National Cislunar Science and Technology Strategy

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Alliance for Space Development

I. Goals and Considerations

The RFI from the Cislunar Science and Technology Subcommittee requesting input for the development of a national science and technology strategy on cislunar space stated that the purpose of the strategy is "to enable a robust, cooperative, and sustainable ecosystem in cislunar space." This response is framed within the authors' assumption that the R&D and standards strategies discussed below are part of a larger *set of legal, financial, and physical systems and incentives necessary to encourage and facilitate the permanent economic and social expansion of society into space*.

The RFI also asks for input on R&D timeframes of 10 and 50 years. While the difficulty of planning on a ten-year timescale in a period of accelerating technological change is significant, the greater challenge of planning in 50-year timeframes is self-evident. What has been demonstrated in multiple disciplines is the ability of *culture* to encourage *emergent properties* that achieve the original intent while being relevant and responsive to an unpredictable future. The responses below will be framed in this framework of guiding principles that influence the research, development, and standards for developing, using, and managing cislunar space.

A foundational principle concerns who a developed cislunar space is for: the positive effects of a growing cislunar economy must be felt by the average person regardless of where in cislunar space they live, and the costs for ignoring the benefits are too great to ignore. Much like GPS, it is acceptable that the benefits of cislunar development be taken for granted. The key concept is that cislunar development should be important enough that quality-of-life is lessened for everyone if it disappears.

The authors also believe that it is appropriate and important that this RFI occurs within the scope of the National Science and Technology Council and not any specific agency since enabling and supporting a vibrant and sustainable cislunar ecosystem will probably involve *many* agencies, especially the Department of Commerce, and not just DoD and NASA. It sends a strong statement that space technology and policy development is an interagency process and not the purview of any single agency.

Finally, much of the discussion below is informed by the authors' recent response to the Request for Comments on Implementing the National Strategy for In-space Servicing, Assembly, and Manufacturing by the ISAM Interagency Working Group. That response is included by reference here: https://newspace.spacefrontier.org/policy/

II. R&D

> *What research and development should the U.S. government prioritize to help advance a robust, cooperative, and sustainable ecosystem in cislunar space in the next 10 years? And over the next 50 years?*

A. Principles and processes

It is useful to separate research from development in this context since they have different roles in a purpose-driven context. Research concerns understanding basic principles and processes within a certain discipline that are separated from any specific function. Development is about achieving a functional capability. In the context of a cislunar ecosystem, Research is around basic knowledge of the system's characteristics (orbits, surface properties, space weather, etc), industrial processes (metallurgy, chemistry, power, etc), and life sciences (partial gravity effects on life, radiation, and health effects of dust, etc). Development involves solving problems based on that fundamental knowledge. Both must be driven and focused by the goal.

This R&D will also be done within many different agencies. Obviously, some of the basic research will be done by NASA. But much of the rest is already being done for terrestrial applications within NSF, DoE, DoD, NIH, etc. Some of it will even be done by our international partners.

Regardless of what research and development are done, NSTC should recommend that a public/private partnership be formed between the various Federal agencies and private sector organizations to jointly prioritize and fund the needed R&D. In some respects this looks more like how NASA's predecessor organization, NACA (the National Advisory Committee for Aeronautics) operated than how NASA has traditionally operated.

B. Annual and Decadal Surveys. *Responsive* R&D in a ten-year horizon needs *annual calibration* and must include consultation with both public and private sector R&D organizations and users. For a fifty-year horizon, the calibration should happen in decadal intervals. While selection committees should be diverse, they should be heavily tilted towards being driven by private sector inputs, for two reasons:

1. To ensure USG R&D has the proper 'legs'; i.e. since it will be the private sector that in the end must turn R&D into scalable, economical, space products & services, their perspective should carry a primary weight in deciding R&D that has legs for a 'robust, sustainable cislunar ecosystem'.
2. To ensure impartiality, the process to drive Government dollars should not be delegated to any specific existing organization such as the National Academies or Aerospace Corp due to their existing biases toward the status quo in terms of speed and ambition.

It is often useful to look at how other industries have solved these problems. The following provide useful insight into short and long-term R&D, often coupled with a standards process that can move quickly and is responsive to members' needs. If a new standards process needs to be created these are some examples to follow. In the case where an appropriate forum exists (e.g. CONFERS, IEEE, ITU, etc), it should be used but not if it impedes progress.

