Models for Facilitating Government-Funded Activities in the Post-ISS LEO Ecosystem

Dr. Erica Rodgers, Nikolai Joseph, Kenneth Wright, Dr. Grace Wusk
Office of Technology, Policy, and Strategy, NASA Headquarters, Washington, DC, 20546, USA

Christie Cox
Space Operations Mission Directorate, NASA Headquarters, Washington, DC, 20546, USA

Patrick Craven, Jason Hay, Amanda Hernandez
BryceTech, Alexandria, VA 22314, USA

Dr. Rachael Lussos
American University, Washington, DC, 20016, USA

Maia Robakidze
Freedom Information Systems, Inc., Madison, AL 35758, USA

NASA is preparing for the retirement of the ISS and transition of LEO activities to one or more Commercial LEO Destinations (CLDs) by 2030. This transition necessitates new models for connecting NASA and other government-funded users of the LEO environment to platforms and opportunities. This paper describes for consideration six models for facilitating government-funded activities in the post-ISS LEO ecosystem. These six models are illustrative and represent a wide trade space of potential options, each relying on unique mechanisms for facilitating activities on one or more commercial LEO platforms or vehicles. We assessed each model across three possible future scenarios varying in number and diversity of LEO activities and commercial offerings, and across five stakeholder-driven model evaluation criteria. We present the highlights of the analysis, including ways to modify and strengthen each model. The Government Research Broker model performs best across all future scenarios, followed by Innovation Campus, Anchor Tenant, and Fee for Service. While Matchmaker and Institute Network exhibit positive aspects, these models perform most favorably in future scenarios with well-established communities and markets. While each model has strengths and weaknesses, no single model in its current form performs well across all criteria in all three future scenarios. NASA leadership can adjust models as desired to align closer to their priorities using combinations of unique model mechanisms. A model that meets leadership priorities is likely a combination of features from multiple models.

I. Introduction

In September 2022, the National Space Council directed the National Aeronautics and Space Administration (NASA) to "develop a plan for the next generation microgravity National Laboratory in a commercial space station world." NASA has been working to develop this strategy, with planning led by the Space Operations Mission Directorate (SOMD) and the Office of Technology, Policy, and Strategy (OTPS).

This report describes six potential models for facilitating government-funded activities in the post-International Space Station (ISS) low-Earth orbit (LEO) ecosystem. These models are one step in NASA's efforts to define and develop a comprehensive strategy.

To help guide decision-making, we score each model by its anticipated performance across three potential future scenarios—dynamic growth, steady growth, and limited growth—and across five model evaluation criteria derived from values echoed by the diverse stakeholder community: ability to meet NASA's needs, adaptability, opportunity for collaboration, market sustainability, and equity and accessibility.

After an introduction to the study background and objectives, limits in scope, and key terms, we describe the study methods and then present the main results of the study: descriptions and scoring highlights of each of the models, including ways to strengthen each model.

A. Background

For almost two decades, the model for facilitating government-funded activities in LEO has been through the cooperatively managed International Space Station National Laboratory (ISSNL). Congress established a National Laboratory on the U.S. segment of the ISS in 2005, and in 2010, Congress directed NASA to enter a cooperative agreement with a nonprofit to manage the ISSNL. The Center for the Advancement of Science in Space (CASIS) was created as a 501(c)(3) nonprofit with the mission to foster scientific discovery and technological innovation in space, expand U.S. leadership in commercial space, and inspire the next generation. CASIS manages all non-NASA research for users such as other U.S. government agencies, universities, and commercial entities, administered through the ISSNL. NASA maintains responsibility for integrating and manifesting all research on the ISS U.S. On-Orbit Segment which includes NASA, ISSNL, the Japan Aerospace Exploration Agency, the European Space Agency, and the Canadian Space Agency.

The ISSNL model has been successful in growing non-NASA interest in utilization of a platform for microgravity research and applications. To date, over 700 projects have flown, with over two-thirds developed by commercial users. In Fiscal Year (FY) 2023, 35 publications were released bringing the total to 265 publications since the ISSNL first began. As in previous years, many of these publications were made possible by research collaborations with other U.S. government agencies including the National Science Foundation (NSF) and the National Institutes of Health (NIH) which funded research in space to address national research priorities in their portfolios. In FY2023, 9 additional flight projects were funded by NSF in collaboration with CASIS, and the NIH's National Center for Advancing Translational Sciences committed to fund and re-launch the Tissue Chips in Space collaboration with CASIS in FY2025. CASIS, in partnership with NASA's Biological and Physical Sciences Division, initiated the Igniting Innovations solicitation, seeking flight research to address the goals of the Cancer Moonshot initiative and accelerating the translation of stem cell and organoid-based disease models and advanced technologies for biomanufacturing. Given this successful trajectory, continuity of a National Laboratory in LEO is an important objective and consideration in NASA's transition from the ISS to Commercial LEO Destinations (CLDs) at the end of the decade.

As NASA takes steps towards enabling one or more commercially provided platforms after the retirement of the ISS in 2030, a new model may be needed to ensure the continuation of government-funded activities in this new era. Commercial platforms after the ISS may provide a venue for NASA-driven, exploration-enabling research and technology development, as well as Earth-focused academic and commercial pursuits. Namely, four NASA-sponsored CLDs are currently in development, including free flying stations by Blue Origin, Nanoracks, and Northrop Grumman and an ISS-attached station by Axiom Space which will detach. Assuming that one or more commercial platforms replaces the ISS in the 2030s, NASA is developing a strategy to continue government-driven activities in LEO and for a next generation microgravity National Laboratory in the post-2030 timeframe.

NASA's OTPS identified six potential models for facilitating government-funded activities in the post-ISS LEO ecosystem. These models are illustrative and are designed to inform strategy development for a future National

Laboratory. No one model on its own represents a complete strategy for a future National Laboratory. NASA's SOMD is using these potential models along with responses from a December 2022 White House Office of Science and Technology Policy (OSTP) Request for Information to inform a combination of models that will best represent its recommended strategy. The strategy will accomplish the goals outlined in OSTP's National LEO Research and Development Strategy and will: represent all U.S. government needs for space-based research; encourage collaboration; be scalable to demand; be platform agnostic, leveraging existing and new ground and space capabilities; provide equitable access for all and act as an honest broker; and foster workforce development. By designing the future construct to represent all U.S. government-sponsored research, collaboration between NASA and non-NASA users is increased and opportunities are consolidated into a single-entry portal for users. This approach will enhance the user experience, reduce overhead, encourage collaboration, and allow resource sharing between agencies.

NASA is actively engaging stakeholders within NASA and other U.S. government agencies, commercial industry, and the user community to define the details of a post-ISS national laboratory strategy. The following issues remain in development: management structure of a future National Laboratory; definition of roles and relationships including NASA, other U.S. government agencies, and commercial platform and service providers, ensuring a future National Laboratory does not generate competition for, but rather supports and bolsters U.S. industry; pathways for international cooperation; proposed changes to NASA's existing National Laboratory authorization legislation; development of a stepwise transition strategy to enable continuity between the ISSNL and the post-ISS National Laboratory, including evolution as the LEO ecosystem matures; and consideration of whether the name "National Laboratory" is the best descriptor for the future construct, particularly since it would leverage multiple commercial platforms and capabilities.

B. Objectives

NASA leadership requested this study to address the challenge of conducting government-funded activities in LEO after the retirement of the ISS in 2030.

NASA senior leadership posed the following question to NASA's OTPS: What are potential models for an ISS National Lab facilitating government-funded or subsidized activities on a commercial LEO platform after the transition of the ISS to one or more private platforms?

In answering this question, we (the OTPS study team) acknowledge important limitations in study scope. We recognize the importance of identifying potential LEO activities of interest before assessing how the models can enable and facilitate these activities. While the study includes an initial characterization of potential LEO activities, further decisions are needed to guide the overarching goals and objectives of the future model and to provide a clear list of activities that will and will not receive government funding or subsidy in the future.

