An Integrated Policy Framework for a Capabilities-Driven Approach to Human Spaceflight

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Executive Summary

Current U.S. national space policy provides neither the direction nor the means to pursue a robust pioneering effort in the human exploration and utilization of space. The Obama Administration's 2010 National Space Policy proposes sending humans to Mars by 2035. However, it provides no clear path to achieve this goal. While the policy does propose the pursuit of near-term capabilities in deep space, it is not obvious to many policymakers how these capabilities would apply to the ultimate goal of a manned mission to Mars. The result is a confused and unfocused program of manned spaceflight, subject to political whim and fiscal uncertainty. Such a destination-driven approach is intrinsically unsustainable. This paper formulates an alternative approach to national space policy that integrates legislative reforms, commercial opportunities, and developing space exploration technologies under a cohesive capabilities-driven policy framework. It identifies near and long-term changes that will be required to ensure a pioneering human space exploration program that is resilient to fiscal, political and programmatic changes over time, resolving long-standing issues in U.S. civil space policy. This approach seeks to be more sustainable than current efforts, providing the flexibility required for an uncertain funding future.

This paper recommends the following policy:

For the President:

- Direct NASA to focus on a capabilities-driven approach
- Set destinations based on NASA's capabilities
- Issue an Executive Order giving NASA the backing to initiate significant changes to its processes

For NASA:

- Transition to a capabilities-driven approach
- Realign technology areas to capabilities
- Establish a one way funding mechanism
- Begin accelerated development of a multi-mission exploration capability:
- Align internal and external activities with the Global Exploration Roadmap
- Enable the commercial sector to provide capabilities
- Reform internal acquisition procedures to complement and enhance a capabilities driven, modular path

- Seek opportunities to increase programmatic resiliency across the federal enterprise, states, and to a lesser degree internationally.
- Improve outreach to explain the benefits of capabilities vs destinations:

For Congress:

- Explore options to provide budget stability and predictability to NASA
- Expand technology investment in NASA
- Improve Interagency management and processes
- Decrease investment risk in the space industry by enabling regulators to address anticipated markets

Introduction

Current U.S. space policy regarding human spaceflight has failed to live up to popular and congressional expectations. In its present form, it names Mars as an ultimate destination, but does not show a clear path to this destination from current capabilities. Furthermore, it places space exploration goals decades out, reducing the impetus to appropriate needed funds and encouraging fiscal and political uncertainty at the federal level. This has resulted in a stagnation of the development of space exploration capabilities, and a consequent lack of direction for manned spaceflight, provoking criticism from stakeholders.

This paper attempts to address this problem by proposing policy changes that would encourage a robust and sustainable approach to space flight that de-emphasizes specific destinations in favor of building capabilities, thereby increasing human presence in space for the long term.

The following five components comprise the main structure of this policy:

1. NASA should focus on a capability driven approach to human spaceflight.
2. The capability driven approach should be symbiotic with private industry.
3. The capabilities-driven approach should be modular and extensible.
4. The technology areas will collaborate in a nodal approach process that allows different programs to reinforce each other.
5. NASA should reform the acquisitions process, within existing regulations, to be flexible long-term, reduce cost-growth and delays, and increase opportunities.

Background

Mars has long been seen as a horizon destination within the space community, a natural goal for a manned mission at an indefinite time in the future. Previous policy regimes have incorporated the destination as one of several possible endpoints of a process of increasing capability in space whereby near-Earth object, cis-lunar (near the moon), and lunar surface operations would provide the experience that would allow humanity to expand into the solar system. The Obama Administration fundamentally changed this approach in the 2010 National Space Policy. This policy removed the lunar component of the existing plan, focusing manned spaceflight instead on a path to Mars, with exploration of near-Earth asteroids and crewed missions beyond the Moon as intermediate steps.

The current policy is manifested in the proposed Asteroid Redirect Mission (ARM), the development of the Space Launch System (SLS), the continuation of the Orion Multi-Purpose Crew Vehicle, habitation aboard the International Space Station (ISS) through 2024, and various smaller programs within the Human Exploration Directorate of NASA. Critics have noted, however, that these programs possess no clear strategy for achieving the stated aim of a human mission to Mars by 2035, since there are no solid near-term objectives that are unambiguously applicable to a Mars mission. The inherent long-term nature of the stated goal reduces the urgency to pursue it and thus the impetus for a coherent implementation of policy. The result is a confused and ineffectual program of human space exploration.

Capabilities vs. Destinations

At a fundamental level, this state of affairs can be seen as resulting from the tension between two different approaches to human spaceflight: a capabilities-driven approach and a destination-driven approach. A capabilities-driven approach is "based on a set of core evolving capabilities that can be leveraged or reused, instead of specialized, destination-specific hardware,"[1] while a destination-driven approach specifies a destination, with the resulting set of hardware and capabilities specifically tailored to that destination. Examples of both approaches exist in the history of spaceflight. The shuttle program represented a capabilities-driven approach, albeit one which fell short of its original ambitions, providing only a fraction of its intended capabilities. The destination-driven approach is clearly embodied in the Apollo program, which designed and created hardware for the express purpose of sending men to the

[1] NASA, *Voyages: Charting the Course for Sustainable Human Space*. Washington DC: NASA, 2011

Moon. While the Apollo architecture was used by the Apollo Applications Program for purposes other than lunar landings (e.g. Skylab), this program was an afterthought. The current policy regime is an uneven mixture of the two approaches. The 2010 National Space Policy calls for both the development of hardware that would open up a variety of destinations in Earth's neighborhood and naming Mars as a compelling horizon destination[2].

The current approach starts with a mission, and then builds systems around the mission in a hierarchical fashion[3]. The process names the destination, defines the science payload, sets the priorities, and then creates iterations of hardware. Any new technology identified along the way is created to fit the need of the mission and plugged into this approach. Every system is top-down in this sense. The goal for the mission puts pressure on technology development and systems innovation. Since a destination-driven mission has well defined needs, it is considered well-managed if it produces only technologies that support that mission. A destination-driven mission may have other needs, or could benefit from superior capabilities, but it has no incentive to develop anything more than absolutely needed by the hierarchical process. This results in systematic limitations: capabilities that could benefit every mission are never developed because they are never deemed essential to any one mission[4].

This also leads to undue emphasis on the stability of any single mission. If political favor changes and budget priorities shift, it follows that some missions will be canceled before completion. The time spent on the singular goal cannot be reinvested and the money spent is wasted. However, this waste is unnecessary. In a capabilities-driven approach every mission contributes to the overall exploration strategy by developing capabilities that can be used again.

