Determining a Post-International Space Station (ISS) Path for US Low-Earth Orbit (LEO) Activities

Nathan Tat[1], Vivian Tat[2], Candise Tat[3]
[1]NASA Johnson Space Center/Jacobs, Jacobs Johnson Space Center Engineering, Technology & Science (JETS), Houston, Texas, United States
[2]The University of Texas Medical Branch, Department of Pathology, Galveston, Texas, United States
[3]Baylor College of Medicine and Texas Children's Hospital, Center for Cell and Gene Therapy, Houston, Texas, United States
https://doi.org/10.38126/JSPG230110
Corresponding author: nathan.tat.100@gmail.com
Keywords: NASA; space policy; International Space Station (ISS); commercial LEO destinations

Executive Summary: As the space sector rapidly evolves, the International Space Station (ISS) is approaching its retirement date. Since decommissioning of the ISS is scheduled for 2030, the United States (US) must identify paths forward for space station operations in low-earth orbit (LEO). Having a manned LEO space station after the conclusion of the ISS program will allow the US to continue possessing a platform to conduct scientific research, advance technology, and investigate the effects of microgravity on physiology. Options to continue LEO operations include having private entities construct and operate commercial space stations, reusing components of the ISS, directing NASA to spearhead efforts in building a new space station, or abandoning US-led space stations in LEO altogether. We recommend that commercial firms build and operate space stations, permitting multiple platforms to be created while maintaining the legacy of the ISS. The US will have facilities in LEO for research and development, thus advancing technological and scientific knowledge for Earth-based applications and future space missions.

I. Background and policy concern

On November 2nd, 2000, the ISS welcomed its first inhabitants. Since then, the ISS has hosted over 260 individuals (Howell 2022). Significantly, the ISS is a hub for manned activities in LEO, which is defined as Earth-centered orbit at an altitude of up to 2,000 kilometers. The frequency of activities in space has been increasing as countries and companies express further interest. Being a flagship effort of NASA, Roscosmos, and other international partners, the ISS has been a cornerstone of space policy, a platform for science, and a pervasive symbol of global cooperation.

However, the ISS is scheduled for decommissioning and deorbiting into the Pacific Ocean over 2030-2031 (Hunt 2022). The Japan Aerospace Exploration Agency (JAXA), Canadian Space Agency (CSA) and European Space Agency (ESA) are some of the current collaborators on the ISS. However, no countries have committed to the ISS past 2030. Being manned, the ISS enables the scientific community to assess the physiological effects of space and have human-controlled experiments (Prysyazhnyuk and McGregor 2022). This allows for a differing capacity compared to unmanned operations, which lacks the capability to accumulate human data and perform human-operated experiments.

The ISS is designed to be operated internationally. For example, the US provides solar arrays and gyroscopes. Meanwhile, Russia supplies the propulsion for station reboost, debris avoidance maneuvers, and other necessary actions (Hoffman et al. 2022). The US is a leader within the international

space industry because of its key role in the ISS program. Maintaining the ISS has allowed the US to advance scientific knowledge and the prestige it holds in space. Some examples where the ISS has improved the US scientific enterprise include hosting protein crystal growth onboard the ISS to better understand cancers, improving X-ray devices, and measuring climate data via payloads such as the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) (NASA 2022). Although Artemis and returning to the moon has recently been a focus of the US space community, LEO offers a unique opportunity to execute different research in an environment more readily accessible to Earth. US commercial launches to LEO must secure approval from government agencies such as the Federal Aviation Administration (FAA), which considers rocket launch emissions and orbital debris during the launch licensing process (Satellite Licensing 2022). As the ISS nears its decommissioning date, the US faces a quandary on how it should proceed with manned LEO operations.

While the space industry accelerates, the US must prepare alternatives to the ISS and decide whether to maintain manned LEO space station operations.

II. Factors to consider

Several partners can be involved in the next generation of space stations, such as organizations from other countries. Other space-faring nations are interested in building stations as well. For example, China has rapidly advanced its human spaceflight program since the first taikonaut launch in 2003. China has constructed its own Tiangong space station independently from the ISS (Samson 2022). Tiangong offers other nations outside of the ISS program a platform for their experiments. For the US, a risk may involve the loss of prestige, as potential partners in space may opt to collaborate with China. The US must also factor in how rising levels of orbital space debris will affect space stations. Over 25,000 space debris objects are of sufficient size to be tracked and cataloged. In addition, even more numerous minute pieces such as paint or remnants of collided satellites pose hazards to future space stations (Ledkov and Aslanov 2022). This will challenge the ability of space stations to safely remain in LEO. Likewise, the commercialization of space exploration may affect the path forward. The US may have to decide which areas are priorities for research and development with the resources available.

