Beyond Earth

An Analysis of Public Policy Models for Human Expansion

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Dedicated to the memory of

Charles "Chuck" Fletcher, Jr.

1932 – 2015

My beloved grandfather who was one of the most extraordinary men I have ever known. I will always strive to make him proud.

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Abstract

A human being last set foot on a natural surface outside of Earth's atmosphere in December of 1972 when the Apollo 17 mission landed astronauts on our moon for the sixth time. Since then, humans have been sent into Low Earth Orbit for various purposes, including service to the International Space Station, but no farther. Significant interest has been generated in recent years to return manned space flight to "deep space," specifically to the moon and eventually to Mars. Deciding on the most effective and efficient model for doing so has proved to be a difficult challenge for policymakers due to various sociopolitical, economic, and technological factors.

This research presents the hypothetical circumstance of an established, self-sustaining colony on Mars and seeks to find the best policy solution to implement it. It explores what is required to make this colony a reality and what research and development is already under way in these areas. An analysis of three models of research and development is then laid out: Public-focused, private-focused, and public-private partnerships. Sociopolitical, economic, and technological benefits and challenges will be given for each model and will be taken into account in a final policy recommendation.

It is the conclusion of this research that a strong focus on the public-private partnership model would be best. It will be able to best address the challenges presented by the other models while still retaining most of the advantages. This affirms recent decisions by the National Aeronautics and Space Administration to focus on the awarding of competitive contracts to private manufacturers to develop and launch the transportation vehicles for manned and unmanned missions, and recommends that they continue to expand this procedure to other developmental aspects of the space program.

Part I: The Hypothetical Circumstance

1. An Introduction to the Space Policy Climate

The string of missions carrying the codename *Apollo* that launched in the late 1960's and early 1970's captivated audiences, both national and international. The National Aeronautics and Space Administration (NASA) facilitated the landing of human beings on another celestial body for the first time in human history. As *Apollo 17* prepared to depart the Moon in December of 1972, Commander Eugene Cernan made a speech that is now frequently quoted:

> *"As I take man's last step from the surface, back home for some time to come – but we believe not too long into the future – I'd like to just (say) what I believe history will record. That America's challenge of today has forged man's destiny of tomorrow. And, as we leave the Moon at Taurus–Littrow, we leave as we came and, God willing, as we shall return, with peace and hope for all mankind. Godspeed the crew of Apollo 17."*[1]

Apollo 17 would become the last in that series of missions, and also the last to have placed humans on a non-terrestrial surface to date. Consequently, this was and still remains the last publicly recognizable quotation from the Moon.

Since the discontinuation of the *Apollo* series, manned spaceflight has not ventured beyond Low Earth Orbit (LEO). This classification of orbit is defined as up to 2,000 kilometers above the surface of the Earth and contains many of the objects that have been launched, such as the International Space Station (ISS) and various types of satellites.[2] Although many unmanned scientific launches have been made – not just by NASA but also by other organizations such as

[1] Elizabeth Howell, "Eugene Cernan: Last Man on the Moon," (Space.com, 23 April, 2013, Web).
[2] Inter-Agency Space Debris Coordination Committee, "IADC Space Debris Mitigation Guidelines," 5-7, (NASA, September 2007, PDF).

the European Space Agency (ESA) – humans themselves have not ventured back into so-called "deep space" since *Apollo 17*.

The United States government has put forth a number of different manned spaceflight initiatives since 1972. They have varied greatly in levels of scope, expense, aggressiveness, and risk, but any plan that survived the rigors of the congressional budgeting process either did not take humans out of LEO or died before gaining any traction. Prime examples of each are the developing of the Space Shuttle as the first reusable – if only partially – vehicle for manned space launches and President George W. Bush's Vision for Space Exploration, respectively. The Space Shuttle was used to ferry astronauts into LEO to conduct various scientific missions from 1981 until its discontinuation in 2011, but it was never intended to venture any farther.[3] The Vision for Space Exploration was an aggressive plan that included returning manned missions to the Moon and eventually to Mars.[4] Unfortunately, many aspects of this plan were either shot down during the federal budgeting process or were never followed up on, and the Vision was scrapped in favor of a new plan by the Obama administration in 2010.

The fate of the Vision for Space Exploration has become an all-too-familiar refrain since the conclusion of the *Apollo* missions. This tends to be caused not so much by a lack of interest, but by being relatively deprioritized. Public surveys consistently show an interest in a stronger space program, but also that it holds far less priority than other major policy areas such as education, welfare, or health care. The translation is that people are interested in space, but do not want to pay for it; they would rather have their tax dollars go into things that they perceive as more relevant to their every-day lives. This has led members of Congress to be highly reluctant

[3] National Aeronautics and Space Administration (NASA), "The Space Shuttle Mission," (NASA, 2013, Web).
[4] NASA, The Vision for Space Exploration*,* 6-7, (NASA, 2004, PDF).

to support stronger public spending on space-oriented programs, unless they represent states or districts that would receive direct economic benefits.[5]

Nevertheless, the Obama administration put forth its own plan for space exploration in 2010. This model removes the Moon as a priority – but does not completely dismiss it either – and instead focuses on Mars and asteroids for manned exploration.[6] Coupled with the success of many privately held companies such as Boeing, Lockheed Martin, SpaceX, and Virgin Galactic in developing and advancing space technology, many people are now starting to take it upon themselves to work towards this vision of not only eventually putting people on another non-terrestrial body, but settling them there permanently as well.

Space has often been called "The Final Frontier," both in serious discussions and in science fiction. SpaceX founder Elon Musk once stated that he sees two different futures for humanity: one where we remain a one-planet species until a mass extinction event occurs, and one where we become a multi-planet species, which is not only a sound preservation tactic, but also far more exciting, in his view. Human expansion is also a way to work towards solving issues of natural resources that are, or will eventually begin to diminish. But what is the best way to go about making these ideas into reality, and how will they be funded and developed? This is a huge, overarching, and multi-faceted question, but one that is worth answering.

2. A Colony On Mars

In order to appreciate the scope of the task of colonizing another planet, imagine the following scenario. There is a colony of somewhere between 100 and 300 people on the red

[5] Joan Johnson-Freese, *Space as a Strategic Asset,* 59-61, (New York: Columbia University Press, 2007, Print).
[6] Kenneth Chang, "Obama Vows Renewed Space Program," (New York Times, 15 April, 2010, Web).

planet of Mars. The technologies and capabilities have been developed, either on-planet or prior to launch, for this colony to act relatively autonomously. These developments include:

- Infrastructure that allows extraction of water where there is none;
- The ability to manufacture oxygen from an atmosphere that does not provide enough;
- Procedures to use that oxygen to not only breathe but also to grow food;
- Vehicles for efficient transportation that can also resist the constant exposure to dust and violent dust storms;
- Living structures to resist the same conditions that are sealed enough to not let breathable air escape but without being an extreme fire hazard;
- Launching mechanisms to send supplies, materials, and scientific samples back to Earth, as well as being able to receive such shipments.

Daunting, is it not? The preceding list is hardly exhaustive, but it provides an idea of the challenges facing such a mission and the technologies that need to be developed in order to make it a reality.

Artist rendering of the Mars One settlement. Source: Mars One

Mars One is an example of a private entity that exists for the sole purpose of making a colony like this happen. They are a not-for-profit foundation that relies on sponsorships, donations, and contracts with a network of private suppliers to further its aims. This organization will be discussed in more detail in Part III, but they are a pioneer attempting to start a new breed of organizations that not only exists independently of governmental agencies, but also operates completely – or nearly so – devoid of any government funding.[7] They are representative of the initiative being taken by some in the private and nonprofit sectors to further the goals of space exploration and technology in ways that governments have been struggling to.

3. Current Advancements

There are many areas of technological development that are relevant to establishing a non-terrestrial colony. A full, comprehensive list in high detail is beyond the scope of this research, but an overview of arguably the three most critical elements to establishment, and what is currently being done to advance in these areas, is appropriate to help illustrate the enormity of this task. These fields are rocketry, water extraction, and provision of oxygen.

Rocketry

One of the first questions to address in setting up a colony on Mars is how to get there in the first place. NASA is currently developing the Space Launch System (SLS), a mechanism that will ferry astronauts beyond LEO. It contains a launch system that is derived from the space shuttle model and will need to be replaced with every launch. The price tag is estimated to reach $18 billion by 2017 and $35 billion by 2025, with an added cost of approximately $500 million

[7] Mars One, "Partners," (Mars One, 2014, Web).

per launch. It is intended to eventually carry astronauts on manned missions to Mars, the Moon, near-Earth asteroids, and the moons of Mars, Phobos and Deimos.[8]

Artist rendering of the Space Launch System. Source: NASA

Although considered by policymakers to be far more viable than the previous *Constellation* development – which was intended to replace the Space Shuttle, but was defunded by Congress due to budget and deadline problems – the program still has many opponents. Several societies and foundations, including the Space Frontier Foundation, have spoken out against the project on the grounds that it will divert critical NASA funding from other areas while not reducing launch costs at all.[9] Private contractors such as Boeing and SpaceX have not yet made any such claims as they have been contracted to handle the crew cabins rather than the

[8] NASA, "NASA's Space Launch System," (NASA, 2013, Web).
[9] Space Frontier Foundation, "Monster Rocket Will Eat America's Space Program," (Space Frontier Foundation, 15 September, 2011, Web).

launch vehicle. But SpaceX's commitment to developing a reusable rocket signals indirectly that CEO Elon Musk does not view the SLS as the long-term solution.[10]

Water Extraction

Water is a primary building block of life as we know it, and along with oxygen, is the top prerequisite for human survival. Mars has shown many signs of having liquid water at some point in its history, but any that remains now is either locked up in the soil or frozen in the polar ice caps. Lockheed Martin has experimented with various technologies that extract moisture from the soil and the atmosphere, and the Mars Desert Research Station in Utah – which simulates living conditions on Mars as closely as possible for extended durations – has field teams working on similar soil techniques.[11]

The Mars Desert Research Station in Utah. Source: MDRS

[10] Space Exploration Technologies (SpaceX), "Reusability: The Key to Making Human Life Multi-Planetary," (SpaceX, 2013, Web).
[11] Mars Desert Research Station, "Goals of MDRS," (Mars Desert Research Station, 2014, Web).