All missions based on a destination-driven approach share the limitations of a hierarchical organization. They have the same limitations irrespective of the ultimate destination of the mission. The hierarchical structure incentivizes the development of technologies that will get the spacecraft to the destination, rather than technologies that might be used for other missions or might prove to be a good foundation for more advanced technologies. Cross-capabilities, or cross cutting technologies, benefit many missions. While there will always be some degree of cross-capability in any technology, it is currently specific missions driving the technology development. However, a capabilities-driven approach focuses on developing

[2] *U.S. National Space Policy*
[3] NASA, *Human Exploration of Mars Design Reference Architecture 5.0*. Washington, DC: NASA, 2009.
[4] National Research Council, *Review of NASA's Exploration Technology Development Program--An Interim Report.* Washington, DC: The National Academies Press, 2008

capabilities that are largely cross-applicable[5]. Therefore, rather than continue to name destinations, and fit the capabilities to the place, NASA should create capabilities and then fit the destinations to that capability. Even if priorities change, the capabilities common to most destinations allow for far more rapid redeployment and mission change.

Past Approaches to Sustainability

The Apollo program is widely held to be the crowning achievement of five decades of space exploration,[6] but it was ultimately unsustainable. In today's budget climate, spending such vast sums on a space exploration program is not politically viable. Furthermore, Apollo was geopolitically motivated, being conceived by the Kennedy Administration for the sole purpose of demonstrating American might and prowess by landing a man on the Moon before the Soviet Union. Once this purpose was fulfilled, Apollo experienced diminishing political returns, and the Nixon Administration cancelled the program with two missions to the Moon yet to fly. This is the peril of a purely destination-driven approach: once the goal is achieved, follow-on missions become increasingly difficult to justify. Hardware and operations tailored for the purpose are suited best for repetition of the goal rather than for building cumulatively or applying experience to other destinations. As was seen in the Apollo program, political leadership demands increasing justification for repeating a mission that was already "accomplished."[7] , Spaceflight advocates frequently reference Apollo as a program to be emulated. However, it occurred under historical circumstances that are unlikely to have a future analog. Even under these ideal conditions, Apollo's destination-driven nature ultimately made it intrinsically self-limiting and unsustainable. [8] In today's fiscal and political environment any such program would likely fare much worse.

While a capabilities-driven approach can in principle meet the standard of sustainability, to date such efforts have either failed to do this or have persisted in a much diminished form with respect to their original ambitions.

The former is exemplified by President George H.W. Bush's ambitious Space Exploration Initiative (SEI)[8], which would have gradually built capabilities over decades. According to SEI,

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[5] National Research Council, Committee on Human Spaceflight, *Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration.* Washington, DC: The National Academies Press, 2014.

[6] NASA History. "Apollo 30th Anniversary," Introduction. Last updated September 20, 2002. Accessed May 3, 2015. http://history.nasa.gov/ap11ann/introduction.htm.

[7] John M. Logsdon, *John F. Kennedy and the Race to the Moon*. New York: Palgrave Macmillan, 2010

[8] Hogan

operations in low Earth orbit (LEO) based around the proposed Space Station Freedom would enable development of a permanent lunar settlement. As SEI developed new capabilities, the program would eventually attempt a manned landing on Mars. However, Congress balked at NASA's estimated cost of $500 billion for such a program, so NASA abandoned the program[9]. A decade later, George W Bush proposed another attempt at a sustainable program, the Vision for Space Exploration (VSE), or Constellation. It had similar ambitions as SEI but was designed to be a "go-as-you-pay" program which assumed continual, but modest, increases in NASA's budget[10]. These budget increases failed to materialize, however. When the program was reviewed in 2009 by the second Augustine Commission, the report specifically identified the program's unsustainability[11]. It was subsequently cancelled in 2010 by the Obama administration[12].

The most successful capabilities-driven effort to date has been the shuttle/station program. Even this program has failed to live up to its original ambitions. The program was first proposed to contain two complementary elements, a space station and a shuttle. As originally conceived, the purpose of the shuttle would primarily be the construction and servicing of the station. The shuttle/station system would be used as a foothold that would enable greater capabilities in space. The Nixon administration declined to pursue the construction of a space station[13]. However, it funded the shuttle even though the shuttle no longer had a clear mission. Although the station was eventually resurrected by Ronald Reagan, its near-cancellation in the 1990s and frequent shifts in the rationale of its mission left its ultimate form significantly less ambitious than was initially envisioned. This compromised its ability to enable greater future capabilities in space. Having survived in one form or another for nearly four decades, the shuttle/station program could be considered the sole example of a sustainable capabilities-driven approach, but its diminished scope, troubled formulation, and lack of extensibility to activities beyond LEO make it a less than ideal model of sustainability.

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[9] Ibid.
[10] Scott Horowitz, "Ares Evolution." *The Space Review*. February 1, 2010. Accessed April 9, 2015. http://www.thespacereview.com/article/1555/1.
[11] Norman R. Augustine, "Executive Summary." In *Seeking a Human Spaceflight Program Worthy of a Great Nation*. Washington, DC: NASA, 2009
[12] Office of Management and Budget, *Terminations, Reductions, and Savings: Budget of the U.S. Government Fiscal Year 2011*. Washington, DC: OMB, 2011
[13] Howard E. McCurdy, *The Space Station Decision: Incremental Politics and Technological Choice*. Baltimore: Johns Hopkins University Press, 1990.

Current Environment

It is possible to combine a capabilities-driven approach with a destination-driven approach into a coherent and cogent policy for human space exploration. However, such work needs to be done carefully. The 2010 Obama Space Policy fails to chart a clear path from a basic capacity to a specific destination. Without a clear prescribed path the two approaches will work against each other, since the most efficient way of achieving one is at the expense of the other, especially in a budget-constrained environment. Destination-driven programs such as Apollo inherently de-prioritize generalization to other destinations, while capabilities-driven programs will contain components that are extraneous with respect to a particular mission destination.

Having two apparently competing goals, with no clear path between them, creates another disadvantage to a hybrid space policy. The goal of a manned mission to Mars currently dominates the conversation about the direction of US space policy. It captures the imagination. It can be easily articulated. It is reminiscent of the "flags and footprints" model of Apollo, a program that defines a period which many see as the glory days of human space exploration. A mission to Mars fits the appealing narrative template established by Apollo, and is therefore a convenient conceptual handle. However, actual work in the continuing development of human spaceflight at NASA more closely reflects a capabilities-driven approach than a destination-driven effort to send humans to Mars.