We also acknowledge the limitation of referring to the future model as an "ISS National Laboratory." We chose to examine the trade space using the generic term "model" to allow for a more comprehensive and creative set of options. We do however provide suggestions on how each model may be referred to as a National Laboratory; this is provided in each model overview.

We discuss additional limits in study scope in the Methods section.

C. Key Terms

We define the following key terms to clarify how we use them in this report, while acknowledging that these terms can carry different meanings in other contexts.

- Model: Collection of mechanisms and related organizational process and infrastructure that acts as a government touchpoint in the LEO ecosystem (the approach to connect users with providers).
- Evaluation Criteria: Representation of stakeholder-identified needs, which we used to score and compare model performance to guide decision-making.

- Future Scenarios: Representation of possible futures for the post-ISS LEO ecosystem used to frame the analysis and enable NASA leadership to compare models, their characteristics, and how they might differ with varying market dynamics.
- LEO Activities: Any action pursued by a user or provider in LEO, including for education, science and research, technology development and demonstration, human and robotic operations, and market stimulation.
- Platform: A facility that remains in orbit, providing space and equipment to enable different activities.
- Commercial LEO Destination: Commercially owned and operated LEO destinations supported by NASA's Commercial LEO Development Program.
- Spacecraft or Vehicle: A volume that launches, returns, or enables LEO activities. Spacecraft and vehicles are defined as transitory, unlike the platforms that remain in orbit.
- User: An entity that seeks access to LEO for conducting a LEO activity, such as commercial, academic, or government users.
- Provider: An entity, usually commercial, that provides users with access to LEO platforms or spacecraft, which the provider owns and operates.
- Stakeholder: An entity with any stake in LEO activities, including users, providers, third-party operators, policymakers, students and educators, and beneficiaries of LEO activities, including the U.S. public at large.

II. Methods

To answer the question posed by leadership, we conducted an extensive literature review followed by a dual stakeholder-driven and scenario-driven analysis that relied heavily on an iterative process of gathering feedback from over 40 stakeholders. Stakeholders were selected to cover a diverse set of interests in LEO activities and provided iterative feedback from November 2021 to June 2022. We engaged with stakeholders through targeted conversations, discussions at national conferences, and during a dedicated meeting of experts hosted by the National Academies of Sciences, Engineering, and Medicine (NASEM). This approach allowed for a strong customer focus while also considering potential outcomes in a range of uncertain future possibilities. We assembled six distinct models, inspired by the literature and insight from stakeholders. Further, the stakeholder community helped inform five model evaluation criteria and three future scenarios to evaluate the models.

Once we developed these key analytical elements, a small study team independently scored (as Pro, Neutral, or Con) five model evaluation criteria for each of the six models. The team considered the evaluation criteria across the three scenarios as illustrated in Figure 1.

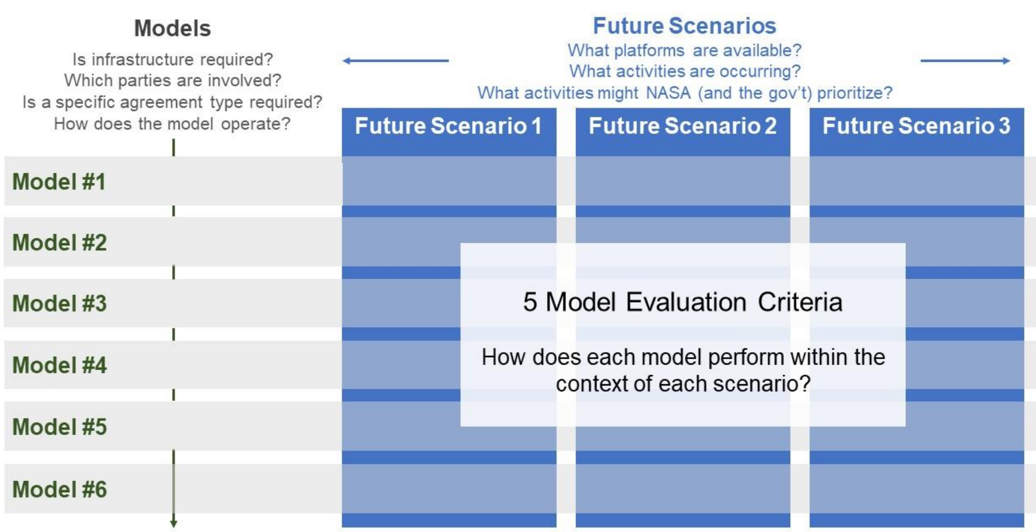

Fig. 1 Study Approach

Generally, we used a Pro to demonstrate the ability for the model to meet (or exceed) the criteria. We used Neutral to demonstrate that the model generally meets the criteria but with some limitations. Neutral was also used in situations where there was a mixture of favorable and unfavorable considerations. We used Con to note that the model did not perform well given the context of the future scenario. We then met, both as a team and then with other stakeholders, to arrive at final scores. This report presents the highlights of this scoring process for each model.

A. Model Development

To develop potential models, we first identified sixteen examples from the literature review and stakeholder discussions [1,2,3]. We considered models inspired by National Science Foundation and Department of Energy National Lab Federally Funded Research and Development Centers (FFRDCs), DoD Manufacturing Innovation Institutes, National Parks, and airports [4,5]. Discussions with stakeholders also provided examples of models to include. To compare and consolidate the various examples, we identified four key characteristics to define a more cohesive and comprehensive set of models: infrastructure, stakeholder roles, the process for accessing LEO, and agreements between users and providers.

In the consolidation process, we also determined that the model should not entail any government-owned infrastructure (in space) and should not compete with commercial providers. Additionally, models should include some level of visible NASA presence, benefiting from the positive NASA brand. Taking these considerations into account and iterating based on feedback from stakeholder discussions resulted in the final six models.

The six models are meant to be illustrative and provide a broad trade-space of possible options. Model characteristics were specified for the purpose of making evaluations, however, options could be further adjusted and even mixed and matched.

B. Stakeholder-Driven Analysis

Integrating perspectives from diverse stakeholders is imperative for the successful development of a future model to facilitate government-funded activities in LEO.

We refined the models, model evaluation criteria, and future scenarios from 43 discussions with different stakeholder groups: 13 NASA, 10 other government agencies (OGAs), 10 commercial, and 10 academic and nonprofit. From these discussions, we heard how different stakeholders valued LEO activities for outcomes like creating and sharing knowledge, demonstrating technology, serving as a springboard to the Moon and Mars, fostering economic growth, and maintaining and building relationships. Additionally, we actively engaged the diverse LEO stakeholder community at multiple conferences, including the 2021 American Society for Gravitation and Space Research meeting, the 2022 ASCENDx Texas summit, and the 2022 ISS R&D Conference. We also heard various international perspectives from the ISS International Partner Working Group, led by NASA's Space Operations Mission Directorate.

Finally, the study included a NASEM Meeting of Experts on May 16, 2022, in which 11 experts with academic, policy, commercial, and international affiliations provided feedback on the primary study elements, including the models, model evaluation criteria, and future scenarios. This resulted in a more refined analysis with clearer understandings of model strengths and weaknesses and other stakeholder considerations.

We wish to acknowledge that we did not assign weighting criteria to the stakeholder-driven model evaluation criteria (ability to meet NASA's needs; adaptability to infrastructure, service provider offerings, and user demands; opportunity for collaboration; market sustainability; and equity and accessibility). In presenting a trade space of options for consideration, we do not make assumptions about the importance of one stakeholder value over another. When comparing the different models, a decision maker may view the model evaluation criteria as a set of priorities from various stakeholders and may look to assign values to each of the criteria to assist in decision-making.

C. Scenario-Driven Analysis

We used a scenario-driven analysis to consider model performance within a range of uncertain future possibilities. This approach enables NASA leadership to compare different models for the post-ISS LEO ecosystem by not only the models' characteristics but also by how those characteristics respond to different future possibilities. The future scenarios are used as a tool to frame the analysis for the models rather than serving as a prediction of the future LEO ecosystem. To develop this tool, we incorporated stakeholder insight and considered assumptions about the future ecosystem (see Limits in Study Scope below). These assumptions have been corroborated through studies on this issue [6]. With this in mind, we defined three future scenarios—limited growth, steady growth, and dynamic growth—that provide a broad range for considering the strengths and weaknesses of each model.

