continuity in LEO services. Additionally, our international allies are, with differing degrees of enthusiasm, prepared to transition from the ISS to the commercial platforms.

Foreign Landscape

The Chinese space station is a competitive and political challenge. I have submitted here a list of our allies who are funding projects on the Tiangong. There is no dispute that in space, when America is present, America leads; but only if we bring all of our policy and political resources to bear. I don't fear cooperation and competition with China on civil and commercial space projects, because the United States has an intangible advantage over China and other competitors, our spirit of innovation and entrepreneurship. But if we are going to be successful in this next stage of space economics, we must be all in and be in it to win.

I am a personal supporter of cooperation with China on civil and commercial programs. Yet I do not believe our community understands how strong a competitor and challenger China is to our civil and commercial leadership. Tiangong has competitive strengths and weaknesses, but for political reasons, a growing number of our allies are signing to utilize the Chinese space station. The answer is not to boycott China or cajole our allies; it is to outcompete as we do best by utilizing the agility and efficiency of the private sector for the sort of next-gen platforms envisioned by NASA CLD.

Lessons Learned, Some Observations:

I understand that others on this panel will be addressing the question of the current and future status of the ISS physical structure, critical components and subsystems. I can say we at Nanoracks have suffered already from necessary unexpected repairs. Some make the headlines and some do not.

On lessons learned and observations allow me to suggest several:

- 1) When you firmly and clearly know it is time to transition from the ISS, it will be too late to prevent a space station gap;
- 2) The NASA CLD program embodies most of the lessons the agency has learned on commercialization. It is a well thought out blend of agency requirements balanced against industry investments and policy risks;
- 3) As with Commercial Crew and Commercial Cargo, having multiple companies is vital to assure continuity of services and growth of the LEO ecosystem;
- 4) Without a doubt, we will never have a modular LEO space station again. We have learned that one cannot have astronauts exercising on the same platform as advanced thin-wafer research and manufacturing. Looking to the future, the CLD free flyers will be better equipped to meet the needs of differing customers, from NASA to the private sector.
- 5) The dream of NASA to solve key breakthroughs in biopharma and other critical research areas has yet to be realized. Not on the space shuttle, not on the ISS. The ISS is a political, policy and technical marvel. But the best chance for research breakthroughs relies on utilization of in-space research hardware and best practices based on the decade of ISS utilization. I believe those breakthroughs will be realized but not on the ISS. Just as NASA's dream of routine access to and from space has been realized not on the government owned and operated *Space Shuttle*, but via the private sector.

- 6) Industry needs more than a Congressional commitment for minimal funding for the CLD program. Guidance is required to NASA to set a date by which NASA, as a customer, transitions to the new platforms. NASA may well use the ISS as a repair test bed or to deploy the modules elsewhere in some non-competitive manner or as raw material for additive manufacturing of new hardware in space. But, at some defined point, as is included in the NASA CLD RFP, the US Government as a customer must utilize the commercial platforms.
- 7) This year marks the genuine opening of private capital investment for commercial space operations. Companies representing a range of the new commercial space markets have gone public. With this opportunity comes challenges and that could well be the subject of another hearing by this Subcommittee. But it is important to note that the private capital markets are investing in both US and non-US space companies. Industry can, in partnership with NASA and other government agencies, dream and implement great space missions.
- 8) Space tourism is not the critical ingredient for the future for our commercial space stations. Tourism may be the most exciting publicly, but legislation enacted by Congress and policy put forth by the Executive Branch have paved the way for the LEO ecosystem, of which tourism is one of many sources of revenue. And a stable and growing LEO ecosystem will drive the Lunar commercial landscape.
- 9) It is clear that the shift to commercial platforms will also mean a shift of jobs from the government to private industry. As with the transition of jobs from the government to the private launch industry, we are seeing companies like Sierra Space, Axiom and Nanoracks hiring from the ISS community.

Conclusions

The challenge to assure a seamless transition is more urgent than when Congress was confronted with the aging *Space Shuttle* program. There is no room for error lest we cede long-held and hard-earned leadership to our adversaries.

These are difficult issues that mix data, policy and emotion. Our choice is clear: either push the ISS modules far beyond the anticipated lifespan or open the door to a new chapter of American leadership that will realize smaller commercial space stations dedicated solely to research and in-space manufacturing or space tourism.

I choose the latter because recent history has shown that multiplicity in space assets is the safest and cost efficient pathway. And that the private sector, working with NASA, produces cost-efficient and reliable results.

Members of the Subcommittee, now is the time for Congress to be all in on the commercialization of low-Earth orbit through NASA's CLD program to ensure there is no space station gap, to ensure the success of American ingenuity and entrepreneurship, and to ensure that no matter who decides to move into LEO with us, that we are leading the way.

The future of LEO is that of private commercial space stations funded with a mix of public and private funding, backed up with the full diplomatic and political force of Congress and the

Administration. Our parent company, Voyager Space, is prepared to invest significant capital in a private space station dedicated to innovative space research. And unlike other NASA programs that depend on commercial practices for efficiencies but are still fundamentally dependent on government funding, the Nanoracks led team is developing a commercial space station that depends on commercial industry for the majority of funding, where. And we are not alone. Industry is ready to lead. I consider the CLD program a pathway to assuring continuation of American leadership in LEO and indeed perhaps of the ISS program itself, with a new generation of cost-efficient hardware which will also continue the ISS tradition of STEM education.

We lack the luxury of our previous challenges. The space domain is today interwoven into the fabric of our society and its continued health is every American's continued health. The lessons learned are clear, we must do all to prevent yet another gap in our basic space capabilities.

With your help Madame Chairwoman and Mr. Ranking Member and all members of the Subcommittee, we will continue to evolve America's core values and ideals into low-earth orbit and beyond.

Addendum – Chinese Space Station Projects

List of selected space science experiment projects for the 1st cycle concerning
UN/China cooperation on the utilization of China Space Station
联合国/中国围绕中国空间站应用开展空间科学实验
第一批入选项目清单

No. 序号	Project Title 项目名称	Name of Organization 申请单位	Country of Organization 申请国家	Research Area 研究领域
1	POLAR-2: Gamma-ray burst polarimetry on the CSS POLAR-2: 中国空间站上的伽玛暴偏振探测仪	1. University of Geneva 2. National Centre for Nuclear Research (NCBJ) 3. Max Planck Institute for Extraterrestrial Physics 4. Institute of High Energy Physics, Chinese Academy of Sciences 1.日内瓦大学(瑞士) 2.国家核研究中心(波兰) 3.麦克斯普朗克外太空物理研究所(德国) 4.中国科学院高能物理研究所(中国)	1. Switzerland 瑞士 2. Poland 波兰 3. Germany 德国 4. China 中国	Astronomy in Space 空间天文学
2	Spectroscopic investigation of nebular gas 星云气体的光谱研究	1. Indian Institute of Astrophysics 2. Institute of Astronomy of the Russian Academy of Sciences (INASAN) 1.印度天体物理研究所(印度) 2.俄罗斯科学院天文研究所(俄罗斯)	1. India 印度 2. Russia 俄罗斯	Astronomy in Space 空间天文学
3	Behavior of partially miscible fluids in microgravity 部分混相流体在微重力下的行为研究	1. Indian Institute of Technology (BHU) 2. University of Brussels 1.印度理工学院(印度) 2.比利时布鲁塞尔自由大学(比利时)	1. India 印度 2. Belgium 比利时	Microgravity Fluid Physics and Combustion 微重力流体物理与燃烧
4	BARIDI SANA - High performance Micro 2-Phase cooling system for space applications 高性能微两相冷却系统的空间应用	1. Sapienza University of Rome 2. Machakos University 3. In Quattro s.r.l., Italy 1.意大利罗马萨皮恩扎大学 2.肯尼亚马查科斯大学 3.意大利 In Quattro s.r.l.公司	1. Italy 意大利 2. Kenya 肯尼亚	Microgravity Fluid Physics and Combustion 微重力流体物理与燃烧
5	Mid infrared platform for Earth observations 中红外地面观测平台	1. National Institute of Astrophysics Optics and Electronics (INAOE) 2. Benemérita Universidad Autónoma de Puebla (BUAP) 1.墨西哥国家天体物理光学电子研究所(墨西哥) 2.普埃布拉自治大学(墨西哥)	Mexico 墨西哥	Earth science in space 地球科学
6	Flame instabilities affected by vortices and acoustic waves (FI-AVAV) 受涡流和声波影响的火焰不稳定性研究	1. Tsinghua University 2. The University of Tokyo 1.清华大学 2.东京大学	1. China 中国 2. Japan 日本	Microgravity Fluid Physics and Combustion 微重力流体物理与燃烧
7	Development of multi-junction GaAs solar cells for space applications 用于空间应用的多结 GaAs 太阳能电池的开发	1. National Center for Nanotechnology and Advanced Materials 2. King Abdulaziz city for Science and Technology (KACST) 1.国家纳米技术和先进材料中心(沙特) 2.阿卜杜勒阿齐兹国王科学和技术城(沙特)	Saudi Arabia 沙特	Space Utilization Technology 应用新技术
8	Tumors in space: Signatures of early mutational events due to space-flight conditions on 3D organoid cultures derived from intra-individual healthy and tumor tissue 太空肿瘤:来自个体内健康和肿瘤组织的3D类器官培养物由于空间条件导致的早期突变特征研究	1. Norwegian University of Science and Technology 2. International Space University (ISU) 3. Vrije University Amsterdam 4. Belgium Nuclear Research Centre 1.挪威科技大学(挪威) 2.国际空间大学(法国) 3.阿姆斯特丹自由大学(荷兰) 4.比利时核研究中心(比利时)	1. Norway 挪威 2. France 法国 3. The Netherlands 荷兰 4. Belgium 比利时	Space Life Sciences and Biotechnology 空间生命科学与生物技术
9	Effect of microgravity on the growth and biofilm production of disease-causing bacteria 微重力对致病菌生长和生物膜产生的影响	1. The Mars Society - Peru Chapter 2. The Mars Society - Spain Chapter 1.火星学会秘鲁分会(秘鲁) 2.火星学会西班牙分会(西班牙)	1. Peru 秘鲁 2. Spain 西班牙	Space Life Sciences and Biotechnology 空间生命科学与生物技术

Jeffrey Manber
Chief Executive Officer
Nanoracks, LLC

Jeffrey has served as the CEO of Nanoracks from 2009 onwards. As employee #1 for Nanoracks, Jeffrey steered the growth of Nanoracks from a garage space in Webster, Texas to the largest customer base for use of the International Space Station. Under Jeffrey's leadership, Nanoracks was a pioneer, and now the leader, in the commercial market for low-Earth orbit utilization.

Today, Nanoracks has customers in over 30 countries, ranging from governmental agencies to universities and companies and most recently the Bishop Airlock, self-funded by Nanoracks, permanently docked to the International Space Station to provide cost-efficient deployment services.

Currently, Nanoracks is working with their parent company Voyager Space Holdings to develop a commercial free flyer space station which will be majority funded by the private sector, and with NASA as one customer, of many.

Jeffrey's prior experience includes serving as Managing Director of Energia USA, the American arm of RSC Energia. In 1991, he carried over the first commercial contract between NASA and the Soviet Union to use the Russian Soyuz as an escape vehicle for Space Station Freedom. Later, Jeffrey represented the Russian space organization when the basic agreements to realize the International Space Station were negotiated.

As CEO of MirCorp, which leased the Russian space station Mir, he oversaw the first ever commercially funded crewed mission, of over 70 days, to the Mir space station. His experience developing the business base for Mir, as well as now on the International Space Station has helped develop a truly international space station customer base for Nanoracks.

Jeffrey also co-developed the first fund dedicated to commercial space on Wall Street (Shearson Lehman/American Express) and has served as an adviser to numerous companies and governments. The author of three books, his second (Selling Peace) chronicles his time working with the Russian space program. Jeffrey has had the privilege of testifying before the Senate and House on numerous occasions.

In 2012, Jeffrey was awarded the NASA Exceptional Public Achievement Medal. Other industry awards include the Space Frontier Foundation's 2017 Pioneer of New Space Award, the 2019 Space Pioneer award for Entrepreneurship from the National Space Society, and the American Astronautical Society's 2011 Lloyd V. Berkner Award for "working tirelessly to advance the cause of commercial spaceflight ranging from early efforts for cooperative commercial space activities with Russia through current commercial science payloads flown on the ISS."

Jeffrey currently serves on the NASA NAC on commercialization and is the Chairperson of the CASIS/National Labs on commercial use of ISS.

Chairman BEYER. Thank you, Mr. Manber, very much. We'll now next hear from Mr. Todd Harrison. Mr. Harrison?

**TESTIMONY OF MR. TODD HARRISON,
SENIOR FELLOW AND DIRECTOR
OF THE AEROSPACE SECURITY PROJECT,
CENTER FOR STRATEGIC AND INTERNATIONAL STUDIES**

Mr. HARRISON. Mr. Chairman, Ranking Member Babin, and distinguished Members of the Subcommittee and Full Committee, thank you for the opportunity to testify today on this important topic.

The fundamental question we're addressing today is what the role of NASA should be in this transitional period from a focus on low Earth orbit to farther-reaching exploration goals on the Moon and beyond.

When former NASA Administrator Jim Bridenstine spoke at CSIS last year, he used the DIME framework of national power—diplomatic, information, military, and economic—to describe how he thinks about the role of NASA. I want to focus my testimony today on NASA's diplomatic and economic roles and how that should impact our thinking about NASA's future in LEO.

NASA has a rich history of building international partnerships around the globe and has agreements with more than 120 nations. These partnerships help advance U.S. interests in areas such as the environment, human rights, and STEM education.

Cooperation in space also increases transparency. It builds confidence and promotes responsible behavior in space. For example, the coalition of nations that operate the ISS have tightly coupled interests in LEO. We all want to protect the investments we've made in the astronauts that serve aboard the ISS. Our mutual interests in LEO have created a strong incentive for us to work together to follow basic norms of behavior, such as avoiding destructive antisatellite testing and the deliberate creation of space debris. NASA's continued leadership of the ISS coalition is critical to advancing this shared goal.

NASA's role in advancing our economic interests is another factor policymakers should consider. Many new commercial space missions are currently being planned, explored, or experimented with by U.S. companies, such as in-space mining and manufacturing. This technology could allow large structures or propellant stores to be built in space using materials that are sourced in space, effectively breaking us free from having to launch everything from Earth.

NASA's role is to explore and take technological risks to improve our understanding of the space environment and to provide the enabling infrastructure that private companies can build upon.

As we think about the diplomatic and economic roles of NASA and LEO, we must be mindful that other nations are competing with us in space. And perhaps our most formidable competitor is China. The competition with China in space is multifaceted and includes an important security element that the Space Force intelligence community encounter daily. But this competition also has

a strong commercial and civil space element that some have called a new space race.

Unlike the space race of the 1960's, however, the goal of this race is not a mere destination. It is not a race to see who can build the biggest space station, plant another flag on the Moon, or be the first to land humans on Mars. The real objective of this race is to see who can build the broadest and strongest international coalition. Whatever group of nations emerges as the leading coalition in space over the next decade will be the ones that set the de facto norms for the space commerce and exploration that follows.

But competition with China does not preclude cooperation. As the Members of this Subcommittee are well aware, we cooperated with the Soviet Union in space throughout the cold war while we competed fiercely with them both in space and on Earth.

Since 2011, however, Congress has placed restrictions on NASA's ability to collaborate with China on civil space programs, a provision known as the Wolf Amendment. This provision was originally intended to pressure China to make human rights reforms and to stifle development of its space capabilities.

After 10 years, it is clear that China has not improved its behavior when it comes to human rights, and China's space programs, both military and civil, have only accelerated. What is more concerning is that China is now reaching out to other nations, including some of our closest allies and partners, and asking them to become partners in its space programs. China is actively building a coalition in space to rival our own.

In conclusion, I would urge the Members of this body to think more holistically about the role of NASA and LEO and the transition plan for the ISS. A precipitous withdrawal of U.S. support for the ISS could create an opening for China to expand its partnerships and ultimately its diplomatic and economic influence in LEO.

