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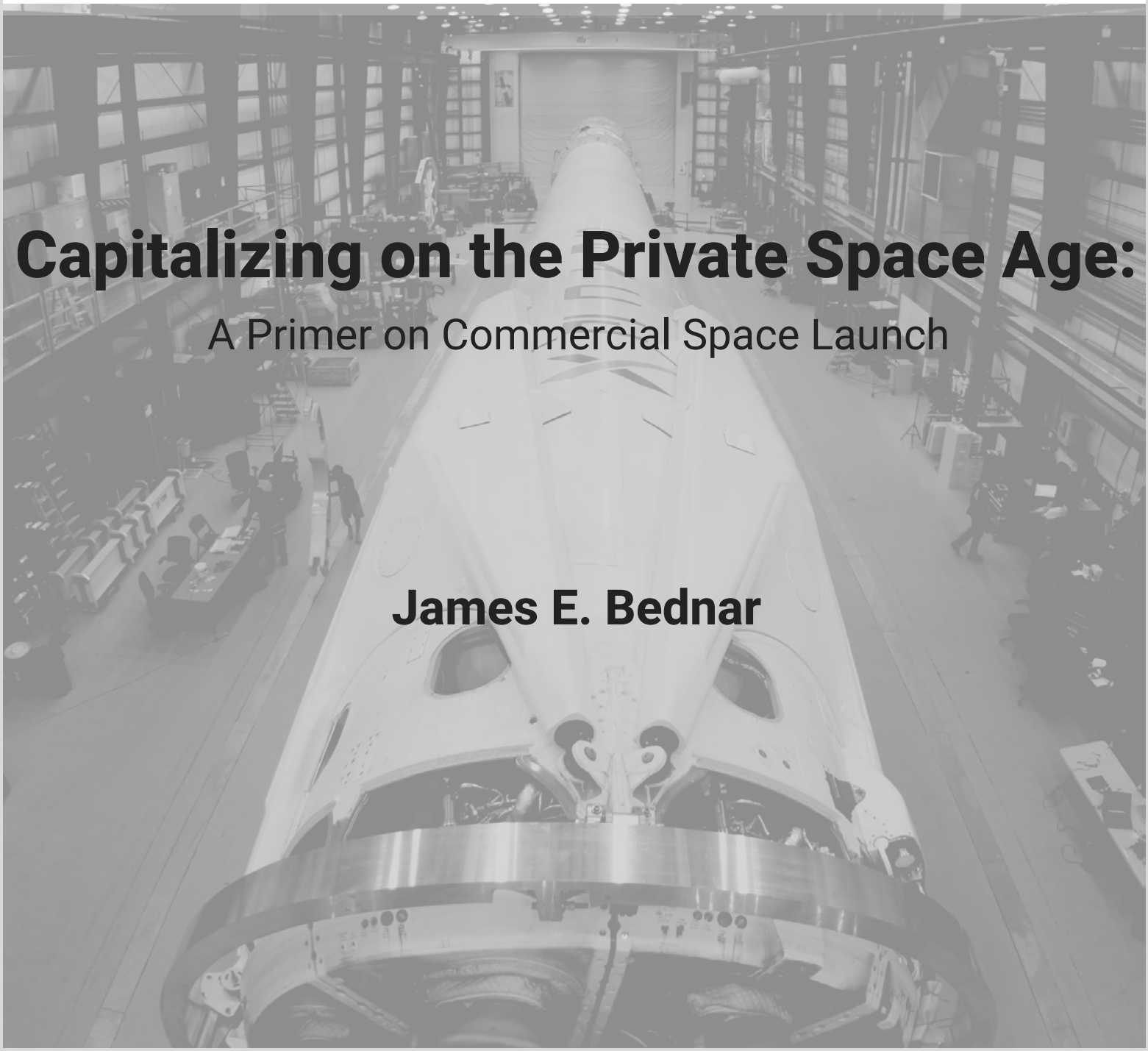

Capitalizing on the Private Space Age:

A Primer on Commercial Space Launch

James E. Bednar

Washington Internships for Students of Engineering

Preface and Acknowledgements

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The Washington Internships for Students of Engineering (WISE) program facilitates opportunities for engineering students to explore how their unique insight can contribute to ongoing public policy debates. During the nine-week program, a selective cohort of students are given the opportunity to conduct in-depth research on a topic of their choosing. Participants have the opportunity to meet with industry leaders, civil servants, and representatives from non-governmental organizations in order to further their understanding of public policy. The program culminates with the publication of a policy paper and a formal presentation of their findings on Capitol Hill.

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Overview

In the past, space launch was a feat achieved by only a select few government entities.From the Apollo program to the Space Shuttle, the United States and other space-faring nations looked towards government to fulfill the operational need of space launch. This trend held true until the early 2000's when the first development of a truly commercial space launch industry was seen. Since its inception, the commercial launch industry has caused a paradigm shift in the way that spaceflight is approached by governments, private sector firms, and individuals alike. The ongoing development of commercial launch has allowed for the development of a budding economic sector, and may one day enable the creation of a new orbital economy.

If such an off-world economy is to develop, its realities will be closely tied to those of the commercial space launch sector. Due to the realities of accessing low-earth orbit, commercial launch products and services will be economically isserpratable from those utilized within a suborbital economy. Efforts to address the intricacies of the relationship between commercial launch and the greater commercial space economy itself would take industry experts a significant amount of time to properly discuss. Due to this reality, this essay will only attempt to provide insight into the commercial launch sector and how its ongoing development may affect future space economies.

While the ongoing development of the commercial launch sector is encouraging, rapid growth suggests that government regulators must find a way to keep pace with the rapid changes that an industry as innovative as commercial launch entails. To provide clarity and insight on the topic of commercial launch, this essay will attempt to provide readers the opportunity to develop a strong understanding of the economic and regulatory realities associated with this quickly evolving industry. The looming development of an international marketplace in low-earth orbit can lead onlookers to envision an overwhelming complexity associated with such developments. With this complexity in mind, this essay will only examine how the United States, through its regulatory posture and current economic outlook, can effectively promote the continued expansion of the commercial launch sector. Special consideration will be given to the topics of reasserting American dominance in space through industry-government partnerships, sustainable job growth, and the impact of innovation in the commercial launch sector.

Introduction

As the commercial space industry has undergone significant growth in recent decades, the sector's policy issues have grown increasingly complex. With numerous private actors in the commercial sector rapidly developing and/or maintaining a consistent presence in mission areas ranging from space tourism to the launch of government cargo aboard privately contracted vehicles, it can be difficult for policymakers and industry professionals alike to fully grasp the increasing entanglement of commercial and government interests within this budding economic sector. In an effort to provide clarity, this essay will focus on the development of launch systems by private industry. Special attention will be given to how the Trump Administration's current regulatory posture and the economic realities of the industry may impact this innovative sector's ongoing maturation.

The Need for American Launch Capabilities

Although the United States manufactures more space launch vehicles per year than any other nation, the country's international standing in the area of space launch has greatly diminished since the discontinuation of the Space Shuttle Program [35]. However, the ongoing development of launch products and services by the private sector presents a unique opportunity for the United States to wean itself off a reliance on foreign launch services[1]. While U.S. astronauts have not launched from American soil since 2011, there have been groundbreaking advances in reusable launch vehicles and engine technology by firms such as Blue Origin, whose American-made BE-4 engine[2] is seen test-firing in Figure 1 below [10, 57].

Figure 1: Test Fire of Blue Origin's BE-4 Rocket Engine [46]

[1] The only operational mode of transportation available to American astronauts is the Russian Soyuz launch system.
[2] Blue Origin's BE-4, which was developed for United Launch Alliance (ULA) and could potentially replace the Russian-built RD-180 engines currently utilized by ULA for some of their launch systems [12].

The debate surrounding the lack of manned spaceflight originating from American soil has been largely settled by NASA's long term support of the Commercial Crew initiative, which will allow commercial partners, such as SpaceX and Boeing, to ferry American astronauts to the International Space Station [37]. Questions surrounding how to approach the future of manned spaceflight, whether it be government-sponsored astronauts or private tourists, is a complex topic that warrants serious discussion. While commercial launch payloads can consist of astronauts, satellites, and static cargo alike, the focus of this paper will not be what is being launched by private industry, but rather how launch vehicles themselves are currently being approached from regulatory and economic perspectives.

State of the Commercial Launch Sector

The United States government, through its partnerships with private industry, currently accounts for approximately 20% of global spending on space [35]. Such trends highlight the strength of the American launch sector, despite the fact that manned missions have not launched from the United States in nearly a decade. Relationships between the private sector and government have been bolstered in recent years, largely due to the development of novel acquisition approaches for space products and services by government agencies. Specifically, the increased utilization of government contracts that fund private industry through a milestone-based model[3] have demonstrated promise as a tool for promoting innovation while reducing the cost of government-sponsored launches [71].

