Integrating National Space Visions

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Abstract

This paper examines value proposition assumptions for various models nations may use to justify, shape, and guide their space programs. Nations organize major societal investments like space programs to actualize national visions represented by leaders as investments in the public good. The paper defines nine "vision drivers" that circumscribe the motivations evidently underpinning national space programs. It then describes 19 fundamental space activity objectives (eight extant and eleven prospective) that nations already do or could in the future use to actualize the visions they select. Finally the paper presents four contrasting models of engagement among nations, and compares these models to assess realistic bounds on the pace of human progress in space over the coming decades. The conclusion is that *orthogonal* engagement, albeit unlikely because it is unprecedented, would yield the most robust and rapid global progress.

Introduction

The social contract between a people and their government is based on shared belief about the value proposition of public-funded activities and investments. General acceptance of such value propositions is their fundamental goodness metric. National space programs are purported to be investments in the public good. Like governance, defense, power infrastructure, transportation infrastructure, environmental protection, frontier technologies (e.g., nanotechnology, biotechnology, agricultural technology, undersea exploration, artificial intelligence), and public welfare (e.g., health care, education assistance, indigent support), space programs are prosecuted in the belief that the substantial resources they require will yield corresponding societal benefits.

Investments made on behalf of societies by their national governments are a powerful policy tool because of their sheer size and because of the conducive policies and laws that often accompany them. These features determine social, institutional, and individual agendas. In planning such investments, nations exercise choice at all levels: in the vision drivers they pay attention to, in the vision they articulate, in the specific goals they pursue, and in their engagement with other nations as they proceed.

This paper is divided into four parts. First we examine nine vision drivers: demonstrated and anticipated needs, historical traditions of what is important to do, comparative standing with respect to other nations, national pride, development and perpetuation of workforce skills, willingness to depend on other nations, interest in commercial profit, the pursuit of knowledge, and manifest destiny.

Next we explore nineteen discrete spacefaring objectives nations might pursue to actualize a national vision, in the following seven categories: direct improvement of life on Earth through "inward-looking" remote sensing and services; scientific exploration of the natural world through "outward-looking" physical and observational missions; military hegemony through strategic and tactical control of the "high ground;" expansion of operational presence into, within, and beyond Earth space; developing space-based resources to benefit and protect Earth; and opening space to large numbers of people.

Finally, with the vision drivers and spacefaring objectives as a foundation, we compare four principal models of mutual engagement among nations: *hoarding*, *emulating*, *interdependent*, and *orthogonal*. We consider how global adjustments to current planning could hypothetically maximize effectiveness of the total human space enterprise.

Vision drivers

Nations only focus resources on space activities that support national priorities, that may in turn be abstracted into implicit or explicit vision drivers. Because of the high barrier-to-entry imposed by the cost of space activities[1], nations' vision drivers are usually stark. Table 1 defines nine vision drivers to which the spacefaring activities of all nations can be traced. Interestingly, all nine drivers are meaningful at all size scales: from the level of what motivates individual people up through the level of what societies comprising billions of people may choose or be led to do.

Table 1. Vision Drivers for National Space Programs

Vision driver	Description
1. Demonstrated and anticipated need	Pragmatic societal needs that can be met or alleviated directly through space-based activities, e.g., Earth resources, early warning, disaster prevention, rescue, telecommunications, agriculture, forestry, navigation, security.
2. Historical tradition	Collective aspiration based on shared memes, possibly based on a "glory" experience like Project *Apollo* or the *Salyut* series. As transmitted to other societies, a belief that such activities define greatness.
3. Comparative standing with respect to other nations	"Space diplomacy" leverage;:demonstration to other nations that a nation can accomplish something that few or no others can, as a way of establishing the *bona fides* for a high-technology posture in international relations.
4. National pride	Demonstration to a nation's own people that it is capable of great achievement, as a way of building political capital "at home."
5. Perpetuation and development of technical skill	Utilizing space projects as a catalyst for maintaining workforce capabilities in high-tech design, production, test, and operations, and for motivating young people to enter technical fields
6. Willingness to depend on other nations	Degree to which a nation believes it can or must rely on others. Acceptance or rejection of autonomy as a viable model for a strategic future. Likely depends on national assets (e.g., financial power, natural resources, labor) and/or historical circumstances (e.g., age of the culture, persistence of frontiers, recent wars or other national crises).
7. Direct profit	Pursuit of a business model in which intrinsic characteristics of space, or space resources, or spacefaring services, are marketable[2]. May be convolved with ideology that market-based economic models are inherently superior.
8. Knowledge imperative	Collective belief that the indulgence of curiosity, and resulting increased understanding of the natural world, is a noble human pursuit justifying societal investment and support.
9. Manifest destiny	Collective belief that society progresses toward a higher purpose, that humankind is destined to expand into available environments and attain increasing control over natural activities. May be convolved with a desire to leave a societal legacy.