Our goal should be to strengthen and expand the ISS coalition of nations, while also building a new coalition to go to the Moon and beyond. It is my view that we should not let go of the ISS coalition before the Artemis coalition is fully assembled and operational.

Thank you, and I look forward to your questions.

[The prepared statement of Mr. Harrison follows:]



**Statement before the
House Science, Space, and Technology Committee
Subcommittee on Space and Aeronautics**

***“NASA’s Future in Low Earth Orbit:
Considerations for International Space
Station Extension and Transition”***

Testimony by:

Todd Harrison

Senior Fellow and Director, Aerospace Security Project
CSIS

September 21, 2021

Chairman Beyer, Ranking Member Babin, and distinguished members of the Subcommittee, thank you for the opportunity to testify on this important topic. The fundamental question we are addressing today is what the role of NASA should be in this transitional period from a focus on low Earth orbit (LEO) to farther reaching exploration goals on the Moon and beyond. When former NASA administrator Jim Bridenstine spoke at CSIS last year, he used the DIME framework of national power (diplomatic, information, military, and economic) to describe how he thinks about the role of NASA. As he noted, the “M” in DIME should really be lower case because by design NASA has only an indirect role when it comes to the military element of national power. I want to focus my testimony today on NASA’s diplomatic and economic roles and how that should impact our thinking about NASA’s future in LEO.

One of the most important but perhaps least appreciated roles NASA plays is in diplomacy. NASA has a rich history of building international partnerships around the globe, and it has agreements with more than 120 nations for science and exploration activities in LEO and beyond. While these partnerships are focused on activities in space, they have far reaching benefits on Earth as well. They help advance U.S. interests in areas such as the environment, human rights, and STEM education in less developed countries. Cooperation in space also increases transparency, builds confidence, and promotes responsible behavior in space.

For example, the coalition of 15 nations that signed the Intergovernmental Agreement that governs the ISS and all other nations that have partnered in different ways on the ISS in the past two decades have a tightly coupled and aligned set of interests in LEO. We all want to protect the investments we have made and the astronauts that serve aboard the ISS. Our mutual interests in LEO create a strong incentive for us to work together to establish basic norms of behavior, such as a prohibition on destructive anti-satellite testing and the deliberate creation of space debris. NASA’s continued leadership of the ISS coalition is critical to advancing this shared goal.

NASA’s role in advancing our economic interests is another factor policymakers must consider when planning for the future of the ISS. It is in our national interests for NASA to continue to be the world’s leader in pushing the limits of space technology in ways that create opportunities for the commercialization of space. To be clear, it is not NASA’s job to commercialize space technology and activities—that is a role best suited for the private sector. NASA’s role is to explore and take risks to improve our understanding of the space environment and to create the infrastructure that private companies can build upon.

Many new commercial space missions are currently be planned or explored by U.S. companies. Some of them have the potential to completely revolutionize the way we use space and operate in space. For example, commercial firms are exploring the potential of in-space mining and manufacturing. If successful, this technology would mean that large structures could be built in space using materials that are sourced in space, and propellant could be manufactured in space to

fuel and refuel other satellites. This would effectively break us free from having to launch everything we need in space from Earth and open up a whole new range of possible space missions. As another example, some commercial firms are exploring novel power and propulsion systems, such as new forms of nuclear thermal propulsion, that could revolutionize our ability to maneuver in space. NASA is an important enabler in the future space economy because it can take technical risks that private companies cannot afford or would otherwise not be willing to take, and it can lower the barriers to entry by providing enabling infrastructure to make more commercial missions feasible. NASA can both advance its science objectives and allow commercial firms to determine whether certain space missions are economically viable.

As we think about the diplomatic and economic roles of NASA in LEO, we must remember that we are not operating in a geopolitical vacuum. Other nations are competing with us in space, and perhaps our most formidable competitor is China.

The competition with China in space is multifaceted and includes an important security element that the Space Force and Intelligence Community encounter on a daily basis. But this competition also has a strong commercial and civil space element that some have called a new space race. Unlike the space race of the 1960s, however, the goal of this race is not a destination. It is not a race to see who can build the biggest space station, plant another flag on the Moon, or be the first to land humans on Mars. The real objective of this race is to see who can build the broadest and strongest international coalition in space. Whatever group of nations emerges as the leading coalition in space over the next decade will be the ones that set the de facto norms for the space commerce and exploration that follows. The Artemis program and the transition plan for the ISS are two of the main levers we control in this race. These programs are vital to maintaining our leadership role and the international coalition NASA has been building for decades.

But competition with China does not preclude cooperation. As the Members of this Subcommittee are well aware, we cooperated with the Soviet Union in space throughout the Cold War while we competed fiercely with them both in space and on Earth. That cooperation yielded many benefits, not just to our space exploration objectives and the safety of our astronauts but also in our diplomatic and military relationship with the Soviets. It opened new lines of communication between our governments that continue to benefit us today, and it provided greater transparency into parts of the Soviet space program that reduced some suspicions and tensions on both sides.

Since 2011, Congress has placed restrictions on NASA's ability to collaborate with China on civil space programs—a provision known as the Wolf Amendment. This provision was originally intended to pressure China to make human rights reforms and to stifle development of its space capabilities. After ten years it is clear that China has not improved its behavior when it comes to human rights, and China's space programs—both military and civil—have only accelerated. What is more concerning is that China is now reaching out to other nations—including some of our

closest allies and partners in space—and asking them to become partners in its space programs. China is actively building a coalition in space to rival our own.

In conclusion, I would urge the members of the body to think more holistically about the role of NASA in LEO and the transition plan for the ISS. A precipitous withdrawal of U.S. support for the ISS could create a diplomatic opening for China to expand its partnerships and ultimately its diplomatic and economic influence in LEO. Our goal should be to strengthen and expand the ISS coalition of nations while also building a new coalition to go to the Moon and beyond. It is my view that we should not let go of the ISS coalition before the Artemis coalition is fully assembled and operational.



Todd Harrison

Director, Defense Budget Analysis, Director, Aerospace Security Project and Senior Fellow, International Security Program, CSIS

Todd Harrison is the director of Defense Budget Analysis and director of the Aerospace Security Project at CSIS. As a senior fellow in the International Security Program, he leads the Center's efforts to provide in-depth, nonpartisan research and analysis of defense funding, space security, and air power issues. He has authored publications on trends in the defense budget, military space systems, threats to space systems, civil space exploration, defense acquisitions, military compensation and readiness, and military force structure, among other topics. He teaches classes on military space systems and the defense budget at the Johns Hopkins School of Advanced International Studies.

Mr. Harrison joined CSIS from the Center for Strategic and Budgetary Assessments, where he was a senior fellow for defense budget studies. He previously worked at Booz Allen Hamilton, where he consulted for the U.S. Air Force on satellite communications systems and supported a variety of other clients evaluating the performance of acquisition programs. Prior to Booz Allen, he worked for AeroAstro Inc. developing advanced space technologies and as a management consultant at Diamond Cluster International. Mr. Harrison served as a captain in the U.S. Air Force Reserves. He is a graduate of the Massachusetts Institute of Technology with both a B.S. and an M.S. in aeronautics and astronautics.

Chairman BEYER. Thank you very much, Mr. Harrison.
 And last we will hear from Captain William Shepherd.
 The floor is yours, Captain.
 Captain, you are muted for the moment.

CAPTAIN WILLIAM SHEPHERD
(USN, RET), FORMER ASTRONAUT,
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Captain SHEPHERD. That never happens. Thanks.

Chairman Beyer, Ranking Member Babin, and Members of the Committee and Subcommittee, thank you for this opportunity to present thoughts on the Space Station and related space activities.

Even before the United States had a national space program, engineers and scientists envisioned an orbiting station above the Earth that would be a stepping stone for the exploration of Moon and the other planets. NASA space shuttles and crews, using robots and space walks, built the large ISS vehicle in the weightless vacuum of space, traveling 17,000 miles an hour—a capability we cannot match today.

Crews aboard ISS live, explore, and do research in a place that's not part of the Earth anymore. ISS is our foothold in the cosmos. In 21 years of continuous operations, ISS has hosted 65 expeditions, hundreds of astronauts and cosmonaut researchers, who have performed thousands of hours of scientific research. In complexity and scale, ISS is my generation's Apollo program.

There are many difficulties in the design and construction of this station. Forming a workable international partnership was not easy. Many aerospace critics in the United States opposed putting Russian elements in ISS's critical path. Others said it could not be done. History has shown all of them wrong. ISS would not be flying today without our partners' unique capabilities and especially those that are Russian.

And ISS has performed beyond its design capabilities. Many systems and components are operating acceptably at twice their design life. ISS has had no major failures or accidents.

One could ask what the benefits are that the Russians brought to the partnership. Working with them, I have seen unique spacecraft and spacecraft system designs, excellent crew equipment and space suits, well-developed life-support system, excellent metalworking and fabrication, simple but effective thermal control systems, solar arrays and controls, good crew-to-computer integration.

And Russian engineers taught us a most valuable technique: mixing the complex along the simple in their system architectures, creating exceptionally robust capabilities. Today, NASA calls this "dissimilar redundancy." This will be a critical characteristic of our future of space missions.

The numerous ISS changes of command have always been highlights. Thirty years ago, an American commander in charge of billions of rubles of Russian State property or a Russian cosmonaut in charge of a huge U.S. spacecraft would have been unthinkable, but this is the reality today.

Since last fall, ISS has experienced moderate internal air leakage to space. Leaks have been traced to the interior of the transfer tun-

nel at the rear of the Russian service module. Leak sources are small surface cracks in the tunnel's aluminum hull.

Engineers and technicians in Russia and the United States are working together to understand and resolve the issue, but the root cause of the cracking, their failure modes, and the impacts on ISS safety in future operations have not been adequately determined. Top-level NASA and Roscosmos management attention is needed now to focus the technical teams, provide the necessary resources, and drive this issue to closure.

Technical operational integration was a major effort in the ISS program. This remains a significant challenge for future programs. Expeditions to the Moon will require crews to operate systems designed and built by many different companies, all with distinct characteristics, controls, displays, computer and verbal languages, et cetera.

Small groups of astronauts on the Moon may have to make do, as the Apollo 13 crew did to fit their square CO₂ absorbers into round receptacles. This was a graphic illustration of what bad integration looks like.

NASA's historical role integrating and verifying hardware and software has been diluted as we rely more heavily on work done by commercial space companies. Considering what we have learned building ISS, this is a big step backward.

A Mars expedition will draw on the best skills and resources from many nations.

And I'm going to go right to the end of my prepared statement.

Space Station is the blueprint to how to do this. If ask you what a Mars program will look like, these questions are behind us.

[The prepared statement of Captain Shepherd follows:]

21 September 2021

Statement of W. M. Shepherd before the House Committee on Science, Space, and Technology

Chairman, Beyer, ranking member Babin, and members of the Committee: I have recently joined the International Space Station Advisory Committee that advises NASA and the multinational partners in the ISS Program. Thank you for this opportunity to present thoughts on the Space Station and related space activities.

Even before the U.S. had a national space program, engineers and scientists envisioned an orbiting station above the Earth that would be a steppingstone for the exploration of the Moon and other planets. NASA Space Shuttles and crews, using robots and spacewalks, built the large ISS vehicle, in the weightless vacuum of space, traveling 17,000 miles an hour. A capability we cannot match today.

Crews aboard ISS live, explore, and do research, in a place that's not part of the Earth anymore. ISS is our foothold in the cosmos. In 21st years of continuous operations ISS has hosted 65 expeditions and hundreds of astronaut and cosmonaut researchers who have performed thousands of hours of scientific research. In complexity and scale, ISS is my generation's "Apollo Program".

There were many difficulties in the design and construction of this station. Forming a workable international partnership was not easy. Combining each partner countries' different "technical culture" was a challenge. Many aerospace critics in the U.S. opposed putting Russian elements in ISS's "critical path"; others said it could not be done. History has shown all of them wrong. ISS would not be flying today without our partners' unique capabilities and especially those that are Russian. And ISS has performed beyond its designed capabilities; many systems and components are operating acceptably at twice their design life. ISS has had no major failures or accidents.

One could ask what benefits the Russians brought to the partnership? Working with them, I have seen unique spacecraft and spacecraft system designs, excellent crew equipment and space suits, well developed life support systems; excellent metal working and fabrication; simple but effective thermal control systems, solar arrays and controls, good crew-to-computer integration. Russian engineers taught us a most valuable technique--mixing the complex alongside the simple in their system architectures--creating exceptionally robust capabilities. Today NASA calls this "dissimilar redundancy". Our thinking here on how we design and build things has changed--this will be a critical characteristic of our future space missions.

The numerous ISS "change of command" events have always been highlights. New station "commanders" from Russia, Canada, Europe, and Japan are supported by the many different ground control teams who keep operations safe and productive. Thirty years ago, an American commander in charge of billions of rubles of Russian state property--or a Russian Cosmonaut in charge of a huge US spacecraft--would have been unthinkable. But it is the reality today.

Since last fall, ISS has experienced moderate internal air leakage to space. Leaks have been traced to the interior of the transfer tunnel at the rear of the Russian Service Module. Leak sources are small surface cracks in the tunnel's aluminum hull. The crew has sealed leak sites, and the leakage rates have reduced. Engineers and technicians in Russia and the U.S. work together to understand and resolve this issue; but the root cause of the cracking, their failure modes, and impacts on ISS safety and future operations have not been adequately

determined. Top level NASA and Roscosmos management attention is needed now to focus the technical teams, to provide necessary resources, and to drive this issue to closure.

Technical and operational integration was a major effort in the ISS Program. This remains a significant challenge for future space programs. Expeditions to the Moon will require crews to operate systems designed and built by many different companies, contractors, suppliers, and countries, all with distinct characteristics, controls, displays, computer and verbal languages, symbols, and other requirements. Small groups of astronauts on the Moon may have to "make do" as the Apollo 13 crew did to fit their "square" CO₂ absorbers into "round" receptacles. This was graphic illustration of what "bad" integration looks like. NASA's historical role, integrating and verifying hardware and software has been diluted as we rely more heavily on work done by commercial space companies. Considering what we have learned building ISS, this is a big step backwards.

There is debate on the technologies that will be needed for Mars expeditions. A Mars exploration will draw on the best skills and resources from many nations. Crew and cargo vehicles going to Mars will be very large. They will be too big to be lifted into space on a single launch, even with large boosters. They will be assembled in low Earth orbit, with robotic operations and human spacewalks. Vehicle designs will be robust, reliable, durable. Crews and their spacecraft will perform extended, independent operations. Space Station is the blueprint to do this.

If you ask what a Mars Program will look like--these questions are behind us.

WILLIAM M. SHEPHERD, CAPT USN ret.

William Shepherd has served as a Navy SEAL, NASA Astronaut, Program Manager, and Senior Government Official with the Department of Defense (DOD). He started his military career in 1971 as an Underwater Demolition "Frogman" and Navy SEAL, with assignments to the Pacific, Atlantic, and European theaters of operation. In 1984, he was one of 17 Astronaut Candidates in NASA's Astronaut Group 10. Captain Shepherd flew as a NASA Mission Specialist on 3 Space Shuttle flights, missions that carried DOD and scientific payloads to space, performed materials and life science experiments in microgravity, and launched the interplanetary probe "Ulysses" into polar orbit of the Sun. In 1993, Capt. Shepherd was selected to serve as Program Manager for the new International Space Station (ISS), leading a 16-nation partnership to design and build a new orbital "gateway" to space.

In 1996 Capt. Shepherd was named by Vice President Gore and Russian Premier Chernomyrdin to command the "First Expedition" to the new space station. Captain Shepherd and his Russian crewmates, Yuri Gidzenko and Sergei Krikalev, trained for 4 ½ years in Moscow and Houston, launched to orbit from Kazakhstan aboard a Soyuz rocket in October 2000, and docked with the Space Station two days later. From Nov 2000 to March 2001, Expedition One brought the new station to life as they conducted 3 construction operations with Space Shuttle crews, managed two Soyuz and Progress dockings, and traveled 58,000,000 miles through space—equal to two-thirds the distance between Earth and Mars. Today, the ISS is a robust 500-ton space "ship" in its 21st year of continuous human operations; a home to hundreds of astronaut-explorers on 65 expeditions, who have conducted thousands of hours of unique research activity. The ISS partnership formed 28 years ago remains a singular example of international cooperation in a very large and complex enterprise.