The current availability of commercial launch infrastructure appears to be keeping pace with the present demand for launch sites throughout the country. Currently, the United States has eleven facilities licensed as commercial spaceports by the Federal Aviation Administration (FAA), with additional launch locations being considered if the need for additional infrastructure should arise, as highlighted by Figure 2 on the following page [4]. While these eleven facilities are privatized in nature,[4] many other facilities are shared between commercial launch providers and government agencies with space launch capabilities[5] [5, 23]. The launch pads of Kennedy Space Center in Brevard County, Florida is a prime example of contemporary infrastructure sharing agreements. SpaceX and NASA intend to share this facility for future Falcon Heavy and Space Launch System (SLS) launches, in addition to ongoing Falcon 9 operations [45, 76].

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[3] Milestone-based contracts fund projects as agreed upon milestones, such as a successful test launch, are reached. This method is oftentimes more cost effective than traditional cost-plus-fee contracts.

[4] The number of commercial spaceports can vary slightly depending on how one defines "commercial." For the number reference above, ten FAA-licensed non-federal launch sites and one university launch site in Alaska are considered, with sole site operators ignored. See Figure 2 for additional insight.

[5] For example, industry-military agreements launch from Air Force bases, while industry-NASA agreements launch from Kennedy Space Center and similar NASA facilities.

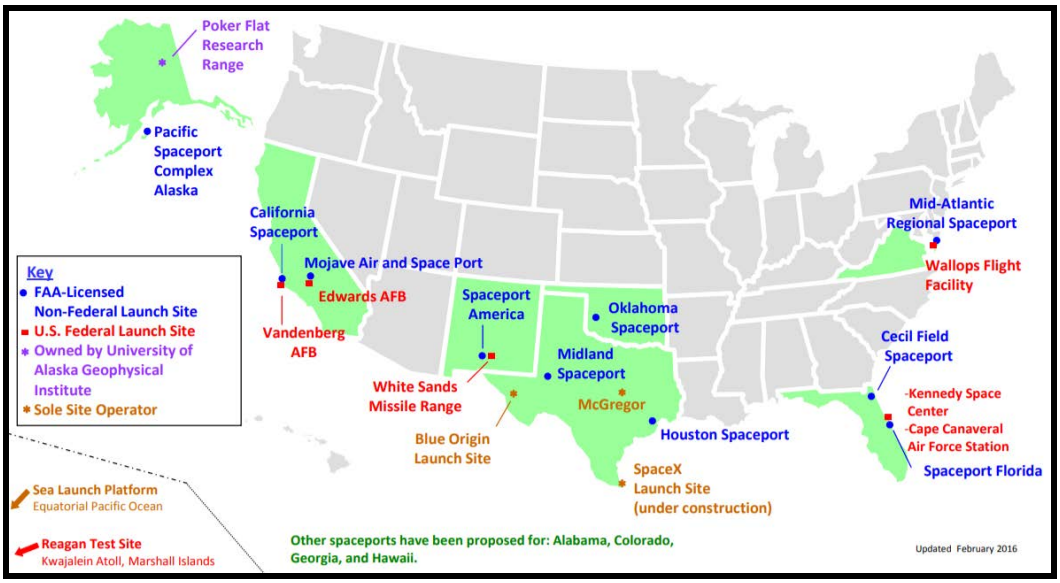

Figure 2: An Overview of the Current Launch Infrastructure in the United States [25]

The economic feasibility and symbiotic nature of such arrangements, combined with the fact that many spaceports serving the private sector are currently well under their maximum launch capacity suggests the construction of additional commercial launch infrastructure to be unnecessary at this time [51]. This trend will likely hold true until the commercial launch sector grows to develop the characteristics of an appropriate economy of scale, such as numerous different launch providers jostling for spaceport availability or the development of lengthy waiting queues for launch opportunities at existing spaceports. If such situations were to arise, further discussion surrounding the possible development of additional launch infrastructure would be warranted.

Policy Question

When an industry is undergoing rapid change, numerous issues are likely to emerge within its associated policy domain. Current discussion surrounding the maturation of the commercial launch sector is no different. Efforts to address all of these questions and concerns would likely take industry experts several volumes to address. With such an overwhelming level of complexity in mind, this essay will only examine how the United States, through its regulatory posture and current economic outlook, can effectively promote the continued expansion of the commercial launch sector. Special consideration will be given to the topics of reasserting American dominance in space through industry-government partnerships, sustainable job growth, and the impact of innovation in the commercial launch sector.

The policy question guiding this essay is as follows: How are current regulatory postures impacting the development of the commercial space launch sector, and how do such regulatory approaches affect the economic realities of the commercial space launch sector as it pertains to continued innovation and sustainable job growth? Before moving forward, the term "commercial" must be explicitly defined within the context of this analysis, as the utilization of this term throughout contemporary literature has been found to be noticeably ambiguous. Currently, the FAA considers commercial launch activities as those that are internationally competed or licensed by the FAA, with many such launches and receiving the majority of their funding from private investors or non-governmental sources [26].

This definition provides a clear and concise reference for the term "commercial" in a regulatory context, yet fails to accurately describe the launch industry in economic terms. As such, for the purposes of this essay, the term "commercial" will refer to private companies that are pursuing the development of novel space launch solutions, and able to realistically maintain their business model in a marketplace in which the United States government is not the sole purchaser of launch services. In short, commercial launch providers are those that can withstand the economic realities of an open marketplace with multiple service providers and customers present.

Background

The Dawn of the Commercial Space Age

When debating the ongoing commercialization of space, it is first and foremost necessary to dispel the fallacy that participation in the domain of space by private citizens and industry alike is a strictly contemporary trend. In fact, a significant amount of private investment has been seen in space exploration since the dawn of modern astronomical science. Dr. Alexander MacDonald, an expert on space economics, notes that one of the main sociopsychological motivators for private investment in space is signaling, or the implicit communication of socioeconomic and societal status through one's participation in the space domain[6] [8, 48]. One must only consider the noticeable increase in national prestige experienced by the United States, or the subsequent loss of international standing felt by the Soviet Union during the Space Race of the 1960's, to conceptualize the sociological and geopolitical impacts that signaling can have in both the space and foreign policy domains[7] [54].

[6] For more information on this theory and its implications for the ongoing growth of the commercial space industry, see *The Long Space Age* by Dr. Alexander MacDonald.
[7] The Space Race is oftentimes recalled as a hostile geopolitical period. However, relations between the US and USSR eventually steadied, assisting in the development of the the strong US-Russian space partnership seen today.

While there has been some level of partnership between private industry and government within the launch sector since the inception of the American space program, the dawn of commercial space launch as we recognize it today can trace its roots back to the early 2000s when multiple teams competed for the $10 million Ansari XPRIZE[8] . The winning of this competition by the Scaled Composites launch system (consisting of the "mothership" of WhiteKnightOne and the suborbital launch vehicle SpaceShipOne, both pictured in Figure 3) signaled the start of the private space race[9] [34]. Before this historic event, there was little-to-no open market competition in the launch sector, as the American government and large satellite producers alike launched all of their spacecraft through traditional contracting methods. With the introduction of significant investments from the likes of Jeff Bezos and Richard Branson, such prohibitive market realities dissolved, as launch systems development could be funded largely through private investment.

Figure 3: The Tandem System of WhiteKnightOne (Above) and SpaceShipOne (Below) [69]

The awarding of the Ansari XPRIZE marked the first time that an entirely reusable system had been developed and launched by a commercial company. Since that time, numerous commercial launch providers, such as SpaceX and Blue Origin, have relied on the principle of reusability to decrease the cost of spaceflight, which in turn has allowed for a robust launch marketplace to develop [19]. While the development of reusable launch systems is an impressive technical advancement, there are numerous other companies, such as Vector Launch based out of Arizona, that are currently pursuing economically viable single-use launch systems [81]. Such companies are attempting to apply the principles of low-cost automobile manufacturing to the development of launch systems for small payloads, which have historically been cost prohibitive utilizing traditional aerospace manufacturing methods.

[8] For more information on the Ansari XPRIZE competition, see *How to Make a Spaceship* by Julian Guthrie.
[9] The successful launches of WhiteKnightOne and SpaceShipOne emanated from the Mojave Air and Space Port, one of the first spaceports to be officially licensed by the FAA.

History of Industry-Government Partnerships

Since the start of the Space Race, there have been consistent partnerships between the American government and private enterprises. While many individuals believe that NASA and the U.S. military build their own launch systems, this is not the case. Rather, the U.S. government has historically opted to closely collaborate on launch systems with industry and university partners in an effort to spur innovation[10]. This approach resulted in an impressive launch volume during the height of the Space Race, as highlighted by the 429 launches executed from 1957 to 1966 [71]. These partnerships have yielded numerous positive results, from the launch of manned missions to the moon to the development of the Space Shuttle program.

In recent decades, government agencies have strengthened these partnerships with private industry. While collaboration on projects such as the Space Transportation System (STS, i.e. the Space Shuttle) was conceived with the operation of such systems by government agencies in mind, this is no longer the case. Instead, initiatives like the NASA-backed Commercial Orbital Transportation Services (COTS) program, which transferred the delivery of the International Space Station's supplies to commercial partners, represent a government-wide transition towards an American space economy where government is but one of a number of customers [16]. This trend may allow government agencies to accomplish future goals with less overhead, COTS provide financially beneficial to NASA, incurring a cost of only $800 million to the government with commercial partners incurring the majority of the program's cost (see Figure 4) [75]. This trend may allow government agencies to accomplish future goals with less required overhead.