Likewise, the National Space Society, Space Foundation, and other non-profits can positively publicize efforts in space and educate the public. In the future, commercial companies from many countries can manufacture or supply new parts. For example, the European joint venture organization Thales Alenia Space has already constructed ISS modules such as *Harmony* and *Tranquility* (Foust 2022). Nanoracks' and Voyager Space's Starlab station has announced plans to partner with the European-based Airbus (Jewett 2023). This cooperative is aimed at providing additional access to the ESA. Thus, other companies could supply equipment or components of commercial space stations to US-based firms.

III. Policy options

i. Option I: Having US commercial space companies construct private space stations

Having a manned LEO space station post-ISS will allow the US to continue conducting scientific research, advancing space technology, and investigating the physiological effects of microgravity. Thus far, a total of $415.6 million in funded Space Act Agreements has been awarded to several corporations: Blue Origin for $130 million, Nanoracks for $160 million, and Northrup Grumman for $125.6 million (Chang 2020). These firms strive to assemble private space stations, also known as commercial LEO destinations. All of these companies have prior experience in the space economy. Seeking to expand their capabilities in space flight, Blue Origin has debuted a team alongside Sierra Space to build a commercial space station by 2027 (Orbital Reef 2022). Nanoracks and Northrup Grumman also work with the ISS program (Manber 2014). These firms anticipate deriving their revenues from commercial LEOs destinations via space tourism and charging external parties in industry, academia and government which send payloads or have experiments onboard these space stations for research purposes. Space tourism is expensive and currently aimed toward wealthy individuals, which may make it difficult for firms to depend on tourism as a sustainable source of revenue. For example, Axiom Space currently charges $55 million for a 10-day trip to the ISS (Cao 2022). This limits the

potential pool of customers. Likewise, onboard research would have to be commercially viable to attract interest and support for the space station. These companies have yet to successfully complete and launch any stations. This means they must debut new technologies and equipment which may take years and considerable cost to develop. Private or commercial space companies could thus play major roles in ensuring that the US has a viable successor to the ISS. Risks must be considered, such as a potential lack of accountability and relative inexperience in construction by private companies compared to NASA-led projects (Hill 2022).

ii. Option II: Repurpose ISS components for new space station

NASA could attempt to retain and repurpose components from the current structure of the ISS. In theory, this would save expenses of potentially up to $300 million per module which would otherwise be needed to design, construct, and launch into orbit (Crane et al. 2017). It would also prevent sections of the ISS from becoming space debris or destroyed in deorbiting procedures. As an extension of this idea, Axiom Space envisions building modules connecting to the current ISS, which will be detachable (Axiom 2023). These modules would allow Axiom to establish its own station after the ISS program concludes. However, reuse of components on a large scale poses several issues. Many elements of the ISS are sourced from other international entities. This hinders or blocks NASA or US-based companies from using them after the ISS is decommissioned. Thus, NASA would not be able to accomplish this unilaterally. If any ISS components were to be reused, they would have to be detached from the current structure and held in orbit prior to integration on another LEO station, possibly at considerable expense or effort. In addition, the ISS' structure has already suffered significant wear-and-tear due to thermal fluctuations and exposure to the harsh space environment. This would make any repurposed part of the space station potentially more prone to breakdown compared to new components (International Space Station Transition Report 2022).

iii. Option III: Creating a new NASA-led space station

A third option is for NASA to spearhead a government-driven successor to the ISS. Until the present day, most space station projects outside of the ISS have been directed by the space agency of a single nation. For example, NASA had Skylab prior to the ISS, while Roscosmos oversaw Mir. As NASA already invested heavily in the ISS, its expertise could help lead efforts to create a replacement. NASA could leverage the experience gained from the ISS and Skylab in creating a new government-managed space station. NASA would also have to decide whether to proceed in partnership with another international coalition. Space agencies in Europe, Japan, Canada and other nations currently collaborate with the US and Russia for the current ISS. If NASA proceeds forward with building its next space station with other allied governments, advantages include strengthening international research and scientific cooperation, diversifying risk and pooling manufacturing and operational costs. However, a disadvantage of a government-led space station is that it would be expensive for NASA to maintain. NASA's contribution to operations of the ISS are costly, as it spends over $3 billion annually for the ISS. Approximately $1.3 billion is focused on operations and research, and $1.8 billion is for space station activities related to cargo and crew transportation (Foust 2022). If NASA leads the construction of another space station, NASA's budget would have to account for construction and operation of the new platform. Building another space station could divert funds from other objectives and missions.