Things cannot be simulated with total accuracy on Earth, however. The temperature swings on Mars are far more extreme, and the composition of both the soil and the atmosphere are different. To control these variables, Mars One is planning to launch an unmanned lander to the surface of Mars to experiment with various water extraction methods. Other challenges involve the quantities of water extracted. The MDRS teams must survive on the water they extract along with what was provided at the start of the mission, and the process is a very slow and tedious one with only small amounts of water being extracted at a time. Therefore, the teams must often go for weeks without showering and are only allowed minimal amounts of water intake. More advancement is likely needed on this front before a mission can depart for Mars.[12]

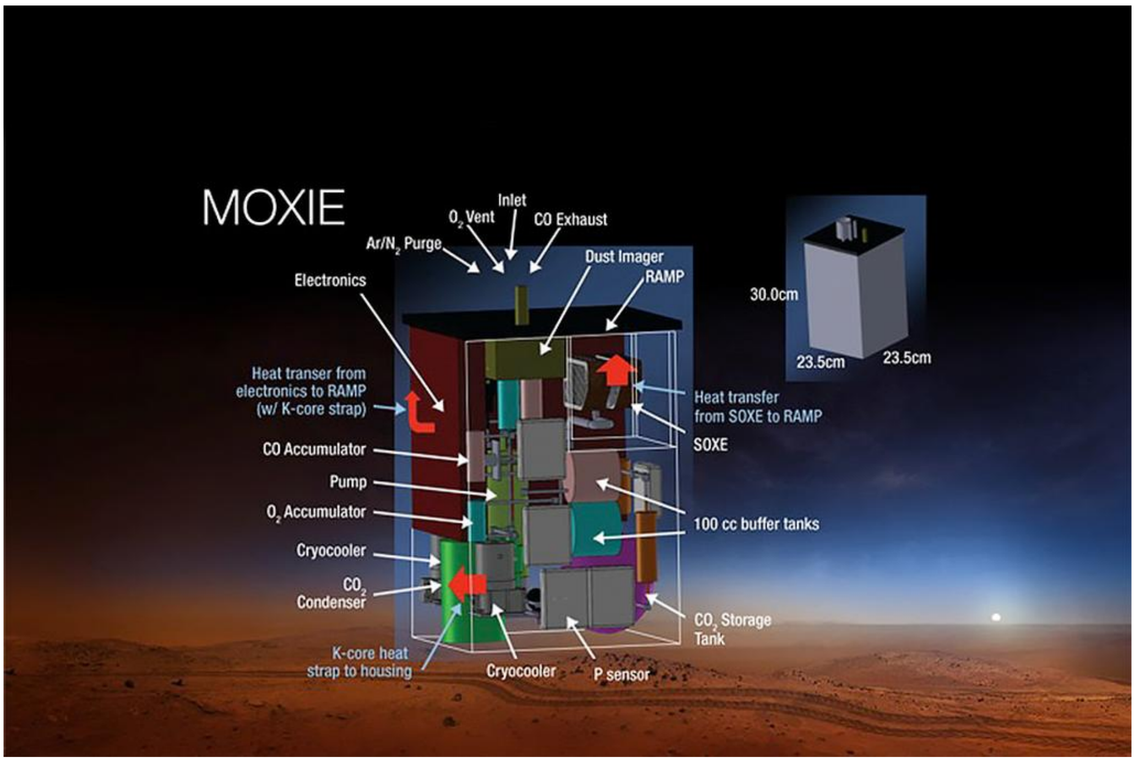
Oxygen

The other fundamental prerequisite for human survival is oxygen. The Martian atmosphere has some, but not nearly enough to survive outside without an insulated suit. Mars does have an atmosphere that is rich in carbon dioxide, however, and NASA is planning to launch another rover in 2020 that will experiment with this. It will contain an instrument called the Mars Oxygen ISRU Experiment, or MOXIE, that was created at the Massachusetts Institute of Technology (MIT) and is designed to produce oxygen from atmospheric carbon dioxide. If successful, this device will be replicated on a much larger scale and could serve not only to provide breathable oxygen for astronauts but also to provide the liquid oxygen that would be required to power a rocket for a return journey.[13]

Oxygen field-testing on Mars prior to manned exploration is critical because it is nearly impossible to replicate the conditions on Earth except in an entirely lab-controlled environment. NASA appears to have placed its trust in MOXIE for the time being as there do not seem to be

[12] Tanya Lewis, "Incredible Technology: How To Mine Water on Mars," (Purch, 23 December, 2013, Web).
[13] Maia Weinstock, "Going to the Red Planet," (NASA, 31 July, 2014, Web).

any other noteworthy oxygen-development projects at present. Mars One advertises a Life Support Unit that has already been developed to extract the necessary gases from the atmosphere and convert them to breathable oxygen, but research done by MIT – detailed later in the Mars One case study – disputes the long-term feasibility of this technology.[14] It remains to be seen whether there will be additional advancements leading up to the launch of the next rover in 2020.



Cross-section design of MOXIE. Source: NASA Jet Propulsion Laboratory

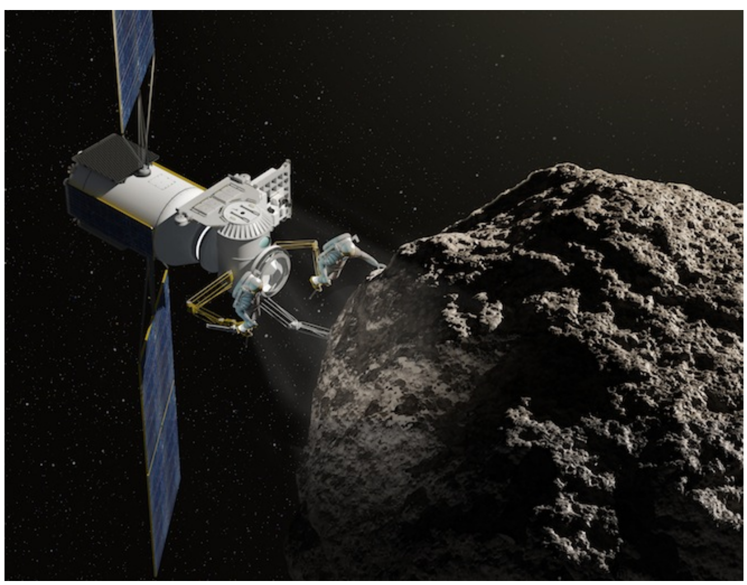
4. Economics of Colonization

The actual financial cost of establishing a colony on Mars is a topic of debate for many in the field. Most have shied away from providing a definitive price tag due to the sheer number of high-cost and high-risk factors involved in development. Only a few outliers such as Mars One

[14] Sydney Do et al, "An Independent Assessment of the Technical Feasibility of the Mars One Mission Plan," 1-7, (65th International Astronautical Congress, 2014, PDF).

have been willing to put an overall price tag on it, and they were immediately criticized industrywide for having a budget that was comically low. NASA has instead chosen to approach the financial process incrementally, working on the project piece by piece rather trying to deal with the sticker shock of a full overall estimate. Given the politics that are pervasive in the budgeting process, detailed further in Part II, NASA's approach seems to be a wise one.[15]

Once a colonization project is officially under way, it will need to have a plan in place to ensure continued economic viability and sustainability. There are many in both the public and private sectors that are pushing for the extraction and transportation of valuable substances from Mars, its moons, and near-Earth asteroids. Mining has long been an extremely profitable industry on Earth, netting $133 billion in profits in 2011. Many developers are interested in expanding these operations to non-terrestrial bodies and are focusing on automated extraction techniques. But some are also keeping an eye towards eventual manned operations, particularly on Mars, once it is proven to be relatively safe and efficient.[16]



Concept art for automated asteroid mining. Source: Wired

[15] Al Globus, "Space Settlement Basics," (NASA, 2013, Web).
[16] NASA, "Public-Private Partnerships for Space Capability Development," 13-15, (NASA, 2014, PDF).

One of the largest problems presented is not from extraction, but the ability to return the mined substances to Earth in a cost-effective manner. Current rocket technology is heavily reliant on the initial burning and thrust of rocket fuel, which requires high amounts of oxygen in order to ignite properly. The significantly decreased levels of oxygen on non-terrestrial bodies provide problems not just for human survival, but for rocket ignition as well. Additionally, flying rockets towards the Sun is much more difficult than flying away from it due to the increases in gravity. Therefore, a more powerful burn would be necessary to return a rocket to Earth, regardless of the payload.[17]

Perhaps the most direct economic benefit would be to the space industry itself. Once the problem of initial oxygen burn in different atmospheres is solved, the relatively weak gravity on non-terrestrial bodies will allow for the use of substantially less rocket fuel per launch on missions to reach targets farther from Earth. For example, launching a supply rocket from Earth's moon bound for Mars would utilize substantially less fuel the same rocket having to be launched through Earth's atmosphere due to the Moon having a fraction of the gravity on the surface. This could eventually lead to significant decreases in costs-per-launch and allow for a higher volume of missions targeting an increasing number of locations, such as asteroids and the moons of Jupiter and Saturn.[18]

All of these scenarios carry their own political, economic, and technological challenges. It is ultimately increased technological development that will enable the eventual sustainability and profitability of human colonization and resource utilization of space, but this process is largely slave to the politics that control the funding of such research and development. The

[17] Tom Napier, "Shooting for The Sun," (The Committee For Skeptical Inquiry, Vol. 20.2, June 2010, Web).
[18] Neil deGrasse-Tyson, *Space Chronicles: Facing the Ultimate Frontier,* 102-103, (New York: W.W. Norton, 2012, Print).

following sections will explore three different models for the funding of these projects: public-focused, private-focused, and public-private partnerships. They will expand upon the processes and inherent strengths and weaknesses of each model, and ultimately provide a policy recommendation for future space operations.