Capt. Shepherd returned to the Navy in 2001 to serve as technical advisor to the Navy's SEAL headquarters in California, and later was the first "Science Advisor" for U.S. Special Operations Command (USSOCOM) in Tampa Fla. During his tour, he introduced mobile fabrication laboratories which placed engineers and small workshop facilities in remote forward bases and outposts supporting special operations, providing military operators with thousands of solutions and technology insertions "at the point of need".

Capt. Shepherd consults with government and industry organizations and is a member of Stevens Institute's System Engineering Research Center (SERC). He manages SERC's Capstone Marketplace, a DOD-sponsored academic outreach program connecting military personnel with undergraduate engineering students to design and build innovative hardware and software prototypes.

Capt. Shepherd received a bachelor's degree in Aerospace Engineering from the U.S. Naval Academy, and master's and engineer's degrees in Mechanical and Ocean Engineering from MIT. He has received NASA's Steve Thorne Aviation Award, the Spirit of St. Louis Medal, and "Honorary Naval Aviator Number 30" designation by the Chief of Naval Operations. He has also received the Defense Distinguished Service Medal, the National Intelligence Medal of Merit, the Gagarin Gold Medal, the Robert H. Goddard Trophy, and the Congressional Space Medal of Honor. In 2009, the International Space Station Program that Capt. Shepherd led on the ground and in space, won the Collier Trophy, recognizing the Nation's greatest achievements in aviation and astronautics.

Capt Shepherd is married to the former Beth Stringham of Houston Texas. They reside in Virginia Beach Va.

Chairman BEYER. Thank you, Captain Shepherd. You finished on a very strong note.

And I appreciate all the testimony.

So now we'll begin our first round of questions, and I get to go first.

So, Dr. Rubins, I'm fascinated by your work on DNA sequencing and the Cardinal Heart studies. What kind of DNA were you doing? Were you doing human DNA or mouse DNA or E. coli?

Dr. RUBINS. Yes, so we did a mix of E. coli, mouse, and lambda phage. We were interested in, could we mix this DNA together, sequence it, and then reconstruct the genomes?

These are the kinds of technologies that we'll be using when we go to Mars to look for signs of life, and they're also the kinds of technologies that we would use to study complex microbial environments. So, if you look at things like microbes in a hospital or microbes on the Space Station, you want to understand what's a human pathogen, what's dangerous to us. And this is the exact kind of technology that you would use to look at this complex microbial environment.

We were very lucky. We were successful, and we had the opportunity, using the research platform of the Space Station, to analyze these complex microbial environments and make the sequencing technology work in low Earth orbit.

Chairman BEYER. Was it easier or harder to do it in low gravity/no gravity? Was that an advantage, or were you trying to overcome the challenges of that?

Dr. RUBINS. Yes, there were challenges. There's always logistical challenges. And these are not things that we can simulate on Earth. So it's things as simple as your pipette tips floating away in microgravity. We have to figure out, how do we do laboratory research when everything is floating? This is one of the challenges.

The technology actually worked incredibly well. It appeared to work slightly better in space than it does on Earth. So sometimes that microgravity environment gives us a technological advantage—for example, when we manufacture optical fibers. So it can give you an advantage that's not possible to simulate in Earth laboratories for a lot of these physical properties.

Chairman BEYER. Looking ahead, do you see—it was mentioned that perhaps one day we should be establishing a formal National Laboratory in space, low Earth orbit. Does that make sense to you?

Dr. RUBINS. Absolutely.

So we have the ISS National Laboratory through the Center for Advancement of Science in Space, and this allows both commercial companies as well as academics to send their experiments to low Earth orbit. This has greatly expanded our access and the number of participants in the International Space Station research community.

And so we've seen a lot of really exciting projects. I think this National Laboratory is really important for allowing participation from academic and commercial companies and making sure that researchers across the United States of America have access to space as this really unique research environment.

Chairman BEYER. I want to ask about your bone density after 300 days in no gravity. But did you figure out what we're going to do about radiation while you were up there?

Dr. RUBINS. Yes, we have done a lot of radiation studies, and this is one of the really important reasons for continuing our research on the International Space Station. We've got a radiation environment in low Earth orbit that we can't simulate right now on Earth. So we can have beams of particular particles, but it's very difficult to get that mix of radiation unless you actually go into space.

And so our radiation research on how it affects fundamental mechanisms in cells, how radiation can cause cancer—there's a lot of parallels for these kinds of processes on Earth. This is really only possible in the space environment.

The CHAIRMAN. Great. Thank you very much, Doctor.

Captain Shepherd, first of all, thank you for the idea of dissimilar redundancy. That's my new word for the day.

But I'm fascinated that, after a bunch of testimony about transitioning from government-to-government to commercial crew, commercial cargo, commercial ISS successor, you said these questions are behind us. Do you strongly believe that we need to maintain the same kind of NASA-led, government-invested program that we've had?

Captain SHEPHERD. I think it's a big question. I'm not sure I can give you a short answer.

But let me just say that one of the biggest issues that we worked with on ISS was integrating all the procedures, controls, displays, equipment, hardware, et cetera, between the partners and especially with Russia. It was a tremendous challenge.

As an example, the crews onboard ISS in the early days, in one of what was three different computer environments, there were 2,500 separate display pages on laptops that you would use to control the station and its systems, and you had to know pretty much what every one of them did. And they were all built by different people.

And so, when we talk about large programs, Artemis in particular but certainly going to Mars, who is going to integrate all this stuff? And, at the end of the day, the astronauts that are going to be on the mission are the final integrators. I think it's very unfair for programs to assume that this is all going to be worked out magically by a bunch of very smart people.

We have to have a more directive role of the government to induce the contractors to not give us very disparate ways to interface and control all these pieces of hardware systems and spacecraft. Now, how NASA assumes that role in the future, I don't know, but somebody's got to do it.

Chairman BEYER. Thank you, Captain Shepherd, very much.

Let me now yield to my friend Dr. Babin for his questions.

Mr. BABIN. Thank you, Mr. Chairman. This is going to be an exceedingly interesting hearing, and I really appreciate this.

My first one, my first question is for Captain Shepherd.

First off, I want to say thank you for your service, Captain. As a Navy Seal, as a father of a Navy Seal myself, I really appreciate that and also your years as an astronaut.

And this question is regarding the Russian Nauka module and aging of the ISS.

A Russian space official recently raised concerns about the deteriorating state of Russia's segment of the ISS due to out-of-date hardware, warning that it could lead to "irreparable failures," quote/unquote. The official was quoted as saying, "Around 80 percent of the in-flight systems on Russia's segment have reached the end of their service period," and concluded, "This means that literally a day after the systems are fully exhausted irreparable failures may begin."

So, first, Captain Shepherd, you worked on the ISS program at the very beginning, you were the first astronaut on Expedition 1, and also serve as a member of the ISS Advisory Committee. How should policymakers view safety and mitigate risk as the ISS ages? And should NASA be worried about the stress placed on the ISS by the inadvertent firing of the Russia Nauka module?

Captain SHEPHERD. I think the answer to this is to reestablish a much more intimate working relationship with our Russian counterparts.

I knew Mr. Solovyov, who is the Russian official you were talking about. He was, at the time, the manager of their mission control station, or center, called the TsUP, in Moscow. Actually, I did not get along with Mr. Solovyov all that well, but I respected his judgment and his ability. But the business of making the Space Station work was to get close together and sit around the table and work out the problems.

Part of the issue with the science module docking, the Nauka that you mention, is, we do not have that correlation with our Russian counterparts right now. I would think that the primary job would be for us to go into exactly how the Russians noticed problems with that module and what they did to counteract them, what the results were when they docked, and how did this result in inordinate motions and probably stresses on the Space Station.

We have not had that discussion in intimate detail, but that would've been very common 20 years ago. I think that, whatever the reason, we've got to reignite the very strong integration that we had with our Russian partners. I'm not sure how to do it, but I believe Congress could be helpful in making that happen.

Mr. BABIN. OK. Thank you very much.

My next question is for Ms. Gatens.

NASA requested information from contractors on a new proposal to procure space suits as a service. The rationale for procuring services, rather than developing a system, is that the contractors can then sell their system to other customers, which could potentially lead to lower prices for the government.

A NASA 2017 report stated, "At this time, no known nongovernmental entity is willing to finance and develop their own complete EVA (extravehicular activity) system independent of a government customer. As is the case with environmental control and life-support systems designed for spacecraft, there is not currently enough demand that EVA capability can be treated as a regular commodity or a service."

The report continued, "Emergency microgravity and service suit capability is required solely by NASA, and there is insufficient market to support effective co-development."

At our recent budget hearing, I asked Administrator Nelson if NASA had identified other customers for space suits, as required by the anchor tenancy requirements of 51 U.S.C. 50503. He indicated that he would look into it.

Who are the other customers NASA has identified that would procure EVA suits or surface suits? Has NASA determined that the long-term viability of the venture is not dependent upon a continued government market or other nonreimbursable government support? And how much private capital is at risk in this venture?

Ms. GATENS. Thank you for the question.

As you noted, NASA put out a draft request for proposals (RFP) to get industry proposals on our change in strategy that will provide spacesuit services commercially. And we recognize that, as we expand the commercial economy in low Earth orbit, there could be other customers. We just had the private Inspiration-4 mission. And we anticipate, as this economy expands, there will be private demand for spacesuit services in addition to the NASA demand.

So we believe that commercializing this procurement the way we commercialized crew and cargo will be the most cost-effective way to go forward as we explore.

Mr. BABIN. OK. Thank you.

I just wonder, from Captain Shepherd, if there's any other lessons we learned from partnering with the Russians relevant to a potential engagement with China.

Captain SHEPHERD. Sir, if I might, can I back step just a bit and talk about the suits for a second?

Mr. BABIN. Certainly.

Captain SHEPHERD. So one of my frustrations, after I finished my time at NASA, was we did very little at NASA in understanding and leveraging the things that we had learned from our experience with the Russians and the Russian Space Agency.

I'd point out the Russian spacesuit, which is fundamentally a different architecture from ours, it is quite durable, it is very simple, and I think it has a lot of design attributes that our system does not. But NASA made almost no effort that I could detect to evaluate that and incorporate any of those design changes in our thinking.

And this is the lost opportunity that we see over and over again, in particularly our relationship with the Russians in this partnership.

If you would ask about the Chinese, besides the political aspect of that, I think there's tremendous value in seeing programs where scientists, engineers, and astronauts from different countries approach the same problem in different ways. I think we would gain a lot from the Chinese if we could have that relationship, but I'm not sure what it will take to make that happen.

Mr. BABIN. OK. Thank you very much. Appreciate it.

Chairman BEYER. Thank you, Dr. Babin and Captain Shepherd.

Mr. BABIN. Thank you.

Chairman BEYER. Let me now recognize the former Governor of Florida, Representative Crist.

Mr. CRIST. Thank you, Mr. Chairman. And I want to thank our witnesses for being here today.

There's no doubt that the International Space Station is crucial to our space program, to our research enterprise, and our international relationships. But as we've discussed today, there will come a time when the Space Station has reached the end of its operational life, and NASA must have a plan in place for the next generation of low Earth orbit activities.

As Governor of Florida when NASA was winding down the shuttle program, I can't help but draw a comparison between the retirement of the space shuttle, which resulted in the rise of a vibrant commercial launch industry, with NASA's current plan to transition the Space Station to a fully commercialized low Earth orbit.

Ms. Gatens, I'm curious, what lessons did NASA learn from the retirement of the shuttle about transitioning to large programs?

Ms. GATENS. Thank you for that question.

Yes, indeed, we did experience a gap in our transportation system when we retired the shuttle that we do not wish to repeat with our U.S. human presence in low Earth orbit. And this is a key tenet of our ISS transition plan that NASA has put together. We cannot have a gap in American human space flight in low Earth orbit.

And this is why NASA is committed to an orderly transition from ISS operations in LEO to U.S. commercially provided destinations in low Earth orbit. We are currently working with our partners in U.S. industry and just put out a request for proposals and received strong industry feedback on these requests for proposals for Commercial LEO Destinations.

We anticipate having those destinations in place by 2028. And so if we extend the ISS so that we can have an orderly transition and an overlap between the time when we'll have these destinations in LEO and when we do retire the ISS, that will allow us to mitigate the risk of a gap.

Mr. CRIST. And how can NASA apply those lessons when developing a transition plan for the Space Station?

Ms. GATENS. We can apply those lessons by planning for this orderly transition and planning to have an overlap in services so that we can ensure that we don't have a gap.

We'll follow along as our industry partners mature their concepts and follow their milestones and make sure we're enabling them to make progress so that we can have these capabilities in place when we need them.

Mr. CRIST. Thank you very much.

Mr. Manber, as we transition to a fully commercialized low Earth orbit, can you speak to the importance of having multiple providers and companies operating in this arena?

Mr. MANBER. Yes. Thank you, Congressman. It gets to the heart of your previous question as well, the lessons learned from space shuttle and America's dependency on one hardware program.

One of the lessons that we all see from the last several decades of the growing public-private partnership between private industry and NASA is the fundamental importance of having different opportunities, different vendors, different choices. If one goes down,

if there's a problem, the United States remains fully engaged in space.

And so, as I said in my testimony, space is far more critical today than it was several decades ago. So it's absolutely imperative that we have multiple platforms giving us multiple choices that also provide the stability that is provided in low Earth orbit. So thank you for the question.

Mr. CRIST. Well, thank you, sir.

And, Ms. Gatens, what is NASA doing to drive interest from the commercial space industry and assure the operation of multiple providers in low Earth orbit?

Ms. GATENS. Thank you for that question.

Well, in addition to our request for proposals for free flyers, we have also enabled the use of Space Station forward port, for Axiom to provide an attached commercial element to the Space Station.

So, as Mr. Manber just expressed, we have multiple options and multiple pathways to getting these services that we will need to follow on to Station.

In addition, we're also enabling demand. So these platforms, private platforms, are going to need other customers besides NASA. And so we're using the Space Station today to allow companies to bring innovative research and try new markets, such as optical fiber, such as regenerative medicine, novel materials that seem promising, to create new markets and stimulate this non-NASA demand that will be required in low Earth orbit.

Mr. CRIST. Thank you very much.

Thank you, Mr. Chairman. I yield back.

Chairman BEYER. Thank you, Charlie, very much.

Next we'll recognize the Ranking Member of the Full Committee, Congressman Lucas.

Mr. LUCAS. Thank you, Mr. Chairman.

Dr. Rubins, NASA's Human Research Program tracks a number of risks that need to be addressed in order to enable future space exploration. The ISS, of course, as you noted, is a key asset in conducting research in mitigating these risks.

Understanding that ISS will not operate forever, how is NASA doing at addressing those risks given the length of ISS operations, making all that work together? And maybe for a moment, can commercial solutions help address those risks?

Dr. RUBINS. Yes, thank you very much for the question.

So the Human Research Program has looked at all of our deep space exploration risks, what we need for lunar missions and eventual missions to Mars, categorized those, and then assessed what kind of research needs to address those risks to develop countermeasures.

We then ranked those research risks in terms of order of importance and looked at how many years we think we're going to need to address each of these risks.

These risks are things like radiation encountered on the voyage to Mars; our closed loop environmental system, how do we scrub CO₂ from the atmosphere, how do we recycle water and provide clean water to astronauts, and the human health risks, things like cardiovascular and bone.

And so some of those risks are things that we've now closed out. We've used the ISS to discover a countermeasure to those risks. Some of them are risks that we are going to assess in the next few years, and we have studies that are hopefully going to close that risk within the next few years. And some of these are longer risks that are really going to require some sustained research in low Earth orbit.