To characterize future scenarios, we used stakeholder input to answer four questions:

- How might NASA's priorities change in different futures?
- Which activities will be available?
- How will NASA and other stakeholders prioritize the activities available?
- What platforms and other resources will be available?

Answering these questions, we characterized three future scenarios, defined by the number of commercial offerings and by the amount and diversity of user activities in the LEO ecosystem.

When developing the future scenarios, we had the following key factors in mind: number of available platforms; availability and diversity of activities; contributing factors to market dynamics; and impacts to user communities. To further inform each future scenario, we identified and characterized potential future LEO activities, including education, science and research, technology development and demonstration, operations, and market stimulation. To various extents, these activities are in or out of scope for NASA as specified in the 2019 Quantifying Demand White Paper [7].[1]

We heard other factors in stakeholder discussion that might be important to readers but are outside the analysis. For example, geopolitical dynamics and how they might change in the 2030 timeframe are not directly incorporated into this analysis but may be useful insight for the decision-making process in combination with this analysis. We also heard that as market dynamics shift over time, the government may wish to consider how models may evolve to support changing needs. Overviews of the three future scenarios are provided below.

1. *Dynamic Growth Future Scenario*

Two or more CLDs in operation. Successful commercial markets spur innovation and capital investment, providing more numerous and more diverse activities.

NASA's investments in the CLD Space Act Agreement have ignited new LEO markets and investments. Early successes resulted in increased venture capital investment and accelerated interest in using and visiting LEO. Multiple, diversified services and activities span multiple providers. Possibly one single exquisite facility supports the activities, but more likely, several CLDs and reusable vehicles compete for user demand, which has expanded in both number of users and variety of demand. In addition to science, human exploration research, and technology demonstration, space tourism has grown significantly, and on-orbit manufacturing is an established market. Lower launch costs and greater accessibility enable new business models with new and improved offerings available every few years. These new business models increase flexibility and enable providers to tailor LEO platform services to specific users.

[1] For the latest estimates on quantified demand (that is the number of projects or crew trips per year) that may be considered for the steady growth future scenario, we refer the reader to the 2023 white paper on Forecasting Future NASA Demand in Low-Earth Orbit: Revision Two – Quantifying Demand, the 2022 ISS Transition Report, the 2022 In-Space Production (InSPA) plans, and the 2023 Request for Information for future Commercial LEO Destinations – Concept Operations and Utilization [17,18,19,20,21]. These documents provide estimates for future LEO activities by considering historical needs from the NASA Mission Directorates, NASA programs such as the NASA Human Research Program, and the ISS National Laboratory.

2. Steady Growth Future Scenario

One or several small CLDs in operation. One or more small commercial platforms are the center of LEO activity, but that activity is not diversified.

With moderate development of the LEO ecosystem, both users and providers continue to increase, though at a slow pace. Whether one platform or multiple small platforms are available, the range of services and activities is not diversified. NASA has sufficient access to LEO infrastructure to meet its primary needs. Other user communities are somewhat more limited, since commercial services remain generalized. Companies lack sufficient development and private investment to offer specialization. Despite these limitations, LEO continues to be a symbol of collaboration and an international environment.

3. Limited Growth Future Scenario

One CLD in operation, though with limited capacity. Low demand or market disruption leads to a lack of mature commercial platforms and few activities.

Despite NASA's efforts to develop the U.S. LEO commercial market, commercial providers have not been able to survive the costs of entry, and expected markets failed to materialize. Investors have pulled out, leaving providers unable to buy down risks and mature technologies. One CLD is operational and can host research but in a much more limited capacity than on the ISS. Therefore, after the retirement of the ISS, the United States has limited access to a LEO platform. Users, including NASA, fly only their highest priority needs. Other users seek means of continuing activities in microgravity without using a LEO platform. Geopolitical dynamics are also shifting. Other nations likely have operational stations and are interested in new partnerships. As the United States shifts attention to the Moon and Mars, it cedes some geopolitical benefit of LEO to others.

D. Limits in Study Scope

In both stakeholder discussions and at the NASEM Meeting of Experts, several topics rose repeatedly as important considerations but ultimately fell outside the scope of this study.

1. Launch and Transportation Costs

This study built assumptions into each future scenario for the purpose of evaluating model performance within different contexts—this includes assumptions on launch costs. We heard from many stakeholders, including those at the NASEM Meeting of Experts, that if transportation costs do not reduce significantly, markets will not be able to materialize. While we make assumptions on the cost of transportation in the 2030 timeframe, transportation itself was not a major focus of this study. Overall, the effects of cost should not be underestimated, and future models should consider transportation mechanisms as a major component.

2. Crewed Versus Uncrewed Activities

The scenario narratives do not differentiate between crewed and uncrewed platforms. Several stakeholders mentioned that future activities can be conducted on uncrewed platforms and recommended that future models take this into account in follow-on analyses. Additionally, certain activities in LEO (such as remote sensing and manufacturing) may be better suited to autonomous, robotic uncrewed operations.

3. International Partnerships

The scenario and model narratives do consider impacts to international stakeholders' involvement, but the complexities of these relationships and future implications cannot be addressed in this study alone. Several stakeholders noted the importance of determining NASA's position towards international partnerships in a post-ISS ecosystem. Doing so requires additional analysis and thoughtful legal consideration, both for current ISS partners and for governments and agencies not in the current ISS partnership, such as emerging space agencies and Artemis Accords signatories. A separate working group led by NASA's Space Operations Mission Directorate has been established to begin discussions with the current ISS partners regarding the future LEO ecosystem. While not fully explored in this work, international partnerships and agreements are likely to impact a model's potential performance in the possible future scenarios, and their implications should be more intentionally assessed.

4. Levels of Fidelity for Models

We relied on literature reviews and stakeholder discussions to develop the models. Those we developed are largely notional and conceptual, representing a wide trade space of potential options. If decision makers select one or more models to iterate on, we suggest doing future work to address the other limits in study scope identified in this section, conducting follow-on analyses, and giving more consideration to cost and legislative changes needed to specify the exact operations, management, and business details of each of the models we present.

III. Results

We present six models for consideration, as shown in Table 1: 1) Anchor Tenant, 2) Government Research Broker, 3) Innovation Campus, 4) Matchmaker, 5) Institute Network, and 6) Fee for Service. The models as shown generally range from more to less government oversight, including options for facilitation of activities within a NASA program office—Anchor Tenant and Government Research Broker—or through a non-governmental organization—Innovation Campus, Matchmaker, and Institute Network.

Table 1. Six differentiated models for facilitating government-funded activities in the post-ISS LEO ecosystem.

Model	Differentiator	Description
1. Anchor Tenant	Long-term agreement for leasing space on a commercial platform	NASA as anchor tenant on CLD with dedicated destination for LEO activities. NASA program office is agent for all government-sponsored activities. Commercial users work directly with platform provider or respond to government proposal requests.
2. Government Research Broker	Customizable research using combinations of transport vehicles and CLDs	NASA program office guided by advisory committee brokers payloads to LEO, conducts mission planning, and negotiates end-to-end services. Flexible contract with CLDs based on short term needs. Crewed and uncrewed missions for flexible government research needs.
3. Innovation Campus	Modern terrestrial campus with workforce focus	Government-owned terrestrial campus operated by non-government entity. Dedicated to advancing research and development. Focused on innovation and building LEO workforce rather than connecting users to platforms.
4. Matchmaker	Neutral third party connecting users to platforms	Nonprofit funded by NASA to match specific users to LEO opportunities based on mission and technical requirements. Provides clear entry point for users and providers. Aggregates and communicates user demand to industry.
5. Institute Network	Network of separate but related efforts to enable commercial scaling and U.S. leadership	Government-sponsored consortia of distinct but related institutes within LEO and terrestrially. Institutes funded through public-private partnerships managed by nonprofits. CLD facilities leased from providers within institutes.
6. Fee for Service	Free market approach	Industry-driven model focused on transactions for services. Users purchase goods and services from providers. NASA is one user and leverages grants and data buys to meet needs.