The lack of a clear path between capabilities and destinations in the 2010 Obama Space Policy has contributed to a disconnect between the idealizations of policymakers and the reality on the ground. A clear example of this problem is the reception of the capabilities-driven Asteroid Redirect Mission. ARM has borne the brunt of considerable criticism by Members of Congress who do not see a connection between the mission and sending humans to Mars[14] Conflict such as this one have become a source of discord which undermines the potential sustainability of a program of human space exploration.

Within NASA, human spaceflight is under the purview of the Human Exploration and Operations directorate (HEO). This office presides over the current operation of the International Space Station (ISS) and develops new capabilities through its Advanced Exploration Systems program (AES). AES works to create key capabilities for exploration beyond Earth orbit, focusing on the areas of Crew Systems, Vehicle Systems, Operations, and Robotic Precursor

[14] Foust, "The Uncertain Road to Mars"

Activities. In all, it operates about 20 small component projects[15]. It strives to create broad-based capabilities that are aimed at the general goal of allowing human beings to live and work beyond Earth orbit, rather than being oriented towards a specific destination. For example, AES is overseeing development of a Space Exploration Vehicle (SEV) for both in-space and planetary surface operations, as well as a next generation space suit, both of which are currently being tested in analog missions representing a variety of space environments.

The HEO is also in charge of the SLS and Orion programs, which are composed of largely repurposed remnants of the cancelled Constellation program[16].

There is no better illustration of the difficulties of building a sustainable capabilities-driven approach in the face of shifting political winds than Orion. The confused nature of Orion's role within the broader manned spaceflight effort can be seen from the moment of its revival post-Constellation, when the Obama administration proposed using an Orion capsule as an escape module for the ISS, a role for which Orion would be overqualified[17]. Another example of this confusion arose with the pronouncements by NASA during the first test flight of Orion that the spacecraft "heralds the first steps on journey to Mars"[18]. In actuality, there is no configuration of Orion in active development that is suited to a Mars mission, and no clear path from Orion to a more suitable spacecraft. Indeed, no plans for crewed hardware of any sort that would expand the capability to reach Mars exist beyond a hypothetical status. The confused origins of Orion, as well as its exaggerated role in the current narrative of future exploration, presents a picture of a desperate scramble for a rationalization for existing hardware rather than a careful plan to develop technology appropriate to fulfill U.S. goals in space.

Forces to Address

There are multiple influential forces to address when considering a capabilities-driven approach to human spaceflight. NASA must consider itself first – institutional resistance and culture are always significant factors to address. Similarly, NASA must consider bureaucratic forces that may hinder or facilitate change. In pursuing any kind of institutional change,

[15] NASA Human Exploration and Operations. Accessed April 9, 2015. http://www.nasa.gov/directorates/heo/aes/#.VSXpwvnF9ii.
[16] Lunar and Planetary Institute, *Constellation and Post-Constellation Hardware.* Accessed April 9, 2015. http://www.lpi.usra.edu/lunar/constellation/.
[17] Todd Halvorson. "Obama Plan Adds Jobs, Revives Orion." *FloridaToday.com*. April 14, 2010. Accessed April 9, 2015. http://www.floridatoday.com/article/20100414/NEWS02/4140351/1006/NEWS01/.
[18] Siceloff, Steven. "Successful Launch of Orion Heralds First Step on Journey to Mars." NASA. December 5, 2014. Accessed April 2, 2015. http://www.nasa.gov/content/successful-launch-of-orion-heralds-first-step-on-journey-to-mars.

particularly a policy this broad, many stakeholders external to NASA will also be affected, such as the commercial sector, regulatory agencies, and Congress. Each stakeholder's interests must be taken into account.

NASA is organized around several managerial nodes with overlapping equities. NASA Mission Directorates and Centers both have programmatic and financial purview.[19] In managing institutional changes as proposed in the policy, it is important that the Centers in particular do not perceive they are giving up more than they are getting. NASA Headquarters will need to make a convincing case that their individual interests will be addressed. Cultural resistance and institutional inertia have hindered even procedural changes in NASA.[20] Buy-in, or the lack thereof, from NASA components will be a key force to address.

The commercial sector is an increasingly important stakeholder, and as such, it can influence change. The commercial space industry has grown significantly in recent years, and this presents a unique opportunity for the government to use private services and hardware to more efficiently and effectively attain its goals of human spaceflight. When increased funding cannot be guaranteed, risk, a major factor in business development and strategy, can be used to improve margins. Increased competition, while good for consumers (in this case NASA), is detrimental to the existing pool of contractors.

Prime contractors are best adapted to government work largely because they can absorb risk and overhead easily. Small and medium enterprises are more susceptible to losses. The Department of Commerce Space Deep Dive shows most space sector companies fall in this category[21] and may not survive reliance on the same approach to contracting given their sales. The space sector is tilted towards small and medium enterprises in number while its rewards system is tilted towards large companies. Small-medium enterprises hold advantages in flexibility which are well adapted to market conditions, but not to a one-buyer anchor-tenant market, such as exists within the space sector[22]. These conditions raise entry-costs and oversight burden.

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[19] NASA. NPD 1000.3E, "The NASA Organization w/Change 2," Chapters 4 and 5. Effective April 15, 2015. Accessed May 5, 2015. http://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PD_1000_003E_&page_name=Chapter4; http://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PD_1000_003E_&page_name=Chapter5

[20] NASA, Jet Propulsion Laboratory. Lesson Number 6477: "Impediments to Implementing Earned Value Management." November 15, 2011. Accessed April 28, 2015. http://llis.nasa.gov/lesson/6477.

[21] Data Source: Department of Commerce, Bureau of Industry and Security, U.S. Space Industry Deep Dive Assessment, September 2014.

[22] Zoe Szajnfarber, Matthew G. Richards, and Annalisa L. Weigel. "Challenges to Innovation in the Government Space Sector," *Defense Journal ARJ* no. 59 (2011).

Congress is a major force to address, as it possesses key powers relative to NASA, through legislation and funding. Congress has the power to limit NASA freedom of action directly through legislation, as well as through appropriations. For example, the 2015 NASA Authorization Act makes specific requirements concerning the development of a road-map in Section 70504 (c), title 51 of the United States Code. The proposed policy is not only compliant with NASA Authorization legislation, it addresses each of the legislative requirements outlined.