Spacefaring objectives

In the last two decades of the 20th century, space activities proposed as feasible within two generations provide ample choices for nations interested to pursue any combination of the nine vision drivers. Indeed, more worthy space initiatives have been identified for the first half of the 21st century than even the richest of nations could afford to pursue simultaneously. Consider the partial lists provided in Table 2 (space objectives with extant precedent) and Table 3 (potential future activities).

A cost barrier separates the traditional objectives from the macro-projects. Two not-mutually-exclusive paths are available for global progress: (1) more nations can pursue the traditional objectives; (2) resourceful nations can strike out into new territory by selecting from among the macro-projects. Nations focused on vision driver #1, and who can resist the temptation of drivers #2, #3, and #4, have no stake in driver #5, and can accept driver #6, can meet their needs for driver #1 by accepting or purchasing space-based services from existing provider nations. This avoids the otherwise insurmountable costs of developing spacefaring capability, while still bringing key pragmatic benefits of space technology to their people.

Table 2. Extant Space Activity Objectives

Category	Objective	Description	Benefit to Humanity
Social and economic	Environmental monitoring	Use Earth orbit as a vantage point to observe weather, climate indicators, pollution, runoff, algae blooms, iceberg locations, forest fires, agriculture burns, eruptions, crop diseases, and urban development.	Better manage human interactions with Earth systems
	Telecommunications and navigation	Use Earth orbit as a relay location for communications assets, and as a reference location for global navigation	Increase economic productivity; make the world “smaller”
Military and political	Surveillance	Use Earth orbit as a vantage point to observe activities such as troop movement, construction, supply chains, equipment relocation, and missile launches.	Preclude being surprised by aggressors
	Missile defense	Use Earth orbit as a basing location for interceptor spacecraft to destroy missiles in flight	Shield populations from attack by aggressors
Science	Space science	Explore other worlds and deep-space destinations; develop and operate in-space telescopes to study distant phenomena.	Deepen human understanding of natural world and context for life
	Microgravity research	Use the native properties of Earth orbit to perform unique experiments, gain new insights into the physical world, and develop new products.	Exploit a new domain of physical conditions
Enablers	Space transportation	Develop and operate rocket-based or hypersonic-based systems that launch orbital assets into space, perform orbit transfers, and return high-value payloads to Earth.	Put assets in space, move them around, and return them to Earth
	Manned space station	Develop and operate the ability to sustain people in space for long durations.	Utilize human presence to enable unique operations or investigations

Models of inter-national engagement

The two most prevalent engagement models for national space programs are *hoarding* and *emulating*. Both originated in the ballistic missile and human spaceflight “space race” between the U.S. and Soviet Union. Each nation jealously protected its own incremental technology advancements as state military secrets; yet at the same time each avidly sought and studied any information about the rival’s program, and calibrated its own requirements accordingly. Both nations hoarded what they had, yet emulated the other’s accomplishments. This yielded two interesting outcomes: (1) two completely independent systems arose that could essentially accomplish the same feats; and (2) other nations saw this as a model for becoming a globally-recognized technological leader.

