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FUTURE DIRECTIONS FOR INTERNATIONAL SPACE COLLABORATION FOR EXPLORATION

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***Abstract*—This paper analyses potential future collaborative space exploration architectures in terms of i) the technical capabilities of contributing partners; and ii) the constraints imposed by internal and international politics. We find that when international partners are considered endogenously, the argument for a "flexible path" approach is weakened substantially. This is because a) international contributions can make "moon first" economically feasible; and b) characteristics of proposed "flexible path" approaches may preclude international involvement due to the disproportionate risk that those contributions inherently bear. This could have serious implications for future collaborations. We also note that while there are multiple feasible collaborative architectures, there is currently substantial overlap among what the international partners are identifying as potential niche contributions.**

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I. INTRODUCTION

Sustainable space exploration is a challenge that no one nation can do on its own. (Global Exploration Strategy, p.2)

Space exploration is an immense undertaking, both technically and financially, that no one nation can accomplish on its own. This reality has been acknowledged explicitly in international framework documents, and implicitly through collaborative bi- and multi-lateral undertakings by all the major players in the space arena. For the first time, there are multiple space agencies ready and capable of making significant technical contributions to a global initiative.

Yet, while international partnerships become increasingly prevalent, echoes of cold war space mentalities in the form of protectionist tendencies and prestige-oriented posturing still underpin internal political agendas. And these internal agendas constrain the set of politically feasible alternatives. The impact of internal politics is particularly evident in the current debates over US Space Policy. Unwilling to give up space "leadership," yet unwilling to fund a program that could achieve it, NASA has been continuously asked to achieve too much, with too little. The most obvious way out of this dilemma is for the US to take a leadership role in a global exploration strategy; however the details of such an approach are far from clear.

Potential international partners have political needs as well. With newfound technical capabilities, comes an expectation to be treated as a "first class partner." While many of the traditional partners respect the complexity of the US internal decision making process, there is a limit to how many unilateral changes in direction they will tolerate.

Defining an exploration strategy that i) leverages the comparative advantages of contributing nations, ii) fits within the resources of contributors, and iii) establishes a sufficiently important position for all, is a complex problem. It is not one that will be solved in this paper. Our goal is merely to add some clarity to an ongoing debate. In negotiations, managing ambiguity is a common strategy for achieving consensus, but in specifying alternatives it is counterproductive. As academics, we have the luxury of addressing that ambiguity directly and examining tradeoffs.

To that end, section II examines the strategies and program elements that have been proposed and defines the terms as we will use them. Section III then analyzes the perspectives of 4 space agencies in terms of their priorities and capabilities. Combined these pieces form the basis for section IV, which explores the "tradespace" of possible collaborative contributions, by focusing on strategies that are both technically and politically feasible.[1] The paper concludes by discussing the key issues that it identifies.

II. Exploration Concepts and Definitions

One key challenge in discussing potential roles and opportunities for coordination in the context of a global exploration architecture is the ambiguity that remains in the definition of key elements and objectives. As a basis for the discussion that follows, this section seeks to clarify the key concepts used in this paper. These definitions are provided in Table 1 in the context of lunar exploration with examples from the Constellation program.

Table 1 – Definition of program elements

Program element	Definition
Robotic precursor missions	In agreement with the 2010 ISEGC reference architecture [1], these are defined as fulfilling several related functions: characterizing the lunar environment, resource prospecting, materials testing, and demonstrating technology and operations concepts. This will require some combination of orbiters, rovers, instruments, communication networks and related infrastructure.
Crew Capsule	Designated Orion in the Constellation plans, the capsule is designed to be capable of transporting four astronauts from Earth for short to medium duration space journeys (for example to lunar orbit). By itself, Orion was not designed to provide the radiation protection necessary for longer duration space flight (such as to the journey to Mars orbit). Any additions to the crew capsule (or separate crew living quarters) are considered as part of the crew capsule in this analysis.
Crew Launch Vehicle	This refers to any human-rated rocket capable of launching a crew capsule to LEO. Under the Constellation plans, Ares I was designed to launch the capsule into LEO for rendezvous with the Earth Departure Stage (EDS) and lunar surface access module.
Earth departure Stage (EDS)	The Earth Departure Stage (EDS) is the main propulsion system that would send the crew capsule and lunar surface access module or a cargo lander from LEO to the Moon. Under the Constellation plans, it is the second liquid stage of the Ares V rocket. Although any lunar spacecraft requires appropriate propulsion, the term EDS in this paper refers only to the EDS required for hardware launched by a Heavy Lift Vehicle. It is assumed that any robotic missions or supplementary cargo deliveries launched on smaller rockets will require only a simpler EDS that will not be separately considered here. Some architectures call for the EDS to be refueled on-orbit.
Heavy Lift vehicle (HLV)	This refers to any rocket capable of launching both the EDS and the lunar surface access module (or cargo lander) together. Designated Ares V in the Constellation plans, it would have a maximum payload capacity of about 414,000 lb to LEO. However, a vehicle with a smaller payload would still be classed as an HLV in this paper if it is capable of carrying out the mission.
Lunar Surface Access Module	This would be the main transport vehicle for lunar-bound astronauts. Designated Altair in the Constellation plans, it consists of two parts: an ascent stage housing the four-person crew; and a descent stage containing the landing legs, the majority of the crew's consumables, and scientific equipment. Note that a complete international architecture could possibly include additional lander designs, as cargo-only landers would also be beneficial.
Surface Robotics	While the robotic precursor missions will employ some similar technology, "surface robotics" refers specifically to the pressurized rovers and assistive robotics that will facilitate human exploration.
Surface Habitation Modules	A specific scenario for a lunar mission has yet to be chosen, but pressurized habitation modules and associated infrastructure will be required for any sustained human presence. These could be delivered by cargo-only landers, likely based on the lunar surface access module.
In-orbit assembly or refueling	This refers to any orbital infrastructure that supports an exploration mission. Although not required by Constellation, a number of ideas have been suggested to enhance future missions; these include refueling and lunar orbit infrastructure to support crew exchange or provide a safe haven for astronauts.[3],[4]

As presented in Table 1, some program elements are much more clearly defined than others. This reflects the reality of the development; while some of the Constellation elements have already begun testing, operational concepts for surface activities have yet to be rigorously defined. These less clearly defined elements are where international contributions are expected to be focused. They are also the elements that won't be needed (or are at least most subject to change) if target destinations continue to change.

Since President Bush proposed his Vision for Exploration in 2004, several unique exploration strategies and frameworks have been articulated, each with different implicit and explicit destinations and architectural requirements. In order to clarify the alternatives that are currently on the table, and their implications for international collaboration and program elements, the below section provides a brief summary of the evolution of the various proposed strategies as well as a discussion of the potential paths.