We have identified any other places that we could do the research to address these risks. And a lot of times there is no way to do that research on Earth. And so these longer-term risks are going to be things that we need to develop countermeasures for before we're going to have a successful mission to Mars. And we do need a platform in low Earth orbit to address these health risks and the really long duration risks.

Mr. LUCAS. My next question, I guess, goes both to Director Gatens, but also to Mr. Harrison, Manber.

We've noted in several comments in this hearing that the international interest in low Earth orbit is not limited to the United States or our partners on the ISS.

Could you tell me about the capacities of the Chinese space station, just as a reference point? What do we know about the Chinese space station, and what do we know about their capacities? Whoever would care to touch that first.

Ms. GATENS. I can touch it, and then Todd can jump in.

So the Chinese space station has gotten off to a strong start. They have launched their first module, and they just launched a new cargo mission carrying supplies. So they're rapidly assembling the station and have started to accommodate the first crew on the space station.

In addition, I know that they are planning for a wide range of activities, including research in some of the key areas that we are doing research on, on the International Space Station.

Mr. HARRISON. I'll just add that we actually don't know as much as we would like to about the specific capabilities and technologies on the Chinese space station because we're not a partner with them. And so we only get to see what they choose to share with us. And of course one of the downsides of that is it naturally leads to more suspicion and mistrust on both sides.

And so that's why I would urge the Congress to look at ways that we could forge more relationships with the Chinese civil space program so that we have better understanding on both sides of, what are they developing, what kind of capabilities do they have, how could that be helpful to some of our science and exploration goals, and, where possible, where do we want to partner with them to achieve our mutual science and exploration goals?

Of course, I would caution, whenever you're talking about bringing in a party like China, we've got to be careful to make sure that we keep all of our existing partnerships in place on the ISS and make sure all of those nations are fully informed and are on board with what we're doing.

Mr. LUCAS. Mr. Manber?

Mr. MANBER. Yes, thank you, sir. A couple of comments, if I may.

First off, looking at the program itself, it's a simpler platform. It doesn't have the volume of the International Space Station. The

cargo delivery is not as robust as ours. It's going to make certain research more difficult. And the crew is not as robust, they don't have the capacity yet. So in that sense, it's not a one-on-one comparison. The ISS is still far more robust.

Having said that, it is a formidable commercial competitor. I submitted into my written testimony a list of our allies that are working with the Chinese, organizations in Japan and France and in Peru. They have some extraordinarily cutting-edge hardware on their platform representing technology from 2015.

And so when we talk about the aging of the International Space Station, it's not only the platforms itself but the capability for research and when do you make that balance of investing further in the ISS as you look at the natural decay.

But to stay focused on your question directly, they are a commercial presence, they are marketing internationally. And I echo that we should engage in some safe way to make sure American presence is in the room, and commercial offers that opportunity in my view.

Mr. LUCAS. If the Chairman will indulge me for half a question.

Are there countries who have sent future astronauts to China to be trained to be able to utilize the facility?

Mr. MANBER. Yes, from what I just read. I turn to my NASA colleagues. But I do understand that ESA (European Space Agency) has training going on, and Russia as well.

So, yes, again, I believe we should be in the room.

Mr. LUCAS. Thank you, Mr. Chairman.

Chairman BEYER. Thank you, Mr. Lucas, very much.

Now let me recognize the gentleman from Colorado, who has some scientific interest in this.

Mr. PERLMUTTER. So I want to start with you, Dr. Rubins. I mean, obviously, part of your testimony today has been about our mission to Mars. And the ISS has played a big role, as you've described, in us learning about the effects of long-term existence in space, what it does to people, what it does to plants, what it does.

Are we, given the fact—and Mr. Manber just talked about it—that our Space Station is aging—we've had a hole, we've had thruster problems—are we in a position to continue to do the experiments for the time that you think it's going to take to then help mitigate the risks when we do go to Mars? I mean, is this Space Station going to last long enough for us to do the experiments that are needed?

Dr. RUBINS. Yes, this is an excellent question. And I flew in 2016 and then just flew this last year. I landed in April. So I have seen the Space Station across the most recent 5 years of life.

And it's in incredible shape. The structures that we have built are very robust. We have done studies at NASA that have proven that we can extend the life of the Space Station out to 2028. And we really don't see any concerns structurally for longer extension of the Space Station.

The equipment is—there's original equipment, but there's also constant addition and improvement of the equipment on board. And so we see things like the DNA sequencer. We are seeing a lot of commercial companies put things like microscopes up there, tools

that are going to allow us to assess human health for long duration.

And we're also adding things to the life support system. So this is one of the most important questions for Mars: How do we keep humans alive for this 2.5-year mission in deep space? Our life support is going to be absolutely critical.

And the microgravity environment of the ISS is incredibly capable. It's large. It allows us to integrate new pieces of the life support system.

So while I was up there, we installed several pieces of equipment to further refine our water processing. We're about 90 percent closed loop, and we're increasing that element of closed loop water processing.

So even today, we are adding new equipment to the Space Station that's going to allow us to solve these gaps and get to Mars safely and successfully.

Mr. PERLMUTTER. Thank you.

And this I will start with Captain Shepherd, I guess, but it's to the whole panel.

You mentioned the ability, the need for somebody to take leadership in integrating all the systems, all that, and not expect, just because we have got smart astronauts, that they can do everything on the fly.

I guess my desire is similar to what we have done with the Space Station, that it be public-private in certain respects, international in scope to the degree we could work with the Chinese, continue to work with the Russians. I would like to see the mission to Mars be that extensive.

But what did you mean about the leadership needed to do the integration? Let me start with that.

Captain SHEPHERD. Sir, let me give you a graphic example. We all use the internet. And the internet runs because somebody established a protocol and everybody signed up. And so now it's an immensely valuable thing for the civilized world. All of our communications protocols are the same way.

What I'm saying is there needs to be a framework. You need to see these expeditions and missions to the Moon and Mars from the standpoint of the crews who will be at the point of need. The people on the surface or the people in the vehicle, what do they have to deal with and how complex is their job? And the integration has to start from that level and come out.

And without some congregation of contractors all agreeing on common standards or NASA imposing or some other agency imposing a standard that all will salute, you are not going to have that. And this is what I'm talking about.

Mr. PERLMUTTER. So why do you think NASA isn't going to impose the standard? What's the problem here?

Captain SHEPHERD. I don't see it.

Mr. PERLMUTTER. You just think everybody's going their own direction?

Captain SHEPHERD. I certainly do. We tried to establish just standards for controls and displays on ISS 20 years ago. And as far as I can tell now, it's being used nowhere else.

Mr. PERLMUTTER. OK. My time is expired. I yield back to the Chair.

Chairman BEYER. Thank you, Mr. Perlmutter.

I recognize the Congressman from Cape Canaveral, Mr. Posey.

Mr. POSEY. Thank you, Chairman Beyer. And thank you for this great hearing that really we needed to have. Thank you again.

Ms. Gatens, following up on Representative Crist's comments and questions, when I hear the Space Station gap, I think of the shuttle gap between the last space launch and the first commercial crew launch 9 years later. It left a gaping hole in Florida's Space Coast economy and work force for sure, a loss of many, many veteran space workers, and left us to rely on the Russians to carry our astronauts to the ISS.

Can you give us some idea of the platforms and the destinations that you expect the private sector to propose?

Ms. GATENS. Thank you for that question.

Yes, in fact, we are seeing a very strong response to our request for proposals for Commercial LEO Destinations. And so we expect to see a wide variety of concepts. And I am looking forward to seeing what our industry partners are proposing there.

In addition, so we believe that due to the——

Mr. POSEY. Can you give us just some idea of some of the concepts we might expect to hear?

Ms. GATENS. Well, I haven't seen the proposals. I have seen some earlier industry studies that show different free-flying concepts made of repurposed elements in some case, upper stages, and other more traditional and inflatable kinds of structures. So I think we have that to look forward to, but I have not seen the proposals yet.

And if I might just follow up on the previous question regarding standards. NASA did work with our international partners to develop an initial set of international standards for our Artemis Program.

So I do agree with Bill Shepherd, that's very important, and we are working toward those standards.

Mr. POSEY. Thank you. And I am glad to hear that. We know that China is trying to change standards in all disciplines over the globe to favor them. And I think we need to take a lead on standard setting for sure.

Do you maintain communications with our Space Force and other military sectors?

Ms. GATENS. Yes. I know our Administrator routinely communicates with General Raymond of the Space Force. And we work with them, obviously, at Cape Canaveral for our launches, and they do our range activities. So we have a close communication with Space Force for our activities in human space flight.

Mr. POSEY. Thank you.

What parts of the ISS are becoming dangerously outdated? I mean, I am wondering if there are elements of the ISS that can be used for other purposes besides just deorbiting.

Ms. GATENS. Oh, yes. Good question.

So parts of the ISS are older than others. There are newer modules that have a lot of useful life left that could potentially be detached and become part of future LEO platforms.

So we're not opposed to entertaining those concepts. We haven't studies those in detail, but that is certainly quite possible.

Mr. POSEY. Is it at all feasible to move any usable portions to a lunar orbit or possibly the surface of the Moon?

Ms. GATENS. I am not an orbital mechanics expert. I could take that question. I do not believe that anyone has really proposed doing that.

Mr. POSEY. OK. Thank you.

Now, Mr. Harrison, in your written and your oral testimony today you mentioned the Wolf amendment and how it originally intended to pressure China to make human rights reforms and to stifle development of its space capabilities.

Then you say, after 10 years it's clear that China has not improved its behavior when it comes to human rights, and China's space programs, military and civilian, have only accelerated. And we know their civilian and their military activities are enjoined.

The Wolf amendment doesn't preclude NASA from working with China. It says that NASA must notify Congress and vet it through the FBI and the State Department.

Are you suggesting that Congress and the FBI (Federal Bureau of Investigation) not be notified per the requirement of the Wolf amendment that you imply is problematic in your written testimony?

Mr. HARRISON. Well, I think the effect of the Wolf amendment has been to limit that cooperation. And so there have been some examples. There was some recent low level cooperation on the Chang'e 4 mission, Chinese mission, with the Lunar Rover where NASA was able to share some information with China.

They did jump through all the hoops and go through the FBI and the vetting process and submit it to Congress and were allowed to do it.

So certainly it's possible. The problem is that it has stifled that ability to cooperate.

I mean, there are examples where NASA was being a little overly aggressive in enforcing those restrictions early on, not allowing Chinese scientists to come to conferences where NASA scientists were going to be participating.

Those things have been worked out since then. But that's just an example of how it has really stymied our ability to engage in a meaningful way with China when it comes to civil space.

And as you say, we can't really tell the difference between many of their military and civilian space activities, and I think that's a shame.

We can tell those distinctions with the Russians because we cooperate with them on the civilian side. We don't have that kind of relationship with China. And, importantly from a military space perspective, we don't have those direct military-to-military space contacts that we would like.

If we had civilian-to-civilian contacts through our civil space activities, that could actually be a good channel of communication to develop so that we don't end up with misperceptions and actions and potential misintended escalation in space in a future military crisis environment.

Mr. POSEY. Thank you for your indulgence and letting the witness answer my question, Mr. Chairman. My time has expired, and I yield back.

Chairman BEYER. Thank you, Congressman Posey, very much.

Now, let me recognize Representative Kim from California for her questions.

Mrs. KIM. Thank you, Chairman.

Thank you so much for all of our witnesses for being with us.

I want to pose the questions to Director Gatens.

NASA's 2018 ISS Transition Report states that NASA intends to begin shifting responsibility for meeting its needs and requirements in LEO by leveraging private industry capacity, innovation, and competitiveness that would offer the prospects of lower costs to the government to enable NASA to apply more personnel and budget resources on extending human space flights beyond LEO and enhancing U.S. leadership in human space flight around the world.

So with that, can you provide more detail for this Committee on how NASA is actively working on or planning to reduce the operational costs of the ISS as well as more details regarding the private sector's role in reducing operational costs?

Ms. GATENS. Yes, thank you for that question.

So we have done some preliminary cost assessment of the efficiencies that we could gain from transitioning from the pretty complex ISS to a more simpler commercially owned and operated platforms in low Earth orbit. And we believe we can save over a billion dollars a year by purchasing services for what we need, we will need, NASA going forward in low Earth orbit, from these privately owned platforms.

As the companies mature their concepts and we learn more about their capabilities and potential prices for these services, we can refine those estimates going forward. That's kind of our cost estimate right now of the savings.

And those savings are important because we can apply those to expand our exploration efforts beyond low Earth orbit to include the Moon and Mars and on to the solar system.

Mrs. KIM. Well, how will NASA make a final determination about end of life in preparation to deorbit the ISS? What kind of factors will drive that decision?

Ms. GATENS. Yes, thank you for that.

We've actually started to generate a list of what we call transition indicators to tell us when we will be ready to make this transition. The first and foremost indicator is that we have Commercial LEO Destinations to transition to. That may sound pretty obvious, but that's a prerequisite so that we don't have a gap in low Earth orbit.

The second transition indicator that we'll be watching is the health of the Space Station. We believe it's structurally sound until 2028 and can go beyond that. But we will be watching that as we go forward.

Other indicators we're going to be looking at are the development of commercial markets and the readiness of the private sector, besides NASA, to do activities in low Earth orbit.

We also want to work with our international partners on this transition plan so that we can have a plan to continue our international partnership in LEO as we do this transition. Not only do we want the international partnership to continue for Artemis, but we want it to continue for low Earth orbit as well, and that's extremely important.

So these are some of the indicators that we'll be looking for.

Mrs. KIM. Well, thank you so much.

Let me ask a question to Mr. Shepherd.

In your written testimony, you highlight the recent leaks placed to the rear of the Russian service module and state: "Engineers and technicians in Russia and the United States work together to understand and resolve this issue; but the root cause of the cracking, their failure modes, and impact on ISS safety and future operations have not been adequately determined."

So can you tell us how frequently are these cracks and leaks appearing, and are they easily resolved? Have they worsened in the past year?

Captain SHEPHERD. Congresswoman Kim, thank you for the question. I think I should defer to other NASA technical experts for the exact details, but I'll tell what you I know based on two meetings with the Advisory Committee.

The cracks have appeared recently. They're quite small. They look like scratches on the surface of the aluminum plate. The plate itself is very thin, but the material is quite ductile. So that allows it to resist basically growth of flaws like cracks.

I have been in the factory where this module is made, and I am pretty sure I may have seen pieces of it in my earlier life. And as far as I know, the Russian engineers and the NASA engineers do not—they have analyzed it. They don't exactly understand why these cracks are appearing now.

There are probably something like half a dozen of them. They're quite small. We've assessed that the length that they would need to grow to, to be a serious problem, they're well short of that. But we know that there are probably other cracks that we haven't found yet.

And so I'm just saying that getting to the bottom of this is a fairly serious issue. I don't think the Station's in any immediate danger. But before we clear the Station for another so many years of operational use, we should better understand this.

Mrs. KIM. Definitely. Because we don't want to jeopardize the long-term operation of the ISS.

But thank you so much. I see that my time is up. Thank you.

Chairman BEYER. Thank you, Madam Kim, very much.

I now recognize Mr. Webster from Florida for his questions.

Congressman Webster? If you are there? Give you another couple seconds to resurface.

And if not, we would love to move to Congressman Brooks from Alabama. Again, if Congressman Brooks is there.

If not, Mr. Babin, I would love to do a second round, for anyone who has questions for a second round. And that might give Congressmen Webster and Brooks an opportunity to come back.

Mr. BABIN. [Inaudible] Mr. Chairman.

Chairman BEYER. Great. Great. Thank you. Thank you, Dr. Babin.

So let me begin.

I have been fascinated by the tension—the debate tension, not the personal tension—between the Captain Shepherd perspective, which I would characterize perhaps as some skepticism that the private sector, the commercial sector is going to be able to come in and provide the same level of coordination, diplomacy, redundancy that—the long partnership that the ISS has had.