iv. Option IV: Abandoning manned LEO station operations

Alternatively, the US could abandon manned LEO operations, as there have been periods in which no American space stations have been orbiting. Instead, focus could be shifted solely to unmanned missions or to other missions beyond LEO such as the Artemis and Gateway programs. For example, the Artemis program is envisioned to return Americans to the moon and would allow the US to strengthen its capabilities for lunar spaceflight. Gateway is a proposed small space station at the moon (Creech et al. 2022). However, transitioning out of manned LEO space stations would affect research in microgravity. Onboard the ISS, a variety of experiments occurs to understand the effects of outer space (Haruki et al. 2015). These rely on human operators to conduct the investigations, and an unmanned station would lack a human presence. The proposed Gateway lunar space station will have less space, as it will only be

one-sixth of the size of the ISS (Pultarova 2023). Not constructing manned LEO space stations would hinder the ability to conduct research.

IV. Policy recommendations

Our recommendations are that even as the ISS orbits, the US space program should allow multiple commercial companies to lead the creation of new space stations (Option I). This enables the US to continue maintaining a manned presence in LEO orbit after ISS decommissioning, thus providing a platform for scientific and technology activities. Likewise, these companies should capitalize on the expanding space economy by ensuring these commercial LEO destinations are physically adaptable. If the space stations can add modules and be easily adaptable for future modifications, this will allow their mission profiles to change and evolve. Having multiple firms build stations diversifies risks. However, this could potentially lead to larger corporations monopolizing efforts and pushing out smaller firms, as they may have a stronger financial base and capability to absorb initial losses. NASA can lend technical experience and advice to these commercial companies (Harrison 2021).

One way to evaluate the outcome of building private space stations is to measure when their first components successfully launch into orbit. This will require a considerable amount of time, so another strategy will be evaluating when the new space stations are ready for use. The ideal timeline would be by 2030 so that any activities onboard the ISS can be finished or transferred to the private stations if required. A third way to evaluate outcomes is to measure how much research and scientific innovation occurs in these new space stations. Though space tourism could generate some revenue, evaluating national science interests will be important. An example would be calculating the number of publications derived from this research, publicizing the inventions and innovations from these commercial space stations and how they impact life on Earth, and strengthening relationships between the operators of these commercial space stations, industry partners, academia, government, and other interested parties.

Space has been a source of innovation and opportunity to the US (White House 2021). To encourage commercial entities to assemble these stations, the government can provide financial incentives and support. The US government already provides subsidies to companies like SpaceX (Zarkadakis 2021). For these private space stations and allocating funds to their companies, the government could attach conditions such as providing a minimal amount of space for US research activities or ensuring that these firms follow space law such as the US Commercial Space Launch Competitiveness Act and UN Outer Space Treaty. For instance, companies which minimize or remove space orbital debris could receive more funding. Likewise, leadership in space has been a national point of pride. Ever since the start of the space race, the US has been a key player in the space industry. Nearly 70% of Americans believe the US should be a leader in space exploration (Atske 2023).

In 2021, the space economy was valued at $469 billion (McKinsey 2022). If the US fails to create an alternative for the ISS, the US will lack a platform for conducting LEO research once the ISS is decommissioned. Throughout the ISS' history, over 3,000 experiments have been performed onboard (Witze 2020). Without an orbital laboratory, the US would be unable to perform these experiments. Future space stations can also host in-orbit manufacturing, research and development, expanding its capabilities (Carrie 2023). In addition, the US will lose a key point of its leadership in space and LEO-related activities. Traditionally, the US has been viewed as a preeminent leader in building LEO space stations, inspiring students to enter this field. Exiting this sphere would mean decreased national prestige and pride.

Having LEO stations in space built by American companies can allow the US to innovate without having to rely on foreign entities. In addition, other countries should also be allowed to access or use these commercial stations. This will facilitate and nurture their space economies and aid the US in cultivating allies in space, ensuring humanity can continue exploring the mysteries of space.