A. Evolution of the US Exploration Program

In response to President Bush's Vision for Space Exploration, NASA's Exploration Systems Architecture Study of 2005 formally defined the Constellation program. This plan emphasized minimizing cost by reusing existing hardware designs and established the goal of landing on the moon by 2020 with the eventual objective of reaching Mars. Constellation led to the development of the Ares I launch vehicle to replace the retiring shuttle as well as programs for the Orion Crew Capsule, the Ares V heavy launch vehicle and the Altair Lunar Module [5].

Over the next five years, key contracts were let and development began on Orion, Ares I/V and to a lesser extent Altair. However, by 2009, when President Obama took office, the program was already several years behind schedule and over budget (see for example [4] pp 11-12). In response Obama chartered the Augustine Commission to conduct an independent review of the Constellation Program. The commission concluded that there was no viable strategy for exploration beyond LEO at current funding levels and proposed a series of solutions including the Flexible Path to involve commercial industry and international partners in future space exploration missions. Based on these findings, President Obama's FY2010 NASA budget proposal (subsequently clarified in his address in Florida, which we will refer to as the White House proposal) cut Constellation funding and adopted a strategy which combined the use of commercial companies to launch crew to LEO, NASA development of a heavy launch vehicle, and use of the Ares I launch vehicle and the Orion crew capsule as a rescue vehicle for the ISS and future exploration missions. Although the eventual destination was still assumed to be Mars, near term targets would include NEOs [7].

This radical change in direction prompted a heated debate in Congress and the press (for some insightful commentaries c.f. [7][9][10][11][12][13]). Strong language, like "*the president's proposed NASA budget begins the death march for the future of U.S. human space flight*" was used repeatedly. During the first half of 2010 the true drivers of US space policy became clear (as will be discussed more in the NASA section below), culminating in a House and Senate proposed compromise. As of this writing (August 2010), the Senate proposal seems most likely to prevail. Although it does not specify an explicit destination, it is quite clear about the program elements that NASA shall develop. The authorization bill instructs the agency to initiate development of a heavy-lift vehicle next year (rather than 2015, as the administration had planned,) [1] rebrands Orion as a full-fledged multi-purpose exploration vehicle, and implied that the crew launch should be government not commercial[14]. It remains to be seen which elements of the White House proposal survive the appropriations process, but it seems fairly certain that key elements of Constellation will persist.

B. International Contributions to the Global Strategy

Following the articulation of the Constellation program, which implied a role for international partners, fourteen space agencies came together in 2007 to make that role more explicit. They produced the Global Exploration Strategy (GES) which would serve as a non-binding framework for international coordination to support a sustainable plan for future space exploration beyond LEO. The framework took NASA's Constellation program as an input and suggested complementary roles for international partners[15]. Since that initial meeting in 2007, several coordination conferences have been held. At these meetings, the various partners have had the opportunity to communicate their interest in particular pieces of the architecture through status presentations. As another step towards defining the roles of international partners, an ISECG Reference Architecture was defined in 2009. However, this document still leaves considerable ambiguity about the roles of the various potential contributors.

C. Architectural Alternatives and Destinations

In all of the above described proposals, Mars is implicitly assumed to be the ultimate destination because it is considered to be both the most scientifically interesting destination in the inner solar system and the destination most suitable for sustaining human life. However, there is significant variation among the strategies in terms of the path they will take. The below discussion briefly summarizes the most likely approaches, as articulated by the Augustine Commission.[4]

- **Moon First:** This option is characterized by a sustained human presence on the moon before going on to Mars. There are three sources of motivation for a mission to the Moon: the scientific value of studying the Moon (or using the Moon as a site for observatories or low gravity science), resource utilization, and technology development in preparation for a future mission to Mars. Astronauts can remain in contact with Earth from the Moon without the long delay that would be experienced when operating on Mars. Furthermore, return to Earth from the Moon in an emergency would be possible within a relatively short time.

  NASA has developed a detailed architecture for many of the required elements under the Constellation program and other space agencies have been considering ways in which they can contribute to such a mission under the Global Exploration Strategy.
- **Mars First***:* This option chooses Mars as the first target destination after no more than a brief test flight program on the Moon. It is currently not a main focus of any space agencies' exploration plans.
- **The Flexible Path**: This option allows for visiting "interesting" in-space destinations such as near–Earth objects (NEOs) or Lagrange points before visiting on-surface destinations on the Moon or Mars. The exact target destinations can be adjusted as the program progresses to tailor destinations to contemporary scientific, public and political goals. Many of the architecture elements mentioned in Table 1 would be required even for the initial NEO missions, and so this provides a path for intermediate technology development and demonstration to support a future Moon or Mars mission. The Augustine Committee argued that this approach achieves exploration firsts earlier because fewer technology development programs are needed to reach a NEO than the surface of the Moon.

  The White House proposal corresponded to a flexible path approach with a NEO as the first destination. The Senate proposal is in theory a refinement of the White House proposal, and it thus assumes a flexible path approach; however the heavy emphasis on correcting the immediate shortcomings of the US space program (assured crew launch and heavy lift capability) means that plans for the future were not extensively defined.

Therefore the two most likely options for space exploration architectures going forward are (1) a program to establish a human settlement on the Moon with potential to then go to Mars, or (2) a flexible path strategy with a NEO as the first destination. Table 2 below outlines the potential architectures under columns corresponding to these two exploration paths. Of the Moon First architectures, the country allocations for Constellation follow the published NASA plans closely, while for the more loosely defined

[1] It must be capable of delivering seventy tons to orbit and use the shuttle's launch pads and SRBs.

GES[14]/ISEGC[1] we have noted any countries which have claimed or demonstrated an interest in the technology (during for example, the series of coordination workshops discussed above). Of the flexible path options, we also noted whether the capability was a US government led effort or a commercial development. This latter approach may allow international organizations more involvement with the plan as subcontractors or shareholders, particularly if US technology export restrictions are further relaxed over coming years.

Some elements discussed in Table 2 are binary developments likely to be undertaken by a single country. For example, it would be unusual for multiple countries to develop a heavy lift vehicle for a joint exploration mission. Other elements are more susceptible to multiple countries contributing, such as surface robotics or surface habitation modules. A good example is the ISS, where only two countries are involved in crew transport, but several more have built modules, and many more have flown payloads. The table notes where multiple contributions might be valuable, and whether the exploration architectures have settled on a single design.