Table 3. Potential Future Space Activity Objectives

Category	Objective	Description	Benefit to Humanity
Enablers	In-space transportation capability	Develop and operate the ability to move assets between locations in cis-lunar or interplanetary orbits.	Increase flexibility of in-space operations
	In-space servicing	Repair, refuel, or restock space-based assets.	Leverage sunk costs; enable modularity
	Lunar base	Build and operate a habitable station on the Moon.	Learn how to survive on another planet
	Space elevator	develop and operate macro-tethers that physically connect Earth's surface with geosynchronous orbit, and are used as elevator cables to revolutionize how material is placed in orbit.	Cheap, clean access to space
Resources	Solar power satellites	Develop and operate macro-spacecraft that convert in-space sunlight to electricity. Transmit the power to Earth's surface via microwave beaming to supply clean electricity.	Inexhaustible clean energy for Earth
	^{3}Helium	Develop and operate macro-mining on the Moon to concentrate ^{3}He implanted in the lunar regolith by the solar wind. Deliver the ^{3}He to Earth. Develop and operate ^{3}He-based fusion reactors on Earth to generate clean electricity.	Large-scale, clean energy easily integrated into existing grid
	Mining	Obtain material resources from asteroids and the Moon for human use *in situ*, in cis-lunar space, or on Earth's surface.	Break Malthusian limits; sidestep launch bottleneck for in-space uses
	Disposal	Remove space debris; remove nuclear waste from biosphere	Make our operating environments safer for routine activities
	Planetary defense	Deflect or destroy Earth-crossing asteroids or comets determined to pose a collisional threath	Protect Earth from impacts that could cause regional damage
Large numbers of people	Space leisure travel	Develop the macro-ability for thousands-to-millions of people to travel to space annually.	Open space to ordinary people
	Settlement	Build and populate communities in space that are economically and technologically self-sufficient	Become a multi-planet species

The pattern established was: obtain indigenous orbital launch capability; then use it to return tangible benefits for the populace and to launch people into space. This pattern still holds. Europe was next to emulate satellite launch capability; scientific exploration; and telecommunications, Earth-observing, and navigation networks. And European roadmaps persistently envision indigenous human space flight systems[3]. (For purposes of this analysis we consider Europe to have a unified space program, consistent with the ESA charter.) Although the U.S. helped Japan and Russian technology helped India achieve orbital launch, possessing this ability defines an important and recognized threshold. China is clearly the next emulator: satellite launch followed by human launch, then spacewalks, lunar probes, orbital stations, and eventually human lunar missions[4].

The U.S. still hoards by nature[5]. A notable exception was the direct transfer in the late 1990s of U.S. habitable-module technology to the Italian aerospace industry, as part of the inter-agency deal to get the International Space Station built by spreading its cost among nations. But as any number of erstwhile or potential partners (on both sides of the ocean) will attest, U.S. restrictions on exporting dual-use technology preclude significant sharing. Indeed, it may be that the U.S. attempt to hoard technology has actually resulted in the proliferation of space-faring technology as it has driven other nations to develop capability they might have otherwise just purchased from the U.S.[6]

Yet the emulation model spreads: more than launch capability is routinely copied. Nations tend to seek not only their own launch systems, but their own satellite buses; remote-sensing, weather-monitoring, and communications-relay capabilities; navigation networks; habitable laboratories on the International Space Station; and robotic exploration missions. At a 30% annual growth rate, the entire Indian space program is structured to emulate capabilities available throughout the global market, from Earth resources to Moon probes[7]. The Indian *Chandrayaan*, European *SMART-1*, *Mars Express*, *Venus Express*, and *ExoMars*; Japanese *SELENE*; and Chinese *Chang'e* robotic missions are just the most recent evidence of a drive to emulate particularly U.S. capabilities in exploration. Whereas the emulating model yields redundancy from a global perspective, it also *de facto* cedes leadership by the practitioners to the nation being emulated. It commits nations' resources to an agenda determined by other nations, and hence fragments the potential of the global supply market.

Canada is a notable exception to the pattern, and defines the third model: *interdependent*. The Canadian space program has never aimed for hegemony in space access; rather it seeks consistent niche roles in others' programs. Canadian robotic manipulation or sensing systems have no missions except via others' systems and architectures; in turn, those systems would have limited capability without the Canadian elements. We can find other, isolated examples of interdependence: the *Ulysses* solar polar observatory, and the *Cassini-Huygens* mission to Saturn and Titan, are the most vivid examples of extra-European scientific cooperation. Neither would have been as successful without the participants' willingness to rely on each other for enabling capabilities. The *Apollo-Soyuz Test Project* was the first U.S.-Russian interdependent program, and the *International Space Station* (ISS) has become the largest. The interdependent model depends on the societal courage to not be autonomous; it is the definition of non-zero behavior[8].