So, Ms. Gatens, since this is largely your role right now, No. 1, is there a larger process within NASA, within the U.S. Federal Government, that takes all of the Captain Shepherd questions in skepticism and posits it against some of the enthusiasm that, say, Mr. Manber has about our ability to stand up the commercial sector to take over the governmental role that we've had in the last couple of decades?

Ms. GATENS. Yes, thank you for that question.

This is something that we consider at NASA as we think forward into our procurement strategies. And we have learned that our industry can be quite strong in developing those capabilities and their ability to take over.

The government's role is to do the hard things, and we have paved the way in low Earth orbit and brought our industry partners along with us. And right now in the Space Station there are over 20 commercial facilities that are owned and operated by gentlemen like Mr. Manber and other companies, and they're bringing customers to those facilities.

And so we know that the response from industry is strong, and we believe that they will be ready for this next step in low Earth orbit, and enabling NASA to move on to the next hard thing, exploring the Moon and Mars and the rest of the solar system.

Chairman BEYER. Thank you.

And to Captain Shepherd, I defer to you for your thoughts.

Captain SHEPHERD. I would like to ask Ms. Gatens and maybe anybody else from NASA how NASA has incentivized the contractors who are currently performing commercial space activities involving NASA astronauts, how NASA has incentivized these companies to best integrate their systems with the astronauts and with each other. I'm not sure I see that.

Chairman BEYER. I would welcome both, either Ms. Gatens or Mr. Manber, to respond to that.

Ms. GATENS. I was going to invite my colleague, Mr. Manber, to respond to that since he has those facilities as well.

Mr. MANBER. Well, thank you.

I'm a little bit surprised at this late stage in the growing public-private partnership that we have enjoyed with NASA. We see the ability of SpaceX to take contractor funding and grow and self-invest.

At Nanoracks, we're far smaller, of course, but we have the European Space Agency as a customer, the German space agency as a customer, UAE (United Arab Emirates) Space Agency. We've self-invested it. They're using our hardware. And it's pretty accepted that the use of commerce as a tool of American power and influence is an important part of that diplomatic, almost soft diplomatic tool.

And so the maturing, for me—for me, the maturing of the public-private partnerships with NASA is a sign that America's presence in space is both robust and adhering to our core American values.

Chairman BEYER. Mr. Manber, let me jump in, because I only have a minute left.

Mr. MANBER. Yes, sir.

Chairman BEYER. I will just posit two questions.

Number one, as we have seen with SpaceX versus Blue Origin, essentially freezing of the Moon to Mars as we work through first the protests and then the lawsuit, and because—and I'm a huge fan of commercial, but we're seeing right now that that commercial thing is really disrupting Congressman Perlmutter's 2033 schedule.

And then, number two, as a businessman myself over many years, what happens when there's no capital, there's not a profitable business model? What keeps us from being in the chip industry, say, in space, that gets to where chips are right now, where you just can't fulfill the need because they didn't build the factories enough?

Mr. MANBER. Well, no method is perfect. We've all endured the delays of the more traditional government contracting.

I agree with you that—I share with you the concerns of having, let's say, too much influence in the hands of a commercial sector. But we've also seen that the pathway of government contracting has produced problems in and of itself. But over the history of this country, I think commercial markets have shown the most resiliency.

And, quickly, the second part of your question. That's the whole point of multiplicity of platforms, multiplicity of vendors. And it's just part of the maturing process. So I think commercial gives us the most robustness.

Chairman BEYER. Great. Thank you very much. Interesting debate. So I am sure it's not over.

Congressman and Dr. Babin, the floor is yours.

Mr. BABIN. Yes, sir. Thank you, Mr. Chairman. I am glad to be going back through with a second round here.

I wanted to ask Director Gatens another spacesuit question.

The NASA IG (Inspector General) recently issued a report on spacesuits and stated: "With the evolving and competing requirements of the eXMU's (Exploration Extravehicular Mobility Unit's), stakeholder programs and the agency's uncertainties about mission priorities, NASA is at risk of awarding a contract without clearly defining key technical requirements.

"Additionally, NASA has yet to formalize its acquisition strategy for next-generation spacesuits.

"According to Federal guidance, agencies are required to perform acquisition planning, including identifying the milestones in which decisions are made and addressing all the technical, business, management, and other significant considerations that control an acquisition.

"Awarding a contract before technical requirements and an acquisition strategy are solidified could result in numerous modifications to the contract, increasing cost and schedule.

"As our prior work has shown, entering a contract before completing development work can exacerbate cost and schedule risks,

particularly if issues are discovered late in the development effort and require costly rework.”

So does NASA plan to issue a final RFP, or will it issue a new draft RFP that addresses these significant concerns and to have contractors express concerns with the draft RFP?

Yes, ma’am?

Ms. GATENS. Thank you for your question. Although I’m not directly involved in the RFP process, I believe our initial plan was to issue an RFP this fall. But I’m happy to take your question and talk with those folks.

I honestly have not seen the industry comments. So I cannot comment on those concerns. But happy to take that question.

Mr. BABIN. OK. Yes, we would certainly love to have some answers there.

OK. Also to you as well, Director Gatens. NASA recently announced that an astronaut would not be returning on a Soyuz landing as planned, and that he would remain on the ISS for another 6 months.

In a few weeks, Russia will launch an actress and a director to film a movie aboard the ISS and they will return after a short stay. This would have been the U.S. astronaut’s seat home.

When did you know that the U.S. astronaut will not be returning to Earth on the fall Soyuz return? Was it before he launched this past spring? And can you provide Congress with the Flight Planning Integration Panel, the FPIP?

Ms. GATENS. Yes, thank you for that question.

So we knew that this would be a potential possibility for Mark Vande Hei’s stay, and he was informed of that before he launched and was perfectly willing to travel to the Space Station with that flexibility in mind, he and his family.

So we knew that possibility. We didn’t know it was for sure until recently when the Russians did ask NASA to formally extend his stay to allow the space flight participant mission.

And regarding the flight planning, I believe we have worked an alternative product that we have been transmitting to Congress to show you our near-term flight planning and our notional longer-term flight planning.

The internal FPIP document has a lot of preplanning dates on it, and so we prefer to keep that one internal. However, if the product that we’ve been sending over is not sufficient, we’re happy to discuss that further and see how we can give you what you need.

Mr. BABIN. We would certainly like to have that, because I don’t believe that that was sufficient.

Ms. GATENS. OK. Well, happy to discuss that.

Mr. BABIN. If you could have that forthcoming, we would appreciate that.

OK. Well, Mr. Chairman, I’m going to yield back the balance of my time. Thank you.

Chairman BEYER. Thank you, Congressman Babin, very much.

Mr. Perlmutter, Congressman Perlmutter, you’re recognized if you have additional questions.

Mr. PERLMUTTER. I don’t. I just enjoy listening to the panel. And I’m sure that once I tell you I don’t have any questions, I’ll think up 10.

But I just appreciate everybody's testimony, and just thank you for your service to our country and for the development of the space program, both as a national program as well as the commercial efforts that we're making.

So I just am proud of all of you. So I'll just leave it at that. Thanks.

Chairman BEYER. Wonderful. Thank you, Mr. Perlmutter, very much.

Is Mr. Webster, Congressman Webster or Congressman Brooks available for questions before we cutoff?

And then, let's give it—Mr. Weber from Texas had waived on to the Committee and I believe is trying to sign on right now. So let's give Congressman Weber a minute to do this.

Ms. Gatens, while we're waiting—are you ready, Congressman Weber?

Mr. WEBER. I am, Mr. Chairman. I appreciate that.

Chairman BEYER. OK. Well, then the floor is yours.

Mr. WEBER. OK. Thank you so much.

This question is for Robyn Gatens. I apologize for being late. But at any rate, I'll start there.

The *National Aeronautics and Space Administration Transition Authorization Act of 2017* required NASA to provide Congress with a transition plan for the ISS to address several specific topics. Quite frankly, NASA delivered a plan that was less than adequate. It was supposed to provide an update this year.

I guess my question for Ms. Gatens is, where is that plan? And will it include all the elements which were required under the previous act?

Ms. GATENS. Thank you for that question.

Yes, we are working on the update to that transition report right now. It's actually going through agency review, and we will be sending it over to Congress in the coming weeks.

I believe that you'll find that it is a much more thorough strategic and tactical plan for ISS transition to Commercial LEO Destinations, as we've been describing. It has evolved since the initial report to include many more details, cost projections, transition indicators, our requirements in low Earth orbit going forward.

So I think it's a more comprehensive report than we previously had due to the maturation of our planning here. So we look forward to sending that over very soon.

Mr. WEBER. Well, that's good news.

The second question is, ISS has flown, as we're all aware, over 100 projects from 100 different nations. Now the Chinese are using their space station to attract partnerships and engagement with other countries while ISS' final years and post-ISS planning remains uncertain. I'm glad to hear reports can be that extensive.

The question is, isn't NASA risking leaving low Earth orbit to the Chinese by setting up development programs to begin in a year or two when it has already had one follow-on station and developed Axiom, for example. Question: Why not double down on that station?

Ms. GATENS. Thank you for that question.

So we believe we need multiple paths so that we have the greatest chance of success for one or hopefully more commercial LEO platforms in low Earth orbit.

So the Axiom commercial element on Space Station is one of those paths. We had always intended to follow that with a commercial free-flyer solicitation, which we have now done, and we have seen strong industry feedback to that request for proposals. So that tells us that was a good strategy on our part. There is strong interest in multiple platforms in low Earth orbit.

Mr. WEBER. Well, I don't see the clock. So how much time do I have, Mr. Chairman?

Chairman BEYER. Just about 2 minutes. Just a little less.

Mr. WEBER. Thank you, sir.

So I am going to follow up with that question for you, Ms. Gatens, if I can.

Do you agree that NASA should be able to assure the U.S. scientific and research community, as well as our international partners, that there is a plan moving forward, together, which provides for the continuity of scientific and research collaboration in space that does leave the world relying on China for activities in microgravity? What do you say to that?

Ms. GATENS. Yes. Thank you for that.

Our plan absolutely emphasizes that plan so that this important microgravity research can continue. When we define what we, NASA, are interested in purchasing services for from private space stations, it not only includes NASA research, but also includes the same kinds of things that we're enabling through the ISS National Laboratory today. So other government agency research, private industry, incubation kinds of commercial research, education, academia research.

So all of those things we think are important to continue as well as our international partnerships. And we're doing that planning right now to define and refine those forecasts so that we can provide industry with an updated plan for the kinds of services that the government will purchase.

Mr. WEBER. Well, thank you for that answer.

Thank you, Mr. Chairman, for letting me piggyback on your Committee. I appreciate it. I yield back.

Chairman BEYER. Congressman Weber, you are always welcome.

Mr. WEBER. Thank you.

Chairman BEYER. If our Committee Members have no more questions, then I want to thank our five witnesses very much. It's been really, really interesting questioning. We never even got to Point Nemo in the Pacific. So we will have to come back and talk about how Ms. Gatens plans to deorbit what's left of the Space Station after everything else has been sorted out. But we really, really appreciate that.

Formally, the record will remain open for two weeks for additional statements from the Members and for any additional questions the Committee may ask the witnesses.

With that, again, my hearty thanks. The witnesses are now excused. And we are now adjourned. So thank you very much, and enjoy the fall equinox.

[Whereupon, at 12:51 p.m., the Subcommittee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Ms. Robyn Gatens

**QUESTIONS FOR THE RECORD
HOUSE SCIENCE COMMITTEE, SUBCOMMITTEE ON SPACE AND AERONAUTICS
SEPTEMBER 21, 2021 HEARING**

Submitted by Chairman Beyer:

- 1) You stated in your written testimony that the International Space Station (ISS) is “certified technically to operate until at least 2028, and there are no engineering issues that NASA is aware of that would preclude safely and productively operating the ISS through 2030.”

- a) When was the most recent certification—through 2028—completed and by what entity?

A: The most recent life extension work was completed incrementally between 2018 and early 2021, NASA, working with its Prime Sustaining Contractor, Boeing, completed the analysis of the U.S. modules on the International Space Station (ISS). The United States On-Orbit Segment (USOS) and Functional Cargo Block (FGB) life extension analyses for the time period through 2028 has been completed with no issues identified that would impact extension through 2030.

- b) Does the current certification consider any effects (or uncertainties of effects) from the July 2021 docking incident of the Russian *Nauka* module in which the *Nauka* module misfired its thrusters? If not, how does NASA plan to assess whether the ISS suffered any structural impacts from the Russian *Nauka* thruster firings and subsequent “flipping” of the ISS?

A: NASA performed a structural assessment following this anomalous event and concluded that it was not significantly more impactful than other events, such as visiting vehicle dockings, so there is no residual structural concern remaining. NASA does include this event in continual structural life usage accounting analysis going forward.

- c) How has NASA assessed the operational viability and structural integrity of the ISS to operate between 2028 and 2030 or longer, if authorized, and have any assessments included life-limiting systems and components as recommended by the Aerospace Safety Advisory Panel in its 2020 Annual Report?

A: NASA recently completed a study of the key structural components of the vehicle and their margins. The results found significant margin on these key structural members to extend to 2030. Additionally, NASA completed another study recently looking at the overall thermal degradation of the ISS surfaces and found no appreciable change to their properties.

- d) How will the efforts in (a-c) inform the ISS transition timeline and transition planning?

A: NASA’s goal is to align the ISS transition with Commercial low-Earth orbit (LEO) destination availability to avoid a gap in LEO. A commercial platform is expected to be available in the 2028 timeframe, enabling a two-year overlap with the ISS. Thus, it is critical to extend ISS operations to 2030. A gap in LEO would impact the robust industry supply of both crew and cargo transportation and many other areas. ISS life extension efforts will ensure ISS transition is appropriately aligned with the transition to Commercial LEO Destinations (CLD) by 2030.

- 2) NASA announced on August 12, 2021 that the agency had stood up an investigation team to “review the activity” related to a July 29 incident, when the new Russian science module for the ISS, *Nauka*, unexpectedly fired its thrusters shortly after successfully docking to the ISS,

resulting in the temporary loss of attitude control so that the entire Station flipped one and a half times in a matter of minutes.

a) What is the current status of the investigation?

A: NASA has completed the structural portion of the investigation and determined that there are no short- or long-term structural impacts from the event. The NASA investigation into causal factors is ongoing. The team continues to compile information obtained through interviews, review of console logs, and review of available documentation, in addition to discussions with Russian experts through existing formal coordination forums. The NASA team was briefed on the Russian Commission investigation.

b) Has this incident been declared a “mishap” or “close call,” as defined in NASA Procedural Requirement 8621.1D, and why or why not?

A: The Multipurpose Lab Module (MLM) Loss of Attitude Control (LOAC) incident is under formal investigation via the ISS Program Investigation Team (PIT), which is the ISS Program’s close call investigation process. NASA is employing the same rigor, techniques and expertise that are required under the NASA Procedural Requirements (NPR). Agency management and the Aerospace Safety Advisory Panel (ASAP) are being regularly briefed. The ISS Advisory Committee will also be briefed on the outcomes.

3) During the question-and-answer portion of the hearing, Captain Shepherd stated, in response to a question about how policymakers should view safety and risk as the ISS ages, that NASA needs to “reestablish a much more intimate working relationship with our Russian counterparts” and that, in particular, “part of the issue with the science module docking, the Nauka...is, we do not have that correlation with our Russian counterparts right now.”

a) What are your perspectives on Captain Shepherd’s assessment of NASA’s ISS workforce’s working relationship with their Russian counterparts, and his recommendation that the relationship be strengthened?

A: The Russian/American workforce relationships remain professional, as evidenced by how well the operational teams in the Houston and Moscow control centers handled the events referred to as one team. We are also working together to understand the root causes of those events and how we can best address them as partners.

b) How is NASA working to strengthen the relationship, and what are the potential challenges to doing so?

A: NASA continues to keep communications lines open as many NASA personnel, from the program manager on down, are in weekly – if not daily – communications with their counterparts. NASA will continue to work with its Russian and USOS partners to ensure that specialist and crew are where they need to be to receive training and ensure the safe operations of the ISS.