Key for Table 2:

Begin development in the short term (2010-2015)
Medium term (2015-2020)
Development in the long term (2020 onward)
Architecture element optional or flexible or not required

Table 2 – Potential Architectures

Program Element	Moon First (Constellation and GES)	Flexible Path, starting with NEO (White House and Senate Proposals)
First Human presence date	2023 (Moon)	2025 (NEO)
Robotic precursor missions	International (both) Includes missions led by the United States, ESA, India, China and Russia, with payload or sub-system contributions by others.	International. International partners not yet specified, but likely to include all interested nations as for Moon First.
Crew Capsule	United States (Constellation) Not Specified (ISECG/GES) May draw on Soyuz heritage.	United States commercial (White House) United States government (Senate)
Crew Launch Vehicle	United States (Constellation) Not Specified (ISECG/GES) but ESA and Russia are most likely non-US participants given LV experience.	United States commercial (White House) United States government (Senate)
(moon) Earth departure Stage	United States (Constellation) Not Specified (ISECG/GES) but ESA and Russia are most likely non-US participants given LV experience, perhaps Japan.	United States government (both proposals)
Heavy Lift vehicle	United States (Constellation) Not Specified (ISECG/GES). Likely to draw on ESA / Russia experience, if sourced outside the US.	United States government (both proposals). Required only at reduced capability for a NEO-only set of missions. Full capability required for full flexible path to Mars.
(moon) Surface Access Module	United States (Constellation). Scope for international cargo landers. Not Specified (ISECG/GES)	Optional
NEO Robotic Assistants	Not required	Not specified (both proposals), implicitly US-centered.
(moon) Surface Robotics	United States (Constellation), though not yet exclusively defined. Not Specified (ISECG/GES) but international participation expected to be significant.	Optional
(moon) Surface Habitation Modules	United States (Constellation), though not yet exclusively defined. Not Specified (ISECG/GES) but arguably ESA and JAXA have demonstrated similar capability with ISS modules.	Optional

(mars) Earth departure Stage	United States (Constellation) Not specified (ISECG / GES), comments as for Moon EDS	Optional
(mars) Surface Access Module	United States (Constellation) Not specified (ISECG / GES)	Optional
(mars) Surface Robotics	United States (Constellation) though not yet exclusively defined. Not specified (ISECG/ GES) but interest from Canada and Japan.	Optional
(mars) Surface Habitation Modules	United States (Constellation) though not yet exclusively defined. Not specified (ISECG/GES)	Optional
In-orbit assembly or refueling	Not required (Constellation) Not specified (ISECG / GES) but interest from Canada.	Required as a flexible path element (White House); not specified (Senate). Scope for international participation.

From this point forward, the list of program elements will be collapsed to focus on the first step on each path.

III. KEY PLAYERS AND THEIR PERSPECTIVES

Having examined the technical content of the various exploration strategies, and to a lesser extent the timeline and motivations for their evolution, in this section we consider the positions of NASA and three key international partners – ESA, JAXA and CSA. We chose to focus on this subset of major space players for practical reasons. Namely, for this analysis to be meaningful, we must be confident in our ability to obtain, interpret and assess the validity of our data (which includes press articles, reports, and some interviews with key individuals). We believed this was possible for the agencies we chose for the following reasons. Among the authors, we have citizens of Canada, the UK, Australia and the USA, (and were able to consult with colleagues from Japan) with professional experience working with/at NASA, ESA and CSA. However we did not feel competent to assess the capabilities of and motivations behind, for example, Russia, China and India's efforts because of language barriers as well as the limits of open, reliable and accessible information. That being said, in keeping with our purpose of framing an important discussion, we welcome the contribution of others with complementary expertise.

In the sections that follow, we analyze each of NASA's, ESA's, JAXA's and CSA's perspectives on exploration in terms of both priorities and capabilities, as expressed internally and on the international stage.

A. NASA'sPriorities and Capabilities

US space exploration has many stakeholders and consequently many different goals. For most of these stakeholders, the goals are not framed in terms of reaching a particular destination, but rather in terms of the effect of achieving any destinations on the US economy and international relations.

Many commentators have analyzed the goals of US exploration in detail, and while their specific recommendations vary, their conclusion that the interests in US exploration form a complex web is almost universal.[4][16] The debates in the 2010 congressional examination of the Obama Administration's proposed exploration policy have crystallized four major drivers of US exploration policy: clear US leadership on critical sections of the exploration architecture; US involvement (perhaps exclusively) on the elements of the exploration architecture which most closely impact US national security; no reduction in US manufacturing and development; and, increasingly, international engagement.

Clear US leadership: It is unacceptable to many in the US that the US is not the world leader in human spaceflight. Exactly what is required of a world leader is unclear. Many in Congress have argued that the US requires at least a nationally controllable capability to launch humans to space. Some set LEO as the goal; others more ambitious targets like deep space or the Moon. The lack of articulation of the capability which constitutes national leadership has contributed to the diversity of views in recent debates. The majority view seems to be that US leadership means that the US retains a national capability to deliver humans to LEO, and does not lag any other nation in its capability to deliver humans to more distant destinations.

US involvement on national security elements: Some sections of an exploration infrastructure have clear national security implications. Launch vehicle technology in particular is so closely linked to military missile development that the US has been historically reluctant to cooperate with any nation on launch vehicle programs. This reluctance, combined with the strong US capability in launch vehicle development, makes it likely that the US would seek to preserve its existing dominant role in exploration launch infrastructure.

No reduction in the amount of US manufacturing and development: A third strong theme underpinning congressional debates on US space policy is employment. The employment interests of individual districts have largely been preserved over more sweeping reforms in US policy. In any international architecture it may be possible to develop US project goals which move workers from one US project to another, but a net loss in workers in the US space industry, would be a very difficult policy to pursue in the current economic climate.

International engagement: Increasingly, US exploration policy is used as a tool of international engagement. The most striking example of space diplomacy was President Clinton's 1993 invitation to Russia to participate in what became the International Space Station. Purely from an internal US point of view, one of the goals of US exploration policy is to further US diplomatic efforts. Such international cooperation may also allow the US to better achieve its own exploration goals.

Of all the participants in an international exploration program, the US has the broadest capability and the most extensive experience. Technically, there is no element of an exploration program that the United States would be incapable of building. At the same time, the support for space exploration across the stakeholders in the US exploration program is insufficient to deliver the funding to meet the goals outlined above. The irony of this position is that the United States requires international cooperation in order to further US leadership and national prestige. It is likely that an exploration program solely within the bounds of US human spaceflight budgets could meet US goals of national security and job retention. The goal of international engagement is best met with international participation in any exploration architecture.

The Augustine Committee's finding that the NASA budget for space exploration has regularly failed to meet the amount required to meet the goals set for NASA is a clear demonstration that the US is financially incapable of meeting its own space exploration goals.[17] The eventual technical successes associated with the International Space Station, Shuttle program and Mars robotic explorers are not in doubt. The failures associated with those programs have largely been failures to deliver on-time and on-budget.