Part II: The Public-Focused Model

1. Historical Perspective

NASA was founded in 1958 in response to the growing perceived threat from the Soviet Union. The latter launched the first space-bound satellite called *Sputnik I* in late 1957, and the United States felt it needed a response. NASA was tasked with developing space technology to equal and eventually exceed what was in the possession of the Soviet Union.[19] Thus the Space Race was triggered, a fight for spaceflight supremacy that would extend until the conclusion of the *Apollo 17* mission in 1972.[20]

NASA was, and is, a publicly funded agency that relies on the United States Congress to provide the operating capital it requires. At the time of NASA's creation, space technology was considered to be an issue of national security. The Cold War was on, both the U.S. and the Soviet Union had significant nuclear capabilities, and both sides were apprehensive that space technology could be used to deliver a nuclear warhead with little or no advanced warning. As is often the case when a military threat is imminent, Congress wasted no time and spared little expense to ensure that the United States was equipped to keep pace with and ultimately exceed the capabilities of the Soviet Union.[21]

Although the backdrop was of a military nature, the stakes were raised significantly in 1961. President John F. Kennedy pronounced that the United States would place a man on the Moon by the end of the decade, a bold proclamation given the relatively basic capabilities at the time. To this point, the Cold War had been mostly exercises in hard power; seeing which country could flex the stronger muscles of military might by constantly one-upping the other and

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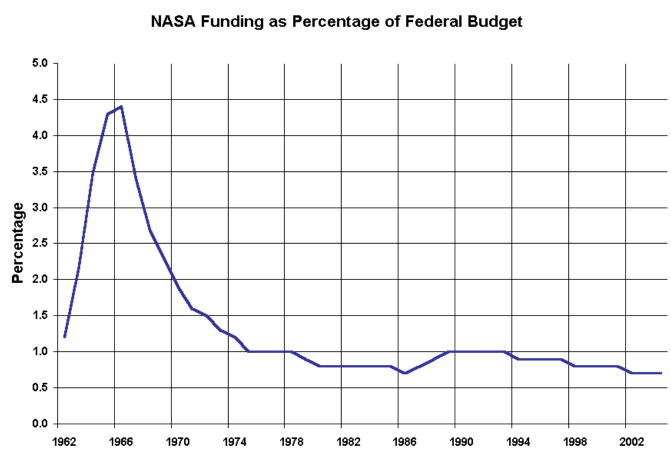
[19] Joan Johnson-Freese, *Space as a Strategic Asset*, 8-10, (New York: Columbia University Press, 2007, Print).
[20] Steve Garber, "Sputnik and the Dawn of the Space Age," (NASA, 2007, Web).
[21] Joan Johnson-Freese, *Space as a Strategic Asset*, 8-10, (New York: Columbia University Press, 2007, Print).

ratcheting up the pressure. The race to the Moon ended up being one of the biggest victories for the United States using what Joseph Nye dubbed "soft power": The ability to get what you want by attraction and persuasion.[22] Over the next eight years, NASA developed new kinds of rocketry and life support elements, launching many test flights, both manned and otherwise. It became a source of national pride for many Americans, commanded the respect of the international community, and continued to establish the United States as a world leader.

What made these developments possible was the significant spike in NASA's funding immediately following President Kennedy's announcement. Starting in 1962, funding rose significantly every year until peaking at 4.4% of the federal budget in 1967, indicated in the figure below.[23] Although the funding would start to tail off after that, the results of this investment became crystal clear when *Apollo 11* made the first manned lunar landing in 1969 and Neil Armstrong became the first man to set foot on the Moon. This would be the first of six manned landings that ended with *Apollo 17* in 1972.



Source: Artemis Project

[22] Joseph Nye, "China's Soft Power Deficit," (The Wall Street Journal, 8 May, 2012, Web).
[23] Neil Degrasse-Tyson, *Space Chronicles: Facing the Ultimate Frontier,* 333, (New York: W.W. Norton, 2012, Print).

As the graph indicates, the funding for NASA as a percentage of the federal budget decreased significantly after 1967 and has continued to hold relatively steady at 1% and under. The dollar for dollar figure ebbs and flows year by year, but when it does increase it is almost never at a rate consistent with the growth of the federal budget or with the rate of inflation.[24] It should come as little surprise that this steep decline and subsequent settling at a much lower level of funding coincided with the decreased competition and perceived threat from the Soviet Union. Scientific discovery – particularly that which requires significant long term planning and budgeting – typically is only of secondary concern to the Congressional Budget Committee who are more interested in items that they perceive as affecting their constituents more directly and immediately.[25]

2. Contracting

Almost since the beginning, NASA has engaged in contracting private companies to design and produce parts of its technology in similar fashion to the United States Military. The military procedure has historically been highly competitive in nature, with different companies presenting proposals with the government awarding the funding to what it deems to be the strongest. As such, the United States Military has a long list of contractors from which it can make its selections.

NASA's contracting has historically not been nearly as competitive, with the agency choosing to sacrifice economical efficiency for the sake of safety and security. The primary contractors have been Boeing and Lockheed Martin for the last fifty years, and in 2006 they

[24] Neil Degrasse-Tyson, *Space Chronicles: Facing the Ultimate Frontier,* 331-333, (New York: W.W. Norton, 2012, Print).
[25] Joan Johnson-Freese, *Space as a Strategic Asset*, 59-61, (New York: Columbia University Press, 2007, Print).

formed the United Launch Alliance (ULA), which was given an essential monopoly on the rights to develop, construct, and launch NASA's missions. The ULA was particularly famous for its 100% safety rating; they have never had an accident during their tenure, on the launch pad or otherwise. However, the ULA had no competition for its NASA contracts, and as a result the price per launch began to rise exponentially. By 2012, the average costs per year had risen to approximately $1.7 billion.

Later that year, a newer private company called SpaceX participated in a debate on Capitol Hill with representatives from the ULA over the issue of whether these development contracts should be competitive. SpaceX CEO Elon Musk argued that the rising costs of vehicle launches were not sustainable – a fact that the Congressional Budget Committee had already established and agreed upon – and that opening the door to other private contractors through competitive awards was the best method going forward. The ULA argued against that idea, saying that the safety of both manned and unmanned missions would be compromised if launches were opened to competitive contracts, a point of view also held by many former astronauts. Ultimately, the ULA monopoly was discontinued and NASA began the process of awarding competitive contracts, although the number of competitors is limited at this point.[26] This will be covered in more detail in Part IV.

3. The Obama Plan

President Barack Obama called for a review commission of all United States space policies and activities a year after his election in 2008. This became known as the Augustine Commission, and it judged the existing launch development program known as *Constellation* to

[26] Brendan McGarry, "Lockheed-Boeing Launch Monopoly to be Ended By Pentagon," (Bloomberg, 2012, Web).

be beyond repair and Congress defunded it shortly thereafter. The Commission also presented three options for a return to manned flight beyond LEO:

- Mars priority with possible equipment tests on the Moon;
- Moon priority in order to develop the capabilities to explore Mars later;
- A Flexible Path allowing for exploration of lunar orbit, the Moons of Mars, and near-Earth objects.

The Commission made no definitive declaration of preference in its final report, but the language suggests that they favored the third option of a Flexible Path.[27]

President Obama announced his new plan in 2010 in a speech at the Kennedy Space Center. The administration had not selected any one of the three recommended plans in entirety, but instead formed a hybrid that took elements from all of them, plus inserting some of its own ambitions. The new policy disregarded short-term plans to return to the Moon due to the lack of viability and instead announced an ambitious plan to have a new heavy lift rocket – one capable of ferrying manned missions into deep space, along with the necessary equipment – ready for construction by 2015 and a manned mission to Mars sometime in the 2030's.

President Barack Obama (D-IL) unveiling his plan at the Kennedy Center in 2010. Source: Ben Cooper

[27] Norman Augustine et al., "Review of U.S. Human Space Flight Plans Committee," 111-115, (NASA, 2009, PDF).

A noteworthy part of this plan is the total reliance on privately owned launch vehicles, something never before seen in a NASA program. The agency had long dealt with private contractors for research and development of launch vehicles and other technology, but it had never had complete reliance on them. Boeing and Lockheed Martin would continue to be major players, but this policy also would potentially allow for other companies to enter the mix, such as SpaceX and Orbital Sciences. This is a nod to the increasing importance of public-private partnerships in the space sector, which will be revisited in Part IV.

There was predictably mixed response to President Obama's plan immediately following its announcement. It found champions in SpaceX CEO Elon Musk and former astronaut Buzz Aldrin in particular, both praising the "Let's do it now" attitude of the plan as well as having an aggressive but realistic timeframe.[28] Among the most vocal critics were former astronauts Neil Armstrong, Jim Lovell, and Eugene Cernan, all of who lamented the cancellation of the *Constellation* program due to the extreme amount of money that had been wasted. They also questioned the viability of the specified timeframe in contrast to the views held by Mr. Musk and Mr. Aldrin.[29]

4. Politics of NASA Budgeting

The budgeting and project planning of NASA is, by its very nature, at odds with the annual Congressional budget planning process. Virtually all of NASA's projects are long term, requiring commitment longer than one budget cycle, and often stretching over dozen or more. Nevertheless, NASA must submit an annual budget proposal just like any other governmental agency, which is subject to review first by the Executive Office of the President and then by the

[28] Buzz Aldrin, "Statement From Buzz Aldrin: A New Direction In Space," (The White House, 2010, PDF).
[29] Neil Armstrong, James Lovell, and Eugene Cernan. "Letter to President Obama," (Politico, April 2010, Web).

Congressional Budget Committee. The budget must go into excruciating detail, every line item is vetted and questioned, and far more often than not, issues of politics come into play.

Members of Congress must balance the needs and demands of the nation that they serve with the needs and demands of the constituency that elects them. Naturally, when these two principles conflict, it is typically the views of the constituency that win out, and NASA's budget is no exception. Representatives that see direct benefit from NASA's activities are much more likely to champion long term NASA programs that will keep adding jobs and economic development to their states and/or districts. For example, Republican Senator Marco Rubio of Florida is normally a conservative budget hawk, advocating spending cuts with strong consistency. But he has been a staunch ally of NASA, often seen at Congressional hearings supporting their positions and funding requests. Florida is home to the Cape Canaveral launch site, as well as many of NASA's developmental projects, both in-house and contracted.[30]

Sen. Marco Rubio (R-FL) meeting with astronaut Joseph Acaba. Source: Marco Rubio

[30] United States Senate, "NASA's Human Space Exploration: Direction, Strategy, and Progress. Hearing Before the Subcommittee on Science and Space of the Committee on Commerce, Science, and Transportation," 5-7, (U.S. Government Printing Office, 17 November, 2011, PDF).

States that do not see this kind of immediate return on investment have representatives that are just as skeptical as Senator Rubio is enthusiastic. While nearly all states have a connection to the space program on some level – even the relatively new company SpaceX already has suppliers in all but five states – there are relatively few with developmental or launch facilities. This makes selling long-term space project budgeting to many representatives a difficult task, particularly when there is not an immediate threat behind the requested funding like there was during the Space Race with the Soviet Union. Indeed, approved space program funding has had the tendency to fall in line with the strength of international rivalries and threats to the U.S.'s supremacy in the field.[31]

It appears that the biggest challenger to the United States' space supremacy in the coming years is going to be China. This should not be particularly surprising due to China's explosion in economic growth. But although their space program is not new, their expanded commitment to it started relatively recently. In 2010, China and India began engaging in what seems to be a new-age version of the U.S.-Soviet Union Space Race of the 1960's, with India pledging to put a man on the moon by 2020 and China by 2025. It remains to be seen if Congress's funding of NASA begins to rise in response to these international challenges.[32]

A Chinese man walking past a space program advertisement. Source: Associated Press

[31] Joan Johnson-Freese, *Space as a Strategic Asset*, 18, (New York: Columbia University Press, 2007, Print).
[32] Jeremy Page, "China a Step Ahead in Space Race," (The Wall Street Journal, 28 September, 2010, Web).

5. Model Summary

The public funding model of the United States space program tends to be the one that the public is most familiar with due to the historical precedent. NASA has been the public face of space exploration and research in the United States and the world over since its creation in 1958. Less well known are the private company contracts that NASA has long taken out with the likes of Boeing and Lockheed Martin to help spurn its research and development programs. Indeed, these contracts have often resulted in what are essentially monopolies and oligarchies that, over time, made NASA's costs skyrocket while maintaining a relatively low level of innovation.