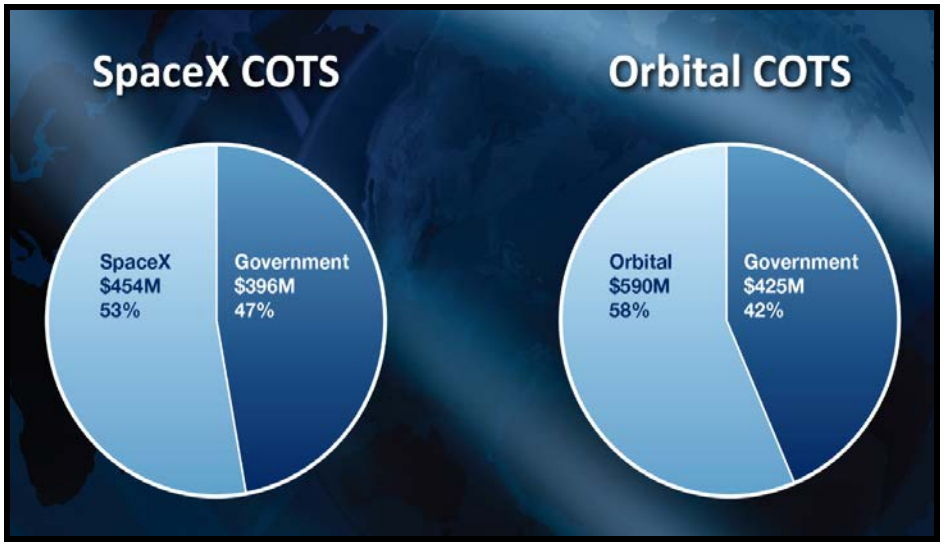

Figure 4: Costs Incurred by Commercial Partners and NASA During COTS [42]

[10] In other words, NASA and research universities partner to develop the science behind spaceflight, eventually entering into contracts with firms like Boeing, who built the vehicles and launch systems themselves.

Programs like COTS have proven to be a boon for commercial firms looking to develop a footing in the launch industry, as the milestone-based contracts utilized for such programs have allowed a level of funding often not possible in the private sector due to the unpredictable nature of investor sentiment. While the launch market is currently developing of a number of unique systems for numerous different launch and payload types, the sector would not have undergone such rapid maturation without the funding granted to startup companies through government contracts.

Current Industry-Government Dynamics

The strength of industry-government partnership is highlighted by the steadily increasing pace of launches by commercial firms. Many launches now leverage a practice called "ridesharing," which allows private companies (i.e. private satellite manufactures) and government agencies (i.e. NASA or NOAA) to share payload space on a single launch, resulting in lower costs for both parties[11] [56]. This approach appears to be developing into a consistent practice, as the frequency of batched payloads has been slowly increasing as the cost of space access continues to decrease [35]. Only a few years ago, the United States lagged behind Russia and China when it came to the number of annual launches [13]. Today, America is a global leader in the launch sector and is projected to set a new record for total launches in 2018 [13].

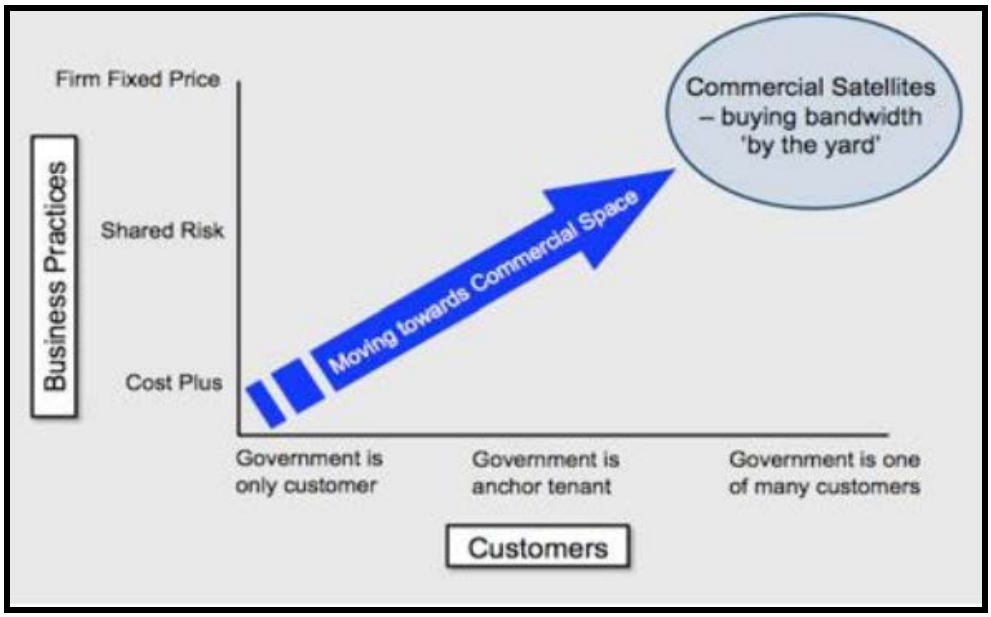

Figure 5: Continuum Towards the Adoption of a Commercial Space Model [87]

[11] The terms "ridesharing" and "batched payloads" will be used interchangeably throughout this essay.

It appears this trend will hold true for the foreseeable future, as the United States is currently the largest manufacturer of launch vehicles, with the only notable international competitors being the European Union and Russia [11]. Global spending on space reached $323 billion in 2015, with an estimated 40% of expenditures going towards commercial space products and services [11]. Of this amount, the U.S. government accounted for 14% (or $45.2 billion[12]) of global spending in the space sector, suggesting plenty of opportunity to strengthen industry-government partnerships as the launch industry continues to develop.

Current Regulatory Environment

Commercializing space has been a clear priority for the Trump Administration. Despite the volatile political rhetoric surrounding most policy issues today, space is one of the rare areas that consistently garners genuine bipartisan support. While the current administration has taken a noticeably different stance than its predecessors[13], there are some commonalities shared among the policies of recent presidential administrations. For example, the Obama Administration's National Space Policy of 2010 directed government agencies to work together, share information, and collaborate whenever possible [58]. By and large, this approach has been continued by the current administration. While the ideology underlying specific policy varies widely between the recent Bush and Obama Administrations, President Trump appears fully committed to promoting space-based commerce and while simultaneously reestablishing America's international prestige in space.

An "America First" Approach: President Trump's Space Policy Directives

The Trump Administration, with the guidance of the National Space Council, has issued numerous presidential memorandums on the topic of space policy. These documents assist in providing insight into the current administration's views towards commercial space launch. The apparent viewpoint underlying each of these documents suggests that while space is currently considered a global commons under international treaties (i.e. The Outer Space Treaty), there is no reason why the U.S. space economy should not be able to dominate on the international stage due to the nation's history in space exploration and current technical capabilities.

[12] Estimated as follows: 14% of $323 billion = $45.22 billion

[13] For example, the Bush Administration called for a manned mission to the moon by 2020, which was subsequently canceled by the Obama Administration due to program delays and budgetary concerns [22].

Space Policy Directive 1

Space Policy Directive 1 (SPD-1) calls for the creation of sustainable mission capabilities for U.S. led manned missions to the moon and beyond [55]. This directive served as a means for the Trump Administration to redefine the U.S. government's approach to deep space exploration. The language of this document was somewhat ambiguous, which has led to some speculation surrounding the possible development of an American-led, terrestrial lunar base [27,55,79] However, under current international law, space is considered a global commons as laid out by the United Nations in the Outer Space Treaty [84]. While SPD-1 sets the tone for the future of U.S. led space exploration, it does not implicitly suggest plans for formal colonization of the moon, outside of the associated announcement of the NASA-led Gateway initiative (highlighted in Figure 6 below).