Political reluctance to disturb the current US worker base may also affect US capability more subtly. An unwillingness to lay-off workers at the Decatur, Alabama rocket production line may see the US continuing to build launch vehicles on that production line, limiting US launch capability to five meter core diameter vehicles.[18] Individual representatives have very successfully lobbied for particular work packages to remain undisturbed in their own districts through the most recent congressional debates on space policy. If this trend continues, then the US capability to *change* from its current capability may well be affected.

In discussing US exploration capability, therefore, it is not a question of what can or cannot be done technically, but how much can be done within the US exploration budget. It is clear that the US faces a difficult choice between ceding some aspects of exploration to international partners, potentially affecting national security and US prestige, and risking total failure to achieve goals due to budget pressures if it pursues a unilateral approach. The most obvious way out of this dilemma is for the US to take a leadership role in a global exploration strategy, however the details of such a role which would be at least satisfactory to a majority of the disparate US stakeholders interested in exploration are far from clear.

B. ESA's Priorities and Capabilities

Europe's overall goal for space exploration is to expand knowledge and stimulate the development of innovative new technologies. Space is also viewed as essential to projecting the image of Europe as a major player on the world's political stage; Europe wishes to be seen as possessing space technology that is second to none and as rising to the space exploration challenges laid down by Russia, China, and the US. By participating in joint projects with other nations, they hope to strengthen global security by sharing challenging peaceful goals. Finally, space is seen as having the potential to help cement a sense of European identity among the citizens of the EU and to inspire the young to develop a greater interest in science and technology. [5],[20]

The first has long been the motivation behind space science and exploration for all of the ESA member states. However, the remaining goals have recently acquired new significance since the 2007 Lisbon Treaty, which implemented fundamental legislative reforms within the EU, crucially including the creation of a European space policy and the establishment of relations between ESA and the EU [21]; this is in contrast to the previous arrangement in which space policy was implemented only at the level of individual ESA member state governments and not at the level of the European Commission. Strengthening European unity and cementing the EU (rather than just its individual member states) as a major political player on the world stage are among the key concerns of the EC and provided much of the motivation for the Lisbon treaty as a whole.[22] The remaining goals outlined above are therefore now likely to play a greater role in motivating ESA's exploration missions than in the past. Indeed the EC has identified space exploration as a new priority area [5] and it is believed that the next EC spending cycle in 2014-2020 could significantly increase ESA's budget to provide for a significant expansion in the scope of future exploration activities.[23]

Although ESA has launched the robotic probes Gioto, Mars Express, Venus Express, and Rosetta, these were not part of any long-term exploration plan. The Aurora plan for the exploration of the solar system was initiated in 2001, but no missions have yet been launched.[24] This was initially envisaged as a primarily European project, but delays led to the first missions becoming joint robotic missions with NASA, the first two of which are known as ExoMars[25]. Human exploration is specifically mentioned as a long term goal, but even the robotic missions require considerable advances in technology and so it may be many years before ESA is able to focus on human spaceflight beyond the ISS. Despite this, the basic requirements for many of the key exploration technologies – such as descent and landing – are shared by both human and robotic missions and so it is reasonable to say that ESA is slowly moving along a path towards its aspiration of human exploration.

The current level of ESA exploration funding would be insufficient to undertake a meaningful exploration program alone, as was seen with the delays to the Aurora program until a partnership was reached with the US. However, this situation could change if additional funding is received from the EC. European technology is certainly rapidly developing towards the point where a complete independent robotic exploration program could be achieved, as the US contribution to ExoMars is predominantly in launch services rather than rover hardware[25]. However, although currently only at a concept stage, Aurora's ultimate goal of human exploration can only realistically be achieved through international cooperation.

ESA is presently well-placed to contribute to the future of international collaboration in exploration; not only are advances being made in robotics, but European industry also has significant experience with manned spacecraft, having built the Spacelab modules and 50% of the pressurized volume of the ISS[26]. ESA currently lacks a re-entry vehicle, but initial development of an evolved ATV with re-entry capability – and ultimately manned launch capability – is underway [27] .

The extension of the ISS until at least 2020 was welcomed by ESA and it is now eager for other countries to become involved.[28] It views the ISS as a stepping stone to future collaborative endeavors capable of reaching goals beyond those that can be attained by any one nation. However, it has learnt from the failed initiative to build a joint crew transportation system with Russia; although the global partners are able to work together with complementary roles, attempting to jointly develop specific hardware is not always practical due to differences in technology. [29]

It is viewed as essential that ESA should play a leading role in future missions and not be seen merely as a second class partner.[20] Development of independent European manned access to space is also necessary to secure ESA's status in the world, although this is likely to first be in the immediate context of the ISS rather than a future exploration mission[30]. ESA has embraced the Global Exploration Strategy, proposing a lunar cargo lander and associated infrastructure as the key European contribution [6]. However, this would represent a significant investment and would depend upon NASA taking a leading role in lunar exploration; if the US does eventually decide to continue with plans for lunar mission, careful negotiation will be required to ensure that ESA is able to extract firm commitments about US goals to ensure that European efforts are not wasted.[3]

C. JAXA's Priorities and Capabilities

Like many national space agencies, the Japanese Aerospace Exploration Agency (JAXA) has struggled to achieve a unified vision for exploration as the organization is continuously exposed to political and economic uncertainties as well as the whim of international partners. To concentrate Japan's space efforts, Japan established its Basic Space Plan in May 2009. This policy outlines Japan's space strategy and guides national decisions for future space activities. The plan identifies five fundamental objectives Japan intends to accomplish through space utilization: 1) build prosperity; 2) contribute to national security; 3) promote diplomacy; 4) develop industries; and 5) invest in national dreams and in the next generation [32].

Under the provisions of the Basic Space Plan, Japan is working to expand its space capabilities and foster a sustainable relationship between industry, government, and international partners. For example, Japan recently reached an agreement with the Japanese fishing industry to allow year-round launches from its Tanegashima and Uchinoura space centers located in southern Japan [33]. These restrictions were previously viewed as a significant barrier to establishing Japan as a leader in space launch and exploration. Japan has also made progress in expanding the capabilities of its launch vehicles. Since the launch of the first H-IIA rocket in 1994, JAXA in conjunction with Mitsubishi has expanded the H-II family to suit a variety of space missions. The first H-IIB was successfully launched in September 2009 and enables Japan to lift eight tons to geostationary transfer orbit (GTO) [34].

Japan is also a capable producer of satellite and robotic exploration technologies. JAXA's *Hayabusa* asteroid sample return mission reentered Earth's atmosphere in June 2010 and has attracted much attention as scientists eagerly wait to learn if the spacecraft successfully collected contents from Itokawa's surface. Looking forward, JAXA has several exciting missions underway such as the Greenhouse Gases Observing Satellite *IBUKI* – launched in January 2010. The *IBUKI* sensor suite is measuring greenhouse gas concentrations at 56,000 locations on Earth's surface in an effort to better understand global climate change [35].