Each model includes the following information to guide senior leadership decisions:

- An **overview** description of the model in practice, as envisioned in the post-ISS LEO ecosystem, including a "National Laboratory" characterization.
- Assumptions about the physical **infrastructure** providing user access to LEO.
- Assumptions about the **roles** of different stakeholders in this model.

- Assumptions about the **process** for accessing LEO, including a flow diagram to illustrate the process, which is defined by three major steps for connecting users (demand) with providers (supply):
  - Step 1: “getting in the door” shows the path for users to follow if they wish to conduct an activity in LEO through the model, such as proposing to the identified stakeholder for activity selection.
  - Step 2: “once in the door” refers to the stakeholder who allocates resources for the selected activities, such as integration, crew time, and mass to orbit, and facilitates the process for users to prepare flight-ready payloads.
  - Step 3: “getting out the door” notes who then decides which flight-ready payloads will be manifested on a flight to the platform.
- Assumptions about the types of **agreements** that users, providers, and other parties might use to receive, provide, or otherwise facilitate access to LEO.
- Highlights from the analysis, which includes a summary of the model’s **scores** across all model evaluation criteria and future scenarios as well as suggestions for strengthening each model.

A. Model 1: Anchor Tenant

1. Model Overview

NASA is an “anchor tenant” for one commercially available LEO platform. As an anchor customer, NASA provides a reliable source of revenue for a specified amount of time. NASA and other user communities have some degree of autonomy over activities conducted in dedicated areas or even individual segments of the platform. An estimated 30% to 90% of total activities on the platform are government-sponsored. The dedicated areas and individual segments or portions of these areas are designated a National Laboratory.

2. Infrastructure

One platform is privately owned, with NASA as its main, and potentially only, long-term customer. As such, NASA might own specialized equipment or other facilities on the platform. However, NASA does not own competing platforms or have an ownership stake in the platform.

NASA has dedicated space and time on the platform. Other users might have dedicated space and time on the platform as well. A dedicated space can be an area within a segment of the platform or an entire segment itself.

3. Stakeholder Roles

The CLD provider owns and operates the platform and leases space to the anchor tenant. The CLD provider has final authority over activities performed on the platform, including the authority to veto activities to ensure safety or avoid interoperation issues. However, as the anchor tenant, NASA has operational autonomy over its dedicated area of the platform, as stipulated in its contract. NASA can also provide input to help the CLD provider decide which activities to allow on the platform. A dedicated NASA program office prioritizes, selects, and awards activities that use NASA’s area of the platform. To offer their perspective on activity selection, user communities can provide input to the program office through a board of directors, user advisory committee, or decadal surveys.

4. Process for Accessing LEO

Figure 2 illustrates the process this model takes for connecting user activities with platforms.

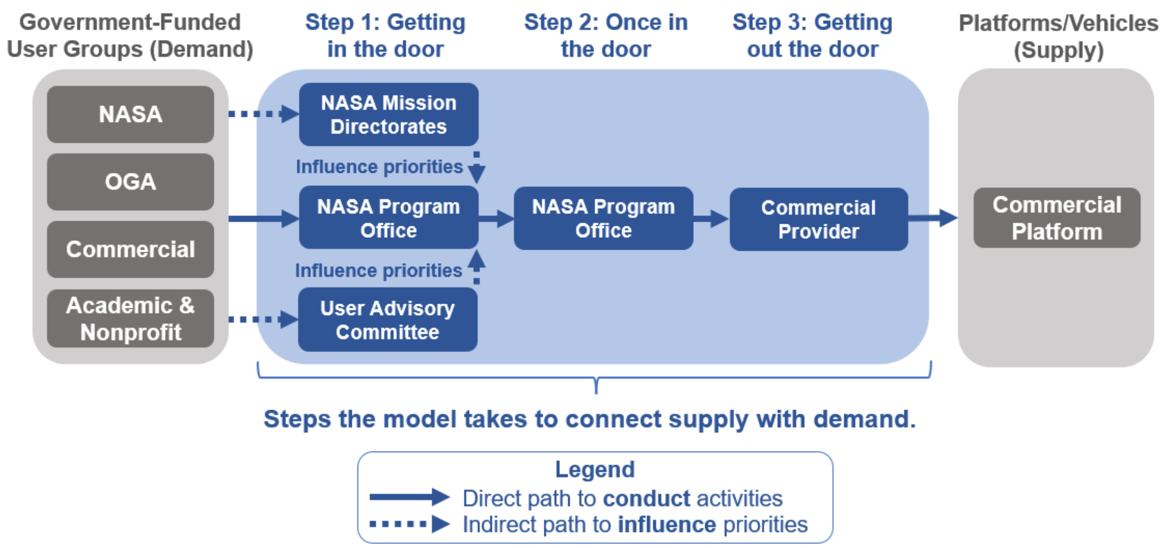

Fig. 2 Process for accessing LEO through the Anchor Tenant model.

The dedicated NASA program office, which selects activities from those proposed, provides a clearly identified point of entry for users seeking to use NASA's area of the platform. After selecting an activity, the NASA program office helps users define requirements, facilitates the process of ensuring flight-ready activities, and allocates integration, crew time, and mass to orbit. The office then works with the commercial provider, who decides which activities to allow on the platform.

5. Agreements Between Users and Providers

The agreement between NASA and the CLD provider is a long-term contract with a high level of commitment between parties. The contract details jointly identified requirements for NASA's area of the platform and lists potential activities. Although the contract might include options for built-in flexibility over the long period, and few options for scalability, these options will be for only preconceived activities and circumstances outlined in the contract.

6. Analysis Highlights

Model strengths. This model performs favorably across multiple future scenarios, demonstrating robustness in the following model evaluation criteria: Ability to Meet NASA's Needs and Opportunity for Collaboration.

Key takeaways. The Anchor Tenant model provides a long-term steady engagement with a CLD. This leads to reliable access for NASA to support a significant portion of its exploration needs and for more collaborative opportunities, assuming they were identified when drafting the agreement. Substantially supporting a CLD also increases the probability of market sustainability. However, the model does not respond well to changing needs or to users with additional requirements that were not considered early in the process. Moreover, it may dampen long-term economic growth by reducing competition and increasing barriers to entry for non-NASA supported anchor tenants as well as users who are not well-established.

Considerations for strengthening model weaknesses. NASA can try to mitigate some of these weaknesses by leveraging flexible contracting pathways, establishing alternative pathways for international partners, and increasing leased space to support future growth or support to underrepresented communities. This model can also be strengthened by looking to the Government Research Broker model to conduct research in transient vehicles, which would facilitate additional research, provide more support to commercial markets, and enhance flexible solutions for government needs.

B. Model 2: Government Research Broker

1. Model Overview

Inspired by transient research space used by Antarctic research vessels, this model entails reconfigurable missions to CLD platforms to maximize flexibility for government needs. The research space is an orbital transport spacecraft (like Dragon, Dream Chaser, or other) that docks at one or more CLDs. Users can conduct research on the orbital transport spacecraft itself or in combination with the CLD platform facilities. Each research space is designated a National Laboratory, or a collection of research spaces is named a National Laboratory.

A new NASA program, similar to the Launch Services Program, but with an expanded role, conducts mission planning and negotiates end-to-end services [8,9]. Acting as a broker bringing payloads to LEO, the program follows payload requirements, finds the launch provider and orbital transport spacecraft, and uses knowledge of the CLD platform (such as interfaces) to determine the best destination for payloads. In the limited growth scenario, where just one CLD is in development, the program office still acts as broker for the orbital transport spacecraft but to the one destination only.

2. Infrastructure

One or more orbital transport spacecraft, owned by a commercial provider, and at least one CLD platform are available. The reconfigurable missions of the Government Research Broker model may include a combination of owned and leased hardware and equipment hosted on the permanent platforms and spacecraft vehicles, as the specific missions require. The CLD platform might provide an exclusive port to government users to ensure availability.