4) The 2020 Annual Report of the Aerospace Safety Advisory Panel, issued January 1, 2021, states that the Panel has closed its longstanding recommendation regarding ISS deorbit capabilities.

a) Please transmit the ISS Deorbit Strategy and Contingency Action Plan to the Committee.

A: The ISS Deorbit Strategy and Contingency plan is considered Controlled Unclassified Information (CUI), and will be provided to the Committee under separate cover.

b) What is the role of Russia in deorbit planning?

A: The Russian segment controls the ISS propulsion system: both the propellant reserves and the thrusters that will be used during the series of ISS deorbit maneuvers. NASA has worked with its Russian partners since the very early stages of ISS deorbit planning to coordinate the parameters of ISS atmospheric re-entry such as altitude planning, footprint targeting, burn duration and thruster sequencing, re-entry modelling, etc.

c) Does NASA's ISS Transition Plan account for a situation in which the ISS must be de-orbited sooner than expected—for example, due to an emergency situation? If so, what is included in the Transition Plan should such a situation arise?

A: Response to an emergency situation is contained in Section 5 of the ISS Deorbit Strategy and Contingency Action Plan, not the ISS Transition Plan. The document includes plans and recommendations in the event of an emergency that necessitates premature ISS deorbit. This section of the document covers expected deorbit decision timeframe, ISS system capability and critical systems list, anticipated vehicle configuration, modified altitude strategy and propellant usage estimates, as well as a contingency deorbit action plan detailing the anticipated altitude and propellant usage timeline for controlled deorbit in the contingency scenario.

5. In the eventual transition from the ISS to non-governmental low Earth orbit (LEO) platforms, what will be done with the ISS research hardware? Who owns the research hardware now, and what are the possibilities of repurposing or otherwise reusing the hardware, either on board the ISS as operated by commercial partners or on board other low Earth orbit facilities? What is the estimated value of the research hardware aboard ISS?

A: The research hardware currently on ISS is a mix of Government-owned and privately-owned facilities. There are over 20 commercial facilities operating aboard ISS today – including a 3D printer, a bioprinter, external Earth observation and materials platforms, and an airlock – that are available for use by both NASA and other paying customers. Disposition of the hardware following the life of ISS will be determined by a variety of factors, including usable life left on each individual facility, intent of the facility owner, and practicality of moving the hardware to a different LEO platform or a return to Earth.

a) Has NASA involved the biological and physical sciences microgravity research community in decisions on the future of ISS research hardware?

A: A new Decadal Survey is underway for this research community and is scheduled to be delivered in the summer of 2023. As with the other Decadal Surveys conducted by the National Academies of Sciences, Engineering, and Medicine, the Committee on Biological and Physical Sciences in Space will work to convene these science communities and work to recommend the highest priority research to be conducted in LEO, as well as venues like sub-orbital flight and the lunar surface.

To give future commercial providers a business model to work toward, NASA is refining its “Forecasting Future NASA Demand in Low-Earth Orbit: Quantifying Demand” white paper, and will define NASA’s anticipated service requirements for future CLD providers. These forecasts will include the anticipated NASA demand for crew accommodation, technology testing, human research, and science, along with

capturing the future needs of non-NASA U.S. entities and potential international partner users. The intent of this activity is to allow future CLD and launch providers to scale their activities to meet the future needs of the U.S. Government, while also allowing them to design for private use of the capabilities.

6. In your testimony, you mentioned that NASA will save money through commercial LEO activities. NASA's Phil McCallister was quoted recently in CNBC as stating that NASA expects to save "a billion to a-billion-and-a-half dollars [annually]" by transitioning orbital science and research from the ISS to commercial LEO destinations.

a) How did NASA determine this level of savings?

A: The savings represents a comparison of current costs to run ISS (including crew and cargo transportation) and a rough order of magnitude estimate of how much it will cost to procure commercial LEO services post-ISS, as well as how much of current ISS costs will likely get transferred to other NASA programs. The amount of these savings will be refined over time as the CLD providers mature their concepts and as NASA gains a more precise understanding of its requirements in LEO.

The rationale for the savings are severalfold: NASA will only be paying for the specific services it needs, which will be less than the quantity of crew and research that the Agency is currently conducting on the ISS today, rather than paying for the cost of maintenance and operations of the ISS with the current level of research and crew; there will be other non-NASA customers for CLD services so that NASA is not paying for all the CLD costs; the CLDs will be newer, requiring less maintenance and fewer spare parts than the ISS; the development and operations of the CLDs should be efficient and cost effective since NASA will be leveraging a private-sector-led business model; and, with lower maintenance requirements (fewer replacement parts and spares), there will be a reduction in transportation costs.

b) When does NASA expect to achieve these savings?

A: NASA expects to achieve these savings after ISS retirement. The latest budget estimate for ISS life extension to 2030 assumes deorbit in January 2031.

c) NASA currently spends about \$4 billion on ISS operations, including research, transportation, and ground support systems. If commercial LEO destinations save the agency \$1-1.5 billion, as NASA has purported, how would the agency expect to spend the remaining \$2-3 billion?

A: The remaining budget would go towards purchasing commercial LEO services and paying for the maintenance and operations of facilities that are currently funded by ISS but will be needed by other human spaceflight programs, such as mission control and the Neutral Buoyancy Laboratory. These details are contained in the ISS Transition Report which NASA provided to the Committee in January 2022.

7. What are NASA's requirements for activities in low Earth orbit once the ISS is retired? What activities does NASA need to continue in low Earth orbit post-ISS, and which does it not need to continue?

A: NASA's current prediction of its future needs in LEO can be found in this white paper:

https://www.nasa.gov/sites/default/files/atoms/files/forecasting_future_nasa_demand_in_low-earth_orbit_revision_two_-_quantifying_demand.pdf

NASA is currently refining this white paper to give future commercial providers a business model to work toward, and to define NASA's anticipated service requirements for future CLD providers.

8. Does NASA require continuous human presence in LEO following the end of ISS operations, and if so, why is that human presence required? Does NASA anticipate that the human presence would be NASA astronauts or non-government astronauts?

A: NASA anticipates having requirements for its astronauts to continue to have access to the LEO environment for the foreseeable future for: human health research, technology development, biological and physical science research, and crew training to enable deep space exploration missions. NASA will also evaluate the services and capabilities being offered by non-Government astronauts to perform activities required by NASA.

9. How much ISS crew time is spent currently on repairs and maintenance—both in terms of percentage of available time and absolute amount of time—and how does NASA anticipate the crew time required for repairs and maintenance will change in the coming years as the ISS continues to age?

A: Please see table below.

These are examples of crew time breakout for some increment pairs:

Increment	Total Crew Time (hrs.)	Total Maintenance (hrs.)	(Maintenance)/ (Total Avail.)	Total Utilization (hrs.)	(Utilization)/ (Total Avail.)
59/60 (2019)	4,199	361	8.60%	2,098	49.96%
57/58 (2018-2019)	1,889	260	13.76%	847	44.84%
55/56 (2018)	3,958	507	12.81%	1,710	43.20%
53/54 (2017-2018)	3,377	414	12.26%	1,315	38.94%
51/52 (2017)	2,676	262	9.79%	1,258	47.01%

Maintenance is 11.44 percent on average for these increment pairs and this is typical for the ISS. NASA anticipates this will remain around this level because other than the ISS structure, all other items can be either repaired or replaced.

10. What are the obligations and responsibilities for NASA, under the ISS Intergovernmental Agreement (IGA) and any other relevant international agreements, for planning, signing agreements, and carrying out Private Astronaut Missions (PAMs)? What input, if any, do the international partners have on the details and arrangements of these private missions?

A: NASA, as the lead integrator of the ISS Partnership, has the responsibility to coordinate all on-orbit activities for the ISS Program. All flight crew assignments, including those for Private Astronaut Missions (PAMs), are agreed to by the International Partnership prior to flight through the Multilateral Crew Operations Panel. Additionally, the ISS Partners coordinate regarding all Space Flight Participants through the ISS Multilateral Coordination Board (MCB). In particular for those PAMs that involve the flight of private astronauts from non-Partner countries, the ISS Partners provide approval through the ISS MCB.

11. What total reimbursable costs will NASA receive for the first PAM planned for early 2022? Will NASA be providing any in-kind services, non-reimbursable services to the PAM, and, if so, what are they?

A: The original June 2019 pricing policy provided a subsidized pricing model for the majority of the costs associated with PAMs, similar to the commercial use pricing. The original June 2019 pricing policy for PAMs was limited in scope and included only life support, crew supplies, stowage, power, data, crew time, and cargo upmass/disposal/downmass.

NASA conducted a detailed assessment of the direct and indirect costs associated with PAMs, which included meeting the intent of the Joint Explanatory Statement of the FY 2021 Consolidated Appropriations Act. Based on the assessment, a new pricing structure was developed for PAMs.

The new pricing policy for PAMs reflects full reimbursement for all direct costs and the indirect costs that are above the ISS baseline capability. In other words, there will be a zero-percent subsidy for costs above the ISS baseline. Updates to the pricing policy were announced to industry, and all mission awards made after January 1, 2021 are subject to the new pricing policy.

In September 2020, prior to adoption of the new pricing policy, NASA had reviewed and approved the Axiom Space Ax-1 mission proposal, including a cost assessment based on the 2019 pricing policy. NASA will proceed with the Ax-1 mission using the original June 2019 pricing for this particular mission only.

For Ax-1, NASA will receive \$3.88M for reimbursable costs, which include ground support services, including training and integration; basic provisions on ISS, including food, oxygen, water, access to waste and hygiene systems; access to information technology hardware; base ISS crew time support; and Ax-1 crew training. This is consistent with the pricing policy in effect for Ax-1. NASA is procuring Ax-1 services to return a large Nitrogen/Oxygen Recharge System tank from ISS and cold science for NASA, in which the Government will owe \$6.56M. This is consistent with fair market value of these services. Therefore, it is projected that NASA will pay a net of \$2.68M to Axiom.

Future PAMs will not be subsidized by NASA; therefore, the PAM provider will be responsible for the mission costs.

12. NASA already has at least one PAM agreement in place for a visit to the ISS. For the purposes of the ISS, what, if any, differences are there, in terms of liability, responsibilities, access, or otherwise, between Government Astronauts, Crew, and Space Flight Participants on the ISS?

A: NASA has established a framework for PAMs (including Private Astronauts, who are considered Space Flight Participants, not Government Astronauts) that is divided into PAM provider responsibilities and NASA responsibilities. The PAM provider requirements and responsibilities include:

- Ensuring the safety of the PAM crew during all phases of the mission;
- Nominal and off-nominal launch and landing operations, including emergency rescue;
- Acquiring transportation for the PAM crew on a U.S. commercial vehicle and ensuring ISS requirements and verification are met;
- Meeting all applicable local, national, and international laws and regulations;
- Providing supplies and resources independently or via NASA per pricing policy (e.g., crew supplies, life support, medications, upmass/downmass, trash services);
- Providing real-time mission support with key positions (e.g., Mission Director, CAPCOM, etc.);
- Selection, training, and medical qualification of private astronauts to meet NASA requirements;
- Ensuring private astronauts meet all medical requirements and providing medical services for private astronauts for all aspects of the mission; and
- Adhering to the liability regime established in the agreement, including participant informed consent, cross waivers, and insurance requirements, and flowing down specified requirements to its vehicle provider, private astronauts, and other related entities.

NASA responsibilities:

- NASA responsibility is limited to ISS integration, interfaces, and safety of the ISS vehicle and crew. NASA is **NOT** certifying launch/spacecraft vehicles or processes, and is only overseeing activities associated with the ISS and ISS crew safety and ensuring ISS interface requirements are met. NASA is not providing oversight, support, or certification commensurate with the Commercial Crew Program (CCP) for PAM missions. No launch vehicle, free flight, or return/rescue requirements are being levied;
- NASA is providing ISS on-board resources and visiting vehicle/integration activities to enable PAMs;
- NASA provides crew training and medical requirements addressing ISS safety, use of habitability equipment, and life on ISS;
 - Minimum crew training is required for each PAM crew to ensure ISS safety. Additional training may be requested for PAM specific tasks such as conducting research, etc., based on PAM mission-specific objectives.
 - Training enables PAM crew to safely operate on ISS and for emergencies, to take rapid actions to save themselves in a manner that allows ISS crew to address anomaly recovery.
 - Additionally, PAM Commander and “escort” training requirements are levied to reduce risks and operational impacts to the ISS and ISS crew.

Due to the lack of a regulatory regime outside of the Federal Aviation Administration (FAA) launch and re-entry, Federal Communications Commission (FCC), and National Oceanic and Atmospheric Administration (NOAA) requirements, NASA has developed an overall liability regime to address the Agency’s liability concerns associated with the risks to PAM crew, ISS crew, ISS vehicle, and other risks to NASA. NASA’s standard PAM liability framework includes six major considerations: FAA licensing; cross waivers; private astronaut waivers, informed consent and assumption of risk; insurance protection for a private astronaut injury; insurance protecting NASA and International Partners’ property and injury to ISS crew; and third parties (based on what has been stated as available in the insurance market), which are discussed in more detail below. There may be variances in the insurance requirements depending on the specific mission profile.

- FAA licensing: A PAM provider must flow down the requirements for their launch provider to obtain the proper FAA licenses. This includes the requirement for liability

insurance based on maximum probable loss (MPL) calculations, which includes pre-launch, launch, and re-entry.

- **Cross Waivers:** A PAM mission provider and its related entities, including the private astronauts, are precluded from making claims against NASA and its cooperating agencies.
- **Private Astronaut Waivers:** Private astronauts and their estates are prohibited from making claims against NASA, International Partners and related entities, and subcontractors. Private astronauts also must sign an Informed Consent and Assumption of Risk acknowledging acceptance of waivers and risk of spaceflight and the mission.
- **Insurance Protection for Private Astronaut Injury:** A PAM provider is required to purchase liability insurance to protect ISS International Partners, NASA, and NASA subcontractors from claims in the event that a private astronaut is injured.
- **Insurance Protection for NASA, International Partners and Property Coverage:** A PAM provider is required to purchase insurance to cover damage they or their private astronauts cause to NASA, Payloads, International Partner hardware on ISS, and injury to ISS crew. Insurance amounts are predicated on limited availability of the market and NASA quantification of risks.
- **Third Party:** No insurance required, PAM provider agrees to indemnify NASA and International Partners against third-party claims.

13. NASA recently released a request for proposals for free-flying commercial LEO destinations (CLDs), or commercial space stations. The solicitation mentions that NASA will only be releasing draft service requirements after the first phase is already awarded around the first quarter of fiscal year 2022, as NASA continues to mature its requirement needs in LEO. How is NASA going to ensure that the CLDs are ready to meet NASA's requirements for when NASA needs to transition from ISS, if the requirements will not be defined until after the awards are granted?

A: Over the summer of 2021, NASA announced a two-phase strategy for the acquisition of CLDs in which NASA will support multiple companies for early design and development during Phase 1. The period of performance of the Phase 1 efforts is expected to be approximately four years, after which NASA plans to transition to Phase 2, which will be for certification of CLDs and service purchases.

When NASA releases its draft service requirements, there will be more than enough time for CLD developers to incorporate the requirements into their CLD designs. This strategy allows NASA to develop requirements for CLD Phase 2 in parallel with CLD Phase 1. NASA has had past success with this strategy with the Commercial Orbital Transportation Services (COTS) and CCP efforts, both of which had the requirements for subsequent services released after initial awards, and there was ample time for these requirements to be reflected in the final spacecraft designs.

14. How many individuals can the U.S. segment of the ISS support at any one time? What, if any, additional safety and risk assessments will NASA be conducting regarding spaceflight participants on the ISS, the number of spaceflight participants visiting ISS at any one time, and the impact of the number of individuals in the U.S. segment on NASA astronaut crew activities?