As an international partner, Japan is a supportive but cautious proponent of cooperative space exploration. During the development of the ISS, NASA imposed several costly redesigns and delays on Japan and other international partners. Congressional budget cuts during the Clinton administration forced NASA to reduce the scope and pace of development for the ISS. Despite the delays, Japan remains loyally committed to the ISS program and continues to contribute astronauts and hardware toward its sustained operation. Most notably, Japan was responsible for producing the Kibo science module, the largest on the ISS. In addition to providing resupply services with its H-II rockets and expendable transfer vehicles, Japan is currently working to produce the HTV-R, a variant of the existing transfer vehicle capable of returning cargo from the space station [36].

Japan's reaction to the recent reorganization of NASA priorities has been largely tempered by global concerns for the economy and security. While highly motivated and technically competent to pursue challenging space exploration missions, Japan lacks the necessary funding to support such aggressive goals let alone a human space program. Japan has expressed great support for the recent decision to extend the ISS through 2020, but the Japanese response to the uncertainty surrounding America's space program has been muted. Unlike the ISS, Japan had no direct commitments to the Constellation program. Analysts speculate that Japan was positioning itself to contribute to U.S. lunar missions by designing the surface landing system; Japan has been developing lunar soft-landing technology using its *SELENE 2* spacecraft, a follow-on mission to the *SELENE 1* high-fidelity lunar mapping mission [37]. Such technology may be adapted to future planetary missions.

Japan's primary objective for space exploration is to promote advanced research and development while reinforcing diplomatic relations and delivering value to society. Japan is motivated to pursue cooperative exploration missions, but a repeat of the ISS debacle would be politically and financially unacceptable. Japan's leadership in heavy industry and electronics make the nation an indispensible resource for future exploration missions. As such, from Japan's perspective, going forward it must be recognized as an equal partner in future missions, and these missions must align with Japan's domestic space priorities.

D. CSA's Priorities and Capabilities

Canada's exploration goals are driven by two factors: public expectation and support for Canadian industry.

Momentum from successful Canadian astronaut involvement in the ISS and in signature engineering projects like the Canadarm has fuelled a public expectation that Canada will continue to be involved in international space exploration projects.

Similarly, Canadian exploration is seen by Canada as an investment which enhances its high-technology industries.

> *"CSA's programs and activities attract highly educated and highly skilled labour that contributes to Canada's knowledge-based economy, helps enhance the Canadian space industry's competitiveness by encouraging dynamic trade relationships with other nations, and increases Canada's ability to compete in the global marketplace".* [39]

The investment in exploration and space science at around C$185 million is dwarfed by the $2 billion commercial satellite market.[39] The Report on Plans and Priorities (RPP) broadens the impact of Canada's exploration to science and technology generally, stating that Canadian achievements in space *"brand Canada as a science and technology focused reliable trading partner."[39]*

Despite these strong protestations of support for the Canadian Space Industry, there are indications that exploration is not a major item on the Canadian political agenda. Canada's funding of the Canadian Space Agency is at much lower absolute levels than other space agencies,[39] [40][2] while the government appears to be dragging its heels on cohesive Canadian space policies. The Long Term Space Plan (LTSP) a policy document begun in September 2008, is still awaiting government approval. In the absence of an official LTSP, the 2005 Canadian Space Strategy is still the relevant policy framework for CSA.

Exploration forms a small part of the mandate of the Canadian Space Agency. The 2010 Report on Plans and Priorities (RPP), the most recent directive for CSA, is targeted at meeting Canadian needs for "scientific knowledge, space technology, and information." Exploration is not explicitly supported as a national goal, and is bundled with Space Science in the RPP. Instead, Canada focuses on three main areas which cross-complement exploration and domestic Canadian priorities: robotics (relevant to its domestic satellite program), space weather (relevant to communications across the high latitudes of Canada), space life sciences (an existing core Canadian strength).

Canada's goals for space exploration are linked to strengthening and showcasing its domestic industries. International cooperation allows Canada to pick projects well suited to its niche strengths and which deliver the most return for exploration investment. As a matter of strategy, Canada prefers to be an essential partner in any exploration strategy. The Canadian goals presented at the International Space Exploration Coordination Group meeting in March 2009 explicitly state that Canadian contributions should be "critical", which gives Canada a degree of leverage to ensure that its own space priorities are met by the broader exploration program.

The financial commitment to exploration in Canada is too small for it to conduct a meaningful exploration program on its own. If pressed, Canada appears to have the technology to conduct robotic exploration missions without international assistance (though an international partner would need to provide launch services). However, this would run counter to Canadian space exploration goals. The ability to work co-operatively with other nations, focus only on niche Canadian specialties and showcase Canadian skills internationally would be key Canadian exploration drivers missing if Canada chose a solo exploration path.

Canada could make a number of important contributions to any international exploration framework. It has a core expertise in micro-gravity robotics, proven through Dextre on the ISS and the Canadarm on each of the Space Shuttle Orbiters. Canada has less experience with respect to planetary robotics, providing only very specialized components for surface missions like the Mars Phoenix Lander and the planned Mars Science Laboratory.[41] Its involvement with the ESA ExoMars mission is limited to in-space instrumentation. [41] Canada also has a strong life-sciences program and this may lead to contributions to environmental conditioning or life-support systems for long duration planetary stays. Life sciences research will also be critical to deep space missions where the effects of radiation on human physiology still represent a significant barrier to exploration.

Canada's robotic expertise has also led to proposals for more Canadian involvement in in-space docking, refueling and assembly. In a recent interview, Daniel Friedmann, head of MDA, one of Canada's leading aerospace firms, envisioned in-space refueling and servicing as an important growth area for MDA which built on existing Canadian expertise.[42]

In theory, a range of exploration projects could meet Canada's strategy for attracting talent, and boosting Canadian science and technology. In practice, Canada does not have the budget or experience to work on critical human-rated components of the exploration infrastructure like crew

[2] The 2010 Report on Plans and Priorities predicts CSA funding will drop to $312 million by 2013, though this is largely as a result of short term stimulus funding no longer being available. Even on a per-capita basis, Canada's space budget is significantly less than that of the United States.

capsules or launch vehicles. A lack of experience would also count against Canada in developing any cargo propulsion elements or any surface human habitation modules. Therefore Canadian contributions are most likely to be in the areas of robotic precursor missions, robotic exploration assistants and any in-space robotics for on-orbit assembly or fuelling.

Canada may also contribute to other exploration projects as a subcontractor. Canada's close working relationship with the United States means that it could offer Canadian expertise to develop particular instrument packages, as occurred with the Mars Science Laboratory. Admittedly, international cooperation of this sort on science missions is commonplace, however many feel a reluctance by the United States to engage internationally in cutting-edge research or applications. Canada is well positioned to take advantage of any relaxation in this attitude.