NASA is subject to Federal Acquisition Regulation (FAR) in its procurement of goods and services, as well as the Code of Federal Regulations, Title 14, Chapter V. Space Act Agreements and competitions also take a share of outlays. NASA's Procurement Tenets interpret FAR very conservatively, as it is often subject to external pressure on compliance. Risk-aversion in acquisition policy is a major limiting factor to a paradigm shift in program organization.

The Problem

It is clear from the examples of SEI and Constellation (among others) that frugality is a necessary, though not sufficient, condition for sustainability. Programs that depend upon continually increasing budgets, however modest the required increases, have historically failed to meet the expectations of stakeholders. The trend of flat or negative funding activity persists to this day (Table 1), despite emphasis by members of Congress on the importance of science and technology funding. Such a program faces significantly greater risk of cancellation or profound reduction of scope. However, while the evidence suggests that it is necessary to adapt a human space exploration program to flat or slightly downward budgetary trends in order to be sustainable, such a program must be carefully employed to avoid the perception of aimlessness, or of goals that are ambitious but so long-term that there is no sense of urgency in achieving them. Both of these conditions apply to today's U.S. human space exploration efforts, which as noted above are often perceived wrongly by policymakers. This paper proposes a policy that will bring these forces into alignment, creating conditions that allow the perception of policymakers to naturally reorient to the reality of the current space exploration efforts. As a result, it should advance the goal of creating a truly sustainable capabilities-driven approach to human spaceflight.

Table 1. NASA Space Technology Budget 2011-2015 (in millions USD)[23]

	2011	2012	2013	2014	2015	Total
Requested	572	1024	699	742.6	705.5	3743.1
Enacted	327	569.4	614.5	576	596	2682.9
Difference	245	454.6	84.5	166.6	109.5	1060.2
%	57.20%	55.60%	87.90%	77.60%	84.50%	71.68%

[23] NASA budgets, 2011-2015

The Policy

Policy Goal

The goal of this policy is to utilize and repurpose current programs in order to revitalize human space exploration. It is to enable sustained human presence beyond Earth, and to establish an American human space program that is resilient, relevant, and sustainable.

Policy Statement

This policy will lead to a shifting of NASA's focus, from destinations to capabilities. The approach combines top-down support with bottom-up vision in a modular system of systems. This policy increases funding for system development. It also facilitates use and development of commercial capabilities. The policy's regulatory recommendations also combine top-down procedure with bottom-up strategy to expedite the acquisitions process, reduce risk and provide more opportunities for the private sector. As a result, it should enable new and sustained methods of exploration.

To establish a permanent human presence beyond low Earth orbit, NASA will expand its exploration technology development efforts and will attempt to exploit existing capabilities. In time, NASA will begin a near-term accelerated development of a spacecraft system. This system should embody a multi-mission exploration capability that ties together key elements of the AES and complements existing capabilities.

The policy can be broken down into 5 major components:

1. NASA should focus on a capability driven approach to human spaceflight.
2. The capability driven approach should be symbiotic with private industry.
3. The capabilities-driven approach should be modular and extensible.
4. The technology areas will collaborate in a nodal approach process that allows these contractors to help each other.
5. NASA should reform the acquisitions process, within existing regulations, to be flexible long-term, reduce cost-growth and delays, and increase opportunities.

Recommendations

Many key decisions on the direction of NASA will be made at the beginning of the next presidential term. Below are recommendations courses of action that can be taken by the Presidential Administration (Executive), NASA, and the Congress. Within each recommendation is an explanation of how the policy goals will be achieved through this course of action.

For the Executive

- **Direct NASA to focus on a capabilities-driven approach:**
  The Executive will communicate and persuade the public on how space exploration will be done by the United States, as done in the Presidential Directive on space policy.

- **Set destinations based on NASA's capabilities:**
  By clarifying the capabilities to be developed and the goals to achieve, the government will provide a more accurate picture of the future needs for industry to follow in order to meet the expected demand. This will allow industry to begin development of technologies and capabilities early on, further driving down the cost, timelines, and technical risk of capabilities-driven programs.

- **Issue an Executive Order giving NASA the backing to initiate significant changes to its processes:**
  An Executive Order will provide NASA with significant protection to pursue this or a similar policy. Similarly, Presidential direction can encourage other Agencies to be more open to suggestions from NASA in its own procedural and strategic development.

For NASA

- **Transition to a capabilities-driven approach:**
  The concept of the capabilities-driven approach was recently presented in the 2012 NASA Voyages report, and its coverage of the greater NASA technology portfolio is still relevant. The capability portfolios it identifies are: LEO crew and cargo access, beyond-Earth orbit crew and cargo access, in-space propulsion, ground operations, in-space operations, long-duration habitation, mobile exploration module, extravehicular activity (EVA) systems, precursor robotics, human-robotic interfaces, and destination systems.

The NASA Administrator is responsible for issuing Agency strategy[24], and for working with the NASA Office of Strategy Formulation to coordinate such long-term strategy efforts within mission directorates and key offices.

- **Realign technology areas to capabilities nodes**:
  A capabilities-driven approach may be described as a series of nodes. Each node contains a portfolio of technologies that enable the development of a capability. For instance the *in-space propulsion* node would contain the technologies that operate outside of earth's atmosphere. It might contain solar electric propulsion *and* nuclear thermal engine technologies. The capabilities are then funded, and that funding is distributed amongst the projects within. Stable funding for capability should be allocated in increments of 3-5 years, if possible. The vitality of any given node is derived from the size of its portfolio and the diversity of technologies within it. This should fall under the purview of the NASA Chief Technologist[25].

- **Establish a one way funding mechanism:**
  Each node must then be connected by strategic need, funding availability, and political imperative. Assuming stable funding, if the costs of any given node are less than expected, excess funds may be shared through a one-way valve: funds can be given, but not directly withdrawn. This allows the weakest point of any node to be tied to the strongest point in other nodes, and serves as a structural strategic redundancy. The interoperable nature of the capabilities, and one-way nature of the funding valve, form the regulation mechanism of the system, promote mutual support rather than political patronage. The resultant system is a set of portfolios that are relatively insulated from the effects of turbulent political whims and ephemeral budget limits. NASA will not likely have the power to create this structure unilaterally, and it may require specific language in a NASA Authorization Bill.

