June 7, 2019

**Forecasting Future NASA Demand in Low-Earth Orbit: Revision Two – Quantifying Demand**

## Prologue

On October 26, 2018, NASA released the white paper *Forecasting Future NASA Demand in Low-Earth Orbit*.[1] It provided a qualitative description forecasting the types of research- and exploration-related activities NASA will conduct in the future in low-Earth orbit (LEO). In the fall of 2018, NASA conducted 12 studies on the potential growth of a LEO economy and how to best stimulate private demand for commercial human spaceflight and other commercial and marketing activities in LEO. NASA utilized the recommendations provided by the 12 studies to develop a five-part plan. This plan, entitled NASA's Plan for Commercial LEO Development, addresses supply, demand, and lays out steps that have been taken to date. As Part Five of NASA's five-part Plan for Commercial LEO Development, the Agency has updated this white paper to include a quantification of the demand forecast, representing the type and amount of services that NASA intends to purchase in the future when those services become available on one or more commercial destinations.

## Introduction

The U.S. Congress's NASA Transition Authorization Act of 2017[2] 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 LEO non-governmental human space flight enterprise." This 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 destinations 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 to enable exploration, technology demonstrations, life cycle testing of systems intended to be deployed in deeper space, and in-flight crew training. Earth science, astrophysics, heliophysics, and planetary science payloads could also be deployed if commercial destinations include external platforms that offer opportunities at an advantageous price points over standalone missions. In addition to NASA's research needs, an ongoing National Laboratory capability will be required to service the needs of other Government agencies, academia, as well as continue to incubate commercial innovations not yet ready for production.

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 rely on NASA as one of many customers instead of as a primary tenant.

Additionally, the "Strategy for Human Spaceflight in LEO and Economic Growth in Space"[3] report, submitted jointly in 2018 to the National Space Council by NASA and the Departments of Commerce and State, details four overarching goals for human spaceflight in LEO, including the objective of achieving a continuous U.S. presence in LEO. This presence would include both NASA astronauts and private citizens.

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[1] Forecasting Future NASA Demand in Low Earth Orbit, October 26, 2018, https://www.nasa.gov/sites/default/files/atoms/files/forecasting_nasa_demand_in_leo_white_paper_final.pdf

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

[3] National Space Council Gets Report on Human Spaceflight in Low-Earth Orbit, November 16, 2018, https://www.nasa.gov/press-release/national-space-council-gets-report-on-human-spaceflight-in-low-earth-orbit

## NASA's Future LEO Demand Forecast Overview

As reflected in the 12 industry studies that were completed in 2018,[4] the near-term viability of private commercial destinations in LEO will likely depend on revenues from significant ongoing Government purchase of services for research and development, as well as technology demonstrations in LEO. In the ISS Transition Report,[5] NASA provided a summary of its expected ongoing needs in LEO. The first part of *Forecasting Future NASA Demand in Low-Earth Orbit* (October 2018) provided a more detailed description, including facilities and platform features that would be required in a commercial destination to support those needs. This document (Revision Two) identifies and quantifies specific services for which NASA intends to be a customer in sections on crew accommodation and training, human research, biological and physical sciences, technology demonstration, space science, and the National Laboratory.

This study quantifies several key areas of future demand, listed in Table 1, needed to address NASA's intended future needs in LEO, including what in what disciplines and at what levels NASA anticipates continuing work and purchasing services to support that work.

*Table 1: Key Quantifications Used in NASA's LEO Forecast for Intended Purchase of Future Services*

| Category | Quantification |
|---|---|
| Crew Accommodation and Training | Minimum two NASA crew for six month stays |
| Human Research | Ongoing LEO research focused on exploration mission analogs; private crew available as additional test subjects; ability to conduct long-duration (> one year) missions |
| Physical and Biological Research | At current NASA research level of ~20 investigations/year |
| Technology Demonstration | Ongoing testbeds for NASA's life support, exercise equipment, medical equipment, plant growth facilities, quantum communications, in-space manufacturing, robotics, and autonomous systems |
| Science | External sites occupied by NASA instruments |
| National Laboratory | ~110 projects/year |

### *Services Acquisition*

NASA is initiating the acquisition process for partnering with industry to enable commercial destinations in LEO. A key element of the approach is to eventually conduct a competition for acquisition of services as those commercial destinations are being developed. A future NASA acquisition strategy for commercial LEO services 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.