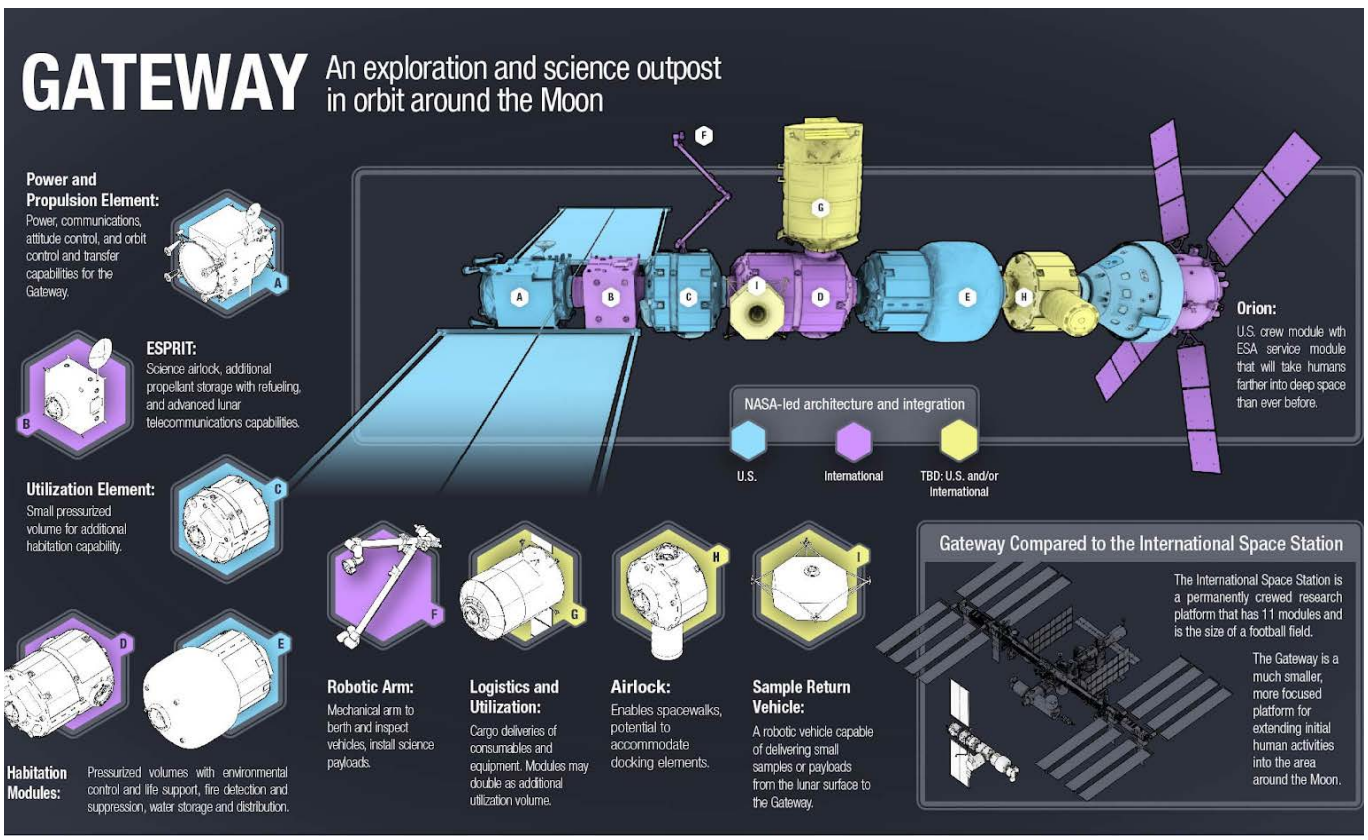

Figure 6: An Overview of NASA's Proposed Orbital Moon Base [47]

Space Policy Directive 2

Space Policy Directive 2 (SPD-2) tasks the Department of Transportation with the development of an updated regulatory framework for all space and reentry activities [82]. SPD-2 requests the creation of a regulatory regime where a single license per launch system would be required for each active commercial launch provider [29, 82]. Such steps would assist in streamlining the launch licensing process while simultaneously increasing the responsibility of the Federal Aviation Administration's Office of Commercial Space Transportation (FAA-AST). Furthermore, the Department of Commerce was directed to review commercial remote sensing regulations, and to develop an office capable of taking the lead on commercial space policy issues [29]. Such an approach leverages the Department of Commerce's international trade expertise, which is a natural fit for a globalized commercial space marketplace.

Additionally, SPD-2 takes the noteworthy step of requesting that agencies review the export controls of the International Traffic in Arms Regulations and the Export Administration Regulations (ITAR-EAR), which both work to ensure that defense-related technologies do not fall into the wrong hands. The creation of a modern export regime for commercial space is of paramount importance as U.S. companies work to keep pace with a rapidly evolving commercial sector. Reform of ITAR-EAR could remove burdensome regulatory hurdles currently faced by American companies seeking to work with international partners on commercial space[14] [77]. The full implementation of these policies remains to be seen. Regardless, such proposed reforms represent an encouraging step towards a regulatory environment where American launch providers are able to thrive in launch markets at home and abroad.

Space Policy Directive 3

Space Policy Directive 3 focuses on the need for a modern space traffic infrastructure. With space set to become an increasingly congested domain (as captured by Figure 7), the proliferation of commercial launch will create challenges in the areas of safety, stability, and tactical sustainment of U.S. military space operations [28]. With the growing popularity of micro-satellites set to further clutter low-earth orbit[15], the proactive development of a modern space traffic regime is necessary to ensure both commercial safety and military viability.

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[14] The debate surrounding reform of ITAR-EAR as it pertains to the export of civilian space technology is particularly contentious, due in large part to the fact that many space flight technologies can be considered dual-use (i.e. both military and civilian applications).

[15] Throughout this essay, "micro-satellites" will refer to cubesats, tube-sats, and other small non-traditional satellites.

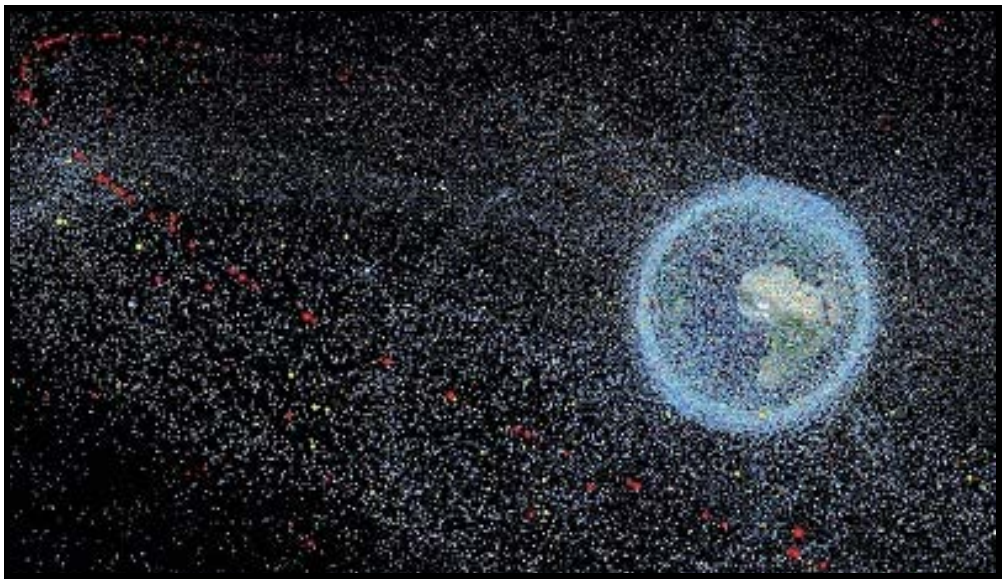


Figure 7: Representation of Objects (i.e. Satellites and "Space Junk") in Earth's Orbit [78]

SPD-3 is set to transfer the responsibility for space situational awareness from the Department of Defense to the Department of Commerce [36]. This effectively moves space traffic management from the military domain to the civilian arena, which appears prudent when the future expansion of commercial launch operations is considered. With space set to become increasingly contested as international militaries work to develop orbital systems, any traffic system developed must appropriately balance U.S. national security risks with the promotion of commercial space activities [63]. While it appears SPD-3 would make the Department of Commerce the lead agency on space traffic management, no enforcement mechanisms for such a system exist. Due to the international nature of space, orbital traffic enforcement will likely require future cooperative collaboration with other space-faring countries.

The Trump Administration's Interagency Dynamics

The main objective of the Obama Administration's National Space Policy was to facilitate the transfer of operational functions to industry partners whenever possible [58]. This push for industry development is underlined by the current Trump Administration's consistent push for regulatory reform. While the proposed SPACE Administration office within the Department of Commerce offers a forward-thinking solution, it would likely prove impossible for one office to independently manage all of the demands presented by commercial space. The promotion of open interagency collaboration has been shown to be a successful approach to commercial space policy, resulting in government stakeholders such as Commerce, NASA, and the FAA actively working towards a synergistic regulatory approach [56].

Department of Commerce

The Department of Commerce has articulated plans to expand the Office of Space Commerce, as reflected in the Department's budget request for the 2019 fiscal year (FY19) [80]. This can be interpreted as a show of support for the expansion of the commercial space industry's voice within government, as laid out by the Department's Strategic Plan [80]. The National Oceanic and Atmospheric Administration (NOAA) recently designated the Office of Space Commerce as the agency's entry point into the commercial space sector, suggesting support for interagency partnerships throughout the federal government [56]. The view of the Department of Commerce on commercial space policy reflects the Trump Administration's belief that today's regulatory environment has the potential to stifle future innovation and prevent the United States from developing into a world leader in commercial space. This viewpoint is timely when one considers the rapidly developing international market, specifically with Chinese startups making notable progress on the development of commercial launch systems [41].

The creation of the Space Policy Advancing Commercial Enterprise (SPACE) Administration has been proposed by the Department of Commerce and could lead to a streamlined regulatory process for commercial launch [15]. The creation of the SPACE Administration would stem from the merging of the Commercial Remote Sensing Regulatory Affairs Office and the Office of Space Commerce, with the creation of a one-stop shop for commercial space policy in mind [32]. The mission of this new office, as stated by Secretary of Commerce Wilbur Ross, is to develop the capability to address any space policy issue presented to it, with topics ranging from remote sensing regulation and economic development to spectrum policy and space-traffic management [68]. The permanent formation of an office with the proposed size and regulatory authority of the SPACE Administration would require legislative action by Congress, which does not appear politically feasible at this time due to the upcoming midterm congressional elections [31].

