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.

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[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 countries[8] 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

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[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 2015[19] authorized another extension of ISS operations through at least 2024.[20]

The NASA Authorization Act of 2005[21] 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 2010[22] 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

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[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."

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[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 solicitation[28] 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]

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[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