NASA is often hogtied by the politics involved in the annual budgeting process that often conflicts with the multi-year and long-term nature of many of their projects. Some congressional representatives are enthusiastic about continuing to pour money into the space program, particularly those who see direct and significant economic benefit for their constituents. Other representatives whose constituents receive less direct benefits are likewise skeptical of providing funding for the space program, often electing to propose budget cuts or even elimination of the program altogether.

The government will almost certainly continue to be a factor in the establishment of non-terrestrial colonies, though the level of that involvement is a matter of debate. Proponents of a continued and potentially increased government presence in the space industry include many former astronauts such as Neil Armstrong and Jim Lovell, particularly when it comes to guaranteeing the safety of those that continue to go into space. The public sector model is an "If ain't broke, so don't fix it" mentality, which emphasizes patience and safety over speed and cost efficiency. It would be the "safest" way to eventually establish a colony on Mars.

Part III: The Private-Focused Model

1. The International Component

There is a school of thought that looks towards the market and private industry in a nearly exclusive capacity to achieve economic success and innovation. In its most extreme form this concept is known as *laissez faire* capitalism, which translates to "leave alone" and involves government having an entirely hands-off approach when it comes to economic activity; it lets the market do all the work and provide its own corrections as necessary. There are not any examples of *laissez faire* capitalism to speak of in terms of practical governmental application, but it represents the thoughts of many, particularly business owners, who want to maximize profits and use those means to improve the economy.[33]

The space sector is starting to see some stakeholders that prefer this approach, such as Mars One, which will be studied in-depth in the next section. They have taken it upon themselves to operate as independently of government intervention as they possibly can, particularly when it comes to funding. Such prospective companies rely on private investment, donations, and contracts with other private entities for the capital to move forward with their missions. Some are focused on developing specific aspects of space technology, such as satellites or improved launch mechanisms. Others, such as Mars One, have an all-inclusive mission and become involve with as many of the planning and development aspects as they can.

The lack of public contracts has historically been a major, and often impossible, hurdle for many space-focused companies to overcome. It is therefore logical for such a company to become global, reaching out to partners in many countries to attract as much investment and cooperation as they can. The money put forth by public contracts frequently comes with many

[33] Encyclopedia Britannica, "Laissez-Faire," (Encyclopedia Britannica, 2013, Web).

stipulations on how the money can be spent, what kind of product(s) should be developed and produced, and so on. Therefore, being free of these regulations – thus allowing a company to pursue its mission in relative freedom – carries attraction to some investors.

This is particularly relevant in the United States. Over the last three decades, the United States Military has become increasingly more secretive about its developments in rocketry and military capabilities as it relates to space. This has been done mostly in the name of national security, but often at the expense of international agreements. This eventually forces the United States to either be chronically disobedient of the treaties it has signed or to pull themselves out of these agreements entirely. Much of the clauses regarding the sharing of technology that are contained within these agreements are two-way, meaning that by pulling out or chronically disobeying, the United States is not obtaining cutting edge research done in other countries.[34]

The net effect of this is a company with U.S. government contracts could find itself hampered when seeking out international investment, either monetary or intellectual. For example, a group of Swiss engineers might be reluctant to provide their services to a company knowing that whatever work they do will end up being classified by the Pentagon and thus enter the complete control of a foreign government. Those same engineers might find themselves far more likely to ply their trade for a company that can guarantee the integrity of their work, and that it will work towards the benefit of the international community as opposed to a specific set of people. This is unlikely to be an issue for one of the major U.S. military contractors such as Boeing or Lockheed Martin, but could be a major hurdle for companies with a civilian focus.

[34] Neil Degrasse-Tyson, *Space Chronicles: Facing the Ultimate Frontier,* 80-81, (New York: W.W. Norton, 2012, Print).

2. Mars One Case Study

"It is Mars One's goal to establish a human settlement on Mars. Human settlement of Mars is the next giant leap for humankind. Exploring the solar system as a united humanity will bring us all closer together. Mars is the stepping stone of the human race on its voyage into the universe. Human settlement on Mars will aid our understanding of the origins of the solar system, the origins of life and our place in the universe. As with the Apollo Moon landings, a human mission to Mars will inspire generations to believe that all things are possible, anything can be achieved."[35]

This is the stated mission of Mars One, a Netherlands-based not-for-profit space exploration company. Bas Lansdorp and Arno Wielders, both Dutch citizens and space enthusiasts, originally founded the organization in 2011 and assembled a multinational team of employees and advisors representing thirteen different countries. They have declared their intentions to establish a human colony on Mars with the first crews departing in 2024 and landing in 2025. They are currently in the stage of crew selection for the first mission and are planning to commence full-time crew training later this year.[36]

The primary role of Mars One is as a mission facilitator. They do not, nor do they have plans to design or manufacture any hardware. They will rely on their contracts with other "proven manufacturers" to cover those bases. Instead they have placed priority on selecting the team of people who will go on the mission, provide their nine-year-long mission training, and contracting the proper equipment and technology needed to accomplish the monumental task. Their current plan includes planned or existing contracts with SpaceX for the launch vehicle and either SpaceX or Lockheed Martin for the landing capsule. Plans exist for the life support and

[35] Mars One, "Mission," (Mars One, 2011, Web).
[36] Mars One, "Roadmap," (Mars One, 2011, Web).

living modules, surface rovers, and "Mars suits," but those agreements have either not yet been settled or not made public.[37] As of April, 2015, SpaceX has not confirmed the existence of any contract, and Lockheed Martin has stated that, although a contract is in the works, they are awaiting design specifications for the landing module from Mars One.

One of the most controversial claims made by Mars One is that the technology for this mission already exists and no further development or invention is necessary. Researchers at the Massachusetts Institute of Technology (MIT) released a study in 2014 after having conducted a full simulation of the Mars One plan, utilizing the intended technology and taking into account the climate of the planet. They found that, in the best-case scenario, the first astronaut would die of suffocation on Day 68 of the mission, and that the entire team would be dead in a matter of months.[38] Mr. Lansdorp, now CEO of Mars One, vehemently disputed the findings of the study, but aside from saying that the researchers were not working with the proper information and variables in hand, he did not offer any substantive counterargument. Additionally, Mars One has yet to publish an in-depth scientific study demonstrating the scientific viability of their plan.

As a self-proclaimed "nongovernmental, international, and a-political" entity, Mars One has had to establish some creative methods of fundraising. They entice donations by promising future rewards from the mission, such as having one's name inscribed on the planet as part of their Kickstarter campaign that expired in 2014. They solicit sponsorship from international companies in the hopes that they will become mission partners, as well as from smaller companies to which they provide various rights and benefits. Merchandise is also available for sale and the proceeds go back into the organization. Most importantly, Mars One has established

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[37] Mars One, "The Technology," (Mars One, 2011, Web).
[38] Sydney Do et al., "An Independent Assessment of the Technical Feasibility of the Mars One Mission Plan," (65th International Astronautical Congress, 2014, PDF).

a daughter for-profit company called Interplanetary Media Group that is responsible for overseeing the foundation that secures funds from its investors.[39]

Another source of controversy for Mars One comes from its prediction of necessary financial capital to succeed in its mission. They have estimated a figure of approximately $6 billion and, although they acknowledge that cost overruns are a possibility, the fact that they use existing technology should help to mitigate that risk.[40] Many analysts, both scientific and financial, have questioned the accuracy of this claim. NASA budgeters have long operated on an assumption of "Take your absolute worst case scenario, then double it" when trying to figure out the funding for a forthcoming project.[41] Unfortunately, Mr. Lansdorp has not helped his company's cause in the public eye, either. He is consistently vague, combative, and unforthcoming when approached by any in the media about the finances of Mars One. Although many of their donation dollars have come from the United States, they are a Netherlands-based not-for-profit company and are therefore not subject to the stringent reporting standards required of not-for-profits under U.S. tax law.

The jury is still out on the viability of the Mars One mission. With training of the selected astronauts scheduled to commence later this year, it will soon become apparent whether the company is on schedule for their stated goal of a 2024 launch. One of the selected crewmembers broke his silence in March of 2015, calling the whole selection process "extremely flawed," and further implicating the whole program as a scam.[42] It remains to be seen if his allegations prove to be true. Regardless, Mars One has become a lightning rod of debate in both the public and scientific forums with strong advocates on both sides, and they will be a major

[39] Mars One, "Partners," (Mars One, 2011, Web).
[40] Mars One, "Mission Cost." (Mars One, 2011, Web).
[41] Joan Johnson-Freese, *Space as a Strategic Asset*, 59, (New York: Columbia University Press, 2007, Print).
[42] Elmo Keep, "Mars One Finalist Explains Exactly How It's Ripping Off Supporters," (Medium, 16 March, 2015, Web).

player to watch in the space industry in the coming years. Many are hopeful that Mars One will publish both scientific studies showing the viability of their model as well as financial reports proving their monetary status.

3. Space and Private Industry

Various private industries have had interests in the realm of space for years. The most common ventures in civilian technology have been seen in the form of orbital satellites to augment service provision in areas such as cellular communications, global tracking and positioning (GPS), broadcast television, and Internet access, to name a few. Some well-known companies involved in satellite-oriented retail and customer service include but are not limited to Verizon, AT&T, Sprint, Garmin, DirecTV, Dish Network, and HughesNet.

Military operations also have a strong role in some private space industry. Many countries throughout the world – but particularly the United States – contract the research, development, and construction of military technology to private companies who can typically do it more efficiently and for cheaper prices. The space sector is considerably smaller, but several of the giants in conventional military contracting remain constant, specifically the goliath companies that are Boeing and Lockheed Martin. Both have been at the forefront of both U.S. military and NASA contracting for years.

A third and relatively new sector is the handful of private companies who have made their company goals primarily that of developing technology for space. SpaceX, which will be examined in a case study in Part IV, was created specifically to be a private rocketry company to develop launch mechanisms for NASA with no declared military aspirations whatsoever. They have also announced intentions to launch a private network of satellites to make high-speed satellite Internet accessible to a wider consumer base.[43] Another company is Virgin Galactic – one of the brainchildren of entrepreneur Richard Branson – that is working towards building its own spaceport in New Mexico and becoming a provider of space tourism.[44] These types of companies have varying approaches in their reliance on government. Virgin Galactic is relatively autonomous, relying as little on government contracting and contribution as it can. SpaceX relies quite heavily, if not solely, on NASA contracting at present, although it is looking to become more self-sufficient with innovations such as the satellite internet network.