An interesting case is the "virtual" human space flight programs of several nations, including several in Europe and Asia. Is this an example of the interdependent model? Borrowing the analogy from ecology, we see these to be largely commensal (neutral impact, as in the case of European flight specialists) or largely parasitic (consume the host's resources, as in the case of politically-motivated launches of communist-nation astronauts) relationships, rather than genuinely symbiotic (benefiting both parties). The test of the difference is whether the host nation would be significantly diminished if the hosted nation were absent; in these cases, they would not. So hosted human space flight is a manifestation of the *emulating* model rather than the *interdependent* model.

Leaders are apt to hoard. For hoarders, interdependence both threatens loss of autonomy and facilitates lesser partners by exposing them to capabilities more advanced than their own. In space activities, the U.S. has far more financial resources than its nearest technical peers (Russia and Europe), and an enormous head start over the only nation that can outspend it in labor buying-power (China). So far, the U.S. perceives little incentive not to hoard.

Currently, the U.S. is extending its strategic dominance into the next generation by developing cis-lunar transportation infrastructure. The world's nations, if they hope to participate in lunar exploration, will ride on either American or Chinese flight systems. In the American case, one might argue that focusing on transportation system development is merely the logical result of putting "first things first." Without transportation there can be no lunar exploration anyway, so in a limited-resource environment the first focus has to be on the transportation infrastructure.

However, the “superpower viewpoint” conveniently coincides with this logic. Senior U.S. Administration officials draw comparisons between “extending the economic sphere of the Earth to encompass the Moon” and the dynamics of superpowers throughout history: “Rome ruled the world because they controlled the roads,” and later, “Britain ruled the world because they controlled the seas.” [9] In such a milieu, especially one compounded with persistent yet increasingly questionable international policies like “containment” of hostile regimes and “technology export control” to attempt to control growth of peers and rivals[10], the U.S. is unlikely to shift from its hoarding strategy to a more interdependent model unless its objectives cannot be met without other nations’ resources.

But at present and foreseeable societal rates of investment in macro-projects in space, the math simply doesn’t work for long-term hoarding. Greater interdependency is coming; the evidence is heavy. First, the U.S. could not afford alone even to build a permanent space station. Then, the Shuttle had to be retired to afford a lunar-capable crew transportation system. Next, the U.S. will not be able to afford development of a lunar lander system while continuing to subsidize ISS operations. This “one-at-a-time” pattern continues even into the 2020s: since the U.S. is designing its lunar transportation infrastructure to be expendable, it will not be able to afford to build a lunar base while flying its yet-to-be-built lunar vehicles. Other nations (save possibly China) will be even less able to afford development of both transportation and surface operations infrastructure, so they will have to choose between them. Will they choose to depend on the U.S. and China for transportation, and focus instead on the destination systems and operations? And will the U.S. be willing to depend on a European, Japanese, and/or Russian Moon base as long as it can control the access highway? Perhaps genuine interdependence is compatible after all with a hoarding strategy – interdependence leads to specialization, which in turn enables providers to protect their unique technology. In this way interdependence via “clean interfaces” could possibly be made attractive to hoarding nations.

Embracing rather than resisting interdependence would enable the quickest possible development of the lunar frontier. Once the inevitability of interdependence for making significant progress in lunar exploration is accepted, effort spent emulating other nations can be seen clearly as wasteful. In this regard, the most important legacy of the ISS might be that it has helped nations begin to overcome their history of emulating the leaders. Helped, but not cured: within the framework of ISS, now four players have the capability to build habitable modules: the U.S., Russia, Italy/Germany, and Japan. But a complete lunar operations infrastructure comprises elements far more diverse than does the ISS. Mobile surface vehicles, construction equipment, resource processing plants, power generation and storage plants, and siteworks like roads and shielding are needed in addition to the type of laboratory and logistics modules, telecommunications and thermal control utilities that could be derived from ISS. A significant lunar basing operation will therefore require participating nations to specialize even more; this in turn will require them to cede expertise in system technologies for which they have been emulating each other up to now.