Federal Aviation Administration

The Federal Aviation Administration's Office of Commercial Space Transportation (FAA-AST) is responsible for the licensing of commercial space launch vehicles and launch sites within the United States. The Department of Transportation formed the Office of Space Transportation in response to the issuance of Executive Order 12465 by President Reagan in 1984 [1]. Since its formation, FAA-AST has gained a specialized level of expertise in the area of commercial space regulation. As the Trump Administration works to reorganize the executive branch's approach to commercial launch regulation, the long-term experience of FAA-AST should be taken into consideration.

Even before the recent announcement of the SPACE Administration by Secretary of Commerce Wilbur Ross, the FAA communicated its intent to expanding the Office of Space Transportation, as reflected by the Department of Transportation's FY19 budget request. The request of $21.6 million for FAA-AST in FY19 represents a requested increase in $2 million worth of funding when compared to FY18 [14]. As budget requests are typically a strong indication of an agency's agenda for the upcoming fiscal year, the FY19 request for FAA-AST suggest the office will continue its ongoing effort to expand its regulatory workforce while at the same time pursuing increased response times throughout the commercial launch licensing process [44].

Such efforts are extremely timely, as regulatory streamlining must be undertaken in the near future if the federal government hopes to keep pace with growing industry demand. With the United States licensing the most commercial launches of any country in recent years, as highlighted by Figure 8, proactive action must be taken by the federal government in order to keep pace with a projected increase in launch frequency [70]. While rapid growth presents regulatory challenges, such developments reflect the American launch industry's prime positioning to capitalize on a growing international market. However, commercial launch firms will only be able to capitalize on this opportunity if they are given the ability to operate unabated by regulatory interference. While FAA-AST has done an admirable job of keeping pace with the demand for licensing presented by the commercial launch sector[16], actions must be taken to ensure that the office can keep up with future demands [18].

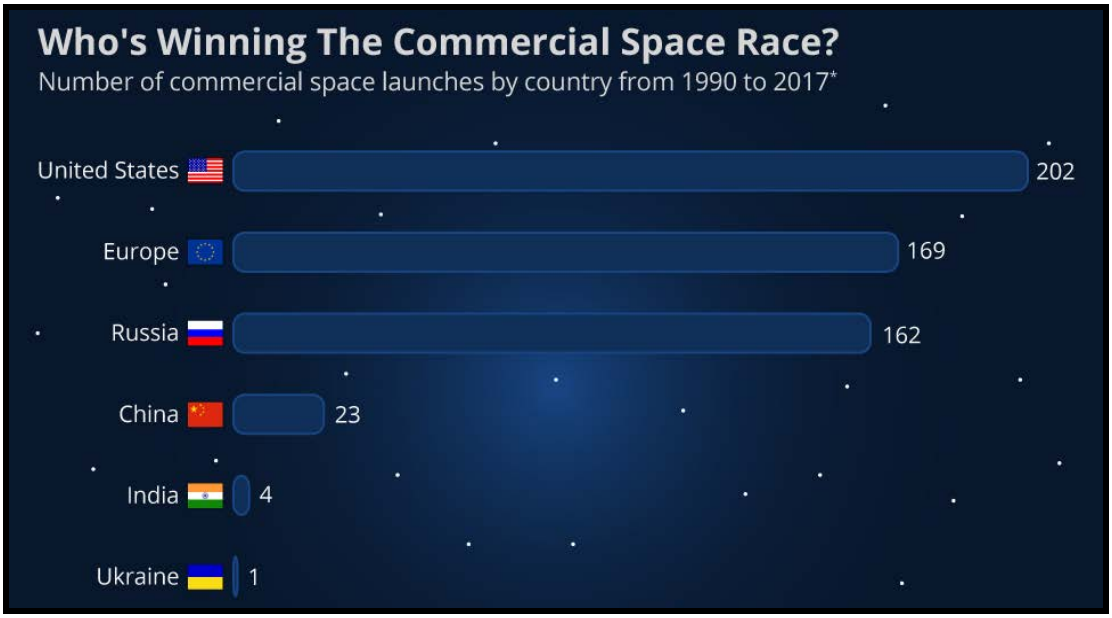


Figure 8: Statistically, The U.S. is the Current Leader in Commercial Space Launch [85]

[16] Despite increased licensing demands, FAA-AST has yet to deliver a license outside of statutory timelines [18].

The FAA-AST is presently working within the context of a congressionally-mandated regulatory learning period for commercial launch licensing, which requires that FAA-AST will not introduce new regulations pertaining to in-flight human safety until September 2023 [66]. This appears to be an extension of the office's effort to regulate launch to the least extent possible while ensuring a necessary level of regulatory oversight. With the debate raging over whether to place the responsibility for commercial space in the hands of the Federal Aviation Administration or the Department of Commerce, the outward-facing literature of FAA-AST's suggests the office to be a logical choice for future regulation of space-based operations ranging from orbital habitats to asteroid mining [66].

National Aeronautics and Space Administration

NASA's goal for commercial launch is to promote the development of the private sector through partnerships on NASA-led projects with private industry, as highlighted by the COTS and Commercial Crew programs [16, 37]. While conducting research for this essay, this sentiment was strongly reinforced by sources throughout NASA, suggesting an agency-wide agreement on this approach[17]. As far as interagency dynamics are concerned, NASA is currently willing to lend their technical expertise whenever necessary. However, NASA is in no way a regulatory agency, and therefore will not be a key contributor to any form of interagency space policy realignment undertaken by the Trump Administration.

Fig. 9: Sierra Nevada's Dream Chaser, SpaceX's Dragon, & Boeing's CST-100 [49]

[17] The conversations referenced above resulted from in-person and over-the-phone conversations with several professionals at NASA Headquarters in Washington, DC. Specific names have been redacted in an effort to protect both professional and personal privacy.

As of this writing, NASA will be reliant on the commercial sector to provide launch services for future missions and ongoing International Space Station operations until the Space Launch System (SLS) is fully functional [35]. However, increasing delays and ongoing technical issues, as recently reported by the Government Accountability Office (GAO), may jeopardize this plan. The GAO's report notes that the Commercial Crew systems of both SpaceX and Boeing are far from flight-ready and appear to be increasingly behind schedule, which could put the United States in a precarious situation with no reliable access to the ISS(GAO Report). Yet, these difficulties do not appear to undermine NASA's commitment to an increasingly close partnership with commercial launch providers. Current issues notwithstanding, the overall success of the Commercial Crew-integrated Capability Program (CCiCap), which funded the development of the now-delayed SpaceX and Boeing orbital transportation vehicles, pictured in Figure 9 above, provides strong support for NASA's plans to increase the agency's utilization of commercial launch providers.

Though not directly related to the commercial launch sector, evaluation of the Trump Administration's current postures towards ongoing NASA projects provides insight into the future of an American-led commercial space industry. The White House has recently announced its plans to turn over the International Space Station to private sector partners and end direct government funding by 2025 [20, 21]. While the American portion of the ISS has been designated as a national laboratory for almost a decade, with shared resources between NASA and private industry partners, such a shift in policy would present a noticeable deviation from current approaches to basic scientific research in low-earth orbit [64]. Additionally, at the time of writing, public battles are playing out over whether or not NASA's ongoing development of the Space Launch System is a prudent investment [70]. However, the main argument for the discontinuation of the SLS, which centers around the fact that commercial launch solutions offer a more effective price-per-pound ratio when compared to that of the SLS become less relevant when deep space travel is considered. While commercial launch services allow for affordable access of low-earth orbit, the SLS is being developed as a deep space exploration vehicle, which is a function that commercial launch services are incapable of providing at this time.

Economic Impacts of Commercialization

Commercial Space: A Trillion Dollar Industry?

Positive sentiments currently surround the economic future of commercial space firms throughout Wall Street Analysis from Morgan Stanley estimates that revenues generated by the commercial space industry will increase to $1.1 trillion or more by 2040, up substantially from the $350 billion generated worldwide in 2016 [72]. With American companies well positioned in the international marketplace, such trends will positively impact the American space industry.

Bank of America-Merrill Lynch recently published an extremely bullish report predicting rapid industry growth, leading to a space industry worth $2.7 trillion within 30 years [30]. Rapidly decreasing launch prices are cited as the main economic driver for such estimates. A decrease in the cost of accessing space, paired with an increasing launch frequency, will drive the creation of other space-dependent industries, ranging from off-earth manufacturing to asteroid mining (as highlighted in Figure 10). However, there is a high likelihood that negative economic indicators will soon develop, ranging from failed startups to technical failures as the commercial launch industry is sure to experience ongoing growing pains throughout its maturation.