IV. ANALYSIS OF POTENTIAL FUTURES

The previous two sections have established the basis for identifying and assessing the feasibility – both technical and political – of potential future global exploration strategies. Section II outlined and compared the major baseline strategies that have been put forward. Section III assessed the value of different levels of contribution to a global exploration strategy from the perspectives of NASA and three key international partners. The goal was to build up a basis upon which to evaluate the "tradespace" of collaborative strategies. Now in Section IV, this "tradespace" is constructed and assessed in both the technical and political domains.

A. The Technical Domain

One of the fundamental assumptions of this work, and the Global Framework for Exploration, for that matter, is that the combined technical and financial burden of space exploration beyond low earth orbit exceeds the resources of any one nation. International collaboration is necessary; the question is thus one of how to best structure such collaboration? To that end, Table 3 provides a structured comparison of the capabilities of each of the agencies in terms of the program elements that will be required for exploration. The idea is to pare down the space of feasible contributions, for analysis in the political domain (section B).

The symbols in the cells are defined as follows, with justifications provided in the sections that follow:

- Capable **(C)**: Either (i) the agency has built something analogous in the past, or, (ii) a definite launch date has been set for the launch of the element or an analog per (i).
- Capability in Development **(D)**: (i) The agency is already putting funds towards this project but has not yet demonstrated success; or (ii) has stated that it is confident that it could achieve the capability in a reasonable timeframe.
- Not Capable **(N)**: The agency is not actively pursuing the area nor does it have any public plans to do so in the future.
- Future capability **(F)**: There are no funds being spent in this area at present, but it is an area that the agency has publicly identified it would like to be involved with in the future.
- **(*)**: An asterisk beside any of the above defined letters indicates that the capability applies only to a subset of the technical tasks that would be required to complete that architecture element (per the definitions in Table 1). By implication, the rest of the technical tasks for that element would be an N or perhaps an F.

Table 3 - Comparison of Technical Capabilities of the Agencies

Program Elements	NASA	ESA	JAXA	CSA
Robotic Precursor Missions (includes satellite reconnaissance and rovers)	**C**	**C**	**C**	**C***
Crew Capsule	**C**	**D**	**F**	**N**
Crew Launch Vehicle	**C**	**D**	**F**	**N**
Earth departure Stage	**C**	**C**	**F**	**N**
Heavy Lift vehicle	**C**	**N**	**D***	**N**
Lunar Surface Access Module (human rated + cargo)	**C**	**D***	**D***	**N**
Surface Robotics (includes buggies, rovers and assistive robotics)	**C**	**D***	**D***	**D***
Surface Habitation Modules	**C**	**C**	**C**	**N**
In-orbit assembly or refueling	**C***	**D**	**D***	**C***

NASA is a very technically capable space agency, with some level of past experience in each of the major program areas. However, many of the elements still require significant additional investment before they will be ready to be used in a mission setting. Thus, given resource constraints, NASA cannot develop all elements of this architecture.

Although *ESA* is unlikely to be in a position to conduct an independent human exploration program, it has developed significant exploration enabling capabilities in both robotics and human spaceflight. While ESA does not yet have independent human access to space, initial development of a human capsule is underway and this will also require human rating for the Ariane 5. ESA will be not in either a technical or financial position to build a heavy lift vehicle in the foreseeable future, but it has conducted a study to outline a possible architecture for a human lunar mission using multiple Ariane 5 launches. There are also plans for a robotic European lander, but this technology has not yet been developed. Finally, the DLR – the German Space Agency – has recently started work on the definition of a future in-orbit assembly and servicing mission[31] and orbital assembly infrastructure has been proposed as a potential European contribution to a future exploration mission [3]. Similar to NASA, ESA is capable of contributing more than is financially realistic.

JAXA's expertises are comparable to those of ESA. Leveraging Japan's place as one of the world's most capable leaders in heavy industry and electronic technologies, JAXA has demonstrated capabilities in robotic missions (e.g., the successful Hayabusa Asteroid sample return mission), has developed an indigenous launch capability and demonstrated human rated habitation modules for ISS (Kibo). Recently, JAXA has announced plans to human-rate the HTV, designated –R, for use in ferrying astronauts back to earth. As with NASA and ESA, the question facing JAXA is one of where to focus limited resources.

CSA is poised to be a niche contributor to a global exploration strategy. While Canada might theoretically have the technical capacity to make major contributions, in practice, Canada does not have the budget or experience to work on critical human-rated components of the exploration infrastructure like crew capsules or launch vehicles. A lack of experience would also count against Canada in developing any cargo propulsion elements or any surface human habitation modules. Therefore Canadian contributions are most likely to be in the areas of robotic precursor missions, robotic exploration assistants and any in-space robotics for on-orbit assembly or fuelling.

B. The Political Domain

Having constrained the space of technically possible collaborations above, the set of politically feasible contributions are assessed. The overriding motivations and concerns are first summarized on an agency-specific basis, and then these political priorities are operationalized in terms of specific program contributions in Table 4 . It must be emphasized that we are considering the political will of contributing particular elements to an international exploration program. This is different from desiring a particular capability in general. For example, ESA associates a human launch capability with legitimacy, but recognizes that this may not be the most appropriate contribution for it to make to an international undertaking, and it is therefore not ranked as a top political priority in this context.

NASA was established in the context of the space race. Although the place of NASA - and more generally space - on the national agenda has fallen from one of primary to ancillary policy, remnants of the legacy pride and national security-oriented justifications for space expenditures still influence US policy to some extent. For example, the prospect of a gap in US launch capabilities tends to bring out protectionist leanings (e.g., "can we trust international partner X not to exploit our position of weakness?") more often than a sober assessment of the technical implications of various tradeoffs. More recently, NASA as a jobs program has surface not so subtly in debates. It often seems that maintaining the current workforce (as viewed on a short-term planning horizon) plays more prominently than any concept of the actual system being developed. Combined, these internal forces make it unlikely that the US would accept (or be able to secure appropriations for) a collaboration that did not include, at minimum US control of launch capability development and the perception that NASA is leading the international efforts. As evidenced by the recent budget discussions, in practice, these concepts translate to Orion, Ares V and if US development of Ares I (which could potentially be done commercially). While various robotic and descent modules are also important, to date there is no budget for them.