There are many other commercial ventures that relate to space but most of them remain prospective for the time being. For example, much of the aforementioned space mining and resource extraction development is still heavily reliant on government funding due to the high amount of risk involved. This is also true of much of the technology being developed to ensure the survival of human colonies on other planets. Once the technology becomes proven in practice and is subject to true field trial-and-error tests, the risk-reward ratio to private companies without substantial government assistance will become more favorable and the market is likely to grow.

4. The Role of Government

The differences between civilian and military space technology bring up the controversial topic that is known as "dual-use technology." This is defined as technology that fundamentally serves both civilian and military purposes. A point of contention for many continues to be that all existing space technology either directly serves or could be appropriated to serve a military –

[43] Alan Boyle, "SpaceX, Google and Virgin Revive Buzz Over Satellite Internet," (NBC News, 21 January, 2015, Web).
[44] Virgin Galactic, "Spaceport America," (Virgin Galactic, 2015, Web).

and potentially weaponized – purpose, but none of it exists solely for civilian activities. This, along with an increasing military reliance on space technology, has led to the Pentagon exerting as much control as it can over the whole sector, both nationally and internationally, due to issues of national security. One of its worst nightmares is an enemy of the United States either destroying or appropriating its militarized space technology, and it has accordingly taken exhaustive precautions to protect its assets.[45]

Unfortunately, this comes with a cost to international relations and cooperation discussed in Part 1. It also establishes a serious problem for private space companies seeking to minimize government interference in its affairs. This could lead a private company that utilizes space to provide its product – but the product actually provided is on the ground and not in space, such as GPS and satellite television – to be hesitant to take government subsidies due to the fear of intervention. By contrast, space-focused products are still relatively young and experimental, so companies that focus in this higher-risk area are typically much more open to government contracts and subsidies to minimize this risk. This particular area is not yet developed enough to exist in the open market with any real degree of autonomy, but further research and development could make this possible in the long run.

5. Model Summary

The private-focused model is, at this point, a hypothetical one. It places the onus on private sector companies and nonprofits to continue developing the capabilities to continue space activities and having little to no reliance on governmental entities. It is particularly attractive in the international community for those who would like to see continued development and sharing

[45] Joan Johnson-Freese, *Space as a Strategic Asset*, 82-105, (New York: Columbia University Press, 2007, Print).

of intellectual property between nations without having everything swallowed up and classified by The Pentagon.

Not-for-profits such as Mars One intend to accomplish this by networking private corporations with different areas of specialty together with a central body to coordinate all the activities and provide training and mission expertise for future crewmembers. This type of structure allows for minimal interference from governmental actors, providing a centralized body that is not interested in maximizing any sort of revenue outside of being able to maintain its operating costs and accomplish its mission. Meanwhile, its private sector partners will compete with each other, driving the costs of manufacturing lower while encouraging innovation.

There is concern about how such private development networks will be held accountable with no governmental oversight, however. The private-focused model encourages speedy innovation, the continued streamlining of costs, and the sharing of ideas between nations. It also potentially comes at the expense of private corruption and safety regulations provided by governmental agencies. It could, once the market becomes less risky and more predictable, lead to expedited developments in colonization of Mars and eventually beyond.

Part IV: The Public-Private Partnership Model

1. Historical Perspective

The United States has a long history of using public-private partnerships (PPPs) to achieve its ends. The aforementioned defense contractors are among the most widely known, with Boeing and Lockheed Martin being contracted to develop and produce much of the Pentagon's cutting-edge military technology. But the use of PPPs goes back much farther than that. The federal government has a general mandate to provide for the welfare of the people, and often it needs to engage the private sector to provide services or complete projects that would be too risky or that provide too little financial incentive for either side to handle alone.

One of the earliest examples of these partnerships was the construction of the Transcontinental Railroad in the 1800's. This was established through partnerships set up with private railway corporations – most notably Union Pacific – incentivizing the building of the Railroad through land grants, subsidies, and loans, with the loans repaid primarily through transportation revenues and land sales. This also allowed the government to impose monetary and safety regulations that they would otherwise have struggled to pass. Ultimately, the aid of the United States government to the private sector allowed the Transcontinental Railroad to be constructed more quickly and effectively than if it had been left entirely to either entity alone.[46]

The United States government has also been heavily involved in the development of the aerospace industry, almost from the very beginning. The "aerospace industry" is a catchall term that includes the outlays for the Department of Defense, NASA, and the National Advisory Committee for Aeronautics (NACA), among others. The government has also historically been involved in stimulating civilian flight development, eventually turning it into the massive

[46] Roger D. Launius, "Historical Analogs for the Stimulation of Space Commerce," 38-43, (NASA, 2014, PDF).

industry that it is today. The overwhelming majority of research, development, and innovation across all sectors of the aerospace industry – NASA and NACA in particular – can be traced back to government investment and contracting.[47]

There are many other examples of PPPs present throughout United States history, such as development of the telecommunications industry and the building of tourism-related infrastructure to the system of National Parks, particularly in the west. PPPs most often come into play when the government wants to stimulate, or even create, an industry in a particular area that the private sector is leery of approaching on its own. NASA has been fostering some PPPs for years, particularly with Boeing and Lockheed Martin. But there is starting to be an uptick in how much the agency relies on them and how open their contracting process is, most notably with the recent success of the industry-disrupting company SpaceX.

2. SpaceX Case Study

Billionaire Elon Musk has had his fingers in all kinds of technological innovations in the last twenty-five years. He originally made his fortune by developing the online payment method known as PayPal, which was later sold to EBay for $1.5 billion. He was then able to get into other aspects of technology, such as acquiring and reinvigorating Tesla Motors, an all-electric car manufacturer that was on the bring of collapse. But arguably his most aggressive and risky business decision was to start a private rocket manufacturer from scratch. It is called Space Exploration Technologies (SpaceX) and it was founded in 2002 with a mission to "revolutionize space technology, with the ultimate goal of enabling people to live on other planets."[48]

[47] Roger D. Launius, "Historical Analogs for the Stimulation of Space Commerce," 47-62, (NASA, 2014, PDF).
[48] SpaceX, "Company," (SpaceX, 2013, Web).

The initial goal of SpaceX was to prove to NASA that they were worthy of one of the lucrative government contracts to re-supply the ISS. This had to be done by successfully building and launching a private rocket independent of government funding, and this proved to be a huge challenge that resulted in several failures. On what Mr. Musk determined had to be the last attempt due to dwindling funding, SpaceX finally launched its own rocket and was subsequently awarded a $1.6 billion contract from NASA in 2008 to re-supply the ISS.[49]

It has been determined that the vast majority of costs involved in a space launch are in the hardware. Each successive launch gets more and more expensive as the hardware becomes more expensive to make, and disposable rockets must be made almost entirely from scratch. Even the reusable space shuttle had to have its fuel tank and booster rockets rebuilt or at least significantly repaired for each launch. SpaceX determined that an overwhelming percentage of the cost (as much as 99.7%) could be removed from the budget of a successive launch if the only requirements were post-flight maintenance and refueling. As such, one of their current top priorities is the development and construction of reusable rocket.[50]

Attempts at creating such a rocket have been made before. NASA has had several budgeted projects for the development of a reusable rocket in which billions of dollars were spent, but funding was always pulled before success could be achieved due to unanticipated budget overruns and failure to meet deadlines. As a private entity, SpaceX is not bound to the line-by-line restrictions that NASA must adhere to, and they have proved to be far more effective. The *Falcon 9* rocket, nicknamed "Grasshopper," has been successfully launched and landed up to an altitude of just below 2,500 feet. It has also been used successfully for ISS

[49] SpaceX, "Company," (SpaceX, 2013, Web).
[50] SpaceX, "Reusability: The Key to Making Human Life Multi-Planetary," (SpaceX, 2013, Web).

resupply missions, but the attempts to land it successfully – upright and on a landing pad – have not yet been successful, being dubbed "Almost but not quite" by Mr. Musk.[51]

The "Grasshopper" rocket. Source: SpaceX

The other current major focus for SpaceX is the development of the next vehicle that will carry astronauts into space. The space shuttle was officially discontinued in 2011 and American astronauts have been reliant on Russian *Soyuz* rockets to ferry them to the ISS and back, an agreement that continues to get more and more tenuous with the increasing strain in diplomatic relations between the two countries. In 2014, NASA awarded the contract to develop the next American manned space vehicle jointly to Boeing and SpaceX, with Boeing receiving approximately two-thirds of the funding. They were chosen over the Sierra Nevada Company, with which longtime giant Lockheed Martin was a subcontractor. Sierra Nevada has attempted

[51] SpaceX, "Reusability: The Key to Making Human Life Multi-Planetary," (SpaceX. 2013, Web).

to protest the decision in court due to "serious questions and inconsistencies in the source selection process." The results of that complaint are still pending as of April, 2015.[52]

SpaceX are no strangers to legal procedures. As mentioned in Part II, Mr. Musk represented the company at a congressional hearing in 2012 concerning the future of launch funding as the costs continued to rise to unsustainable levels. He argued for a more open system of public-private contracting similar to what the U.S. military uses, which would allow for quicker development, more competitive price tags, and ultimately more successful missions. His opponents from the United Launch Alliance (ULA) argued against that logic on the premise that open contracting could lead to compromises in safety standards and presented the ULA's 100% safety record as evidence. Many former astronauts, including Neil Armstrong and Jim Lovett, were also supporters of maintaining the status quo.