References

Atske, Sara. 2023. "Americans' Views of Space: U.S. Role, NASA Priorities and Impact of Private Companies." Pew Research Center Science & Society, 20 July 2023. www.pewresearch.org/science/2023/07/20/americans-views-of-space-u-s-role-nasa-priorities-and-impact-of-private-companies/.

"Axiom Space Named in Top 50 of Fast Company's Most Innovative Companies for 2023." Axiom Space, 2 Mar. 2023. www.axiomspace.com/news/fastcompanymostinnovative. Accessed 21 March 2023.

Brukardt, Ryan. 2022. "How Will the Space Economy Change the World? | McKinsey." www.mckinsey.com. November 28, 2022. https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/how-will-the-space-economy-change-the-world.

Cao, Sissi. 2022. "What You Pay for Blue Origin's Spaceflight Depends on Who You Are." *Observer*. June 23, 2022. https://observer.com/2022/06/blue-origin-space-tourism-pricing-marketing/.

Chang, Kenneth. 2022. "Jeff Bezos' Company Is Carrying Scientific Cargo to Space. It's Not Amazon.," *The New York Times*, October 13, 2020. https://www.nytimes.com/2020/10/13/science/blue-origin-jeff-bezos.html.

Crane, Keith, Benjamin Corbin, Bhavya Lal, Reina Buenconsejo, Danielle Piskorz, and Annalisa Weigel. 2017. "March 2017 Market Analysis of a Privately Owned and Operated Space Station." https://www.ida.org/-/media/feature/publications/m/ma/market-analysis-of-a-privately-owned-and-operated-space-station/p-8247.ashx.

Foust, Jeff. 2022. "ISS Partners Weigh Options for Using Commercial Space Stations." SpaceNews. October 26, 2022. https://spacenews.com/iss-partners-weigh-options-for-using-commercial-space-stations.

Foust, Jeff. 2022. "NASA Outlines Cost Savings from ISS Transition." SpaceNews. February 6, 2022. https://spacenews.com/nasa-outlines-cost-savings-from-iss-transition/.

Gebhardt, Chris. 2021. "Mike Suffredini Talks Axiom Module Additions to ISS, Ensuring No Gap in LEO Station Access." NASASpaceFlight.com. November 19, 2021. https://www.nasaspaceflight.com/2021/11/axiom-suff-interview/.

Gerstenmaier, William. June 6, 2019. NASA Interim Directive (NID): Use of International Space Station (ISS) for Commercial and Marketing Activities.

Harrison, Todd. 2021. "NASA's Future in Low Earth Orbit: Considerations for International Space Station Extension and Transition." *www.csis.org*, September 2021. https://www.csis.org/analysis/nasas-future-low-earth-orbit-considerations-international-space-station-extension.

Haruki, Risa, Takuya Kimura, Hitomi Iwasaki, Kana Yamada, Ikuo Kamiyama, Mitsutomo Kohno, Kazuaki Taguchi, et al. 2015. "Safety Evaluation of Hemoglobin-Albumin Cluster 'HemoAct' as a Red Blood Cell Substitute." *Scientific Reports* 5 (1). https://doi.org/10.1038/srep12778.

Hoffman, Edward, Matthew Kohut, and Laurence Prusak. 2022. *The Smart Mission.* MIT Press.

Howell, Elizabeth. 2018. "International Space Station: Facts, History & Tracking." *Space.com*. February 8, 2018. https://www.space.com/16748-international-space-station.html.

Hunt, Katie. 2022. "NASA Plans to Retire the International Space Station by 2031 by Crashing It into the Pacific Ocean." CNN. February 2, 2022. https://www.cnn.com/2022/02/02/world/nasa-international-space-station-retire-iss-scn/index.html.

"International Space Station Transition Report pursuant to Section 303(C)(2) of the NASA Transition Authorization Act of 2017 (P.L. 115-10)." 2022. https://www.nasa.gov/sites/default/files/atoms/files/2022_iss_transition_report-final_tagged.pdf.

Jewett, Rachel. 2023. "Airbus Joins the Voyager Space Team for Starlab Commercial Space Station - via Satellite -." Via Satellite. January 4, 2023. https://www.satellitetoday.com/space-exploration/2023/01/04/airbus-joins-the-voyager-space-team-for-starlab-commercial-space-station/.

Ledkov, Alexander and Vladimir Aslanov. 2022. "Review of Contact and Contactless Active Space Debris Removal Approaches." *Progress in Aerospace Sciences* 134 (October): 100858. https://doi.org/10.1016/j.paerosci.2022.100858.