Reconfigurable aspects of the orbital transport spacecraft provide flexibility to users. These aspects include the spacecraft itself (within limitations), instrumentation, and other equipment that changes between research-focused missions. Reconfigurable aspects of the spacecraft can—and in some or most cases, may be expected to—work in tandem with the facilities or crew on the CLD platform.

3. Stakeholder Roles

The NASA program office serving as the broker has final decision-making authority for selecting payloads and finding the best launch service provider and CLD platform to host the payloads. This is an expansion of previous NASA programs that includes a diverse set of stakeholders with varying priorities. NASA prioritizes activities through a user advisory committee, which includes both NASA and non-NASA users. The CLD provider has final authority over activities that use their platforms or ports.

4. Process for Accessing LEO

Figure 3 illustrates the process this model takes for connecting user activities with platforms.

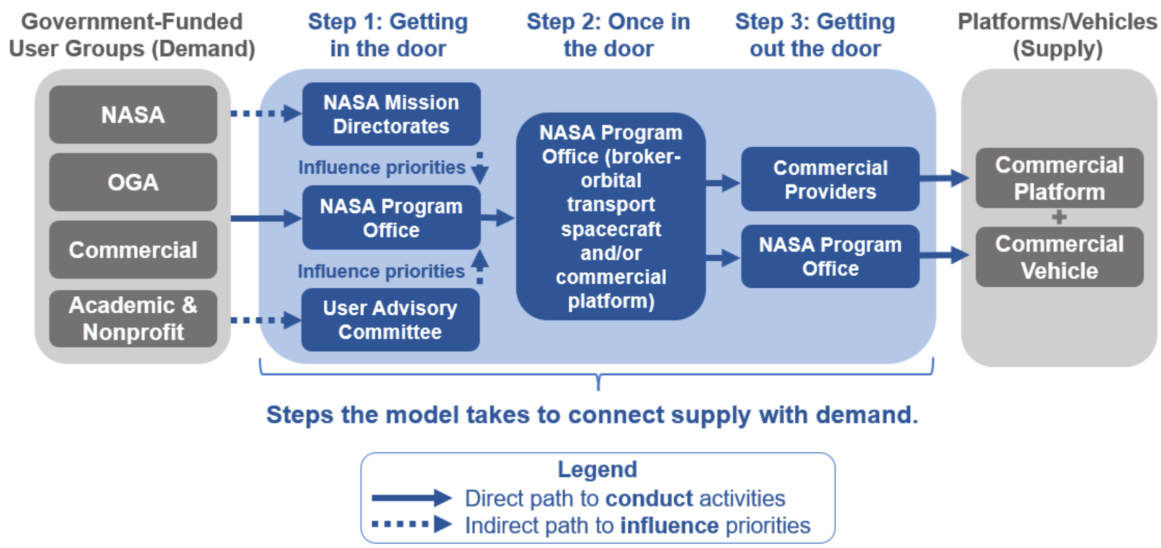

Fig. 3 Process for accessing LEO through the Government Research Broker model.

The NASA program office leads the process for users' LEO access. The program office, with input from NASA mission directorates and a user advisory committee, selects which activities can be supported through the model. It then facilitates the user process to achieve flight-ready payloads and also allocates integration, crew time, and mass to orbit. The program office determines payload priorities and, as broker, aggregates the payloads and finds the best launch provider, orbital transport spacecraft, and CLD platform for hosting the mission (if the mission will dock), given payload requirements. Finally, the program office guides the mission from pre-planning to post-launch if the mission does not dock to a CLD. If the mission docks to a CLD, then the commercial provider decides which missions are allowed to dock to the platform.

5. *Agreements Between Users and Providers*

The agreement between NASA and other orbital transport providers is a long-term contract, with built-in flexibilities. The agreement between the NASA program office and CLD providers is more flexible and based on shorter term mission needs. The NASA program office coordinates individual activities of user communities for various services. This includes transportation services to and from the CLD, which requires different contract terms and liability waivers. Users who receive grant funding through the formal proposal and review process enter formal agreements with the granting agencies, whether NASA or others.

6. *Analysis Highlights*

Model strengths. This model performs favorably across multiple future scenarios, demonstrating robustness in the following model evaluation criteria: Ability to Meet NASA's Needs, Adaptability, Opportunity for Collaboration, and Equity and Accessibility.

Key takeaways. The Government Research Broker model provides a reliable option for NASA to continue activities in LEO in any future scenario, especially if the ecosystem does not develop as desired or expected. The range of built-in flexibilities can buffer against major changes in available infrastructure and against how capabilities within CLD platforms may develop. The model meets the needs of all but one of the stakeholder-driven performance criteria. The model falls short in terms of market sustainability, as there is potential for competition to arise between the CLD platforms and the orbital transport spacecrafts. The high level of government involvement, combined with the ability to optimize the government's research space as needed, make this model a viable option for consideration. Note that NASA's Commercial LEO Program has precluded sortie-style research options from CLD awards. Should this model be considered, that should be taken into consideration.

Considerations for strengthening model weaknesses. This model's potential shortcomings in market sustainability can be designed against early to ensure that this model benefits both industry and NASA. Ensuring the orbital research vessel is designed to work in tandem with CLDs is one such consideration, in addition to incentivizing port standardization. Another is ensuring the orbital transport vehicle has NASA-specific hardware that will not be on the CLD. We also suggest that combining aspects of this model (e.g., flexible, orbital transport vehicle usage) with aspects of the Anchor Tenant model (e.g., reliable, government commitments) may benefit both industry and government, though with increased resource requirements.

C. Model 3: Innovation Campus

1. Model Overview

A terrestrial innovation campus is the center for microgravity research, operations, and innovation, similar to a NASA concept called Sally Ride National Laboratory [10]. The concept details the creation of a new FFRDC or University Affiliated Research Center (UARC), including a new government-owned campus (or center or lab) operated by a non-government entity. The Innovation Campus is dedicated to assisting and preparing advanced science and R&D projects for LEO flight opportunities. With participation open to all user communities, the campus promotes partnership, innovation, developmental R&D, and mission planning efforts for LEO. The campus attracts high-quality candidates, uses expertise from key sectors (academic, commercial, and others), facilitates academic exchanges, and promotes education and training in STEM and other disciplines. The physical campus is designated a National Laboratory.

With NASA as the sponsor agency, a third party operates and maintains the government-owned campus using a standard FFRDC or UARC model [11]. The third party can be a nonprofit, an academic institution, or a commercial contractor.

As envisioned in the Sally Ride National Laboratory model, the Innovation Campus does not connect payloads to platform providers. This campus can, however, be used in combination with another model that does connect with platform providers. Similarly, the campus in this model is limited to LEO efforts, but the model can be expanded in scope to incorporate other human spaceflight efforts related to lunar and other domains.

2. Infrastructure

A terrestrial innovation campus attracts, aggregates, and develops a skilled workforce from academic institutions, industry, or other organizations. The campus hosts specialized facilities, equipment, and other infrastructure that various users can access for advanced research, development, testing, and evaluation.

3. Stakeholder Roles

NASA is the government sponsor that owns the campus and has final decision-making authority. As designated by NASA, a third-party operator (nonprofit, academic institution, or commercial contractor) conducts and manages day-to-day activities. Other user communities contribute through academic exchanges, multi-user partnerships (including international partnerships), and other projects hosted at the campus as the NASA budget allows. The campus provides a clearly identifiable point of entry for new users, which the third-party operator guides through the process.

4. Process for Accessing LEO

Figure 4 illustrates the process this model takes for connecting user activities with platforms.