- **Begin accelerated development of a multi-mission exploration capability**:
  By simultaneously planning for multiple destinations, NASA would find that their ideas coalesce around certain applications of technologies. These technologies will allow NASA to exploit their existing products to establish new, common platforms for exploration. These platforms would most likely take the form of a multi-mission space

[24] NPD 1000.5B, 5.a
[25] Ibid

exploration vehicle. This vehicle would be modular in nature, with new capabilities added and removed as missions suggest or require. Every exploration mission would simultaneously become a testing ground for both matured and maturing technologies. Ideally such a vehicle would serve as a deep space exploration module, existing only in orbits and never attempting to land. Ultimately, constructing and supplying such a craft may become the most pronounced use of the Orion capsule and the SLS, the two highest profile capabilities currently in development.

NASA should shift its programmatic emphasis, as outlined in NPG 7120.5, from success and risk, to include multi-mission usefulness.

- **Align internal and external activities with the Global Exploration Roadmap**:
  The International Space Exploration Coordination Group, a consortium of 14 major space agencies (NASA included), has produced the Global Exploration Roadmap (GER), which lays out a set of technology priorities that are being developed worldwide. These priorities were identified by consensus among the agencies and represent their institutional interests. NASA will be in a better position to collaborate with partner agencies by formally adopting the priorities in the GER.

  To improve internal alignment, NASA should increase coordination between centers and mission directorates through administrative mechanisms, such as cross-center programs and/or teams and reviews.

- **Enable the commercial sector to provide capabilities**:
  A capabilities-driven approach reduce the investment risk for the commercial sector by changing the nature of its contracts. A dedicated capabilities-driven approach would likely have a larger number of smaller contracts, while a destination driven approach would have a smaller number of larger contracts. As seen in the Voyages document, capabilities-driven projects have the potential to be more flexible and modular than destination-driven programs. Federal regulations already in place could be modified to make this sort of contracting easier to adopt[26]. This would create stability within the industry, more contracts available for competition, and would reduce the damage to a company if a bidder fails to win a large, primary contract.

[26] The Code of Federal Regulations, Title 14, Chapter V, Part 1274, Subpart .1, creates uniform requirements for NASA cooperative agreements with commercial firms. Following this recommendation, § 1274.102 (c)(1) should be modified to include projects intended for the direct benefit of NASA.

- **Reform internal acquisition procedures to complement and enhance a capabilities driven, modular path:**

  NASA should use legal work done for DARPA's Cyber Fast Track program to support more flexible use of FAR, such as FAR Part 35.016 research proposals and using FAR Part 38 Federal Supply Schedule[27] with firm fixed-price contracts[28]. Specifically, these changes should provide faster contract turnover from reduced oversight requirements, a wider selection pool from lower entry costs for contracts and awards, concurrent work on individual programs where value is justified, and increased security through end-to-end encrypted network tunneling. Procurement Information Circular (PIC) 12-06B reproduces the broad language of the Office of Management and Budget (OMB) memoranda it is based on (M-12-16 and its most recent extension, M-14-10) instead of shaping it for NASA-specific applicability; the very point of open regulatory language is for it to be applied differently for different users. NASA must stop limiting its own freedom of action and argue for its rights and responsibilities under existing regulation.

- **Seek opportunities to increase programmatic resiliency across the federal enterprise, states, and to a lesser degree internationally:**

  NASA currently pursues many interagency and international programs. Horizontal programmatic planning (i.e. across institutions) would turn these isolated, but useful programs into a coherent whole-of-government and whole-of-NASA strategy for shared capabilities development.

  For example, the Small Business Administration (SBA) currently promotes commercial participation[29] and this can be used to NASA's advantage. All agencies are mandated to contribute to the Small Business Innovation Research program[30]. OMB Memorandum M-12-16, "Providing Prompt Payment to Small Business Subcontractors"[31], suggests there

[27] Acquisition Central. "Part 38—Federal Supply Schedule Contracting." Accessed November 27, 2014. http://www.acquisition.gov/far/html/FARTOCP38.html.
[28] "Black Hat 2011: New Program to Reduce the Complexity of Government-funded Security Research." Infosecurity Magazine. August 4, 2011.
[29] Small Business Administration. *U.S. Small Business Administration FY 2015 Congressional Budget Justification Budget Request in Brief*. Washington, D.C.2014. https://www.sba.gov/sites/default/files/files/SBA_FY15_Budget%20Highlights.pdf
[30] E.g. DoD: Department of Defense. "DoD SBIR/STTR Program." Office of the Under Secretary of Defense for Acquisition, Technology & Logistics OUSD(AT&L). Accessed December 5, 2014. http://www.acq.osd.mil/osbp/sbir/about/index.shtml
[31] Office of Management and Budget. M-12-16 "Providing Prompt Payment to Small Business Subcontractors." July 11, 2012.

is an opportunity for NASA to foster cross-agency synergy. NASA can simultaneously access the resources of multiple agencies, and faster than in the past.
NASA should issue internal guidance similar to that provided by NASA Procurement Information Circular 12-08, which allows for direct contracting of "small disadvantaged businesses." By employing this guidance, more opportunities for small businesses could be created; direct contracting eases the regulatory cost for both NASA and companies by accelerating payments.
Another opportunity for inter-agency cooperation is with the DoD. The Defense Procurement and Acquisition Policy Office of the Department of Defense explicitly encourages interagency procurement with NASA specifically[32]. These types of opportunities can offer more resilient capabilities development through diversified funding sources and program stakeholders.

- **Improve outreach to explain the benefits of capabilities vs destinations:**
  Maturing technologies provide many small and modest successes spread over time. This will need to be explained well to the public, as a capabilities-driven approach does not have the singular high profile and emotional accomplishments of the Apollo program. Rather it has many small rewards that keep exploration present in the mind of the public. Progressive steps towards sustainable and permanent exploration become things people expect to see and they feel a loss should they be cancelled. It is important for NASA officials to refrain from making public claims about destinations prematurely.

For Congress:

- **Explore options to provide budget stability and predictability to NASA:**
  NASA must work with Congress to communicate the importance of multi-year authorization bills and the ramifications of unstable funding. While there is no guarantee that the bills will have their requests appropriated, Congress will have the information needed to fully understand the implications of funding instability. The policy recognizes that NASA's continuing resolution sets a low bar for congressional action on this scale, but smaller steps could provide more consistency.