## NASA's Future LEO Demand

The following sections provide additional descriptive detail for the various categories of needs that NASA has for post-ISS operations in LEO. The descriptions will generally include the following:

- Intended demand quantification (the amount of the identified service that NASA intends to purchase)
- Facilities needed (the types of on-orbit facilities needed to support NASA activities)
- What NASA will provide (the unique capabilities or facilities that NASA does not anticipate purchasing and will provide; generally tied to exploration needs and risk reduction that may not have commercial application)
- Resources for NASA equipment (the "utilities" that are anticipated as needed to support desired operations)
- Services NASA will buy (the specific services NASA intends to purchase in support of desired operations)

The details in the following sections reflect NASA's current intent with regard to future needs, and may change over time. Questions or suggestions from industry regarding these projected future needs are encouraged, and should be provided through the Request for Information (RFI) accompanying the Commercial LEO Development rollout plan.

[4] Study Input Informs NASA Course for a Vibrant Future Commercial Space Economy, May 28, 2019, https://www.nasa.gov/feature/study-input-informs-nasa-course-for-a-vibrant-future-commercial-space-economy

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

***Crew Accommodation and Training***

NASA will continue to have a requirement for its astronauts to have access to the LEO environment, for training, procedure validation, and proficiency purposes. NASA intends to provide some equipment, such as an Exploration-class Food System or an Exploration-class Environmental Control and Life Support System (ECLSS), to understand the crew health effects and gain experience and testing with the designs. Inclusion of these systems will satisfy needs in other categories below (such as Technology Demonstration of Exploration ECLSS) while also supporting NASA astronaut training and maintaining proficiency in the LEO environment. For this type of crew accommodation equipment, the commercial provider should not assume that these system are available to support their crew. NASA will purchase other services from the platform provider to support the NASA astronauts as well.

*Table 2: Crew Accommodation and Training Requirements*

| Intended Demand Quantification | What NASA Will Provide | Services NASA Will Buy |
|---|---|---|
| • Accommodate two NASA astronauts | • Exploration Food System<br>• Exploration ECLSS<br>• Exploration Exercise<br>• Medical Equipment<br>• (see HRP and Tech Demo for details) | • Crew Accommodations<br>• Galley<br>• Transportation (four crew-trips/year, shared with private astronaut missions) |

***Human Research***

Based on the current NASA Human Research Program (HRP) path to risk reduction plan[6], 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, can only be conducted in cislunar space with the Gateway, while others, such as behavioral health and performance challenges and radiation, will be able to use ground-based facilities such as those at Johnson Space Center and Brookhaven National Laboratory. 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 the HRP path to risk reduction. Specifically, NASA desires to perform exploration analog studies with representative crew sizes, vehicle volumes, and constraints. A LEO destination intended 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.