- **CONFERS**
  The satellite servicing Consortium for Execution of Rendezvous and Servicing Operations (CONFERS) [1] provides both R&D and standardization processes for the satellite servicing sector. While much of the R&D CONFERS does is Development, it can provide basic Research if requested by its members.
- **IRTF/ISOC**
  The Internet was primarily standardized and built through the work of the US Government and three explicitly non-Government organizations: the Internet Society (ISOC)[2], the Internet Research Task Force (IRTF) [3], and the Internet Engineering Task Force(IETF) [4]. All three involved individuals from academic, industry, and Government. The IRTF was organized to respond to research and development requests from ISOC or the IETF based on industry and government input. ISOC, through membership fees and grants, provided the bulk of the research funds. The IETF was unique in that the process recognized only individual input and did not recognize corporate or Government entities as participants.

While these models have been shown to work over time, they do require strong 'immune systems'. The ISOC/IETF process had two takeover attempts happen during the 1990s as the Internet grew: one by Microsoft and the other by China. The risk is worth the reward.

C. 10 Year Horizon

The fundamental challenge in creating a robust cislunar ecosystem is in discovering business models that require cislunar resources to close. Those resources include everything from hard mineral resources to microgravity to an unparalleled view. So far, the only business models that close are those that depend on LEO/GEO orbits and directly serve terrestrial markets such as communications, Earth observation, and geolocation. In order to enable some of the notional business models such as Space Solar Power, Lunar tourism, or platinum group mining, the basic costs need to be lowered and new capabilities developed.

While time is indeed money, lowering costs for core needs such as transportation, dense power generation/storage, habitation, manufacturing, etc can have the most impact when discovering and enabling these nascent in-space businesses. One strategy for lowering costs is combining the in-space capability with terrestrial R&D needs that create synergistic growth and feedback with terrestrial businesses. For example, advanced robotic mining techniques developed for space can provide immediate benefits to terrestrial mining companies.

With this in mind, decisions about what R&D to fund should consider whether the knowledge learned directly lowers the costs of subsequent R&D or of doing business in the cislunar ecosystem. This is a necessary criterion to intentionally start the desired 'virtuous cycles'; where increased capability & lower costs leads to more players, even more capabilities, & even lower costs.

D. 50 Year Horizon

1. Accelerating R&D

A fifty-year R&D program should, in addition to being responsive to industry and Government needs, focus on solutions that inherently accelerate the rate of change such that what is expected to take 50 years takes only 20 or 30.

The program should also not accept the objection that some area of research or development is too far into the future. The purpose of any 50-year R&D program is to drag the future, kicking and screaming, into the present.

In some cases, the Government can accelerate development in the cislunar ecosystem by changing the way the Federal government operates in cislunar space. As one of the main operators of large spacecraft in LEO, MEO, and GEO, the US Government can set an example by baselining designs for serviceability as a requirement for future government missions. It would serve as "training wheels" for space operators to become accustomed to the operational flexibility that modular servicing with 'open standards' would bring. This could also be accomplished in cooperation with the interoperability facility discussed in Interoperability Testing below[5].

2. Goals and Leadership Matter

There will be a challenge around envisioning what kind of world will exist in 50 years. One way to solve that problem is to embrace the fact that technology development is exponential in the long term and set R&D agendas around goals that recognize that. Then, rather than extrapolating forward from current trends, it is far more illustrative to extrapolate backward from some future state. That future state should also be ambitious since the pace of development will match the goal rather than being as fast as possible. For example, imagine that in 50 years the balance of material used in space comes from space rather than the Earth or that the population of American citizens in space is large enough that it requires its own ZIP code.

This is where leadership matters. While this RFI does include a goal, it is difficult to measure performance against it and it is also not easily sold to either Congress or the public at large.

III. Standards

> *What key technical standards are most useful to develop in support of activities in cislunar space, and how could these standards enable and support a vibrant and sustainable cislunar ecosystem?*

"The wonderful thing about standards is that there are so many of them to choose from."
- either Rear Admiral Grace Murray Hopper or Andrew Tanenbaum

The power and allure of standards in technical fields are difficult to downplay but repeatedly we learn that most of the effort spent in developing them is wasted. The problem is that it is impossible to know ahead of time which 'standard' will succeed. Becoming an adopted standard is always earned. It cannot be imposed or agreed to a priori. The most famous example is the Protocol Wars[6] between the IETF's TCP/IP based Internet and the ITU's Open Systems Interconnection protocols. The ITU's process was explicitly not open and participation was tightly controlled. The IETF's process was incredibly open and literally let anyone join by simply subscribing to an email mailing list. At a panel at Princeton in 2014 Vint Cerf described the early culture as a key aspect of why TCP/IP ultimately dominated:

> *"Cerf said the social development of the Internet was as important as the technical development. From the beginning, contributors worked to develop a governance system that was both flexible and open to contribution at many levels. As the scope and technical capabilities of the Internet changed, the management of the system was able to change with them."*

Using that same culture of bottom-up, as needed, experimental, and open development for developing cislunar space would serve us well and discourage the use of standards as regulatory capture.