- **Expand technology investment in NASA:**

[32] "Interagency Acquisition." Defense Procurement and Acquisition Policy.

Most exploration technology is funded through the Space Technology and the Exploration Systems R&D budget lines. Congress should find ways to increase these budget lines without deep cuts elsewhere in the NASA budget.

- **Improve interagency management and processes:**
  The current interagency process impedes unity of effort and a whole-of-government approach. The government is structured for vertical stovepipes, although horizontal integration is key to the effective implementation of this policy (as well as many other critical challenges facing the federal government). While Executive efforts are good, it will take congressional action to create sustained changes, such as the Goldwater-Nichols Act (1986), which reorganized the Department of Defense.

- **Decrease investment risk in the space industry by enabling regulators to address anticipated markets:**
  Regulatory authority over activities on celestial bodies and in space needs to be bestowed on an agency to provide a predictable regulatory environment for commercial actors. Whether authority is given to an existing or new office, the organization must maintain a dialogue with industry to facilitate the growth of markets in space to an extent that they are capable of aiding government missions as the need arises. Investment risk will decline as the regulatory agency clarifies the future regulatory environment.

Policy Assessment

NASA should focus on a capability driven approach to human spaceflight.

The technologies in each capability portfolio can be mapped to the current Technology Areas identified in the NASA strategic technology roadmap, although not directly, as there are 14 Technology Areas[33], and only 11 major capabilities. Formally organizing these into capability nodes will promote information sharing and encourage collaboration by aligning management of similar projects with shared goals. Progress on a given project may inform similar projects that they were previously unaware of, making the greater capability more robust. This may reduce waste, focus the efforts, and make progress clear to policy makers.

In addition to the aforementioned strengths, capabilities are hardier than destinations. Destinations have been around forever, but the means to reach them haven't been. Acquiring those capabilities can be a slow process, but the benefits extend beyond any single mission. Rather than rehash the rest of the benefits, the focus of the assessment will be on the risks and potential drawbacks of the policy.

Poor prioritization of capabilities may be the greatest risk to the success of a capabilities-driven approach. It is the clearest identifiable structural weakness. Overemphasis on any one capability could draw support away from all of the other ones. This does not imply, nor even suggest, that all capabilities are of equal relevance or priority. It is conceivable that political interest could create sinks and draw funding to district specific efforts. Even if it is not done with malicious intent, the influence is the political reality. To mitigate the effects of such influence, a one-way funding mechanism could be implemented. There will be powerful capabilities, lucrative ones that draw more support, and the onus will be on them to support the secondary capabilities that they will rely on.

A failed prioritization, whether due to over politicizing or budget fluctuations, can result in a negative feedback cycle: funding is consumed by a hopeless effort, which ruins the chances for other technologies associated with it. However, a well prioritized portfolio can unlock a positive feedback cycle, where new capabilities open up other new capabilities. In order for these network effects to be realized a careful analysis must recognize these level of effort thresholds and executive decisions must be made concerning whether or not the goals are

[33] NASA, "Space Technology Roadmap" 2012, Accessed from: http://www.nasa.gov/sites/default/files/501627main_STR-Int-Foldout_rev11-NRCupdated.pdf

practical or worthy. The nodal approach relies on these network effects to reduce risk and optimize funding allocations.

Additionally, capabilities need to reach a certain maturity before they become useful for exploration, and to reach that maturity they need to meet a threshold of investment[34]. This threshold is the minimum of investment required for the technology to become exploitable. The threshold can be reached through some combination of funding, labor allocation, and prioritization in systems planning. If the threshold is not met, the investment may become a waste. Investment and capability maturation are not linearly related; there are scenarios where very early stage technologies may consume limited resources without a clear gain in capability. Occasionally, the technological fundamentals of a capability have not been established, and more work outside of NASA may be required. Radiation protection is an example of this. Capabilities need to be prioritized and well timed to reduce risks of waste. Fundamentally, this is a major hazard of the capabilities-driven approach: if clear priorities are not established, it may become just as aimless as a failed destination.

The development approach should become symbiotic with private industry, and facilitate the growth of the commercial sector.

The commercial sector is a crucial component to the success of the national space program, and will therefore play a critical role in the success of a capabilities-driven approach. It will also make it easier to sustain human spaceflight in the face of budgetary constraints and unpredictable political environments. Industry can be utilized to realize the fullest potential of government space programs.

Existing commercial services can be treated as a capability for NASA. For example, services provided by SpaceX's Falcon 9 rocket give the option of a lower cost launch capability. As stated by the Commercial Spaceflight Federation, "NASA's commercial crew and cargo programs are key to our future LEO presence and to enabling the Agency to achieve the Nation's ambitions beyond-LEO utilizing the SLS and Orion transportation systems."[35]

[34] Wicht, A, Szajnfarber, Z. "Portfolios of promise: A review of R&D investment techniques and how they apply to technology development in space agencies", *Space Policy* 30, no 2. (2014): 62
[35] Commercial Spaceflight Federation. *Ensure NASA's Human Exploration is Sustainable.* 2015.

In his written testimony to the Senate Committee on Commerce, Science, and Transportation, Eric Stallmer, President of the Commercial Spaceflight Federation, describes the importance of the private sector contributing to human spaceflight:

> "In the Fiscal Year 2015 appropriations bill, Congress included language that strongly reaffirmed the importance of the private sector contributing landers, habitats, and propulsion systems to beyond LEO human spaceflight through public-private partnerships as is occurring via the AES program… Including the commercial space industry as an early partner in reaching U.S. human exploration goals beyond LEO is a logical extension of the successful COTS and CRS partnership model proven in LEO, and can help alleviate budgetary constraints and compliment the Agency's investment in its transportation systems."[36]

NASA's AES program has harnessed the strengths of the commercial sector in recent years through the use of creative contracts and the current policy, but there is more to be done in order for industry to aid human spaceflight in the future[37].

In order to facilitate the growth of the commercial sector and allow industry to function as an able partner rather than purely as a supplier, an ecosystem has to be developed[38]. This ecosystem will consist of markets where buyers and suppliers maintain capabilities that will be available for purchase by NASA as needed.

A market for space transportation services requires buyers beyond NASA, such as the satellite industry. These buyers will share the work of sustaining the industry. As an example, the government should continue to encourage companies to create private space stations. These stations could sustain the market for the domestic human launch providers after the International Space Station[39] is decommissioned. If the market expands and enables commercial independence in space it will reduce costs to government and allow NASA to spend its resources on further human exploration and technology development.