	ULA	SpaceX
Capability Sustainment (independent of # of launches)	$1Billion (+ TBD classified portion)	$0
Cost per launch (medium class)	*$180M*	*$75M*
Cost per launch (heavy class)	*$350M*	*$125M**
Total Launch Costs*	$1.7B*	$1B*
Total Cost of Current Program	**$2.7 Billion** + TBD classified portion	**$1B**

Estimated savings with Falcon (assuming 8 EELV launches per year): **~$1.7B - $2.2B per year**

**Cost for 6 Medium and 2 Heavy ULA launches.*
**Cost for 8 Falcon Heavy launches. Reflects commercial pricing for Falcon Heavy.*

Source: Next Big Future

Ultimately, SpaceX won the argument due in large part to the numbers shown above. They were able to prove that their model was far more economical and sustainable over the long term, and the ULA's monopoly was discontinued. SpaceX has been reaping the rewards since

52 Christian Davenport, "Sierra Nevada Corp. protests NASA space contract awarded to Boeing, SpaceX," (The Washington Post, 27 September, 2014, Web).

then, with contracts and future considerations currently sitting at around fifty missions and approximately $5 billion in government contracts.[53] Their success is likely to convince other manufacturers of aerospace equipment to test the market and create a larger environment of competition for SpaceX, Lockheed Martin, Boeing, and others. For his part, Mr. Musk encourages this kind of competition and has made a point to not acquire patents on any of SpaceX's products or designs.[54]

3. Current Space Public-Private Partnerships

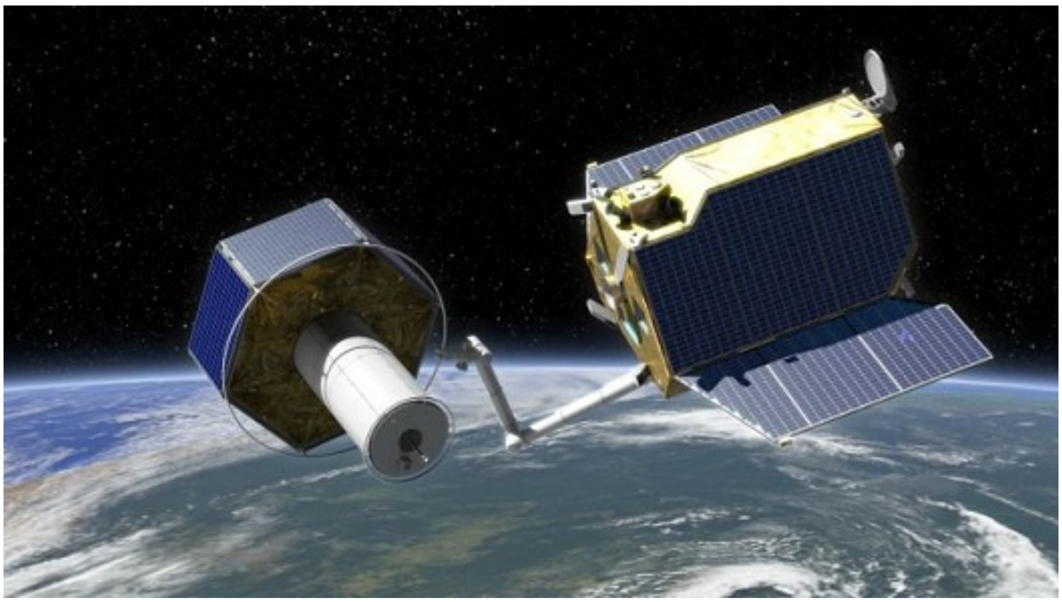
In April 2014, NASA released an overview of the PPP areas it considered to be essential to driving both economic growth and its mission as an agency. Some, such as interplanetary small satellites, are reasonably well known to the general public due to strong media coverage. Others, such as robotic mining, are far less so. NASA identified eight industries that it believes are areas for excellent PPP growth. These are all industries that it wants to spur growth in, but still are not ready to be taken on entirely by the private sector due to high-risk factors and thus require some level of government subsidization and incentive.

Satellite Servicing

Satellite launches have become a relatively common practice over the last twenty years. Many different entities, ranging from governments to private companies, have launched satellite technology to further their aims, be they military, communicative, or navigation in nature. Once launched, these satellites are usually considered to be disposable; it would be far less costly to just abandon the satellite once it runs its course rather than spending the time and effort to repair

[53] SpaceX, "Company," (SpaceX, 2013, Web).
[54] Kim Bhasin, "Elon Musk Explains Why SpaceX Doesn't Patent Anything," (Business Insider, 9 November, 2012, Web).

it to extend its life. Additionally, if a satellite should accidentally be sent into the wrong orbit, many of them do not have much in the way of self-corrective measures. This means they become entirely sunk costs since they cannot perform the tasks they were designed for from the wrong orbit.



Concept art of a service satellite repairing a commercial satellite in orbit. Source: Airbus Defense and Space

This has led to a demand for a way to be able to service these satellites once they leave Earth. Servicing can mean in-flight repair, routine maintenance and upkeep, and orbital correction. By 2010, NASA had identified eighty-six companies that had the potential to become effective satellite servicers for the 1,046 known active satellite flights in orbit around Earth, both owned by private industry and by the United States government. More importantly, NASA also estimates that there are around 2,500 nonfunctional satellites in orbit around Earth that could be reactivated or salvaged. NASA calculated that the global satellite market generated $190 billion in revenue in 2012, and implementing regular satellite servicing would allow the satellite industry to reduce costs by cutting the number of necessary replacement launches, saving satellites launched into incorrect orbit, and potentially recovering deactivated ones.[55]

Interplanetary Small Satellites

The satellite industry is continuing to grow due to the growing reliance of orbital technology for communications, navigation, and asset tracking. Companies are increasingly demanding smaller, lighter, and less costly satellites to perform increasingly complex functions, all of which have been able to be done with some degrees of success. Interplanetary satellites – satellites that are intended to orbit around a body that is not the Earth – do not yet have much in the way of commercial demand, but private startups such as Planetary Resources are working on developing such satellites for the purposes of robotic mining. If Planetary Resources proves their concepts to be effective, this could kick-start a much larger market beyond the current usage, which is almost entirely governmental.[56]

Robotic Mining

With the global mining industry earning $133 billion in profits alone in 2011 and being expected to continue to grow over the next few years, many believe that the top moneymaker in space could be mining and resource extraction. Not only could such resources be valuable commodities on the open market, but they also are crucial to NASA's long-term mission plans to the Moon, Mars, and near-Earth asteroids. Among the critical materials that could be harvested and processed entirely in space are hydrogen and oxygen, both critical to survival of life as we know it and therefore crucial to the success of any long-term manned mission.

NASA has identified five companies – four of them based in the United States – that are working on developing automated mining technology specifically for the locations of the Moon

[55] NASA, "Public-Private Partnerships for Space Capability Development," 5-8, (NASA, 2014, PDF).
[56] NASA, "Public-Private Partnerships for Space Capability Development," 9-11, (NASA, 2014, PDF).

and asteroids. Of those five, Astrorobitic, Moon Express, and the aforementioned Planetary Resources appear to have the most in the way of investment and funding capability. Astrorobotic in particular has development partnerships with Carnegie Mellon University and Caterpillar – one of the largest construction equipment manufacturers in the world – and was awarded a contract by NASA to develop technology to explore caves on Mars as well as the Moon. Development in this area could end up being one of the most critical factors to the continued growth and development of long-term space initiatives, both scientific and otherwise.[57]

Microgravity Research for Biomedical Applications

NASA has been creating conditions of microgravity – the perception of weightlessness – for many forms of research for some years now. One of the strongest areas with commercial application deals with biomedical research being performed in microgravity conditions. Specific areas of interest include treatments for diseases that often affect the elderly, cancer treatments, treatments for infectious diseases, tissue engineering and regenerative medicine using stem cells grown in space, and protein crystallization for drug discovery and development. Microgravity can be useful in these areas due to its tendency to reduce stresses on tissues and increases in the virulence of certain bacteria, among other reasons.[58]

The private sector interest primarily comes from biomedical companies working to develop and sell medical products to improve treatment options and increase their overall revenues. They do not possess the facilities to recreate microgravity conditions, and thus rely on NASA to provide the means to carry out this research. For their part, NASA is interested in the effects of microgravity on the human body, particularly for extended durations. In late March of

[57] NASA, "Public-Private Partnerships for Space Capability Development," 7-16, (NASA, 2014, PDF).
[58] NASA, "Public-Private Partnerships for Space Capability Development," 15-19, (NASA, 2014, PDF).

2015, NASA launched a yearlong mission to the ISS to perform such a study on American astronaut Scott Kelly and Russian cosmonaut Mikhail Komienko.[59]

Liquid Rocket Engines for Launch Vehicles

Liquid rocket engine development is one of the most publicly recognizable development fields of NASA due to its fundamental importance to the space program. It is difficult to focus on something space-oriented if one cannot get into space to begin with, so this is an area of constant research and development despite having a relatively small clientele that currently consists of launch service providers and spacecraft operators. Despite this small demand base, commercial launches still generates between $2.5 and $3 billion of revenue per year on an average of nineteen launches per year. That average was expected to rise to thirty-one launches per year starting in 2013, which will lead to increases in the overall revenue generated per year.

Developments in this sector are crucial for the continued advancement of NASA's goals. Improvements in liquid rocket engines will allow for longer flights with more efficient rockets that cost less, and will allow NASA to continue to expand its reach farther into deep space. Due to the limited number of clients, subsidization from the federal government provides much of the incentive for private companies such as SpaceX, Orbital Sciences, and Aerojet Rocketdyne, to involve themselves in research and development.[60]

Wireless Power

In a world where people increasingly want to shed as many wires and physical connections as possible, wireless power has become a research area of significant interest. NASA is co-sponsoring aggressive research initiatives that are seeking to find a way to provide wireless power to land-based power grids by beaming the power down from orbit. If successful,

[59] NASA, "One-Year Mission and Twins Study," (NASA, 2015, Web).
[60] NASA, "Public-Private Partnerships for Space Capability Development," 20-24, (NASA, 2014, PDF).

this could be a groundbreaking method of providing efficient electrical power to a world that seems to require more of it every day. The U.S. alone currently consumes approximately 3.8 trillion kilowatt hours of power every year, with that number expected to grow to 4.9 trillion by 2040. NASA's specific interest in the field deals with the remote powering of surface rovers, aerospace vehicles, and potentially even launch propulsion. Given the need to use space-oriented facilities and technology for such research, partnerships with companies such as LaserMotive, LLC have proven to be mutually beneficial.[61]

Space Communications

Space communication is the field of space technology that has the most practical, every-day use to the general public, though much of the time unconsciously. As previously mentioned, satellite technology is instrumental in providing services such as telephone, television, the Internet, and navigation, among many others. It is currently a relatively small portion of the enormous telecommunications industry – space technologies generated $190 billion in revenue in 2012, approximately 4% of the $4.9 trillion market – but it experienced a five-year growth rate average of 9.48% from 2007 to 2012, which was higher than both U.S. and world economic growth rates during that period. The industry is expected to continue to grow due to the increasing demands for data services and bandwidth.

The telecommunications industry is vast, and a full analysis is beyond the scope of this research. But the main point of emphasis in space communications research tends to be on trying to move past reliance on slower and less reliable radio waves and to a laser-based communication system. This would not only improve commercial terrestrial communication, but also allow for greater efficiency in asset-to-asset communication in space itself, a key focus for

[61] NASA, "Public-Private Partnerships for Space Capability Development," 25-28, (NASA, 2014, PDF).

many of NASA's current and future projects. Most of the research continues to be governmental and is often classified due to its militarily sensitive nature, but some PPP's have been forming through companies such as Planetary Resources to continue improving existing technologies.[62]

Earth Observation Data Visualization

Many satellites in orbit have instruments on board – sensors and cameras primarily – that allow continuous photography and data gathering on Earth's surface. These images and data have many uses ranging from commercial to scientific to military. Estimates from 2011 show the U.S. geospatial industry as being responsible for $73 billion in revenue and approximately 500,000 jobs classified as "high-wage." Several companies focus specifically on satellite observation as their primary product output, of which Digital Globe, Planet Labs, and Skybox are among the most prevalent.