A: The U.S. segment can nominally support eight crew members for a short duration for a total of 11 crewmembers on board (three on the Russian Segment). The toilet is the limiting factor, though a second toilet is onboard and in test and evaluation. Once that is fully operational, the U.S. segment could support

as many as 10 crew members, for a total of 13 on board. This is limited by the capability of the NASA Oxygen Generator (though stored oxygen could be used to provide some additional capability), and NASA's mission planning ensures there is no overlap between Space Flight Participant (SFP) missions and NASA direct U.S. crew vehicle handover missions. Therefore, the total number of crewmembers on board for an SFP mission is no different than the number on board for a direct NASA handover.

15. NASA currently provides crew time, power, and transportation to support the scientific investigations of NASA researchers and NASA-funded researchers on the ISS.

- a) Does NASA plan to provide fundamental science researchers with equitable access and support for a non-ISS platform or capability?
- b) Would NASA be managing and paying for that support, or would NASA be supplementing research grants to cover those costs?

A: Models for the evolution of the ISS National Laboratory (ISSNL) construct to a potential orbital national laboratory construct are under study based on the successes and lessons learned from the ISSNL, but would provide continuity for academia, research institutions, U.S. Government agencies, and developing industries to continue their work using the unique environment of LEO.

16. How do current policies on intellectual property rights and royalty payments for commercial activities conducted on board and/or in partnership with the ISS compare to those applying to similar activities involving other government-funded research and development facilities, such as NASA's Jet Propulsion Laboratory (JPL) or the National Laboratories of the Department of Energy?

A: Intellectual Property (IP) rights are largely determined by the legal instrument involved (although some modifications can be negotiated). The Jet Propulsion Laboratory (JPL) is a Federally Funded Research and Development Center (FFRDC) operating under a contract between NASA and the California Institute of Technology (Caltech). When JPL does work with/for third parties (commercial entities, academia, etc.), these activities are frequently done through Space Act Agreements (SAAs) entered into by NASA (with the SAA IP clauses drafted to address Caltech's IP rights under their contract).

The ISSNL is operated by the Center for the Advancement of Science in Space (CASIS) pursuant to a Cooperative Agreement (CA) between CASIS and NASA. Commercial users of the ISSNL through the CASIS CA are subject to the IP rights set forth in the applicable subaward, a Grant or User Agreement (UA) (given to entities that fully fund their research) they have entered into with CASIS.

To facilitate the commercial development of critical technologies needed for human space exploration, NASA takes steps to ensure that its contractors and partners retain the maximum rights permitted by law, unless the Agency has identified a specific need to obtain rights in intellectual property for NASA's own purposes. It is part of NASA's mission to "seek and encourage the fullest commercial use of space," so it is NASA's intent to ensure that its contractors and partners are able to leverage investment to advance commercial space activities.

- a) Has NASA seen evidence that the current regime for intellectual property rights and royalty payments are a significant barrier to LEO commercialization activities through the ISS?

A: The Federal Acquisition Regulation (FAR) encourages tailoring, innovation, and the use of sound business judgment, to the extent not otherwise prohibited by law. This significant flexibility allows NASA to tailor procurement approaches to varying needs and timelines and to procure certain goods and services in a more streamlined, commercialized fashion. However, NASA also must adhere to certain bedrock principles required by statute. As an example, the FAR currently includes mechanisms that protect private sector intellectual property, while at the same time allowing for significant tailoring through the deviation process. NASA has tailored the FAR clauses in multiple contracts to protect private sector intellectual property while ensuring that the Government retains a license to use the intellectual property generated under the contract.

Submitted by Congressman Weber:

1. **Can Congress facilitate the development of markets for good and services provided in low Earth orbit? Concerningly, NASA and Congress purportedly support a robust, diverse market in LEO, while on the other hand, some of our colleagues actively push legislation that creates red tape and hurdles to companies seeking to grow their businesses through a range of services in LEO. These companies have folks standing by to, for example, film movies in space. This is one example of a mission that could generate revenue and allow companies to continue building out a market. How can we say to these companies, “we want a market to exist, and for the U.S. to be competitive in this market, but you cannot do X, Y, Z, even if it you have folks lining up to do it?” The U.S. Congress should support free market principles off-planet as we do on-planet.**

A: As part of the strategy for the Commercial low-Earth orbit (LEO) Development Program, NASA is facilitating both supply of Commercial LEO Destinations (CLDs) as well as non-NASA demand for those CLDs. Regarding demand, NASA has pursued, and will continue to pursue, competitively-awarded grants to companies with promising concepts for performing commercial microgravity research and experimentation with the potential to lead to in-space manufacturing concepts. In addition, NASA is supporting Private Astronaut Missions, which can enable a broader range of commercial and marketing activities than what NASA astronauts can perform. In addition, NASA continues to support the International Space Station (ISS) National Laboratory/Center for the Advancement of Science In Space activities, many of which have commercial potential. As with any initiative on the ISS, NASA must continually balance the needs and desires of a variety of stakeholders.

Material for the Record (MFR) Q from Rep. Posey
(transcript pg. 51-52, lines 1109-1110)

Q: Is it at all feasible to move any usable portions [of ISS] to a lunar orbit or possibly the surface of the Moon?

A: Moving something from the International Space Station (ISS) to lunar orbit or the lunar surface requires significant delta V (propulsive capability) based on the amount of mass to be moved. It is not feasible to move an entire ISS module to lunar orbit due to its large mass. In addition, much of the ISS hardware has been on orbit for many years so its long-term reliability and maintenance would need to be addressed. If there were some specific hardware such as an Environmental Control and Life Support System (ECLSS) subsystem component that was required by another space system and was cost-effective to transfer, then it may be feasible to move the hardware from ISS to lunar orbit. In the cases we have considered so far, it has been more practical to send new hardware directly to the Moon.

*Responses by Dr. Kathleen “Kate” Rubins***Kate Rubins QFRs****1. Astronauts on board the International Space Station (ISS) conduct experiments on behalf of researchers on the ground.****a. What training, education, and/or preparation is involved in planning and operating a Principal Investigator’s (PI’s) experiment on the ISS?**

A: Astronauts receive both generalized and specialized training in preparation for conducting experiments aboard the orbiting laboratory. They take science courses such as biological/life sciences, gene expression, fluids combustion, Earth science, materials science, and also receive training on the main scientific facilities that are on the International Space Station (ISS). They learn how to operate the various gloveboxes, robotics instruments, and even collection of samples from themselves for human research. Additionally, they receive briefings that provide overviews of some of the specific research they are expected to conduct during their mission. In some cases, they will receive experiment-specific training from the payload developer (PD) or principal investigator (PI). For some intensive crew-interaction investigations, PDs and PIs may be tied in via space-to-ground loops that allow them to talk the astronauts through precise steps in executing the experiment in orbit. Their training primarily focuses on building a solid foundation that will enable them to successfully execute any of the research they encounter during their mission.

Many investigations are developed using other research platforms (such as suborbital flights, drop towers, and others), ensuring that the experimental designs are optimized prior to launching to ISS. This stepping-stone approach can help prevent/reduce the number of variables or challenges that crew might encounter with an experiment on station.

b. As a scientist yourself, to what extent has your training and experience as a molecular biologist helped you conduct these experiments?

A: My laboratory training (15+ years) helped me understand methodology used in research experiments. Understanding how PIs design experiments and the variety of equipment used to study molecular and cellular processes helped me with carrying out experiments onboard the ISS. In addition, when we were developing new technology for space station equipment, I could integrate my bench-top laboratory experience with understanding how a space operator needs to work in a microgravity laboratory. Being able to bridge the researcher’s perspective and professional space flier’s perspective was very valuable in developing several major molecular scientific research programs onboard the station.

2. What are the expectations and responsibilities for NASA astronauts when Private Astronaut Missions (PAMs) are conducted on Station, and to what extent will the processes, procedures, and experiments be different when up to four occupants of the International Space Station are non-government astronauts?

A: Our Government astronauts are performing tasks that they have been asked to do by NASA. They perform research and technology development activities critical to enabling future exploration missions to the Moon and Mars. NASA astronauts conduct experiments that contribute to fundamental scientific knowledge, improve human health, understand Earth’s climate, advance in-space production of materials, improve critical life support and exploration systems, and inspire the next generation of STEM learners. They also conduct critical extravehicular activity (EVA) and intravehicular activity (IVA) operations to maintain the space station infrastructure and ensure visiting vehicles safely arrive and depart.

To enable a private astronaut mission, NASA and the private astronaut mission provider will sign an order that details the activities that will be conducted onboard the ISS. The order outlines specific activities that NASA astronauts will take part in, and the activities will vary depending on the private astronaut mission. The mission and NASA astronaut participation are both subject to NASA's [pricing policy for private astronaut missions](#). On board the station, the private astronaut crew commander is responsible for the day-to-day integration and leadership of the private crew, working under the construct and leadership of the space station commander and NASA's Mission Control Center authority.

NASA and PAM mission planners will coordinate in-orbit activities for the private astronauts to conduct in coordination with space station crew members and flight controllers on the ground.

3. A roundtrip human mission to Mars may take roughly two years. The longest single stay on board ISS was 340 days, and a handful of cosmonauts had stays lasting just over a year on Mir.

a. As a scientist, can you explain how much researchers can extrapolate from the small sample size of these 1-year stays in low Earth orbit (LEO) to assessing risk and developing mitigations for longer stays with future astronauts?

A: One-year missions in low-Earth orbit (LEO) are stepping stones in a greater system of research that will prepare us for human spaceflight to Mars. These one-year missions, in combination with research conducted on other mission durations in spaceflight (such as studies on Space Shuttle or six-month ISS missions) and in ground analog simulations, allow us to characterize the pattern of human adaptation to the spaceflight environment over these durations. In many cases, based on the observed patterns, we can extrapolate how these patterns in adaptation will continue to develop over longer-duration missions such as a two-year Mars mission. These durations are important in helping us determine when body adaptations begin to "level off" (stop changing), if adaptation continues with increased exposure to the spaceflight environment, the amount of time needed to test the effectiveness of mitigations, and whether reverse adaptations also need to be tested. Some of these require days, others require months, but not all require a full Mars mission duration to adequately test.

Another way to compensate for the small number of human research subjects is to use model organisms (such as yeast, algae, fungi, tardigrades, and rodents) to identify potential biomarkers and countermeasures. Experiments using these models can provide fundamental insights into the combined effects of deep-space stressors (radiation, microgravity, etc.) on humans. This research, along with human research data, will enable researchers to investigate and extrapolate the potential effects of long-duration missions on humans.

In addition to LEO and ground-based analog investigations, Gateway and Moon missions within the Artemis program will prepare NASA to understand factors important to successful adaptation to long-duration spaceflight.

b. What are the biggest sources of uncertainty in evaluating and planning for the risks of longer-term travel in deep space?

A: NASA's Human Research Program (HRP) has organized hazards astronauts will encounter on a continual basis into five classifications, including space radiation, isolation, distance from Earth, gravity fields, and hostile/closed environments. Pooling the challenges into categories allows for an organized effort to overcome the obstacles that lie before a mission to Mars. These hazards are being studied using

ground-based analogs, laboratories, Artemis missions, and the ISS, which serves as a test bed to evaluate human performance and countermeasures required for the exploration of space. The resulting data, technology, and methods developed serve as valuable knowledge to extrapolate to multi-year interplanetary missions, and HRP remains committed to preserving the health and vitality of the crew that will someday touch down upon Mars. While these five hazards present significant challenges, they also offer opportunities for growth and innovation in technology, medicine, and our understanding of the human body.

4. What capabilities are required in any post-ISS platforms to support cutting-edge research by NASA and NASA supported researchers?

A: NASA has examined its potential future needs in LEO, such as space life and physical sciences research derived from the 2011 National Academies' Decadal Survey (and expected from the next Decadal Survey to be released in 2023), research on the effects of the space environment on humans, technology demonstrations, Earth science, astrophysics, planetary science, reliability of environmental control and life support systems intended to be deployed in deeper space, and crew training.

For those areas requiring or substantially benefitting from LEO, such as operational testing in microgravity, NASA will need a commercial habitation service that supports a crew presence at a level sufficient to meet the objectives that are defined in HRP's path to risk reduction and the Decadal Survey for NASA's Biological and Physical Sciences Division (BPS). The ability to launch CubeSats provides additional opportunities for science and technology demonstrations.

NASA also forecasts an ongoing requirement for non-NASA access to basic life and physical sciences; remote sensing; technology demonstration; and science, technology, engineering, and mathematics (STEM) activities that currently meet the requirements for flight under the National Laboratory allocation.

Facilities to support NASA and non-NASA research alike would include things such as refrigerators/freezers, microscopes, microbiology facilities (glove box, incubators, bioreactors, microplate reader), DNA analyzers, centrifuges, rodent facilities, plant growth facility, cell culture facilities, biofabrication facilities, chemical processes/reacting system, fluid and thermal research facility, Materials Processing Facility, combustion facility/furnace, external viewing sites, small satellite deployment, windows, and equipment racks.

5. As a scientist, what would you want in a future non-ISS LEO capability to enable breakthrough science?

A: Equipment similar to that found in the molecular biology laboratory and clinical laboratory are critical to allow for high-value scientific experiments. For example, small DNA sequencers, Polymerase Chain Reaction (PCR) machines, microscopes capable of cellular imaging with fluorescence capabilities, facilities for growing mammalian and microbial cells for research study and/or bioproduction. It is critical to survey scientists/end users to ensure that we don't just have the four walls of a research laboratory, but the equipment and trained operators to perform this valuable research. Flexibility and ease of operability of the equipment is critical, as well as the ability to use Earth-based Commercial Off the Shelf laboratory equipment and the adaptation of that equipment to the microgravity environment is key. Special emphasis on small, portable, and upgradable molecular biology equipment (handheld blood analyzers, miniature sequencers), combined with facilities to grow cells, house rodents or plants, gloveboxes, and incubators to support science operations is important to allow many types of research and

enable breakthrough science. Another NASA objective would be to perform iterative research on orbit rather than wait for samples to be returned to Earth for analysis. This would accelerate research progress.

*Responses by Mr. Jeffrey Manber*Questions for the Record to:

Mr. Jeffrey Manber

Submitted by Chairman Beyer

1. You stated in your written testimony that your biggest concern is that we do not have a gap in low Earth orbit (LEO). In addition, during the hearing, Ms. Gatens stated that “We cannot have a gap in American human space flight in low Earth orbit” and that “NASA is committed to an orderly transition from ISS operations in LEO to U.S. commercially provided destinations in low Earth orbit.”
 - a. To what extent do NASA’s plans, including having commercial destinations in place by 2028 and an extension of ISS to 2030 for a two-year transition period, address your concerns about a gap?

ANSWER – NASA’s plans do address my concerns. Both the timeline and the multiplicity of planned platforms are critical for addressing his critical point for American leadership. Having said that, as with any government program or policy, the details of the transition will be crucial here.

- b. What other actions should NASA be taking in order to avoid a potential gap?

ANSWER – There must be certainty in the transition. The biggest threat to the development of commerce in a new environment like LEO is uncertainty. This transition must include three things to be successful. First, NASA and Congress must be crystal clear to the international community when we will end our participation in the ISS; NASA and Congress should provide realistic funding, timelines, and program requirements in a transparent manner; and finally, NASA and Congress must maintain a competitive environment for these capabilities.

2. With respect to China’s competing space station and partnership development, you noted that “The answer is not to boycott China or cajole our allies; it is to outcompete as we do best by utilizing the agility and efficiency of the private sector for the sort of next-gen platforms envisioned by NASA [Commercial LEO Destinations].” What do you believe is required to outcompete?

ANSWER – Specifically, maintaining the current momentum. Assuring the robust transportation system remains in place to service multiple commercial platforms. The United States should work to be the flag of choice for all activities in space. This means creating favorable regulatory environments, supporting commercial operators by purchasing their services rather than competing with them, and developing international partnerships that benefit US commercial space operators.

3. How would an extension of ISS authorization through 2030 affect suppliers of products and services in LEO? How do potential customers of LEO products and services view the currently authorized date for ISS operations, which is through at least 2024?

ANSWER – As previously said, what is required is certainty. International ISS partners particularly may well hesitate to enter into commercial alliances or agreements if the ISS date keeps being extended and ISS utilization is allowed to continue. Given the majority of capital for the private free flyers are from the private sector, investor confidence is paramount.