The regulatory environment needs to be clarified in order to benefit industry's ability to develop capabilities of value to NASA's human spaceflight goals. The 2010

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[36] *U.S. Human Exploration Goals and Commercial Space Competitiveness,* 114th Cong. (2015) (written testimony of Eric W. Stallmer, President, Commercial Spaceflight Federation).
[37] CSF. *Ensure NASA's Human Exploration is Sustainable.* 2015.
[38] *U.S. Human Exploration,* 114th Cong. (2015) (written testimony of Eric W. Stallmer).
[39] CSF. *Ensure NASA's Human Exploration is Sustainable.* 2015.

National Space Policy advises easing regulations on the space industry to create an environment conducive to commercial development. It directs the government to "Minimize, as much as possible, the regulatory burden for commercial space activities and ensure that the regulatory environment for licensing space activities is timely and responsive…"[40] While regulatory leniency is crucial in the near-term, future policy must direct regulators to create a more predictable environment for commercial actors in potential space-based markets. This includes the regulation of in-space activities, specifically commercial activities on celestial bodies. There is currently a dearth of regulations and regulatory power to address these commercially untouched regions and activities. There is no agency engaged in regulating commercial activities on the moon or asteroids, although there are several offices which may be suited to the task.[41]

Finally, incentive for funding space programs can be increased through cooperation with the private sector, which will provide further predictability for capabilities-driven programs. Technology development has the potential to produce substantial economic return through the private sector. NASA has a strong history of developing talented people whom the private sector hires and uses to build the industrial base. Major capabilities like in-space propulsion, require new materials and control systems to be developed. The private sector will find ways to use and capitalize these technologies. Additionally, as exploration of NEOs and in-situ resource utilization (ISRU) advances, there will be new opportunities for in-space construction and habitation. Therefore, a strong partnership with and development of industry will further enable a successful capabilities-driven approach.

A potential weakness of policies promoting the use of the commercial sector's capabilities would be seen in the event that the commercial sector does not receive proper government support to develop their services and hardware. If the commercial sector is unable to provide reliable and affordable services, the government will not acquire commercial capabilities. Instead, the majority of the development costs of a capabilities-driven approach will fall on government. In this event, human space exploration will continue to be restricted by and dependent on the current budgetary environment.

Ideally, development costs will be shared with industry, but this depends on the government shifting its relationship with industry to more of a partnership than that of a buyer

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[40] President of the United States, National Space Policy of the United States of America (Presidential Policy Directive 4/PPD-4) (June 28, 2010)

[41] David, Leonard. "Space Law 101: Filling the Legal Vacuum." SpaceNews.com. March 31, 2015. Accessed April 6, 2015. http://spacenews.com/space-law-101-helping-fill-a-legal-vacuum/.

and supplier. It is essential that these capabilities be fostered to build a capable partner, rather than acting as a roadblock to the development of reliable and capable hardware which will advance human space exploration.

If the government does provide the necessary environment to facilitate the growth of industry, the opportunities that arise from a strong commercial sector will significantly improve the affordability, timeline, and reach of human space exploration.

The development approach should be modular and extensible.

Developing a common suite of capabilities means development costs are not budgeted for a single mission, but distributed across many. Flexibility is designed into every system by approaching the capabilities as interchangeable components in a greater system. A benefit to the capabilities-driven approach is the advantages gained from interoperability and flexibility. Interoperability means that technologies can be swapped out of different systems, precluding redundant technology development programs. For systems to become more interoperable compatibility needs to be introduced as an initial requirement. Interoperable capabilities, such as common payload connection points, can reduce the dependence on specialists for missions. Interoperability also helps establish a baseline for standards to be put in place. For example, a spacecraft docking with the ISS may need to share the water supply. If NASA requires spacecraft use a specific standard on water purification to become certified, not only do the separate systems become interoperable, a standard is set. This helps new entrants to the space market simplify their own design requirements. Once standards are in place they systems can interact, and improved standards can be adopted more efficiently. While designing systems and protocols to be very compatible from the beginning may be more expensive in upfront costs, but over the life of a technology is becomes considerably cheaper by reducing replacement requirements.

By using standardized and compatible components, NASA can freely assemble the technology it needs to reach any destination rather than being confined to technology that will work for only one destination. Compare this to a DDA: NASA identifies a destination, which identifies the capabilities of the spacecraft, and determines technologies required for the mission. The CDA transposes the roles of technology and destination through creating common capabilities. Any mission then becomes expandable as well, within the policy and budgetary parameters outlined to NASA.

Modular development requires horizontal coordination and centralized strategy between decentralized actors (e.g. Centers and Mission Directorates). In particular, improved systems

engineering will be needed to predictably control the cost of integrating components. If the cost of integrating components is not sufficiently controlled, there is a risk that programs will experience the scheduling delays and increased overhead this policy is meant to avoid[42].

In capabilities-driven exploration, a major tenet is the sustainability of the exploration activity. In this context, sustainability uses and develops technologies that enable new paths, while reducing costs. Programs need to fit into, and produce a benefit for, any greater system being developed (such as a space transportation system). Sustainable programs should produce something greater than the sum of their parts. A primary example of this is ISRU, which consists of using the resources available at a destination to perform needed functions that might otherwise have to be imported. ISRU techniques could allow a mission to extend its stay indefinitely in some respects, through converting native resources into necessary goods. For instance, it has been discovered that water ice exists in the shadow of lunar craters. A future lunar mission might include the capability to melt that ice and capture the water and gases released during the process. Those gases could be distilled and compressed into fuel for rockets, while the water could be used in other ways, for example as a crew consumable. Sustaining capabilities, like ISRU, enable missions to be planned in very different ways than they are with a singular destination in mind.

The technology areas will collaborate in a nodal approach that will allow capability areas to help each other.

The nodal approach distributes the risks[43] associated with maturing new technologies. When a technology is tied to a single mission the successful development of the technology is linked to the funding of that mission and it forms a single point of failure. By placing technologies into independently funded nodes, there is less likelihood any one technology will be for terminated as a consequence of larger funding shifts. The arbitrary nature of funding fluctuations are felt by all nodes, and development of capabilities will only fluctuate in the temporal dimension, rather than in some absolute way.