NASA is concerned with this data not just to improve scientific understanding of the Earth itself, but also to provide insights that will aid them in their non-terrestrial aims. Many of the satellites providing this information are dual-use, serving both NASA and private industry. With the demand for data increasing every year, it is likely that the geospatial industry will continue to grow as a result.[63]

4. Other Related Sectors

In the context of establishing a planetary settlement, there are other PPP areas that NASA could open up and explore further. An established colony needs to not only contain the elements necessary for survival, but also carry some level of attractiveness so as to encourage continued migration. The following is a list of potential opportunities – though hardly comprehensive –

[62] NASA, "Public-Private Partnerships for Space Capability Development," 29-31, (NASA, 2014, PDF).
[63] NASA, "Public-Private Partnerships for Space Capability Development," 32-36, (NASA, 2014, PDF).

that NASA could explore in sectors beyond what was reported in their "Public-Private Partnerships for Space Capability Development" report, particularly as it relates to colonization beyond Earth. Many of these technologies could also serve double purposes to improve the quality of products and technology in Earth-bound industries as well.

Inner and Outer Wear

NASA has worked on developing and advancing the spacesuit that allows humans to exist for short periods of time outside of a controlled, sealed space station or spacecraft. But a colony would require much more intensive usage of these suits, and they would need to be constructed in ways that are considerably more durable, cost-effective, and comfortable for the wearer. Not only would these be required for any work or movement outside of sealed shelters, but they would also be fail-safes in the event of the loss of atmosphere within such a shelter.

Prototypical design of a next-generation spacesuit. Source: Japan Aerospace Exploration Agency

Many companies have long specialized in creating increasingly durable, water-resistant, and heat-trapping clothing, particularly for cold weather climates. NASA could expand its research on new and improved inner and outer wear suitable for environmental containment by awarding competitive contracts to companies who could demonstrate significant strides in the area while also working to improve cost efficiency. Some examples of such developers are L.L. Bean, Oshkosh (who has been contracted by NASA in the past), Gerry, The North Face, Columbia, Mountain Hardware, and adidas.

Consumer Electronics

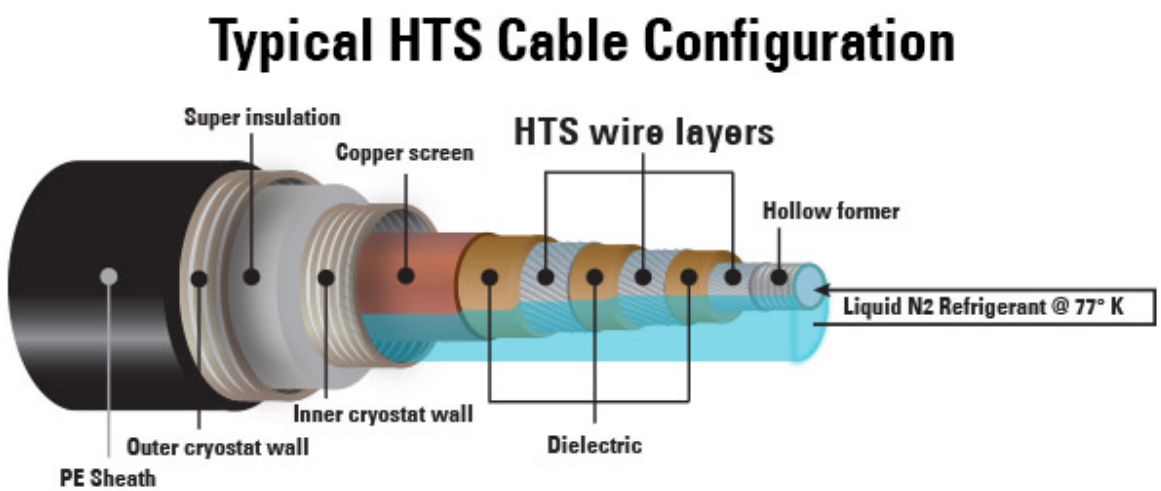
NASA and its contractors have expended much effort making the components and technology critical to survival and scientific practice resistant to the hazards of space. In order to prepare for long-term colonization, such steps should also be made to protect small electronic devices that have become both commonplace and crucial to peoples' everyday lives. These developments are not needed as much in LEO, as they are shielded by the structure of the ISS and the environment is completely controlled. But on a particularly dusty planet with a foreign atmosphere, more developments would need to be taken to protect the everyday items of the future colonists. Potential options for government contracts include Apple, Microsoft, Sony, Samsung, Garmin, Bose, Yamaha, Panasonic, and LG.

Ground Transportation

The Lunar and Martian rovers have been staples of NASA's development programs for the last few decades. Improvements are consistently being made in the areas of tire development, engine shielding and efficiency, fuel tank storage and efficiency, fuel types, and framework weight and integrity. NASA has done some contracting in this area, but the process could be expedited by encouraging other major manufacturers to do their own research and development in these areas. This is particularly relevant to colonization since much of NASA's recent work has been for unmanned rovers, and the Lunar rovers used during the *Apollo* missions were entirely open and designs for vehicles that are fully enclosed and environmentally sealed would be helpful. Potential options for contracting include General Motors, Honda, Toyota, Michelin, Goodyear, Mercedes-Benz, Rolls Royce (already an aerospace contractor), and Tesla.

Hardline Power

In order to keep a non-terrestrial colony up and running, providing constant and uninterrupted power will be a primary concern. Such power source development could be approached with both fossil fuels and renewable energy options, such as solar and wind power. Wind power in particular could be a valuable source on Mars since it is subject to powerful dust storms that have winds topping 60 miles per hour.[64] Fossil fuels such as petroleum and natural gas could be explored as possible options that could end up being more cost-effective, but both of these sources are dependent on having oxygen present in order to burn properly, so the provision of oxygen issue would also have to be solved at the same time.



Cross-section of a superconducting power line. Source: Superconductor Technologies, Inc.

Transmission of created power can also be developed so as to reduce power losses due to heat transfer from the power source to the power receiver. Scientists have experimented with superconducting material for power transmission on Earth that have a net power loss due to heat

[64] NASA, "Mars Facts," (NASA, 2011, Web).

that approaches zero assuming the conditions are cold enough, and many believe that continued development of these kinds of superconducting transmission lines could be key to sustainable power transmission on a non-terrestrial world.[65] Potential options for both power sourcing and power transmission research contracting from NASA include Exxon Mobil, British Petroleum, Shell, Solar City, Inc., the Massachusetts Institute of Technology, and Aeronautica Windpower.

5. Model Summary

Elements of the public-private partnership-focused model have been historically used to supplement the public-focused model that NASA has maintained since its creation. But the last few years have shown an increasing trend towards more reliance on PPP's and less so on the public sector. The cost problems presented by the United Launch Alliance caused NASA to discontinue that monopoly and instead open the field for more open competition similar to what is seen in the United States Military. This has provided the incentive for manufacturers to focus on innovation again, improving the products themselves while also improving cost efficiency. There have also been an increasing number of private startups focusing specifically on space technology, such as SpaceX, Planetary Resources, and Aerojet Rocketdyne.

Supporters of this model believe it to be the best balance between maintaining an acceptable level of government oversight while also breathing life back into an industry that had grown unsustainably costly and stagnant. It would allow some improvements in the speed of research and development without sacrificing all governmental regulation in the process. It is neither as cost-effective or speedy as the private-focused model, nor as accountable and safety-centric as the public-focused model. But it does provide a good balance of all these factors,

[65] Roger Hinrichs & Merlin Kleinbach, *Energy: Its Use and the Environment*, 5th ed., 320-322, (Boston: Brooks/Cole, Cengage Learning, 2013, Print).

which would lead to an accountable, reasonable, and yet more efficient means of colonization than the status quo has maintained.

Part V: Conclusions

1. The Public Model

The public-focused model can be summed up as the status quo. Since NASA's creation in 1958, the space programs of not just the United States but also the Soviet Union and other countries around the world have relied predominantly on the public sector to provide both the means and the methods to move forward with advancements and innovations. It has usually been up to NASA to incentivize the private sector to get involved in space activities due to the high risks and uncertainties associated with the industry, and they have historically been highly selective. Only in more recent times has NASA started to provide more open-ended means for companies to operate more autonomously, albeit still with substantial government contracts to help compensate for the continued high risks and unpredictability associated with current space research and development.

Strengths and Advocates

The primary strength of the public-focused model is the accountability it provides. The more oversight NASA has, the more regulations it can impose on design and manufacturing to prioritize the health and safety of both its human and technological capital. As a public agency, NASA is funded by and accountable to American taxpayers, and there are often high levels of scrutiny that come along with their use of public funds. Their caution can be seen with the monopoly granted to the United Launch Alliance, which maintained a 100% safety record throughout its time as NASA's exclusive launch partner. Another example is the *Apollo* series of missions which, despite enormous risk and some mechanical issues – particularly that of *Apollo 13*, which was later dramatized – never experienced any casualties. Indeed, the only fatalities resulting directly from space launches were the two Space Shuttle disasters: *Challenger* in 1986, and *Columbia* in 2003, the latter of which ultimately decided the fate of the Space Shuttle which was officially discontinued in 2011. It would be irresponsible, however, to gloss over the fatalities that have resulted from projects in the testing and experimental phases, which are numerous and well-documented.[66]

The second strength is also related to safety, and that is the exercising of a high amount of patience. Explicit NASA regulations and strict procedures tied to both development and launches have often caused slowdowns in progress, but have also allowed NASA to maintain a good overall safety record. A sad but potent reminder of patience not being properly displayed in launch procedures can be seen with the *Columbia* Space Shuttle disaster, which was lost during reentry. It was later discovered by a review board that there were institutional problems within the administrative hierarchy of NASA that likely led to some potential pre-launch issues being overlooked or glossed over, and structural changes were recommended.[67]

It is in that spirit of safety, patience, and accountability that the public-focused model finds most of its support. Many former astronauts count themselves in this group, such as Neil Armstrong, Jim Lovett, and Eugene Cernan, all former *Apollo* mission commanders. The United Launch Alliance also championed this approach, pointing to its flawless safety record as proof of the model's viability. Several former NASA directors are also on record with the support for continued strong governmental oversight for the space program in the future.

Weaknesses and Opponents

The primary overall weakness of this model is the sustainability of funding, or lack thereof. The combination of the political budgeting process, presidential administrations with differing goals and levels of seriousness, and a relative lack of competition all have led NASA to

[66] AirSafe, "Deaths associated with US space programs," (AirSafe, 2015, Web).
[67] NASA, "Columbia Crew Survival Investigation Report," xxix, (NASA, 2008, PDF).

have their budgets continually shrinking as a percentage of the overall budget while their mission costs continued to rise. They were eventually forced to remove the ULA monopoly or else risk launch costs rising so high that they could no longer be afforded at all. This problem was compounded by the ULA not devoting enough resources to the innovation and streamlining of their products since they had no competition-driven incentive to do so.