*Table 3: Human Research Requirements*

| Intended Demand Quantification | Capabilities Needed | What NASA Will Provide | Resources for NASA Equipment | Services NASA Will Buy |
|---|---|---|---|---|
| • Exploration Analog Studies with four crew (two NASA and two commercial) for a minimum of 30 days up to 1-3 years<br>• ~10 experiments/year at ~5 kg/experiment | • Crew Exploration vehicle representative volume ~100 $m^3$<br>• Ability to isolate crew from other commercial platform activities<br>• Autonomous operations testing capability with comm delay | • Exploration ECLSS<br>• Exploration Exercise Equipment<br>• Exploration Medical Equipment<br>• Exploration Food System with cold stowage (refrigerator and freezer<br>• Virtual Reality/ Augmented Reality Countermeasures | • Power ~15 kW<br>• ~8-12 Rack Volumes (2 rack equivalents for HRP-unique hardware in addition to resources required for Exploration ECLSS, Exercise Equipment, and Food System identified in Table 6<br>• Command and Data Handling (C&DH)<br>• Thermal Control<br>• Potable Water Bus<br>• Waste Water Bus<br>• Vacuum<br>• Access for crew to maintain equipment | • Crew Accommodations<br>• Transportation for NASA research payloads and supplies<br>• Return Samples<br>• Participation by commercial crew<br>• Commercial Crew Time<br>• Data and communications<br>• Interfaces for NASA equipment<br>• In-situ sample processing and analysis to limit sample return for blood, urine, saliva, omics, chemistry, cytometry |

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

***Biological and Physical Sciences***

NASA's strategy for implementing research in the areas of space biology and physical sciences (including fundamental physics) is driven by recommendations from 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,"[7] and "Assessment of Implementation of the Decadal Survey on Life and Physical Sciences at NASA."[8] Fundamental research and applied exploration research are not mutually exclusive, and advances in one area often enable advancement in the other. NASA's Space Life and Physical Sciences Research and Applications (SLPSRA) Division within the Human Exploration and Operations Mission Directorate (HEOMD) is charged with developing the portfolio that prioritizes research enabling 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 environment. The highest physical sciences research priorities are studies of combustion and phase-change associated energy transfer. Tables 4 and 5 provide NASA's forecast for LEO demand in biological and physical research.

*Table 4: Biological Research Demand Quantification*

| Intended Demand Quantification | What NASA Will Provide | Resources for NASA Equipment | Services NASA Will Buy |
|---|---|---|---|
| • ~10 Biological Research investigations per year<br>• ~500 kg/year launch | • Plant Growth Facility (see Table 6)<br>• Microbial Monitoring System (part of Exploration ECLSS) | • See Table 6 | • Centrifuge (small)<br>• Cold and Conditioned Stowage<br>• Rodent Research Facility<br>• Microbiology and Microscope Facility |

*Table 5: Physical Sciences Research Demand Quantification*

| Intended Demand Quantification | What NASA Will Provide | Resources for NASA Equipment | Services NASA Will Buy |
|---|---|---|---|
| • ~10 Physical Research investigations per year<br>• ~500 kg/year launch | • Quantum Science Facility | • Power<br>• Volume<br>• Thermal<br>• Command and Data Handling (C&DH) | • Chemical Process/Reacting System Facility<br>• Fluid and Thermal Research Facility<br>• Materials Processing Facility<br>• Advanced Microscope Facility<br>• Materials Exposure Platform<br>• Combustion Facility/Furnace |

***Technology Demonstration***

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 more broadly create new space capabilities and opportunities 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.

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

8 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 6: Technology Demonstration Demand Quantification*

| Intended Demand Quantification | What NASA Will Provide | Resources for NASA Equipment | Services NASA Will Buy |
|---|---|---|---|
| • Exploration ECLSS Testbed<br>• Four-crew continuous metabolic load | • Exploration ECLSS and Equipment | • Power - ~10 kw<br>• 7-8 racks<br>• Thermal Control<br>• Command and Data Handling (C&DH)<br>• Spares Stowage<br>• Potable Water Bus<br>• Waste Water Bus<br>• Access for crew to maintain equipment<br>• Venting<br>• Vacuum Resource<br>• Sample Return | • Equipment accommodation/interfaces<br>• Crew time for maintenance (if not NASA-crew-maintained)<br>• Transportation for initial system and spares<br>• Data<br>• Sample Return |
| • In-Space Manufacturing Testbed | • N/A | • N/A | • Three companies competing in NextSTEP right now to make a FabLab. NASA would buy services from selectee(s)<br>• Transportation for raw material and sample return |
| • Plant growth testbed | • Exploration plant growth facility | • Power - <2 kw<br>• ~1 Full Rack Volume<br>• Thermal Control<br>• Command and Data Handling (C&DH)<br>• Potable Water Bus<br>• Special Lighting | • Equipment accommodation/interfaces<br>• Crew time for maintenance (if not NASA-crew-maintained)<br>• Transportation for initial system and spares, recurring supplies<br>• Data<br>• Sample Return |
| • Accommodation of other technology demonstrations, including communications, power and energy storage, robotics | • Technology demonstration hardware | • Power<br>• ~2 rack volumes<br>• Thermal Control<br>• Command and Data Handling (C&DH) | • Equipment accommodation/interfaces<br>• Crew time for operations<br>• Transportation for demonstration hardware<br>• Data |