However, by connecting each node to each other, there is the risk that insufficient funding delays all human space exploration activity. This could lead to every node trading favors

[42] Analogs exist in systems integration across fields, such as for information resources management. Lane, Jo Anne, and Barry Boehm. "System-of-Systems Cost Estimation: Analysis of Lead System Integrator Engineering Activities." Information Resources Management Journal 20, no. 2 (2007): 23-32. Accessed May 6, 2015. doi:10.4018/irmj.2007040102

[43] Szajnfarber, Z. “Space science innovation: How mission sequencing interacts with technology policy” *Space Policy* 30, no 2 (2014): 83

to get smaller pieces of the pie in order to get anything developed at all. Or it may result in node developing a very conservative approach, and only focusing on small projects that can be completed quickly. However, these risks are apparent in the current system already.

The one-way funding mechanism is intended to circumvent these possibilities by negating any political favor how nodes are funded, by allowing flow between the nodes. While this carries the risk of the Banker's Paradox (those who are the lowest risk are loaned to most easily), this is not a certainty. Rather than hard rules that compel fund sharing, upper management will need to support and encourage project managers in developing a culture of fund sharing. Actions like detailing managers can help build empathy towards capabilities that are struggling, and find ways to help.

NASA should reform the acquisitions process, within existing regulations, to be flexible long-term, reduce cost-growth and delays, and increase opportunities.

By linking key capabilities, NASA makes them more resilient to financial stress from political changes. An efficient platform for shared acquisitions/capabilities reduces risk. One study shows that risk-averse NASA experiences more high-level incidents precisely because it suppresses low-level incidents.[44] By increasing attention to high-level risks relative to low-level risks throughout the acquisition process, NASA will reduce its overall risk.

A platform with lower entry costs, thanks to faster turnaround from controlled oversight, can expect many new participants, increasing ideas and opportunities, allowing for concurrent development of capabilities. DARPA's Cyber Fast Track model is an example: 90% of grant winners were first time contractors[45]. Through reduced costs and increased participation, the Cyber Fast Track program was able to assign much of this new talent to old problems, and even pursue multiple approaches to the same problem. This would drive higher performance of capabilities that must be shared by virtue of capabilities-driven development.

Any change to acquisitions that deviates this much from the norm will require front-end costs, even if some of those can be cannibalized from DARPA's work. It will take months of legal work to properly defend and define a new approach, even if it complies with regulations.

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[44] U. S. Bhatt, D. E. Newman, B. A. Carreras, I. Dobson. "Understanding the Effect of Risk Aversion on Risk." Paper presented at the Thirty-Eighth Hawaii International Conference on System Science, January 2005, Big Island, Hawaii, Copyright 2004 IEEE. http://iandobson.ece.iastate.edu/PAPERS/bhattHICSS05.pdf.

[45] Defense Advanced Research Projects Agency. "DARPA - Open Catalog." Last modified November 6, 2014. http://www.darpa.mil/opencatalog/CFT.html.

Another risk of a capabilities-driven approach extending to acquisitions is having "all the eggs in one basket." While core capabilities will be less likely to be tampered with externally, if they ever are tampered with, it would cause significant damage to NASA's overall development.

This policy will balance strengths and weaknesses of decentralized/centralized approach. Horizontal coordination with centralized procedure, as suggested by this capabilities-driven approach, will only result in increased efficiencies if coordination mechanisms used between the Centers and Mission Directorates function well. Ideally, this coordination should be done beforehand, so that planning and contracts can be done quickly, ensuring the promised reductions in overhead and oversight costs. Similar risks would be involved with multiple parallel acquisition processes.

Organizational resistance is a major limiting factor. Risk-aversion can lead to a conservative institutional cultural which increases organizational resistance. Attempts at shifting equities will affect some stakeholders negatively, possibly through increased competition within the pool of contractors. Indeed, even Centers and Mission Directorates may resist if they believe their equities are being diminished through the coordinating process. Care must be taken to align NASA internally. For example, NASA PIC 14-01 deviates from FAR FSS pricing and mandates the use of 15.404-1 proposal analysis, which can be more stringent and time consuming. However, this is far easier to modify than mandatory policy or external forces.

Similarly, other components of the United States Government, such as Agencies and Congress, may contest even targeted reductions in oversight as limiting their influence. NASA will need to pay particular attention to allaying these fears, and a DARPA pilot program does not provide a suitable analog in this respect. NASA must find the correct balance between stakeholder equities by gauging their concerns early in the process. To that end, NASA must present a coherent business case, preferably at a higher level of detail than that outlined by the Office of Federal Procurement.[46] For example, OMB is also pushing Performance-Based Acquisition, while lamenting a lack of understanding on the part of agencies on when to use it. If NASA demonstrates this in its business case, it will meet far less resistance from regulators and oversight agencies.

Conclusion

[46] Office of Federal Procurement Policy. "Development, Review and Approval of Business Cases for Certain Interagency and Agency-Specific Acquisitions." September 29, 2011. Accessed May 1, 2015.

The policy recommendations in this paper have laid out a more cost-effective, secure, and sustainable path to human space exploration by advising a dedicated capabilities-driven approach. There are five major components to this policy:

1. NASA should focus on a capabilities-driven approach to human spaceflight.
2. The capabilities-driven approach should be symbiotic with private industry.
3. The capabilities-driven approach should be modular and extensible.
4. The technology areas will collaborate in a nodal approach process that allows these contractors to help each other.
5. NASA should reform the acquisitions process, within existing regulations, to be flexible long-term, reduce cost-growth and delays, and increase opportunities.

These components and the individual recommendations for the Executive, NASA, and Congress provide a path to secure the future of human space exploration. It is necessary that action be taken, as it has been shown that the current path is unsustainable. The previously mentioned policies upon which the capabilities-driven approach depends offer the strongest chance for success.

The policy is resilient in its modularity; individual components complement each other, but do not require each other to function effectively. This allows NASA to make significant contributions toward a sustainable approach to human spaceflight, even if there is difficulty in implementing individual policy recommendations. However, as NASA has seen in past attempts at capabilities-driven development, partial implementation of recommended policy will only lead to partially capable systems. As outlined in this document, failure to fully implement and execute most of these changes will lead to larger costs, fewer successful programs, and more risks for the government in the long and short-term goals of space exploration.

NASA is on the cusp of major changes in the space sector. NASA must be an innovative institution capable of capitalizing on change, both internal and external. Failure to do so has seen the space agency struggle in the past. NASA has the capabilities to lead the way for the world's space agencies. The modular capabilities-driven approach and supporting policies that have been defined in this document can ensure NASA's mission for years to come.