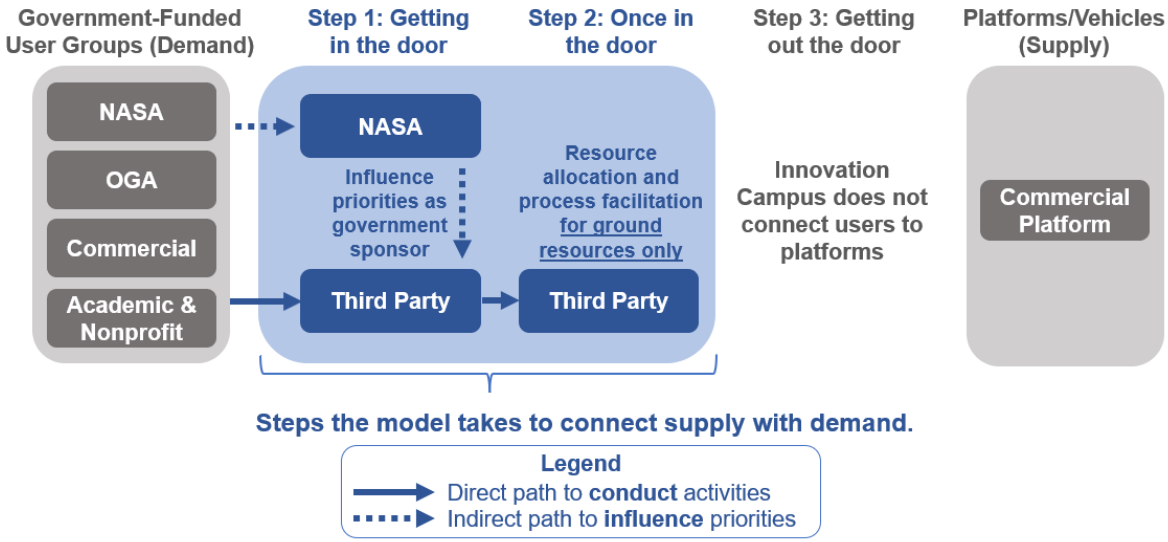

Fig. 4 Process for accessing LEO through the Innovation Campus model.

The campus maintains an open-door policy for OGA, commercial, international, and other users. The campus supports users through design and development of missions and projects and partnership opportunities. For all approved activities, a third-party operator who manages day-to-day operations allocates resources and facilitates processes for ground resources only. As mentioned previously, this model does not include a process to connect users to platform providers for LEO activities.

5. Agreements Between Users and Providers

The agreement with the third-party operator is likely a long-term management and operations contract. Agreements required for other campus activities, such as establishing partnerships or using specialized equipment and facilities, may involve other flexible types of agreements, such as Space Act Agreements, CRADAs, contracts, and grants. While the agreements for campus activities remain both targeted and flexible, the campus relies on long-term investments to build and maintain its workforce.

6. Analysis Highlights

Model strengths. This model performs favorably across multiple future scenarios, demonstrating robustness in the following model evaluation criteria: Ability to Meet NASA's Needs and Opportunity for Collaboration.

Key takeaways. The Innovation Campus model is designed to augment efforts in LEO with ground-based resources and can best do so in a dynamic environment, where there are many stakeholders and enough funding to support activities. Assuming a separate model can connect users with CLDs, this model can help ensure the government maintains a skilled LEO workforce, with the added benefit of scaling to account for mission needs beyond LEO. These benefits significantly drop off however, as opportunities in LEO decrease. In future scenarios with less opportunity, the sponsoring agency typically must focus efforts on mission priorities. Tangential activities and non-government users or partners would most feel the effects of these prioritizations. The model can potentially support a steady growth scenario, but with limited resources.

Considerations for strengthening model weaknesses. The utility of this model could be enhanced by efforts to expand participation across the government, including adding other agencies as sponsors—similar to the Institute Network model—and by enabling pathways for industry to access campus resources. We also note that this model must be combined with another model to access to space and in-space platforms to further enhance benefits to all users.

D. Model 4: Matchmaker

1. Model Overview

A "matchmaker" connects user community activities directly with CLD providers based on mission and technical requirements. The matchmaker is a neutral third-party nonprofit organization funded by NASA. The matchmaker provides a clearly identified point of access to LEO for both users and providers.

Throughout the process, the matchmaker supports current and prospective users to ensure mission success. Meanwhile, CLD providers benefit from the dedicated marketplace made possible by the matchmaker, making their services accessible to customers. The suite of services provided by the matchmaker to coordinate, facilitate, foster, support and aggregate is designated a National Laboratory.

2. Infrastructure

Facilities, hardware, and other infrastructure are available from CLD providers. The matchmaker has no direct connection to infrastructure but must remain knowledgeable of existing platform and infrastructure capabilities to offer effective matchmaking.

3. Stakeholder Roles

NASA is the sponsor agency for the matchmaker, which is a third-party nonprofit organization. The matchmaker oversees day-to-day matching of user activities to platform options. In addition to objective matchmaking and communicating user demand to industry, the matchmaker may coordinate research activities, facilitate technology transfer, foster emerging companies, and support multi-agency programs. NASA oversight and feedback is incorporated into matchmaking decisions and activities.

Both platform providers and users across all communities participate through the matchmaker. New users have a clearly identified point of access that assists them throughout the process, answers their questions, and provides guidance to ensure mission success.

4. Process for Accessing LEO

Figure 5 illustrates the process this model takes for connecting user activities with platforms.

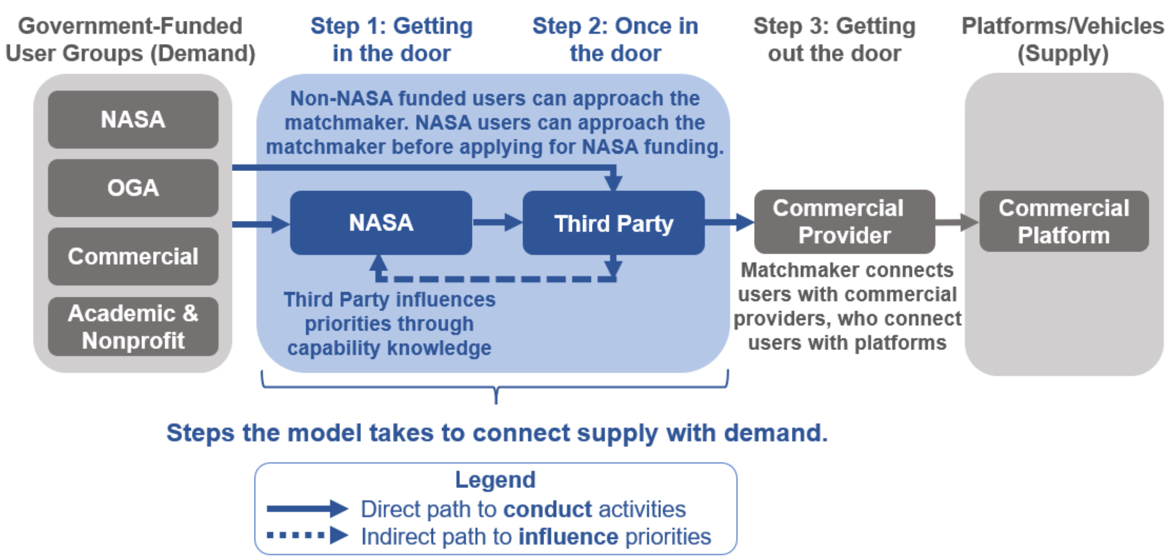

Fig. 5 Process for accessing LEO through the Matchmaker model.

NASA sponsored users approach NASA directly to seek funding for activities or for technical expertise. The matchmaker provides users with mission and technical expertise, analyzes available options, supports user-provider coordination based on available services and demand, and facilitates the process to prepare activities for flight. The matchmaker can also assist CLD providers, prospective customers, and facilitate joint projects and technology transfer on behalf of the government. The matchmaker connects selected user activities directly with the commercial provider, who then decides which flight-ready activities will go to a commercial platform.

5. *Agreements Between Users and Providers*

Typically involving flexible contracting mechanisms, agreements are based on need, customer affiliation, and service provided.

6. *Analysis Highlights*

Model strengths. This model performs favorably across multiple future scenarios, demonstrating robustness in one model evaluation criterion: Adaptability.