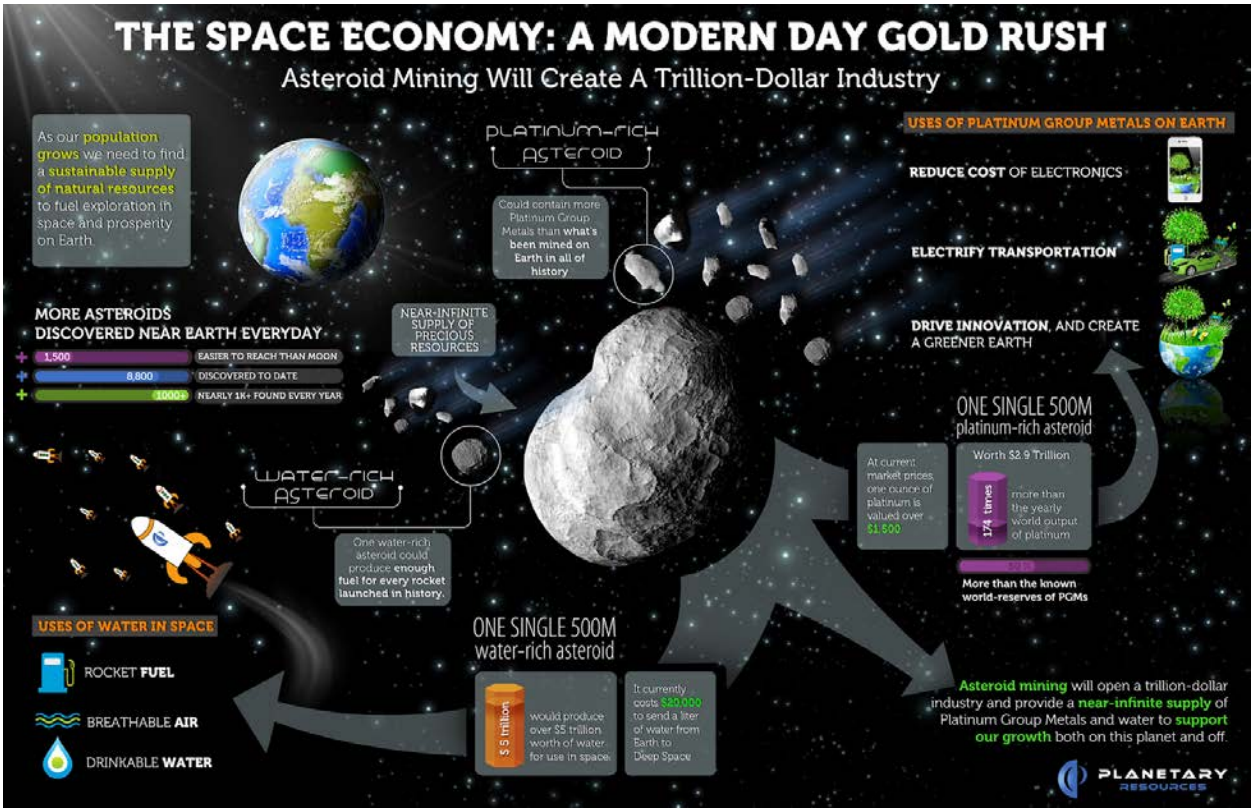
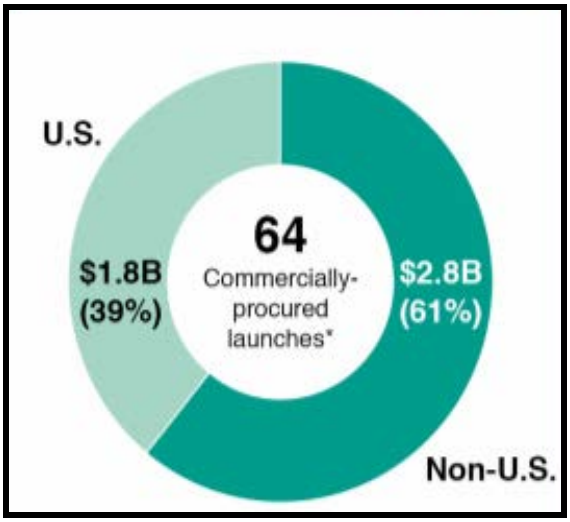


Figure 10: An Overview of the Theoretical Economics of Asteroid Mining [39]

Mixed Indications from the Commercial Launch Sector

Analysis of economic data on the financial state of the American launch sector yields conflicting insights. American companies saw $1.8 billion in commercial launch revenues throughout 2017, or more than one-third of launch revenues available globally [2]. This performance is impressive when compared to the $2.8 billion in revenue earned by all other international competitors combined, as show by Figure 11 [2]. Such performance suggests a strong outlook for American launch companies. Yet, such signs of strength are mitigated when considering that launch companies saw overall revenues decline by 16% within the past year [3].



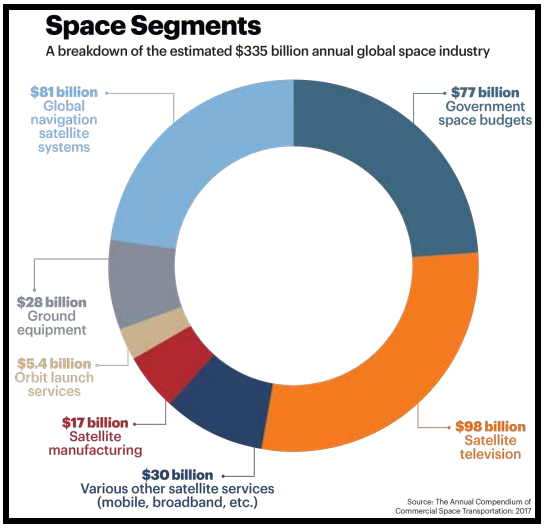


Figure 11 (Left): The U.S. Accounted for Over a Third of Revenues in 2017 [2]
Figure 12 (Right): An Economic Breakdown of the Global Space Industry [67]

Diminishing financial returns are typically seen as a warning sign, especially in high-risk sectors like commercial space launch. However, this trend may point towards the long-term economic viability of the sector. While revenues declined, the number of overall launches remained consistent, suggesting an overall decrease in the cost per launch [3]. If accurate, this is an encouraging trend for commercial launch, as it highlights the steadily decreasing cost of access to space.Globally, launch services comprised approximately $5.4 billion (or 1.6%) of the space industry in 2017, as captured by Figure 12 [67]. Extrapolating upon this trend with the more conservative estimate by Morgan Stanley, and controlling for a proportional rate of growth across all space industry subsectors, it is estimated that the commercial launch industry could be worth $17.6 billion by the year 2040[18].

[18] Estimated as follows: $5.4 billion / $335 billion × 100 = 1.6 %, 1.6% × $1.1 trillion = $17.6 billion

A recent study by the Department of Transportation estimates the commercial launch market is currently worth $9 billion, with consistent growth yielding a $27 billion valuation within a decade [13]. This analysis indicates the space launch sector is economically viable in the near future. More conservative estimates put the American commercial launch sector exceeding $5 billion by 2024 [40]. Regardless, the overall financial viability of the American launch sector is empirically supported, with continued growth expected to bolster the sector's future performance.

Job Creation Through Commercial Space Launch

The discontinuation of the Space Shuttle program led many communities, especially those located throughout Florida's Space Coast, into a devastating economic decline [62]. As data from the Bureau of Labor Statistics highlights, commercial employment in the space industry peaked at around 267,000 jobs at the height of the Space Shuttle program, and has steadily declined since the program's termination in 2011 [40]. While it is difficult to extrapolate upon such limited data, there appears to be a correlation between macro-level employment trends in the space industry and the frequency of launches.

As the commercial launch sector continues to grow, so will the need for both skilled and unskilled labor. This is consistent with the demands of traditional technology startups, as both engineers and support staff are required for sustainable growth. Vector Launch, a small startup that is working to develop extremely affordable launch services for small payloads, anticipates that 200 employees will be on its payroll by the end of this year [86]. While such hiring may appear inconsequential on a macroeconomic level, when the 80 small space-based startups across the country are denoted, such job growth can be interpreted as a strong indicator of sustainable job creation throughout the commercial launch sector [86]. Statistical analysis indicates that high skills levels are strongly correlated with high wages across all economic sectors within the United States [35]. As the number of commercial launch providers increases, so too will the numbers of highly skilled workers employed in areas ranging from aerospace engineering to systems manufacturing.

SpaceX, a firm well known for manufacturing their launch systems in-house, was found to be aggressively expanding their workforce at the time of writing[19] [53]. A state of rapid workforce expansion throughout the launch industry suggests that commercial space can generate a multitude of new jobs throughout the country. Furthermore, the launch sector enables an estimated $276 billion industry for ground and satellite services, which will need to expand their own workforces as the commercial space economy continues to develop [35].

[19] SpaceX was found to be seeking 500 additional employees in the states of Washington and California at the time of writing [53].