Manber, Jeffrey. 2014. "Testimony of Mr. Jeffrey Manber Director, NanoRacks LLC before the Senate Committee on Commerce, Science and Transportation Subcommittee on Science and Space". http://images.spaceref.com/docs/2014/here_to_mars_Manber_Testimony_040914.pdf.

NASA. *International Space Station Benefits for Humanity.* 2022. https://www.nasa.gov/sites/default/files/atoms/files/iss_benefits_for_humanity_2022_book.pdf

"Orbital Reef | Orbital Reef Space Station Advances to Design Phase after NASA Review." August 22, 2022. www.orbitalreef.com. https://www.orbitalreef.com/news/sdr-milestone.

Prysyazhnyuk, Anastasia and Carolyn McGregor. 2022. "Space as an Extreme Environment: Technical Considerations," January, 143–64. https://doi.org/10.1007/978-3-030-96921-9_8.

Pultarova, Tereza. "NASA's Moon-Orbiting Space Station Will Be Claustrophobic, Architect Says." Space.com, 8 Jan. 2023. www.space.com/lunar-gateway-station-claustrophobic-architect-says. Accessed 6 Aug. 2023.

Samson, Victoria. 2022. "The Complicating Role of the Private Sector in Space." *Bulletin of the Atomic Scientists.* January 17, 2022. https://thebulletin.org/premium/2022-01/the-complicating-role-of-the-private-sector-in-space/.

"Satellite Licensing FCC Should Reexamine Its Environmental Review Process for Large Constellations of Satellites Accessible Version Report to Congressional Requesters United States Government Accountability Office." 2022. https://www.gao.gov/assets/730/723690.pdf.

"The Privatization of Space Is Taking Off, but Not Everyone Is over the Moon." 2022. The Hill. May 10, 2022. https://thehill.com/changing-america/3481856-the-privatization-of-space-is-taking-off-but-not-everyone-is-over-the-moon/#:~:text=These%20commercial%20stations%20represent%20a.

White House. 2021. "United States Space Priorities Framework." The White House. December 1, 2021. https://www.whitehouse.gov/briefing-room/statements-releases/2021/12/01/united-states-space-priorities-framework.

Witz, Alexandra. 2020. "Astronauts Have Conducted Nearly 3,000 Science Experiments Aboard the ISS." *Nature*, November 2020. https://doi.org/10.1038/d41586-020-03085-8.

"X-37B Orbital Test Vehicle Concludes Sixth Successful Mission". United States Space Force, 12 Nov. 2022, www.spaceforce.mil/News/Article/3217077/x-37b-orbital-test-vehicle-concludes-sixth-successful-mission/.

Zarkadakis, George. 2021. "The Risks of Privatizing Space." August 21, 2021. https://www.georgezarkadakis.com/the-risks-of-privatiZIng-space/.

Nathan Tat earned both his Bachelor's and Master of Science degrees from Rice University. His graduate program was focused on the disciplines of Space Studies, and his undergraduate education was centered on Economics and Business. Nathan is a Space & Satellite Professionals International (SSPI) "20 Under 35" Honoree and was a delegate for the Space Generation Advisory Council (SGAC) North, Central America and Caribbean Space Generation Workshop. He is interested in bridging STEM and business within interdisciplinary areas such as space economy and policy.

Vivian Tat is pursuing a Ph.D. in Experimental Pathology and an MPH in Epidemiology at The University of Texas Medical Branch at Galveston. Currently, Vivian is examining the host innate immune response to beta-coronaviruses. She received her B.S. in Public Health with Distinction in Research and as a Polymathic Honors Scholar with an Evidence and Inquiry certificate from The University of Texas at Austin.

Candise Tat earned her MPH in Health Promotion and Behavioral Sciences with a concentration in Genomics and Bioinformatics at The University of Texas Health Science Center at Houston School of Public Health. She also conducts research in cancer immunotherapy at Baylor College of Medicine Center for Cell and Gene Therapy. Candise received her B.S. in Biochemistry and Cell Biology with a minor in business from Rice University.

Acknowledgements
The authors would like to acknowledge and thank Dr. Yvette Seger, Dr. Sophia Kaska, Jennifer Zeitzer, Donna Tat, and Andy Tat for their comments and support on this publication.

Disclaimer
The views and opinions expressed in this publication are those of the authors and do not necessarily reflect the official policy or positions of Jacobs, NASA or other entities.