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Forecasting Future NASA Demand in Low Earth Orbit

Introduction

The U.S. Congress's NASA Authorization Act of 2017[1] directed NASA to develop an International Space Station (ISS) Transition Plan, specifically "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 (LEO) non-governmental human space flight enterprise." This vision may include a transfer of all or parts of the ISS itself to commercial entities, in concert with the ISS International Partner agencies, or a complete transition off the ISS to other commercial platforms in LEO. In either scenario, NASA intends to segue its government role from a supplier of its own LEO services to a customer of commercially-provided services for its needs.

NASA has examined its potential future needs in LEO, such as space life and physical sciences research derived from the National Academies Decadal Survey, remaining research on the effects of the space environment on humans, technology demonstrations, life testing of systems intended to be deployed in deeper space, and crew training. Earth science, astrophysics, and planetary science payloads could also be deployed if platforms offer opportunities at an advantageous price point over standalone missions.

Although there are many LEO commercial service and capability suppliers on the horizon, the ultimate viability of a non-government enterprise is dependent upon whether there will be sufficient demand for those capabilities and services beyond NASA's needs. In a mature, sustainable LEO market, commercial entities will have realistic business cases that do not rely on NASA as a primary tenant, but as one of many customers.

This paper will summarize NASA's forecast for its future requirements in LEO to aid private industry and academia in planning for future work, research, and activity in LEO.

NASA's Future LEO Demand Forecast

The viability of a private space station, or a commercially-operated ISS, will likely depend on a significant ongoing government investment in the form of research demand. In the ISS Transition Report[2], NASA provided a top-level summary of its expected ongoing needs in LEO. This paper provides a more detailed description of that forecasted need, including facilities and platform features that would be required to support those needs. This forecast is broken down into sections on human research, fundamental research, space technology, and space science. Use of a private platform for NASA crew training was not specifically assessed, but is an additional potential need area.

Budget

At this time, NASA has not attempted to quantify future budgets for the activities described in this forecast, or other resources such as crew hours. However, NASA does expect to continue to pay for transportation costs for the crew and cargo necessary to fulfill its requirements. Today, NASA's ISS research budget is approximately $365M/year (not including transportation but including integration costs) and the ISS transportation budget is approximately $1.8B/year for cargo (resupply and research) and crew transportation. Other budgets, such as the Human Research Program ($140M/year), currently cover the cost of the NASA development of hardware for flight or ground research and don't include the transportation and on-orbit resources required to conduct on-orbit research, so those funds would not transfer to the commercial sector. Some portion of the current transportation budget would need to be allocated to support NASA research and technology needs in LEO going forward, as well as pay for other private space station resources such as crew time. A future NASA acquisition strategy for commercial LEO services

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[1] NASA Transition Authorization Act of 2017, PUBLIC LAW 115–10—MAR. 21, 2017, https://www.congress.gov/115/plaws/publ10/PLAW-115publ10.pdf (accessed 6.09.18)

[2] International Space Station Transition Report, March 30, 2018, https://www.nasa.gov/sites/default/files/atoms/files/iss_transition_report_180330.pdf (accessed 6.09.18)

would be heavily dependent on the offerings of commercial service providers – for example, whether pricing includes transportation services. NASA's acquisition strategy for LEO services will be developed as details of future service offerings become available.

Human Research

Based on the current NASA Human Research Program (HRP) path to risk reduction plan[3], and assuming continued favorable outcomes of HRP research during ISS six-month missions, most currently identified human health and performance risks for deep space missions should be sufficiently mitigated by the end of 2024. However, there will be some exploration risk areas requiring additional mitigation research, validation of countermeasures for efficacy, and optimization of exploration biomedical systems that will require significant efforts and development. Some of these – such as effects of the radiation environment beyond LEO - could only be conducted in cislunar space with the Gateway, and some – such as behavioral health and performance challenges and radiation – will be able to use ground-based facilities such as at Johnson Space Center and Brookhaven National Laboratories. For those areas requiring (or substantially benefitting from) LEO – such as operational testing in microgravity – NASA will need a platform that supports a crew presence at a level sufficient to meet the objectives that are defined in the HRP path to risk reduction. A LEO platform intending to host NASA human research will likely need to support crew health and safety, access to and from LEO, and the research capabilities needed to enable the activities identified in HRP risk reduction plans.