***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 are dependent on the selection of meritorious proposals sponsored by the NASA's Science Mission Directorate (SMD). SMD includes available research platforms -- including ISS and Gateway -- in its Announcements of Opportunity, and a LEO platform would continue to provide opportunities for science investigations. Historical usage of the ISS's external accommodations for science instruments has ranged from one to five experiment sites in use at a given time. The availability 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, which could be done either autonomously or with crew assist. The ability to launch CubeSats provides additional opportunities for science and technology demonstrations.

***National Laboratory***

The Government will continue to maintain a National Laboratory capability in LEO. While the exact scope of this commitment is yet to be determined, NASA can forecast 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 meet the requirements for flight under the National Laboratory allocation. While many of these activities will require facilities in common with NASA activities, it will be necessary for the Government to purchase services that can accommodate the needs of both.

*Table 8: National Laboratory Demand Quantification*

| Intended Demand Quantification | Capabilities Needed | Services NASA Will Buy |
|---|---|---|
| • Life Science<br>• ~60 Payloads/year | • Refrigerator/Freezer<br>• Microscopes<br>• Microbiology Facility (glove box, incubators, bioreactors, microplate reader)<br>• DNA Analyzer<br>• Centrifuges<br>• Rodent Facilities<br>• Plant Growth Facility<br>• Cell Culture Facilities<br>• Biofabrication Facilities | • Crew Accommodations<br>• Galley<br>• Transportation (four crew-trips/year, shared with private astronaut missions)<br>• Sample return<br>• Crew time |
| • Physical Sciences (including Advanced Manufacturing)<br>• ~20 Payloads/year | • Microscopes<br>• Chemical Processes/Reacting System<br>• Fluid and Thermal Research Facility<br>• Materials Processing Facility<br>• Combustion Facility/Furnace<br>• Refrigerator/Freezer<br>• MISSE | • Payload accommodation<br>• Data<br>• Sample return<br>• Transportation<br>• Crew time |
| • Remote Sensing<br>• ~5 Payloads/year | • External viewing sites<br>• Small satellite deployment<br>• Window | • Payload accommodation<br>• Data<br>• Transportation |
| • Technology Demonstration<br>• ~20 Payloads/year | • Small satellite deployment<br>• Equipment racks | • Payload accommodation<br>• Data<br>• Transportation<br>• Crew time |
| • STEM<br>• ~5 Payloads/year | • Common with above facilities | • Payload accommodation<br>• Data<br>• Transportation<br>• Crew time |

**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, leading to a robust LEO ecosystem in which NASA is but one of many customers. In the ISS Transition Plan, released in 2018, NASA defined key principles to guide strategic planning for the future of LEO. This included NASA's ongoing needs for which it intends to become a customer in a commercial LEO marketplace. NASA's just-released five-point Plan for Commercial LEO Development builds on previous work with a comprehensive approach, including quantifying NASA's long-term needs for services in LEO. This paper addresses the fifth element of the plan, describing and quantifying NASA's long-term needs, and expanding on the groundwork laid by the original paper last year, for use by commercial suppliers in their ongoing planning.