Related to the stagnation that has pervaded the public-focused model is the snail's pace at which projects get planned, executed, and completed. It is the unfortunate downside of having such a safety-centric organizational mentality: Everything slows down, projects get delayed, and some never get finished at all, leading to wasteful spending and sunk costs. This is a standard that many do not want to compromise, particularly former astronauts. But by the time the ULA was disbanded, things had slowed so much that many in the industry were beginning to wonder if manned flight would return to deep space in fifty years, if ever.

This model has plenty of opponents who have championed reform of NASA's operations for some time. Former astronaut Buzz Aldrin was particularly critical of the slowdown and was extremely concerned for the future of the space program. He welcomed the discontinuation of the ULA monopoly and applauded the awarding of NASA's next manned module contract to Boeing and SpaceX. Likewise, SpaceX CEO Elon Musk publicly advocated for more open competition for NASA's lucrative development contracts in the hopes that it would spur investment, innovation, and greater efficiency.

2. The Private Model

The private-focused model is, at this moment, purely hypothetical. As such, it does not directly have any specific industry advocates or opponents outside of theorists. But those who agree or disagree with the implementation of such a model are likely to be inverted with the views of the advocates and opponents of the aforementioned public-focused model, and in line with the opinions of the forthcoming public-private partnership model. Nevertheless, it does present its own set of strengths and weaknesses that as worthy of examination.

Strengths

The primary strength of the private-focused model lies in its potential efficiency. If there were enough companies competing with each other in enough sub-sections of the space industry market – rocketry, launch services, mining, satellite servicing, and so on – then the industry would begin to see unprecedented growth similar to what has been seen in many other technology markets in the last twenty years. Companies would push each other to keep creating better, more efficient, and cheaper products and constantly try to one-up the other as is often seen in a capitalist economy. This kind of rapid growth could lead to massive expansion from Earth in much quicker fashion than anyone could have predicted.

The second potential strength comes in the form of international relations and cooperation. The removal of significant government intervention from the model – particularly that of the often militarily-driven United States – would make the sharing of scientific data and technological know-how less of a political battle and more of a common sense and good faith business practice. Scientific research installations such as CERN in Switzerland already publish much of their findings for the scientific community to read, regardless of nationality, and astronomy is often treated in similar fashion. But technological developments have the reputation of being held far closer to the vest, particularly by governments who do not want their rivals – or enemies, in some cases – acquiring the same knowledge that they possess and mimicking them or developing countermeasures. Removing these political hurdles through this model would open up the industry substantially.

Weaknesses

The primary weakness of this model is that it is not feasible in the current environment. First, the industry has not yet reached that level of private sector autonomy required, or even come anywhere near it. There is still too much risk and uncertainty involved for most companies to risk putting their fingers into the space industry without some kind of government contract or compensation to cover them. Second, the current political climate is not friendly to this kind of technology sharing. Governments are becoming increasingly distrustful of each other, and in some cases, simply distrustful of everyone. This has led to tighter restrictions on information sharing, even in strongly capitalist economies such as the United States. Third, the not-for-profits that work to spearhead these networks of affiliated companies, such as Mars One, are often reliant on networks of donors to raise their funds, and the space exploration field does not share anywhere near the same kind of philanthropic draw that many other fields enjoy. These things could all come with time, but are not feasible in the current climate.

The second potential weakness is the inverse of one of the public model strengths in regards to safety and accountability. The less governmental oversight that exists, the more profit-driven companies will be able to get away with unscrupulous or corrupt dealings, many of which may end up jeopardizing the health and safety of future astronauts. Corporate fraud is a continuous problem, particularly in capitalist economies, and with the experimental and oftvolatile nature of space industry projects, this is a virtue that many in the field are absolutely unwilling to compromise on such a level.

3. The Public-Private Partnership Model

The public-private partnership model has existed as an extension of the public-focused model almost since the formation of NASA in 1958. The agency has long been authorized to award research and development contracts to private and/or not-for-profit corporations when it feels that it would be beneficial financially, economically, or when it would be likely to improve the overall quality of the product. This model would instead prioritize the contracting of nongovernmental organizations to handle much, if not all, of the research and development, with NASA providing direction and guidance based upon its mission as well as maintaining protocols of safety and business ethics.

Strengths and Advocates

The primary strength of the public-private partnership model is that it is the "jack of all trades, master of none" in the space policy conversation. In comparison to the public-focused model, its processes are speedier and more economically viable in the long term. Contracting out the vast majority of research and development to nongovernmental organizations will allow for an expedited process due to the removing of most of the bureaucratic "red tape" that exists to keep governmental agencies like NASA in check. These same restrictions also force NASA to elongate many of its projects and thus end up with large amounts of wasteful spending, so transitioning to a more contractor-heavy model will almost certainly decrease that economic deadweight loss significantly.

Another strength is that this model does not totally leave a highly uncertain and volatile industry to its own devices. The public-private partnership model allows for continued governmental oversight of development and enforcement of safety regulations on the developed products to ensure the safety of both physical and human capital. The *Columbia* disaster in particular shows what can happen when even the smallest security and safety precautions are overlooked or discounted, and until such time as space travel becomes a commonplace occurrence, strict adherence to these kinds of regulations are important to enforce. Outside of the obvious goal of protecting human life, too many mishaps at this point would threaten to kill the industry. Governmental funding would become even scarcer than it already is, and private industry would shy away from the risks of development.

The third strength is risk mitigation for the private sector. The dangers and uncertainties of space development are the primary factor that makes the private-focused model problematic at this point, and the public-private partnership model addresses it by providing monetary compensation that not only help a company's bottom line, but also provide insurance against accidents and developmental hiccups. This has historically been seen in PPP's in other sectors, such as the aerospace industry and the transcontinental railroad, and it has proven to be an effective method of encouraging the private sector to engage in higher-risk projects.

The public-private partnership model has support from influential decision-makers across multiple sectors. Members of Congress, corporate executives, and even NASA officials have started putting their support behind increased reliance on this model. Particularly noteworthy individuals offering support include former astronaut Buzz Aldrin, SpaceX CEO Elon Musk, Senator Marco Rubio, President Barack Obama, and NASA Head Administrator Charles Bolden. Much of the support for this model derives from the notion that the status quo for the last twenty years is unsustainable, and increased reliance on public-private partnerships is seen by many as the most viable way to reinvigorate the space program.

Weaknesses and Opponents

The primary criticism to the public-private partnership model stems from the claim that it will not do enough to ensure accountability and the safety of human capital. The findings in the wake of the *Columbia* disaster pointed to inefficiencies and structural problems within NASA itself that had to be addressed, and there is a fear that these problems will crop up again if the agency becomes complacent. This model raises a concern of prioritizing cost-cutting and financial efficiency – or "cutting corners," as some opponents have coined it – over human safety and discretion. Indeed, some believe that the public sector already does too little to ensure the safety of NASA's personnel, and the public-private partnership model would only exacerbate that perceived problem.

The other major issue deals with corruption and the problem of the iron triangle. The iron triangle is a political theory that draws connections between policymakers, bureaucratic agencies, and interest groups. It shows a relationship between policy-making, financial support, and favors and low regulation in a specific field, industry, or policy area that all work to the benefit of the parties involved, but to the detriment of the overall society that they serve. Many believe the U.S. military contracting system – coined the "Military-Industrial Complex" by President Dwight Eisenhower in his farewell address – to be a good example of an iron triangle, where many policymakers support increased defense spending and deregulation in return for campaign financing, support, and even favors. The stronger the relationship of a government with its private contractors, the higher the risk of an iron triangle becomes. This is an area that warrants further research in relation to space policy, but is beyond the scope of this thesis.

The detractors of this model include those who oppose the private-focused model, and for many of the same reasons. Other interest groups oppose it as well, however. For example, the companies who were beneficiaries of the old model – namely Lockheed Martin and the United Launch Alliance – have been vocal in their opposition to NASA's contracts becoming more competitive. They cite reasons of safety and accountability, but they also have a monetary concern as well. The new competitive nature means they are at risk for losing contracts they once held without question and will be forced to streamline accordingly, which could damage profit margins. This has already been seen when NASA awarded the contract to design and build the next U.S. manned vehicles to Boeing and SpaceX, while Sierra Nevada Corporation – for which Lockheed Martin was a subcontractor – was left out. Additionally, political scientists and policy researchers who fear another iron triangle similar to the one that is theorized to exist with the U.S. military are likely to be apprehensive about this model based on similar concerns.

4. Policy Recommendation

By process of elimination, it is the conclusion of this research that the public-private partnership model is the most viable option for the U.S. space program going forward. This is particularly important when it comes to establishing a human colony on Mars, which will take the collaboration of public and private actors across many different industries to be able to pull off successfully. The company viability and fiscal mystery aside, the Mars One case study does provide an effective blueprint for how the individual industries can be networked together to form a large, cohesive, and interdependent unit. It just appears that, at this point in time, that central actor role is best left to a well-established governmental agency such as NASA.

The public-focused model simply is no longer a sustainable option. Costs were rising exponentially on a yearly basis while funding was not keeping pace. Given NASA's historical reliance on some level of private sector involvement, it did not appear that the situation could be salvaged without opening the contracting process up to a much more competitive level. Steps will need to be taken to ensure the safety of human capital and the accountability of both the agency and the private companies involved, but this should be an accomplishable task.

As mentioned previously, the private-focused model is a purely hypothetical one at this point and is not realistic for this industry yet. The risks that private companies have to absorb with experimental technology – sometimes entirely new, with no certainty whatsoever – are too great for there to be significant autonomous interest in space capability development. Billionaire entrepreneurs such as Elon Musk and Richard Branson are statistical outliers, at best, and most will not be willing to take that plunge without some kind of governmental contract or other kind of insurance. This model could be worthy of reconsideration at a later time once the space program has advanced to a greater level and the risks have been mitigated.

If NASA were to appropriate a higher percentage of its funding to private research and development, that would increase the speed, financial viability, and quality of the technological yields. Additionally, once this has been shown, it will likely increase Congress's willingness to provide more funding for NASA's budget due to the increased participation of more of their constituents in space developmental projects. Representatives will, after all, be more likely to support increased funding if they know that their constituents would be directly benefitting from space-oriented activities within their districts and states.

The combination of all these factors should lead to a major uptick in the space industry. More money will be flowing in with more economic and employment benefits – not to mention technological developments for both space and Earth – flowing out. When applied to the space agenda set forward by President Obama in 2010, this could see not only manned missions to the Moon and to Mars sooner than expected, but also the establishment of permanent colonies and research outposts on both bodies, with more to come in the distant future. Establishments there would lead to not just scientific discoveries and technological advancements, but also economic growth across all sectors of the economy.

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