Investment in the Commercial Launch Sector

Billionaires such as Jeff Bezos and Richard Branson are notable investors within the commercial launch industry, with each pursuing goals ranging from lowering the cost of accessing space to the creation of space tourism. While these investors seem to have genuine interest in the improvement of space technology, many venture capitalists view commercial space as a lucrative business opportunity. This belief has led to an increasing rate of investment throughout the space industry, as captured by Figure 13 below. Such investments are driving the development of innovative advances in space technology, highlighted by Blue Origin's ongoing development of the BE-4 rocket engine in conjunction with United Launch Alliance[20] [10, 12].

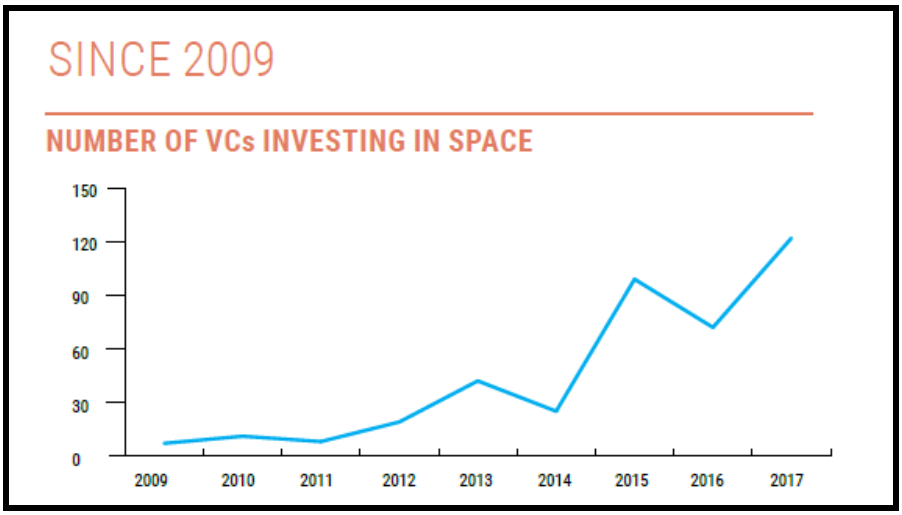


Figure 13: Investments by Venture Capitalists Have Rapidly Increased Since 2009 [72]

Developments by these prominent companies suggest that only established firms are pursuing innovation in the commercial launch sector. However, there are many smaller companies also working to provide unique space launch solutions for certain market subsectors. For example, Vector is a notable contributor to smaller launch demands of batched cube and micro satellite payloads, with the goal of doing such launches for less than $3 million per launch, a fraction of the cost of a launch on a larger private rocker, such as SpaceX's Falcon 9 [86]. While a promising contributor to the private space launch industry, vector is not the only company pursuing the need for specialized launch provisions for small payloads. In recent years, an average of eight new space-based startup ventures were founded annually, which is almost triple the level of company creation in this sector that was seen in the early 2000's [11]. Such trends suggest an increased interest in this sector. Yet, such promising trends must be weighed against the high rate of failure that aerospace startups typically demonstrate.

[20] Please reference Footnote 2 for more information about the ongoing engine development partnership between Blue Origin and United Launch Alliance.

Key Conflicts and Concerns

Balancing Regulation and Innovation

Regulations and government oversight tend to lag industries undergoing periods of rapid innovation. This is reasonable, as the pace of commercial innovation has historically been much quicker than the pace of government regulation. As the legislative and executive branches begin to grapple with how to effectively regulate the commercial launch industry, it is important that a balance between regulation and innovation is struck. Some amount of regulation is needed to ensure both consumer and environmental protection However, over regulation can stifle innovation, especially in an economic sector as technology-dependent as commercial launch. While this debate is ongoing, there are some encouraging signs that suggest industry will be given enough regulatory leniency to continue the pursuit of cutting-edge system development.

The Department of Transportation is currently in the midst of an eight-year regulatory learning period, which is not set to expire until 2023 [11]. One of the focal points of this learning period surrounds the fact that the FAA-AST is not currently pursuing the regulation of launch systems with human safety in mind. In other words, commercial launch firms are currently allowed to develop their systems in any manner, with human factors[21] and safety considerations set to be considered at a later date. This is an appropriate approach, as commercial companies are pursuing numerous different launch systems, ranging from rockets with reusable first stages to plane-rocket hybrids.

Recent history has shown that the development of launch systems can be a dangerous endeavour, as witnessed by the deadly crash suffered by Virgin Galactic in 2013[22]. In the future, human factors must be taken into regulatory consideration, as a commercial space industry with tourism will require strict consumer standards. Yet, strict regulations at a point early in the development lifecycle of this industry could serious stifle innovation and threaten the American launch sector's global competitiveness. Such considerations should be strongly considered moving forward, especially as the Trump Administration continues to develop their executive branch strategy on just how to approach the countless policy questions that currently surround the commercial space sector.

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[21] Human factors, or the study of how people interact with systems, must certainly be considered moving forward. Experts indicate that the majority of aerospace-related incidents resulted due to human error that could have been avoided with proper human factors engineering. Such discussions must certainly be taken into consideration as the commercial space industry works to develop their own industry standards [52].

[22] The National Transportation and Safety Board found that human factors played a large role in causing this fatal accident [38].

Dynamics of Interagency Partnerships

The Trump Administration currently finds itself at a crossroads when it comes to how commercial space policy could be best addressed by the federal government. The current debate focuses heavily on whether or not the Department of Commerce or the Federal Aviation Administration's Office of Commercial Space Transportation should take the lead on commercial space policy for the federal government. NASA Administrator Jim Bridenstine recently noted ongoing disagreements between Commerce and the FAA on which agency has the ability to delegate "authorization and continued supervision of non-traditional space activities," articulating the fact that both sides have strong arguments in this area [70].While NASA itself would have no regulatory input, as such functions fall outside of the agency's mandate to advance scientific knowledge, there have been strong indications that the agency would be willing to advise and support the regulatory regime that results from the ongoing debate.

Regardless of how the Trump Administration decides to approach the creation of a guiding commercial space policy and its associated regulations, it is important that the expertise of each respective agency and office is not lost as a result of such processes. The creation of a separate cabinet-level department for commercial space may not be required at this time, but it could present a viable option in the future. With such a fluid situation presented by the commercial launch sector, any policy or regulatory reshuffling should be undertaken with the ability to keep up with the dynamics of the space industry in mind. With an economic sector undergoing such unpredictable expansion, it may be wise to consider further promotion of interagency cooperation for the time being - with reshuffling of the overall federal commercial space policy to be considered at a later date when the industry is displaying greater signs of maturation.

National Security in the Modern Space Economy

As the space domain becomes increasingly commercialized, the national security of the United States must be considered. The proposed reform of ITAR-EAR is a welcome step that will assist commercial firms develop international partnerships. At the same time, these reforms must not allow possibly hostile nations access to technologies that could be utilized in a military context. Such dual-use technologies have presented significant difficulty to commercial adoption in the past, as highlighted by the complexity currently seen by proposed export of intentionally peaceful technologies like nuclear energy reactors. While promoting the export of space technology has the potential to greatly improve the international standing of American commercial space firms, the Trump Administration should ensure that proactive steps are taken throughout the reform process to ensure national security.

In addition to proposed ITAR-EAR reform, the ongoing development of the Space Fence program presents an opportunity for the United States to promote both national security and the commercialization of low-earth orbit. As joint project between the U.S. Air Force and contractor Lockheed Martin, this ground-based system will scan and track the skies for small orbital objects (i.e. “space junk”) that has the potential to damage or destroy orbital systems such as satellites. One version of the Space Fence has already been installed on Kwajalein Atoll in the Marshal Islands, with another system scheduled for construction in Western Australia, as pictured in Figure 14 below [83]. Such a system is fulfills a critical national security function as the number of launches - and by extension, orbital debris - will lead to a situation where a lack of situational awareness could prove dangerous for civilian and military operations alike.

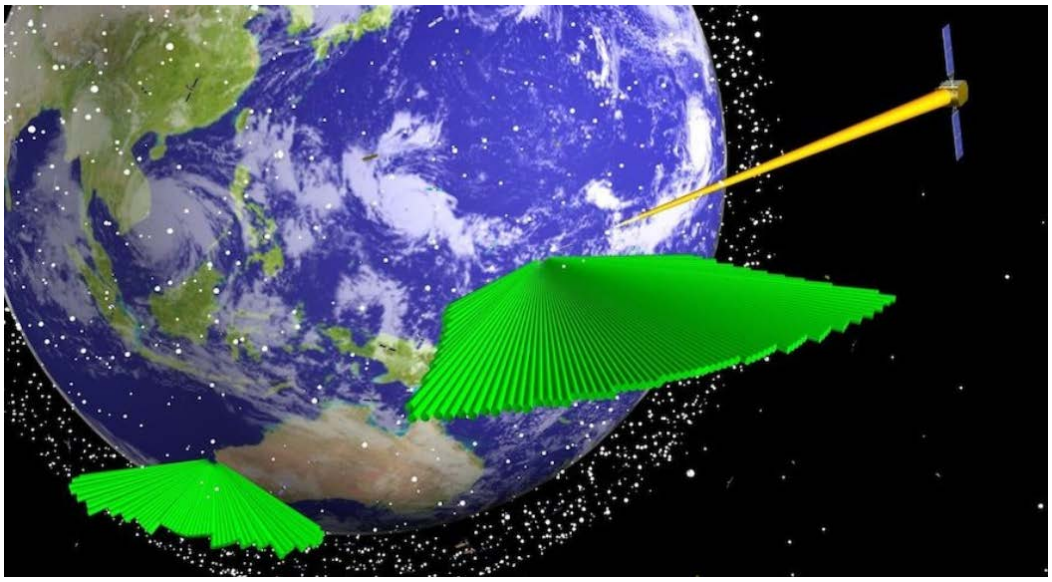

Figure 14: A Representation of the Space Fence Detecting “Space Junk” [83]

These developments are complemented by a soon-to-be completed Pentagon report on the viability of a space-based military branch, as requested by President Trump. While the Air Force currently fulfills military functions in space through the Air Force Space Command, a dedicated military branch may be warranted as the commercialization of space continues to developed. However, congressional approval would be required for the creation of a “Space Force,” and such a process would be lengthy and difficult within the current political environment. While the national defense authorization bill for FY19 does not explicitly approve the development of an independent space force, it does include measures that may speed up the acquisitions process for space systems and requests an in-depth review of the United States national security in space [50].