ESA and the EC are committed to space exploration both because of the opportunities that it provides for European technology development and for reasons of prestige and scientific interest. ESA is enthusiastic about international collaboration to enable Europe to accomplish more than it could afford to accomplish alone, but it is nevertheless viewed as essential within Europe that ESA should play a leading role in future missions and not be seen merely as a second class partner; this would imply a significant role in both an exploration mission itself and its robotic precursor phase. Although it is perceived that the development of independent European manned access to space is necessary to secure ESA's status in the world, this need not be in the context of an exploration mission. As ESA has at least tentatively investigated all architecture elements aside from the HLV, it is likely that the opportunity to contribute to a human exploration mission in any kind of prominent and critical manner would be politically acceptable. HLV development is not practical in Europe due to budget constraints, which make it essential for a European launch vehicle to be commercially competitive in the satellite launch market. The capabilities of an HLV are simply not currently required in this sector.

With respect to *JAXA*, while the agency may not be independently capable of manned exploration, Japan may be satisfied to pursue a less ambitious strategy on its own, if it better aligns with national objectives, rather than play an insignificant role in a global initiative. Japan's enthusiasm for international missions has been tempered by past experiences with the United States, and Japan is an emerging leader in space among Asian nations. In 1993, Japan was instrumental in founding the Asia-Pacific Regional Space Agency Forum (APRSAF) designed to promote cooperation in space among Asian nations and enhance the development of Asian space programs. A number of highly successful initiatives have been conducted through the APRSAF such as the Sentinel-Asia and SAFE environment and disaster monitoring satellites and the STAR satellite technology program [38]. If Japan were to contribute to an international exploration initiative, it is important for Japan to contribute to robotic operations as well as launch services to maintain and extend the nation's leadership in these core competencies.

Finally, *CSA's* goals for space exploration are linked to strengthening and showcasing its domestic industries. International cooperation allows Canada to pick projects well suited to its niche strengths and which deliver the most return for exploration investment. As a matter of strategy, Canada prefers to be an essential partner in any exploration strategy. The Canadian goals presented at the International Space Exploration Coordination Group meeting in March 2009 explicitly state that Canadian contributions should be on the "critical path", which gives Canada a degree of leverage to ensure that its own space priorities are met by the broader exploration program.

On the surface it may seem like these political needs are in conflict. The US *needs* to lead and maintain control of the "critical path." While the international partners *need* to be treated as valued partners, and protect against impacts associated with unilateral changes by the US; the reality is that past actions have not been forgotten. However, a deeper analysis reveals that these desires may not be so contradictory.

Table 4 captures how the above described motivations translate into priorities at the level of particular architectural elements. Any of the cells marked "N" in Table 4 have been blacked out. The symbols in the cells are defined as follows, with additional explanations provided in table notes as appropriate:

- High priority **(H)**: Not contributing this element would be politically untenable for the agency's authorizer (i.e., this element is required to meet the base internal political requirements)
- Moderate priority **(M)**: The nation/region would really like to contribute this element, and will negotiate hard to contribute at least something market "M". Unlike "H", however, this is not a political "show-stopper."
- Low priority **(L)**: Either (i) this element has been de-emphasized in agency budgets, or (ii) the agency has explicitly indicated that this element is not a priority contribution to a global exploration strategy.
- **(*)** as before, asterisks are used to denote a desire to make a partial contribution only. It should be noted that a lack of asterisk does not imply that the agency must provide the entire system.
- **(--)** is present in the squares that were ruled out on technical grounds (i.e., N in the previous table).

Table 4 – Comparison of the political expectations of the agencies with respect to contributions to a global exploration strategy

Program Elements	NASA	ESA	JAXA	CSA
Robotic Precursors	M	H*	H*	M*
Crew Capsule	H	M	L	--
Crew Launch Vehicle	H	M	M*	--
Earth departure Stage	M	M*	L	--
Heavy Lift vehicle	H	--	M*	--
Surface Access Module	M	M*	M*	--
Surface Robotics	M*	M*	H*	M*
Surface Habitation Modules	M*	M*	M*	--
In-orbit assembly or refueling	M	M	L	M*

C. Identifying Desirable Architectural Alternatives

When the technical and political feasibility tables are overlaid (see the center four columns of Table 5), there is limited new information to be gleaned. The main takeaway is that the US has laid fairly explicit claim to what we are calling its "security core" and is also technically capable of delivering it. Further there are multiple politically feasible solutions for dividing up the rest. The "security core" includes a crew capsule and launch vehicle, as well as a heavy launch vehicle; in recent months, the US Congress has made it eminently clear that these program elements are tightly linked to national security interests, particularly with respect to industrial base concerns. This set of US "must haves" has effectively served as an input to all discussions about a global framework. As a result, the traditional partners have taken care to stake their political capital on complementary niches. The picture becomes more interesting when alternative futures are considered in the analysis.

Table 5 adds a representation of the uncertainty associated with which exploration strategy will be employed, to the above static technico-political discussion. In the table, the symbols from Table 3 and color scheme from Table 4 are overlaid in the center four columns. The outer columns adopt the color scheme from Table 2, restated here for clarity.

- Green: This element will definitely be needed in this architecture scenario and development will begin within the decade.
- Blue: This element will definitely be needed in this architecture scenario but development won't be imitated in the near future (so there is some potential for cancellation).
- Black: This element is either i) not needed; or ii) uncertain with a reasonable potential for cancellation should circumstances change.

Examining Table 5, there are several key takeaways. First, the main opportunities for international contributions are focused in the area of robotic precursors and planetary access and operations. Second, if a flexible approach is taken instead of the baseline "moon first" strategy of constellation, the importance of these planetary access and operations elements becomes, at best uncertain, at worst null. Third, where for the US contribution the technical systems required for a "flexible path" vs. "moon first" architecture are similar, there are huge

Table 5 – Dynamic Technico-political View

Program Elements (Moon first)	NASA	ESA	JAXA	CSA	Program Elements (NEO first)
Robotic Precursors	C	C	C	C*	Robotic Precursors
Crew Capsule	C	D	F	N	Crew Capsule
Crew Launch Vehicle	C	D	F	N	Crew Launch Vehicle
Earth departure Stage	C	C	F	N	Earth departure Stage
Heavy Lift vehicle	C	N	D*	N	Heavy Lift vehicle
Surface Access Module	C	D*	D*	N	Surface Access Module
Surface Robotics	C	D*	D*	D*	Surface Robotics
Surface Habitation Modules	C	C	C	N	Surface Habitation Modules
In-orbit assembly or refueling	C*	D	D*	C*	In-orbit assembly or refueling

differences among the expected contributions of the international partners to these different potential futures. Viewed this way, the uncertainty produced by internal US politics may have more direct implications for the international partners than it does for NASA.