It is unclear that any of the likely participating nations save Canada appreciate the degree to which their individually limited resources will combine with their mutually-reinforcing appetite for progress to force interdependence among them. Of course, efficient progress is not inevitable. The easy alternative to interdependence is that nations simply accept slower progress, as they labor autonomously to continue to match each others’ capabilities. However, should the interdependence model come to pass in extending human presence to Earth’s Moon, it could prove to be one of the most significant legacies of lunar settlement for human societal development. The evidence would be that, like Canada, otherwise competitive nations eschew or relinquish the tradition of matching each other’s capabilities, and instead pool their unique capabilities to accomplish meta-objectives. This would be progress indeed.

Maximizing return on the global human space investment

Our analysis can be applied at a higher level. If nations' joint desire for combined progress can overcome their attraction to the emulating model, then perhaps they could develop the courage to choose orthogonal paths in space development, rather than work toward a singular objective selected by one of them.

Table 2 listed several potential space futures that will not occur as long as the world's spacefaring nations apply their resources – either complementarily or competitively – toward an eventual goal of human planetary exploration. Yet each of these alternatives would yield substantial benefits for humanity, as the table indicates. Would it be possible for nations just crossing the threshold of spacefaring autonomy, e.g., India or Japan, or without a particular need to follow, e.g., China, to target such alternative objectives? From the standpoint of our global species, the result would be to make humanity's "portfolio" of advanced space activities more robust by becoming diversified.

The predominant factors determining the question of feasibility for such an orthogonal model of engagement are likely the very human motivations, discussed with respect to Table 1, that drive nations' actions. Often, the courage of a nation is a direct function of the courage of its leadership. Taking an orthogonal path would require the temerity to pioneer new areas of technology and benefit, and be seen as fundamentally different from "the pack." But there is also a quantifiable factor governing the feasibility of orthogonal engagement: presuming that the dominant spacefaring leader defines one agenda, and that follower nations sign on to this agenda to enable it through the interdependence model, how many nations could be spared to take on other agendas? That is, how many of Earth's nations will it take to "do" the Moon, and can there be residual capacity that could be applied to other goals at the same time? For example, suppose as seems likely that the U.S. sets its sights on lunar operations to build confidence for human missions to deep-space exploration targets like near-Earth asteroids and Mars. Then suppose that European investment in habitable systems and Japanese investment in mobile robot systems are combined with the U.S. investment in lunar transportation infrastructure to comprise integrated lunar surface operations. Is there enough global space capital and high-technology capacity remaining to enable another macro-project? Could Hong Kong financing, Russian access to Earth orbit, and Taiwanese carbon nanotube materials technology be combined to develop a space elevator in parallel with everyone else's pursuit of lunar surface operations? Were that to be feasible, wouldn't the result be a revolution in access to space that in turn opened yet more diverse futures?

Such questions are rare. The total potential value of human investment in space development is diminished when nations simply duplicate each others' focus. The interdependence model maximizes efficiency for pursuit of a common vision, but the orthogonal model maximizes the global value proposition. As occurred in the evolution of economic civilization itself, "division of labor" would maximize total return to the species, and therefore the rate of progress of human technological evolution, by enabling parallel progress on multiple worthy goals. Nations already committed to investing vast resources in space programs could conceivably choose to pursue complementary or independent objectives. The result would be an ambitious, robust "global portfolio" that would yield greater societal benefit sooner than default plans based on the emulating model. Just as in the economic management of industrial enterprises, courageous choices of what to pursue, versus what to purchase or leverage through partnering, could make our collective development of space more relevant to larger fractions of the population, more exciting to those who seek inspirational goals, and faster for all.

References

[1] For perspective, consider that the total cost of restoring U.S. capability to operate human lunar surface missions is widely believed to be of order $100B, spread over 15 years. This sounds like an enormous sum, yet Americans spend about $100B per year on pizza, alcoholic beverages, and cosmetics. Joyner, R., "Space Systems." *Aerospace America*, American Institute of Aeronautics and Astronautics, December 2005.

[2] Saradzhyan, S., "Russia Looks to Consolidate Space Industry," *Space News*, July 31, 2006. Reports plans by Russia to increase its share of a $22B per year international market from 11% to 21% by 2015.

[3] 2005-vintage ESA roadmaps used for reference by NASA and other agencies show human technology demonstrator missions by 2016, human Moon missions by 2026, and human Mars missions by 2035.

[4] Westlake, M., "Space program engenders pride…and pause," *Aerospace America*, American Institute of Aeronautics and Astronautics, July 2006.

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[10] Westlake, M., *op cit*.