Key takeaways. The Matchmaker model generally is better served in future scenarios with an abundance of opportunities, allowing for NASA's needs to more easily be met and for more collaborative opportunities. The model's performance does not stand out in any evaluation criteria except for adaptability. Given this, the model's performance may be more dictated by limitations from the future scenario, rather than inherent limitations of the model itself. Given the adaptable nature of the matchmaker, this may mean that limitations can be designed against if considered early on.

Considerations for strengthening model weaknesses. Successful implementation of this model requires that the matchmaker understands the government's needs. A government program office, like the one in the Anchor Tenant model, working as a close partner to the matchmaker would help mitigate any disconnects.

E. Model 5: Institute Network

1. *Model Overview*

The Institute Network is a network of individual but related efforts with a focus on commercial scaling and maintaining U.S. leadership. Designed after the Manufacturing USA manufacturing innovation institutes (MIIs), NASA and OGAs form a consortium to identify and jointly fund newly proposed institutes, which are considered public-private partnerships. Institutes can involve multiple user communities (commercial, academic, international) and include co-investment from commercial participants and potentially other participants. A third-party nonprofit organization manages each institute, coordinating the activities of its members and the use of infrastructure. The capabilities provided through the networked institutes are designated a National Laboratory.

NASA and OGAs benefit from cost-sharing and participant co-investment for new institutes while agreeing to fund new institutes that are designed to meet their needs. Other participants benefit from access to the network, infrastructure, and other capabilities to advance research and scalable commercialization activities.

2. *Infrastructure*

Participants in the network include CLD providers and other providers of platforms, hardware, and other infrastructure. The network enables collaborative use of these facilities among its various members for LEO activities.

3. *Stakeholder Roles*

NASA and OGAs fund new institutes designed to meet their needs as well as the needs of their stakeholders. A third-party nonprofit organization manages these institutes, but depending on the design, management of the institute can incorporate NASA oversight and feedback. The third-party nonprofit organization also coordinates the use of infrastructure.

Companies co-invest in individual institutes, but other user communities can contribute to investment in an institute as well. The participating members in an institute can establish multi-user projects and use available infrastructure for project activities, as approved by the managing third-party nonprofit. New users can join pre-established institutes or form new ones with other potential participants.

Institutes can enter into a wider network with other established institutes to tackle larger challenges and wider focus areas. Similar to the MIIs, industry is expected to increase funding for individual institutes over time (potentially freeing up government funds for investment in other areas or in new institutes).

4. Process for Accessing LEO

Figure 6 illustrates the process this model takes for connecting user activities with platforms.

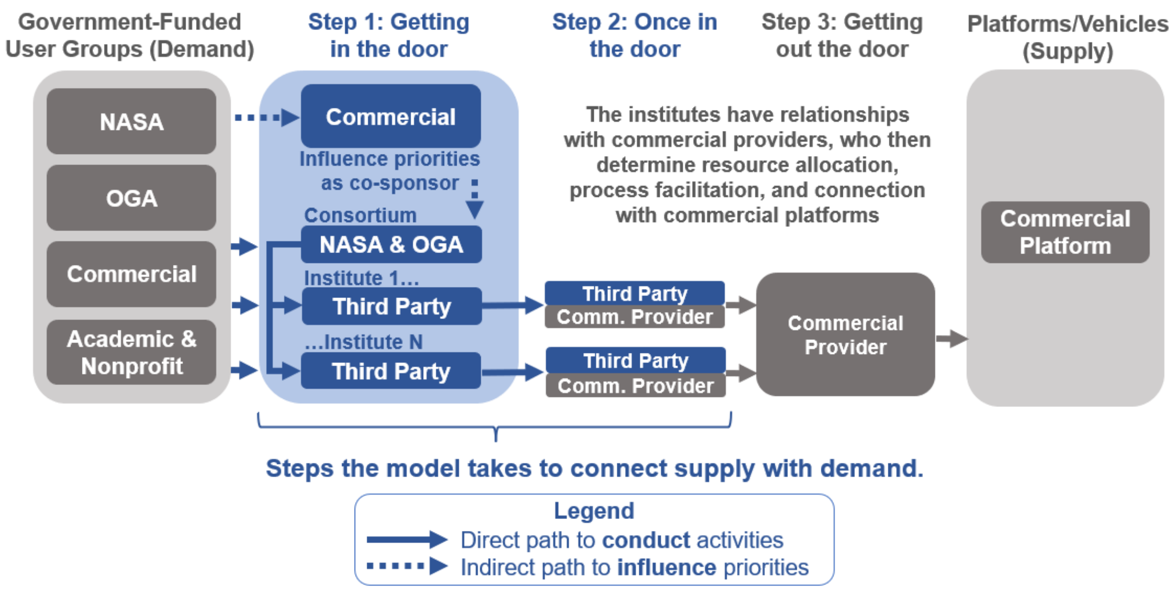

Fig. 6 Process for accessing LEO through the Institute Network model.

NASA and OGAs guide the creation and selection of institutes and can route interested participants to existing institutes that meet their needs. Users can either coordinate with the third-party nonprofit managing the institute or work directly with the provider, as directed by the institute. Since commercial providers are part of the institutes, the providers are responsible for bringing selected activities to commercial platforms.

5. Agreements Between Users and Providers

NASA, or a consortium of government agencies that includes NASA, solicits new institutes through Requests for Application. Institutes are co-funded by the government consortium and industry, though the government decreases its funding over time. Applications for new institutes guarantee co-investment from commercial participants and potentially other participants.

6. Analysis Highlights

Model strengths. This model does not perform favorably across multiple future scenarios, demonstrating lack of robustness in all five model evaluation criteria.

Key takeaways. The benefits of the Institute Network generally scale across future scenarios. This model advances commercial capabilities in areas of interest to the government and is best positioned to do so in a dynamic growth scenario with many opportunities and players. The model's ability to bring many user communities together in support of government needs, with emphasis on advancing industry, is a unique way to advance the country's LEO capabilities. For this reason, NASA may want to consider this model after a successful transition to CLDs and demonstration of some success. NASA can also incorporate lessons learned from the MIIs (or similar programs) once the LEO ecosystem is more established.

Considerations for strengthening model weaknesses. This model's weakness can be mitigated through efforts to grow and diversify the LEO economy in preparation for future gains. Alternatively, rather than investing in a new network of new institutes, NASA can consider how this model builds upon or adds something new to current, established institutes that span LEO, lunar, and terrestrial topics (such as the Space Technology Research Institutes [12], the Translational Research Institute for Space Health [13], or the Lunar Surface Innovation Initiative [14]). We also suggest that this model may be able to support a LEO ecosystem that is not yet fully established if it is implemented in a more limited capacity.

F. Model 6: Fee for Service

1. Model Overview

This model embodies a free market approach, in which users purchase goods and services from commercial providers. Users may purchase these goods and services directly from the providers and may also coordinate with other users to reduce costs, pool resources, and ensure needs are met in LEO. NASA awards grants for research and uses data buys to meet its central needs. NASA's grant announcements and requests for proposals (RFPs) communicate market demand to commercial providers. The collection of activities enabled by grants and data buys is designated a National Laboratory.

2. Infrastructure

All platforms, equipment, and other systems are commercially owned. NASA does not maintain any infrastructure in LEO.

3. Stakeholder Roles

CLD providers have authority over all decisions about their platforms and infrastructure. These providers coordinate with NASA and other user communities as customers only. NASA, either independently or jointly with OGAs and international partners, funds grants in niche areas of research and development and purchases goods or services through NASA's commercial LEO services budget.

NASA can purchase goods and services in several ways, and NASA-funded users may use these as determined by NASA. Examples of how NASA can purchase goods and services include purchasing accommodations for crew; space to host a payload or other hardware; time to tend to a NASA-flown or CLD-owned payload; use of external space to host science payloads for a specified amount of time; and consumables or materials. NASA also contracts with commercial providers to purchase data with broad utility, such as for human research and technology performance.