4. Redwire Space sent the attached letter, dated September 27, 2021, to me and the Ranking Member, which states that the U.S. government should “establish a regulatory environment and processes that ensure that the ISS is fully utilized as an incubator for commercial development during its remaining life” to include “ensuring private sector entities retain their intellectual property rights” and “avoiding any onerous expenses such as royalty payments prior to the maturation of commercial operations and profit generation.”
 - a. Do you agree with these recommendations? Why or why not?

ANSWER – We support continued reforms to assure vibrant private sector investment in ISS research and manufacturing. There should be no difference between IP issues for a given company working on the ISS vs working in a national laboratory in any given state.

- b. Have you seen evidence that the current regime for intellectual property rights and royalty payments are a significant barrier to LEO commercialization activities through the ISS?

ANSWER – It is hard to quantify but there remains some suspicion towards working on the ISS from non-aerospace companies. It is for this reason we announced the George Washington Carver Science Park as our collection of hardware and services onboard the ISS, in order to better quantify the necessary reforms utilizing science park metrics known to companies and organizations.

Responses by Mr. Todd Harrison

Responses to Questions for the Record
from Todd Harrison

1. You stated in your written testimony that “we should not let go of the [International Space Station] ISS coalition before the Artemis coalition is fully assembled and operational.”

a. How would you define a fully-assembled and operational Artemis coalition?

I would define it as having permanent hardware in cislunar orbit or on the lunar surface that we are jointly operating with our international partners. It doesn’t have to be continually inhabited, like the ISS, but it needs to be something that is at least remotely operate on a continual basis.

b. In your opinion, do our international partners have the capacity to actively contribute to the ISS coalition as the Artemis coalition ramps up?

Yes, I think they have the capacity to do both simultaneously. Other countries are actively investing in and promoting their space industrial base, so the capacity to contribute is there. It is a matter of political will and priority, just as it is in the United States. I think we can make a strong argument for other countries to do both if we are stepping up to do both ourselves.

2. You stated in your prepared testimony that “China is now reaching out to other nations—including some of our closest allies and partners in space—and asking them to become partners in its space programs” and that “China is actively building a coalition in space to rival our own.” How does this situation affect the potential development of a commercial low Earth orbit (LEO) market?

The primary aim of Chinese and Russian efforts to recruit partners is to build prestige and legitimacy for their civil space activities, which directly challenges U.S. leadership in space. I think the effect on the commercial LEO market is minimal because the partnerships they are seeking are for space exploration, namely their lunar program, and are not commercial in nature.

3. Aerospace industry and professional organizations are advocating for extending ISS operations, as noted in the attached letter that was sent to me and the Ranking Member on September 20, 2021 by the Aerospace Industries Association and the Commercial Spaceflight Federation. Do you have any comments on these organizations’ priorities for extending ISS operations through 2030 and seeking full funding for commercial LEO development? What factors should Congress be considering regarding a potential extension of ISS operations?

While I agree that we should extend ISS operations, I don’t think we should set a date. It should be based on when we have the Artemis coalition fully assembled and operational (as I mentioned in my testimony). After more than 20 years of operating the ISS, I think NASA’s primary role in helping build a sustainable commercial presence in LEO is mainly to provide enabling infrastructure and expertise as needed. I don’t think the U.S. government needs to provide significant subsidies for commercial LEO—if it is viable and sustainable, it needs to be primarily self-funded.

Responses by Captain William Shepherd (USN, Ret)

13 January 2022

Congress of the United States
 House of Representatives
 Committee on Science, Space, and Technology
 2321 Rayburn House Office Building
 Washington D.C. 20515-6301

Dear Chairman Babin, and Members of the Committee:

In response to your 28 October 2021 letter, copied with key paragraphs in italics, I am providing answers to each in **bold font** as follows:

1. *You stated in your written testimony, in regard to air leaks in the transfer tunnel of the Russian segment, that “the root cause of the cracking, their failure modes, and impacts on ISS safety and future operations have not been adequately determined” and that “top level NASA and Roscosmos management attention is needed now.” You also stated during the question-and-answer portion of the hearing that “we know that there are probably other cracks we haven’t found yet” and that “before we clear the Station for another so many years of operational use, we should better understand this.”*
 - a. *What do you recommend be done to address your concerns?*
 - b. *What approach would you recommend for NASA and Roscosmos to take to determine if there are other, as-yet-unknown cracks?*
 - c. *What evidence would you want to see, regarding the known and potential unknown cracks and any necessary mitigations, that would adequately address your concerns for clearing the ISS for extended operations?*

A NASA Roscosmos bi-lateral team, reporting to Heads of Agencies, should explore possible causes of the observed flaws, cracks, and leaks. Since the testimony last Fall, I believe an additional site has been identified in the ISS’s “PrK” transfer chamber that is also a suspect damage area. Additional experts in other branches of government, industry, and academia may be needed for these analyses.

All failure mechanisms that could generate these cracks should be considered including mechanical stress, impacts, thermal, chemical, radiation, and any other influences on the ISS transfer compartment. Combined effects must be explored.

Parallel, ground testing of replica panels, with duplicate materials, dimensions, loads, and other structural details should be initiated. Testing must be conducted to induce failures similar to those seen on ISS. Test items should be taken to “failure” until similar flaws and cracks are evident.

The ground and flight “history” of the Service Module, and its PrK vestibule, including material lots, their production, acceptance testing, fabrication details, storage and handling, launch, and operational use must be investigated as additional contributors to the root causes of these problems.

Failure modes for any compromised structures must be identified. Means to monitor the onboard state of ISS structures in critical areas may need to be expanded.

2. During the question-and-answer portion of the hearing, you stated, in response to a question about how policymakers should view safety and risk as the ISS ages, that NASA needs to “reestablish a much more intimate working relationship with our Russian counterparts” and that, in particular, “part of the issue with the science module docking, the Nauka...is, we do not have that correlation with our Russian counterparts right now,” and that you “believe Congress could be helpful in making that happen.”

a. What, if any, actions do you believe Congress could consider to help NASA strengthen its working relationship with Russian counterparts?

b. What do you see as the biggest barriers to a stronger relationship at the working level between the NASA and Roscosmos ISS teams, and what can be done to overcome those barriers?

In the early days of the ISS Program, in-person meetings with Russian managers, engineers and others in the program were extensive and frequent. NASA specialists were typically in various Russian facilities on a daily basis to observe the design, fabrication, testing, launching and operations of the Russian Segment of ISS, as well as the conduct of all training activities for ISS crews. Russian experts were allowed similar access to the development of the US Segment. Today, more stringent “International Traffic in Arms Regulations” have been imposed on NASA and ISS Program personnel, and these have reduced the quality and timeliness of the interactions between U.S, Russian, and other international partners. In summary, I believe the early levels of technical and operational information exchanges for ISS personnel with foreign counterparts were highly productive, and should be restored to the greatest extent possible.

3. Aerospace industry and professional organizations are advocating for extending ISS operations, as noted in the attached letter that was sent to me and the Ranking Member on September 20, 2021 by the Aerospace Industries Association and the Commercial Spaceflight Federation. Do you have any comments on these organizations’ priorities for extending ISS operations through 2030 and seeking full funding for commercial LEO development? What factors should Congress be considering regarding a potential extension of ISS operations?

I agree with the AIAA and Commercial Spaceflight Federation letter, that ISS’s lifetime should be extended, provided the station can be maintained, operated, and flown safely. An extension to 2030 appears reasonable, given that present and any emergent technical anomalies can be mitigated.

If anything, the unique research aboard ISS should be increased. NASA and Roscosmos should resume the advanced power and propulsion experiments and tests that were scheduled in early ISS configurations. Both the US and Russia were to contribute components to a “Solar Dynamic” power system that would have been attached in place of one of ISS’s solar arrays. The system was to have a

large solar reflector, heat collector, and Brayton-cycle engine/generator. These plans were halted in 1994 as a result of limited program funds. This technology promises significant improvements in power generation efficiencies and will likely be a key technology for extensive Moon and Mars explorations. Another important power and propulsion test well suited for ISS's capacities can be an advanced electric or plasma drive system that would neutralize the station's on-orbit drag, improve its microgravity environment, and provide more efficient maneuver and reboost thrust. Prototype engines are in development now in ground laboratories. This technology, if proven in space operations, can pave the way for interplanetary travel with greatly reduced transit times for cargo and crew vehicles. The ISS is the best and perhaps the only resource for full-up system testing. We should not miss opportunities to explore these concepts now.

4. *NASA announced on August 12, 2021 that the agency had stood up an investigation team to "review the activity" related to a July 29, 2021 incident, when the new Russian science module for the ISS, Nauka, unexpectedly fired its thrusters shortly after successfully docking to the ISS, resulting in the temporary loss of attitude control so that the entire Station flipped one and a half times in a matter of minutes.*
 - a. *Has NASA requested that the ISS Advisory Committee, of which you are a member, examine the issues regarding the Nauka incident?*
 - b. *If so, what is the current status of the investigation?*
 - c. *Has this incident been declared a "mishap" or "close call," as defined in NASA Procedural Requirement 8621.1D, and why or why not?*

Regarding Roscosmos's "Nauka" docking, the Stafford Advisory Committee has been briefed several times by key NASA managers and engineers, and Russian specialists, on the events of the docking incident. These briefings are continuing, and a third NASA review of events with our team is scheduled for 27 January.

In reference to NASA 8621.1D requirements to classify the Nauka flight and docking incident, I would like to defer to NASA Headquarters, who can best characterize the import of these events.

Sincerely,
William Shepherd
 William M. Shepherd

Appendix II

ADDITIONAL MATERIAL FOR THE RECORD

LETTER SUBMITTED BY AEROSPACE INDUSTRIES ASSOCIATION AND COMMERCIAL SPACEFLIGHT FEDERATION, REFERENCED IN CHAIRMAN BEYER'S QUESTIONS



September 20, 2021

Chairman Don Beyer
Subcommittee on Space and Aeronautics
Committee on Science, Space, and
Technology
U.S. House of Representatives
Washington, DC 20515

Ranking Member Brian Babin
Subcommittee on Space and Aeronautics
Committee on Science, Space, and
Technology
U.S. House of Representatives
Washington, DC 20515

Dear Chairman Beyer and Ranking Member Babin,

Our combined organizations represent hundreds of U.S. companies employing hundreds of thousands of Americans across the space sector, from large manufacturers and integrators to the small- and medium-sized businesses at the heart of the aerospace supply chain. Our members have been critical contributors to the International Space Station (ISS) since its inception and provide manufacturing, logistics, transportation, and other support necessary for its continued operation.

As the Subcommittee on Space and Aeronautics considers the future of the ISS, AIA and CSF support extending ISS operations to 2030 as well as full authorization and funding of NASA's Fiscal Year 2022 (FY22) request for commercial low Earth orbit (LEO) development.

AIA and CSF support:

- Maintaining a continuous U.S. human presence in space by extending ISS operations to 2030; extending associated cargo and crew transportation programs; and, continuing microgravity research programs to ensure human space exploration and scientific research efforts are maximized.
- Full authorization and funding of NASA's FY22 request for commercial LEO development to spur U.S. private industry activity in LEO, including commercial use of the ISS and future commercial LEO destinations, as NASA expands U.S. human presence beyond LEO.

Congress has a long history of providing bipartisan, bicameral support for the continuation of the ISS. Its extension, coupled with support for commercial LEO development programs, will further the nation's global space leadership, avoid any gaps in U.S. LEO presence, and enable the continued growth of the U.S. space industry in LEO and beyond.

We look forward to continuing to work with the Subcommittee on Space and Aeronautics on this important issue.

Sincerely,

Aerospace Industries Association
Commercial Spaceflight Federation

LETTER SUBMITTED BY MR. PETER CANNITO, REDWIRE,
REFERENCED IN CHAIRMAN BEYER'S QUESTIONS

Redwire
8226 Phillips Hwy
Suite 101
Jacksonville, FL 32256

September 27, 2021

The Honorable Don Beyer
Chairman
Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology
U.S. House of Representatives
Washington, DC 20515

The Honorable Brian Babin
Ranking Member
Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology
U.S. House of Representatives
Washington, DC 20515

Dear Chairman Beyer and Ranking Member Babin:

The future of the International Space Station (ISS) and the U.S. presence in low Earth orbit (LEO) and beyond are among the most important issues in space policy. Redwire Space appreciates the Subcommittee's attention to this issue in the upcoming hearing.

Redwire supports the ISS in a variety of ways, including via its next-generation roll-out solar arrays (iROSA). The first two of six arrays were recently installed on the ISS. When all six arrays are installed, they will generate a 20% to 30% increase in power (120 kilowatts) for ISS life support, research, and other vital operations. Additionally, Redwire is a substantial ISS research partner, conducting a wide variety of experiments related to on-orbit manufacturing. Redwire is the only company that has successfully manufactured products on the ISS for external customers, demonstrating a critical capability for long-duration space exploration in support of crewed missions to the Moon and Mars.

Moreover, Redwire is not just exploring the boundaries of technology, it is also at the forefront of commercialization. Specifically, Redwire is developing hardware to support microgravity biotech manufacturing and R&D—particularly a new industrial freezer that holds ultra-cold temperatures without external power. Additionally, Redwire has been and will continue to fly payloads that will produce advanced materials in space, such as ZBLAN optical fiber, which could dramatically enhance communications capabilities. Lastly, Redwire has also produced items in space for promotional, media, and other forms of private sector activities, and such operations are only expected to grow in the near future. Redwire's multi-faceted partnership with NASA provides a unique perspective on the future of the ISS and a transition path to a sustained LEO presence after the space station's retirement.

The ISS is the cornerstone of the human presence in LEO for the U.S. and its international partners, which in turn drives substantial economic, scientific, national security, and diplomatic/soft power benefits for the nation. Global competitors are taking steps to catch and surpass the U.S. in LEO crewed platforms because they understand the value of leadership in this vital arena. Therefore, Redwire strongly supports a continuous American human presence in LEO, both for its direct value to the nation and to maintain a U.S. advantage in LEO relative to international competitors.

In the near term, maintaining a continuous U.S. human presence in LEO entails extending ISS operations, along with associated transportation and R&D programs, to 2030 so that the space station can be fully utilized. The U.S. cannot afford to have a “space station gap” during which America has no crewed LEO presence while China does.

At the same time, it is vital that NASA’s request for LEO commercialization be authorized and funded to promote private sector use of the ISS. This is key to the transition from the ISS to future platforms as it will enable the U.S. government to be one of many customers, rather than shouldering the entire burden of designing, constructing, and operating a LEO destination. During the ISS’s remaining operational lifetime, the U.S. must leverage the space station to serve as an incubator for new and innovative commercial activities. Congressional funding for activities that will help generate sustainable demand for commercial products and services in LEO will be critical. Moreover, Congress should ensure that NASA’s processes and procedures are conducive to private sector operations to facilitate and expedite the growth of such activities.

LEO commercialization policy should focus on the following priorities:

- Ensuring that the U.S. government is a stable and committed customer for U.S. commercial entities;
- Specifically, the U.S. government should act as a catalyst and customer for LEO commercialization products and services. This should include robust funding by NASA for on-orbit production activities and applications research that will lead to financially sustainable commercial operations. LEO commercialization currently receives less than one percent of ISS funding. That level should be increased substantially; and
- The U.S. Government should establish a regulatory environment and processes and procedures that ensure that the ISS is fully utilized as an incubator for commercial development during its remaining life. This includes:
 - Providing robust and low-cost access to the ISS, astronaut time, and any related overhead costs;
 - Ensuring private sector entities retain their intellectual property rights; and

- Avoiding any onerous expenses such as royalty payments prior to the maturation of commercial operations and profit generation.

Redwire Space and the U.S. commercial space industry as a whole look forward to working with Congress and NASA to ensure a vibrant, continuous U.S. human presence in LEO throughout the life of the ISS and beyond.

Sincerely,

A handwritten signature in dark ink, appearing to read 'P. Cannito', with a stylized flourish at the end.

Peter Cannito
CEO/Chairman
Redwire