A. Open

An open process means that any individual or organization can join and that all processes and procedures are done publicly. There are cases where certain members have special privileges but these are well known, limited, and can be terminated.

B. Voluntary

The vast majority of standards should be voluntary. The designation of a standard as mandatory should be limited and even then promotion to a mandatory standard should follow a long period of experimentation and real-world experience. Of the over 9,000 published specifications by the IETF, only 126 are actual Internet Standards and became so only after years of operational use.

C. Free

All standards regardless of their status should be publicly available at no cost. In the case where a standard is based on intellectual property owned by a company or individual, that IP must be licensed freely before it can be published as a standard of any status. The IETF's BCP 79[7] is a useful guide for IP licenses in open standards.

D. Earned

Becoming a standard only happens after the specification has earned significant, voluntary adoption, not before. This requires that they not only be *flight proven*, but *market proven.* Forcing a 'standard' before *both* have occurred is a premature optimization that is almost always sub-optimal, overly expensive, and dangerous. It also strongly encourages gaming of the standards system to unfairly benefit one vendor over another.

E. Interoperability Testing

One of the challenges experienced with the Internet is that no published specification was ever complete enough to deal with all corner cases and engineering 'creativity'. This led to interoperability problems even though both implementations were technically compliant. The most effective solution became an annual interoperability event started in 1986 called Interop[8]. At each event, a custom network, InteropNet[9], was built that all vendor hardware had to connect to and prove it operated correctly and without interfering with other devices. While companies began viewing Interop as a must-attend tradeshow, engineers still attend and use the event to bulletproof implementations far faster and safer than doing it with customer networks. Interop is now credited with the rapid acceleration of TCP/IP technology in the late 1980s that set the stage for the Internet explosion in the 90s.

In the case of cislunar interoperability testing for published specifications, the challenge is replicating the environment. The *government* could incentivize an Earth-orbital interoperability and testing facility optimized for testing out ISAM and other standards-related technologies in Earth orbit[5]. ISS, while useful, is expensive & has a low-risk tolerance. An ideal orbital test facility would have the following features:

1. <u>Capable of High Risk-Tolerance</u>: There are a lot of ISAM technologies and capabilities that are hard to test on a platform like the ISS because of its risk posture. An ISAM test facility needs to be a place people can try things earlier in the process, where there's often more information to be gained, and where lessons learned can save a lot of analysis paralysis. It does not, however, have to be continuously crewed.
2. <u>Co-orbital with another Human Spaceflight Facility</u>: If you can tap into the crew/cargo logistics stream of a larger facility - such as one of the proposed Commercial LEO Destination facilities post-ISS- without dealing with all of the red tape associated with it, can make it a lot cheaper to operate a testing facility.
3. <u>Solving market coordination problems</u>: In many cases, cislunar market development involves multisided market coordination problems (e.g. "chicken and egg" problems). Fuel depots need satellites to exist that need to be refueled yet no one will build such a satellite until there are depots to do the refueling. An orbital test facility can help reduce market coordination risk by encouraging interoperability testing without exposing customers to development risk.

F. Government as a forcing function

While much of the discussion above suggests that the US Government should take a light role in developing the R&D and standards processes, doing nothing at all with regards to standards may be just as suboptimal as only using government-produced standards.

Government can assist in advancing the standards cause, while not harming it, by bringing the future forward more quickly by the correct set of actions. But under no conditions should government "just pick one" standard because an industry is hung up in a chicken & egg scenario or no clear standard has emerged. The option should always be to incentivize forward motion by, for example, funding several of the most promising existing options and encouraging interoperability over choosing a single standard. Public policy practitioners are just as prone to premature optimization as any engineer.

A good example of this is the recent CONFERS-generated consensus statement for refueling interfaces; stating essentially what should any refueling system do[5]. While the government-facilitated initiative required significant work with multiple vendors with competing fluid interfaces, that difficult process developed a very useful beginning 'standard' for in-space refueling. It also facilitated mutual understanding and some level of trust within an otherwise competitive sector. Other systems standards processes such as power/data interfaces or structural connections, can be ‘facilitated’ in this way. What is important to understand is that the Government was acting in its role as a large anchor customer rather than its coercive role of forcing a solution.

A useful and immediate next step is going through the same process but for spacecraft interface software standards. While much of the recent work has focused on the physical latching and power/data interface, little work has been done on developing software APIs and network interface standards for enabling spacecraft to talk to each other’s modules through the physical interfaces. It is indicative of our industry that the focus was on the hardware first and the software second while the rest of the modern industry uses 20+ year old software interface standards by default and rarely considers hardware interfaces because of how standards have made those choices trivial[5].

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