Other government-sponsored user communities can contact platform providers directly for their needs. Some user communities may prefer to use NASA as an intermediary when working with providers. User communities can also provide input about critical research areas through decadal surveys and other means.

4. Process for Accessing LEO

Figure 7 illustrates the process this model takes for connecting user activities with platforms.

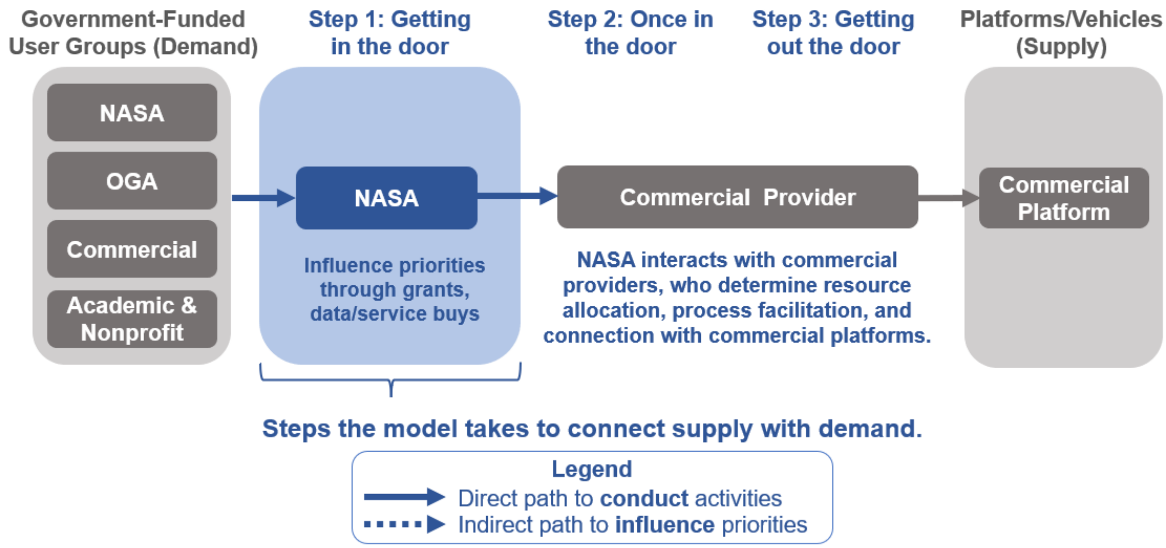

Fig. 7 Process for accessing LEO through the Fee for Service model.

NASA communicates demand for future goods and services to commercial providers and gathers input from user communities on their needs. Agency priorities guide research topics and data needs, informing potential grants, services, and data buys. Users can go through NASA to influence priorities; however, the commercial provider has the ultimate say on what activities are flown and, in the marketplace, which data and services can be purchased. Once the commercial provider determines what activities can be accommodated, they take the payloads through the steps to connect with a platform.

5. Agreements Between Users and Providers

Agreements are likely in the form of contracts between users and commercial providers. Contracts provide a low level of commitment for either short- or long-term services, as agreed upon by the user and provider. Follow-on contract options depend on the availability of the platform. NASA maintains its grant review process and uses an RFP process for services and data buys. When NASA jointly sponsors a grant or service/data buy, a more complex interagency or international agreement might be necessary.

6. Analysis Highlights

Model strengths. This model performs favorably across multiple future scenarios, demonstrating robustness in the following model evaluation criteria: Adaptability and Market Sustainability.

Key takeaways. The Fee for Service model represents a flexible, free market and is particularly well-suited to steady and dynamic growth future scenarios in which the commercial potential of LEO is more fully realized. The model can generally adapt to activities, infrastructure, etc., however, activities may skew towards those that generate the most revenue. To support market sustainability, NASA's demands are clearly communicated and financially supported through grants and service/data buys. However, the cost of conducting activities in LEO is primarily driven by supply and demand and set by the commercial providers. Users and providers whose interests align well with NASA's interests may seek funding through NASA grants and service/data buys, but others are largely left to fund and fend for themselves. Barriers to entry, including cost, expertise and know-how, and willingness to work directly with commercial providers, may prove prohibitive for new entrants, academic researchers, other government agencies, and the international community.

Considerations for strengthening model weaknesses. A free market approach somewhat limits NASA's ability to strengthen the model's limitations. However, economic policies may help channel commercial investment into areas that better meet NASA's needs, enable collaboration across the government, and ensure accessibility. The U.S.

government can also encourage practices that promote equity and accessibility and provide incubation support to businesses (similar to current ISSNL-CASIS efforts) to steer economic development.

IV. Summary

NASA is preparing for the retirement of the ISS and transition of LEO activities to one or more CLDs by 2030. NASA's Commercial LEO Development Program has already awarded contracts to four primary commercial entities to work towards this transition [15,16]. As NASA and other user communities continue to prepare for this transition, NASA and these communities need a plan for how to carry out government-funded activities in LEO post-ISS.

In light of this challenge, NASA senior leadership tasked OTPS with answering the following question: What are potential models for an ISS National Lab facilitating government-funded or subsidized activities on a commercial LEO platform after the transition of the ISS to one or more private platforms?

To answer this question, we conducted a stakeholder-driven analysis to identify a trade space of six differentiated model options. The six models are illustrative and representational of a potential trade space. We then evaluated their performance in three potential future scenarios, according to evaluation criteria deemed important to stakeholders. These results are summarized in Table 2 below. To further aid in leadership decision-making, we provided considerations for how to strengthen each model by mixing and matching different model aspects.

Table 2. Aggregate view of model strengths according to the five model evaluation criteria.

Model	**Model Evaluation Criteria**				
	Ability to Meet NASA's Needs	**Adaptability**	**Opportunity for Collaboration**	**Market Sustainability**	**Equity & Accessibility**
1. Anchor Tenant	✓		✓		
2. Government Research Broker	✓	✓	✓		✓
3. Innovation Campus	✓		✓		
4. Matchmaker		✓			
5. Institute Network					
6. Fee for Service		✓		✓	

✓ Marks an overall model strength across the future scenarios, meaning the model evaluation criteria received a Pro in at least two future scenarios.

The Government Research Broker had the most model strengths across the future scenarios, followed by Innovation Campus, Anchor Tenant, and Fee for Service. While Matchmaker and Institute Network exhibited positive aspects, these models performed most favorably in future scenarios with well-established communities and markets.

It is important to note that these scores are specific to the six models as currently defined, and the scores likely would change if the model definitions were to change. While each model has strengths and weaknesses, no single model in its current form performs well across all model evaluation criteria in all three future scenarios. To this end, we intend for the model comparison to be a useful process in identifying relative strengths of models to inform future decisions.

A decision maker may seek a model that exhibits robustness to a set of unknown future scenarios, meaning the model is able to perform well in a variety of environments and ecosystems. In this case, the overall model strengths in Table 2 provide a good starting point. The Government Research Broker, with four model strengths, rises as a relatively robust option for the future, particularly in regard to meeting NASA's needs, allowing for adaptability, providing opportunities for collaboration, and providing equity and accessibility.

NASA leadership can adjust models as desired to align closer to their priorities, using combinations of the unique model mechanisms provided in our analysis. The best performing model that meets leadership priorities is likely a combination of features from multiple models. By considering a model early on and taking necessary steps towards implementation, NASA can help enable government-funded user communities perform research in microgravity as one or more CLD replaces the ISS by 2030.

Acknowledgements

OTPS works transparently to provide strategic advice, supported by independent assessments and rigorous analysis, to inform NASA senior leadership on key areas to align with mission and agency-level activities. In its role as an independent office, OTPS relies on the inputs of a broad community of internal and external subject matter experts and stakeholders involved in NASA's future. For the study described in this report, OTPS considered many inputs while shaping the study itself and interpreting and reporting our findings. We thank NASA's International Space Station Division, Center for the Advancement of Science in Space, report reviewers, and over 40 stakeholder discussants who shared these invaluable inputs. Taking the next steps to prepare for a post-ISS LEO ecosystem requires the diverse perspectives of all those involved, and the study team gratefully acknowledges all those who contributed.

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