Fundamental Research

NASA's strategy for implementing fundamental research in the areas of space biology, physical sciences, and fundamental physics is driven by recommendations from experts at the National Academy of Sciences (NAS), and documented in two publications: Recapturing a Future for Space Exploration, Life and Physical Sciences Research for a New Era"[4] and "Assessment of Implementation of the Decadal Survey on Life and Physical Sciences at NASA"[5]. Fundamental research and applied exploration research are not mutually exclusive, and advances in one area often enable advancements in the other. NASA's Space Life and Physical Sciences Research Applications (SLPSRA) division within the Human Exploration and Operations Mission Directorate (HEOMD) is charged with developing the research portfolio that prioritizes research that enables human exploration according to the NAS recommendations. SLSPRA's highest research priorities for long-term use of LEO in life sciences are studies of plants, model organisms (including rodents) and studies of the microbiome of the built environment. The highest physical sciences research priorities are studies of combustion and phase change-associated energy transfer.

Table 1 provides a summary of SLPSRA's priority research areas, derived from the NAS recommendations. The table maps these areas to existing ISS facilities and capabilities and scenarios of crew presence in cases of LEO platforms that are long-duration (such as ISS) or short-duration (such as vehicle sorties). The platform scenarios address the need for continuous crew presence, crew-tended (intermittent) presence, or no crew at all (automated). This summary is based on NASA's knowledge of previous experiments on ISS and assumptions about the operational and environmental characteristics of future platforms. Future platforms with novel operational concepts – for example, a reliance on highly capable automated or teleoperated capabilities – or different environmental characteristics could enable research in unexpected and helpful ways.

[3] "Integrated Path to Risk Reduction." NASA Human Research Roadmap, National Aeronautics and Space Administration, https://humanresearchroadmap.nasa.gov/intro/

[4] National Research Council, "Recapturing a Future for Space Exploration Life and Physical Sciences Research for a New Era", The National Academies Press, 2011.

5 National Academies of Sciences, Engineering, and Medicine, "A Midterm Assessment of Implementation of the Decadal Survey on Life and Physical Sciences Research at NASA", The National Academies Press, 2018.

Table 1. Summary of NASA's Long-Term LEO Needs for Fundamental Research

Research or Demonstration Area	Existing ISS Facility or Capability	Platform Required for Successful Implementation			
		Permanent Platform, Continuously Crewed	**Permanent Platform, Crew-Tended**	**Short-Duration Platform, Continuously Crewed**	**Short-Duration Platform, Uncrewed**
Microbial Observation	Multiple capabilities exist on ISS	Maximizes Research	Enables Limited Research	Does Not Enable Research	Does Not Enable Research
Plant and Microbial Responses and Adaptations to Spaceflight	Centrifuge (non-human)	Maximizes Research	Enables Limited Research	Enables Limited Research	Enables Limited Research
Plant and Microbial Systems for Life Support	Biofilm Facility (Generic Cell Culture)	Maximizes Research	Enables Limited Research	Does Not Enable Research	Does Not Enable Research
Artificial Gravity as a Human Multisystem Countermeasure	Does Not Exist	Maximizes Research	Enables Limited Research	Does not Enable Research	Does Not Enable Research
Reduced-Gravity Multiphase flows	Flow Boiling facilities are limited on ISS currently	Maximizes Research	Enables Limited Research	Enables Limited Research	Enables Limited Research
Flammability and fire suppression in space	Combustion Integrated Rack	Maximizes Research	Enables Limited Research	Maximizes Research	Enables Limited Research
Development of New Materials to Support Exploration in Hard Space Environments	Solidification Using a Baffle in Sealed Ampoules (SUBSA) Translation Stage, Levitation Furnaces, High Temperature Furnaces, Materials Science Research Rack	Maximizes Research	Enables Limited Research	Enables Limited Research	Enables Limited Research
Active Two-Phase Flow	Two Phase Flow Separator - NOT Currently on ISS	Maximizes Research	Enables Limited Research	Enables Limited Research	Enables Limited Research
Zero-boiloff Propellant Storage	Cryogenic Fluid Management Demonstrations (current ISS capability is only for "model fluids")	Maximizes Research	Enables Limited Research	Enables Limited Research	Enables Limited Research
Rodent Research	Exists, but would need to expand to accommodate rats and also to answer some advanced research questions	Maximizes Research (crew monitor required for health of rodents)	Does Not Enable Research	Does Not Enable Research	Does Not Enable Research
Model Organisms (Invertebrates)	Many different types of capabilities currently exist on ISS	Maximizes Research	Enables Limited Research	Enables Limited Research	Enables Limited Research

Space Technology

NASA's space technology research objectives in LEO are primarily to develop and mature new capabilities to meet the needs of NASA's exploration, space operations, and science missions ("pull technologies"), and secondarily to create new space capabilities and opportunities, more broadly, for government and private industry ("push technologies"). NASA space technology development projects tend to be modestly funded in comparison to major science and exploration programs, and so are more likely to take advantage of existing infrastructure in the form of hosted and secondary payloads, rather than sponsoring their own dedicated launches, missions, and platforms. Affordability is expected to be a driving constraint for technology efforts in space. In some cases, the anticipated space technology research can be accomplished with automated or remotely-operated systems. Others, such as life support systems, require a continuously-crewed platform. Potential space technology activities include:

- Ongoing testing of NASA's deep space environmental control and life support system (ECLSS), which will include atmosphere revitalization and management, water reclamation, waste management, and environmental monitoring. This testing will require a continuously-crewed platform with accommodation for approximately 7-8 ISS-sized equipment racks of ECLSS hardware and appropriate interfaces for power, thermal cooling, ventilation, and vacuum venting. The ability for NASA to maintain access to be able to perform upgrades to this system will also be important;
- Testing and demonstration of evolving technologies for instruments and supporting systems to enable new capabilities in remote sensing of Earth and other bodies, heliophysics, and astrophysics – such as small satellite sensor webs and constellations;
- Space environment testing of a wide range of new technologies for space vehicles, systems, and components (propulsion, structures, communication, power, thermal control, guidance, navigation and control, computing, data management, etc.);
- Development and demonstration of in-space manufacturing and assembly;
- Base for "drop testing from orbit" for entry, descent and landing technology research and development – for Earth return vehicles, for other planetary entry prototypes, and for understanding atmospheric breakup;
- In-space research in autonomy and self-sufficiency – analog for locations deeper in space;
- Lifetime testing of systems and components in use on vehicles and platforms operating deeper in space;
- Variable-g lab for testing systems for lunar, Mars, or small body environments;
- Testing of future extra-vehicular activity suits and technologies;
- Continued monitoring of orbital debris environment and demonstrations of mitigation techniques.

Science

The fields of astrophysics, heliophysics, planetary and Earth sciences will always need dedicated spacecraft that allow for instrumentation and accommodations to be optimized for specific observations and science measurements. However, recent history shows that the defined infrastructure for transportation, power, thermal control and communications provided by ISS has proved a valuable platform for investigations in LEO. Future NASA uses of a LEO platform in these fields is dependent on the selection of meritorious proposals sponsored by the NASA's Science Mission Directorate (SMD) and on the degree to which science payloads can continue to take advantage of transportation services which are mostly or entirely funded by other users. SMD includes possible research platforms including ISS in its Announcements of Opportunity and a LEO platform would likely continue to provide opportunities for science investigations.

The provision of infrastructure in LEO can provide a cost effective opportunity to acquire science data. SMD instruments have been more likely to use ISS external viewing sites than to require internal accommodations. Future SMD investigations would likely need an ability to deploy from the logistics carrier to the final manifested location. This could be done either autonomously or with crew assist. The ability to launch CubeSats provides additional opportunities for science and technology demonstrations.

The new Earth Science decadal survey recommended a much more competition-dependent program than in the past with several new competed programs. ISS or another LEO vehicle would be a potential platform for new experiments in these programs. The In-space Validation of Earth Science Technologies (InVEST) program in Earth Science makes use of CubeSats to demonstrate new technologies on orbit[6]. Earth Science, Astrophysics, Heliophysics as well as Planetary Science have increasing interest in using CubeSats and SmallSats, to achieve science goals.

Even though no concrete plans currently exist, a LEO platform could enable additional types of science investigations. For Planetary Science, the microgravity environment of ISS or another LEO platform might allow for the studies of the planetary processes such as studying the behavior of small particles in microgravity. If the relevant analogy for the microgravity environment can be attained, then experiments on dune formation, asteroid angle of repose, low-g sample collection, etc. might be done in the platform's environment to simulate the gravity on asteroids, the Moon, Mars, etc.

For Astrophysics, a LEO platform might enable the assembly of large telescopes either by humans or robotically. Astrophysics is also studying the use of ISS as a platform for detecting the light from transient astronomical events, such as the sources of gravitational wave events.

For Heliophysics, areas of possible interest include studies of important upper atmosphere-ionosphere coupling processes, impacts of space weather events on ionospheric conditions, remote observations of the aurora and of inner magnetosphere, detailed measurements of the Sun's spectral irradiance, and observation of primary cosmic rays.

Summary

NASA and its international, academic, and commercial partners are working together to expand the capabilities of humanity to operate and be productive in LEO. In the ISS Transition Plan, NASA defines key principles to guide strategic planning for the future of LEO. This includes NASA's ongoing needs for which it intends to become a customer in a commercial LEO marketplace. Those needs have been described in more detail in this paper so that commercial suppliers can use the information in their planning. NASA's ongoing research and crew and LEO access requirements will continue to drive NASA's need for the ISS in the near-term, and either a commercially-operated ISS or private LEO platforms – or a combination of both – in the medium- and long-term.

[6] In-Space Validation of Earth Science Technologies (InVEST), https://esto.nasa.gov/techval_space.html , (accessed 5.09.18)