Combined, these takeaways suggest that a core conclusion of the Augustine Commission, that a flexible path approach which phases the development of surface landers and equipment may be the only feasible alternative, may change if the scope of analysis is broadened to include international partners. Specifically, if one assumes a planetary destination, there are multiple sets of contributions that could satisfy all of the political/technical needs/capabilities of each party. The US could maintain its launch expertise (security), and manufacturing workforce (jobs) by contributing at minimum the HLV and potentially the crew launch vehicle as well as the Orion crew capsule. Further, since the world would be contributing to a US-defined architecture, it could certainly claim leadership of the collaboration. This would leave a diverse set of 1) precursors, including remote reconnaissance satellites and planetary robotics, 2) cargo and potentially crew surface access modules, and 3) multiple types of surface robotics and habilitation models, for international partners to contribute.

Within that set, ESA could define its place as a "first class partner" particularly if it contributed either a modified Ariane upper stage to serve as the EDS, or a surface access module. Either of these should easily be considered on the critical path as they would be ferrying US Astronauts at some point. Further, such a contribution would likely guarantee a European Astronaut a place on an early mission – a key intangible in ESA's political calculus. This also leaves "critical" pieces for the CSA to contribute in the areas of assistive and potentially stand-alone robotics. The CSA's governing intangible also relates to Canadian "boots on the moon" although it is harder to assess what size contribution would be necessary on their part. Realistically though, the CSA will participate in any global exploration strategy, and find a niche for their flexible capabilities. While JAXA is intent on breaking into the launch sector, they could likely be excited by a key role in surface robotics and potentially surface access. As with ESA and CSA, placing a Japanese astronaut on the moon is an extremely important intangible.

However, the political calculus changes quite significantly if the US chooses a NEO stop on a flexible path. Firstly, NEO precursors are quite different from moon/mars precursors, in terms of interest, scope and prestige. While they may be technically interesting and novel (to date each of NASA, ESA and JAXA have only attempted one autonomous NEO visit each, where there have been numerous planetary precursor-like missions), the US NEO plan has been described as uninspiring because, in the end, an asteroid is simply not the moon. For similar reasons, international space agencies may prefer to spend their limited exploration budgets exploring more exciting destinations. Finally, there is less scope for building block precursors, depending on the selected target.

Second, the other key international niches of surface mobility and habitation would be effectively eliminated from the picture with a NEO strategy. Interestingly, a NEO destination has limited impact on the near-term US plans, except to the extent that the reduced up-mass requirements make Japan's HLV a viable alternative option. From a US perspective, the main value of the flexible path approach is that it delays the need to invest in surface landing and exploration equipment and provides a more realistic fit for the expected budget profile. The goal is theoretically to get to the moon and mars after the NEO (in fact, based on Augustine numbers, this strategy won't actually delay the human presence on Mars) but realistically, this is an options based strategy – and those options could easily be cancelled.

Given past experience (e.g., ISS) it is unlikely that the international partners would commit significant resources to an effort that makes the value of their key contributions completely contingent on future US decisions (i.e., a lunar descent module has limited utility if the infrastructure for journeying to lunar orbit was cancelled). Furthermore, the initial conceptualization of the flexible path approach was routed in a money spreading strategy (i.e., given a constrained yearly budget, how can the architecture be developed in stages so as to keep the public engaged by making measurable accomplishments?). What this means is that if NASA does decide to carry out the whole flexible path plan and continue on to the Moon and Mars, they may be in a position to proceed independently. With these considerations in mind, the international contribution value proposition is far less appealing.

V. CONCLUSION

It is generally agreed that no single nation has the budgetary capacity to conduct a planetary exploration initiative on its own, within a reasonable timeframe. The Augustine commission argued convincingly that Constellation as planned is unrealistic. The Report offers a flexible path approach as a feasible alternative that spreads the budgetary burden over an extended period, while achieving frequent successes – like human visits to NEOs. However, based on six months of vocal criticism, it's clear that Congress, at least, does not consider the flexible path "*an exploration program worthy of a great nation.*" As a result, it seems likely that an HLV, crew capsule and crew launch vehicle will be pursued by the US in the near term, whether or not a target destination is clearly defined. If the Augustine estimates of development costs and schedules are accurate, this will limit NASA's ability to work on anything else for the near future, if it is not already over committed as is. The Augustine commission suggests in passing that international collaboration may be a viable cost-saving approach, but does not elaborate on this potential alternative because it is outside the scope of their mandate.

With this paper, we have shown that when international partners are considered endogenously, some of the most contentious suggestions of the Augustine commission may no longer hold. Specifically, we find that while a flexible path approach -- with a NEO as a first destination -- may be the only way to achieve the dual objectives of a) excitement and b) budgetary realism for NASA, when international contributions are considered, there are multiple politically and technically feasible architectures that would allow a "moon first" approach. In terms of excitement, the negative response to Obama's budget proposal illustrated that NEO's are not sufficiently exciting no matter how practical. In terms of realism, if NASA focuses on its "security core" while relying on the contribution of some key components (including lunar descent modules) from international partners, NASA gets surface access essentially for "free" and ample opportunities exist for the international partners to find niches that satisfy their base political criteria while extending their capabilities in meaningful ways.

However, the "moon first" alternative still needs to be fleshed out significantly in terms of both i) firm commitment from all parties and ii) partitioning of international roles.

Firm commitment from all parties is a key to a mutually satisfying strategy in this context. In terms of US commitment, as discussed above, a disproportionate level of uncertainty is born by international partners because of the nature of their contributions. Launch vehicles and a crew capsule are needed in almost every future alternative. However, without a destination the value of such development is unclear. The converse is of course also true, if international partners fail to deliver key components as promised, the US may be left with a bigger *truck to nowhere*. Given the lack of unilateral alternatives, it may be time for all parties to commit to trusting each other.

Once a strategic level commitment to a global destination has been made the details of how the "rest" of the architecture should be divided up will require substantial negotiation, and it must be done among the partners, rather than individual agencies claiming niches in the US architectures. In current framework documents, these questions have not been explicitly addressed and they need to be. An important part of these future negotiations will be intangibles political needs, like "boots on the moon" for country X. Part of that negotiation will need to involve an agreement to a longer term strategy. While past experience has shown us that long term strategies tend to change, the reality is that no one will commit to anything if an attempt isn't made to resolve some key ambiguities (including destination, criteria for astronaut spots, nature of each party's contribution).

In laying out these conclusions, and suggesting that the "moon first" architecture needs to be re-evaluated with an international scope, we have ignored a key sentiment of the Augustine Commission's Report: That a sustainable exploration strategy should be capability driven, rather than destination driven. We argue for a clear destination, not because this is the most sustainable technical approach, but because it may be the only politically feasible approach. In this case, Congress has reaffirmed the adage that "*if the politics won't fly, the system never will.*" What this means in this context is that whether or not a flexible path makes more sense technically, cancelling a program that employs thousands of workers in key congressional districts is not politically feasible. If there is to be any program, it must satisfy the vested interests, and given the alternatives that do that, we believe that picking a destination and getting the world on board is the best strategy.

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