Viable Policy Directions

Performance-Based Launch Vehicle Licensing

The current light regulatory approach undertaken by the Federal Aviation Administration's Office of Commercial Space Transportation regarding vehicle licensing is a prudent step that will allow commercial firms to continually pursue innovation. However, the current regulatory framework will need to be updated moving forward, especially in areas where vehicle launch and reentry licensing is concerned. Impending regulatory reassessment presents a good opportunity for FAA-AST to explore the possibility of shifting to a performanced-based launch vehicle licensing regulatory regime. While the current regulatory approach utilized by the office has been proven effective thus far, updating launch licensing requirements would allow for a level of regulatory friction to be removed.

For an example of how performance-based regulatory reform could positively benefit the commercial launch industry, consider the launch system of Virgin Galactic. As an updated version of the original Scaled Composites launch system,[23] the current launch solution utilized by Virgin Galactic relies on an airplane transports a suborbital vehicle to a predetermined cruising altitude, where the suborbital vehicle, known as SpaceShipTwo, is then released and allowed to continue its flight independently (SpaceShipTwo - Virgin Galactic). This system has been proven to be an effective solution for suborbital spaceflight, but it does not fit the traditional definition of a space launch vehicle.

As such, Virgin Galactic is currently required to obtain two licenses from the FAA - one for the airplane portion of the system and another for the suborbital launch vehicle [88]. This regulatory situation appears reasonable when one considers that there is not a large number of launch vehicles currently utilized that fall under this specific subcategory. However, in the future it is highly likely that the number of hybrid or non-traditional launch vehicles will increase substantially. As such, it is advised that regulations shift towards a performance-based regime, under which launch vehicles would be able to seek licensure, regardless of their modality or methodology of achieving sub-orbital flight. This would make for easier licensure for FAA-AST while at the same time cutting the regulatory burdens and friction currently experienced by firms seeking to develop non-traditional launch systems for commercial purposes.

[23] Please see "The Dawn of the Commercial Space Age" found within the Introduction section of this essay for more information on the original Scaled Composites launch system.

Allow Executive Agencies to Leverage Strengths

Debate is currently ongoing throughout the executive branch over which agency should take the lead on future development of federal commercial space policy. Such debate is warranted, as each cabinet-level department involved brings a unique set of regulatory competencies to the table. The Federal Aviation Administration, through its Office of Commercial Space Transportation, has a long history and notable specialization in the area of commercial space licensing. On the other hand, the Department of Commerce has a long history of promoting the development of American businesses in both the U.S. and international markets. Additionally, other executive branch agencies, such as NOAA and NASA, have unique perspectives that have the potential to complement those held by Commerce and the FAA.

As a result of these interagency dynamics, it is suggested that a regulatory regime is developed that will allow existing executive agencies to leverage their particular strengths for the greater benefit of U.S. commercial space policy. While the creation of a federal organization like the proposed SPACE Administration within the Department of Commerce has the potential to place the vast topic of commercial space policy under one roof, this does not appear to be the most effective approach. As is often the case, the creation of a new federal office will likely create additional layers of bureaucracy that could stifle the federal government's ability to respond to the dynamics of space commerce. With this in mind, it is suggested that the current executive offices remain as-is, and the development of an office like the SPACE Administration is abandoned. Instead, the creation of semi-permanent regulatory body with representation from each executive branch department and agency with a vested interested or existing expertise in the area of commercial space policy is suggested. The creation of such a regulatory body, which could mimic the organization of bodies such as the National Space Council and meet on a monthly or bi-monthly basis, would allow consensus driven regulations to be developed with appropriate representation from stakeholders throughout the executive branch. A sunset clause of five years is suggested for this proposed "Space Policy Council," with the option to renew the organization for an additional five-year term to be presented if deemed necessary in the future.

Such an organization would allow for the Department of Commerce to lend its expertise on the dynamics of global trade while simultaneously letting the Federal Aviation Administration provide effective input on the topic of commercial launch licensing. This proposed organization would allow for future development of an authoritative and all-encompassing federal policy on the topic of commercial space. Under this proposal, the responsibility for regulation development would still fall to each respective federal agency or office, effectively allowing regulations guided by this sweeping commercial space policy body to be enacted as currently done. In other words, FAA-AST would remain responsible for the development of commercial launch regulations.

Bibliography

[1] Exec. Order No. 12465, 3 C.F.R. (1984).

[2] Satellite Industry Association. "2018 State of the Satellite Industry (2 Pager)." News release. Accessed July 14, 2018.

[3] State of the Satellite Industry Report (SSIR). *2018 State of the Satellite Industry Preview*. Satellite Industry Association.

[4] "Active Launch Site Operator Licenses." Federal Aviation Administration: Data & Research. Accessed July 16, 2018. https://www.faa.gov/data_research/commercial_space_data/licenses/.

[5] United States Air Force. 45th Space Wing. "Air Force Awards AFSPC-52 Launch Services Contract to SpaceX." News release, June 21, 2018. 45th Space Wing: Patrick Air Force Base. Accessed July 16, 2018. http://www.patrick.af.mil/News/Article-Display/Article/1559450/air-force-awards-afspc-52-launch-services-contract-to-spacex/.

[6] H.R. 2909, 115th Cong. (2017) (enacted).

[7] Baroudos, Constance, and Loren B. Thompson. "Banning Russian Rockets Endangers U.S. Access to Space." *The National Interest*, May 10, 2016. Accessed July 15, 2018.

[8] Bergstrom, Carl T. "An Introduction to the Theory of Honest Signaling." The Theory of Honest Signaling. September 4, 2002. Accessed July 14, 2018. http://octavia.zoology.washington.edu/handicap_old/handicap_intro_2.html.

[9] Bodner, Matthew. "Energomash Raises Alarm over U.S. Ban on Russian Rocket Engines." *SpaceNews*, July 10, 2018. Accessed July 15, 2018. https://spacenews.com/energomash-raises-alarm-over-u-s-ban-on-russian-rocket-engines

[10] Butler, Amy, and Guy Norris. "ULA CEO Outlines BE-4 Engine Reuse Economic Case." *Aerospace Daily & Defense Report*, April 15, 2015. Accessed July 19, 2018.

[11] United States. Congressional Research Service. *Commercial Space Industry Launches a New Phase*. By Bill Canis. 2016.

[12] Chang, Lulu. "Blue Origin Is Working on the BE-4, a Rocket Engine That Can Launch 100 Missions." Digital Trends. April 19, 2018. Accessed July 14, 2018. https://www.digitaltrends.com/cool-tech/be-4-blue-origin/.

[13] Chao, Elaine L. "Commercial Space: From Experimental to Entrepreneurial." Connections. June 14, 2018. Accessed June 25, 2018. https://www.transportation.gov/connections/commercial-space-–-experimental-entrepreneurial.

[14] United States. Department of Transportation. *Budget Highlights: Fiscal Year 2019*. By Elaine L. Chao. 2019.

[15] Coldewey, Devin. "SPACE Administration Would Streamline Federal Oversight of Commercial Launches." *TechCrunch*, May 28, 2018. Accessed July 15, 2018. https://techcrunch.com/2018/05/28/space-administration-would-streamline-federal-oversight-of-commercial-launches/.

[16] "Commercial Orbital Transportation Services (COTS)." National Aeronautics and Space Administration. August 3, 2017. Accessed July 14, 2018. https://www.nasa.gov/commercial-orbital-transportation-services-cots.

[17] Commercial Space Launch Amendments Act of 2004, H.R. 3752, 108th Cong. (2004).

[18] U.S. Congress. House. Transportation Committee: Subcommittee on Aviation. *Commercial Space Transportation Regulatory Reform: Stakeholder Perspectives*. 115th Cong., 2d sess. H. Doc. 2018.

[19] Davenport, Christian. *The Space Barons: Jeff Bezos, Elon Musk, and the Quest to Colonize the Cosmos*. New York: PublicAffairs, 2018.

[20] Davenport, Christian. "NASA's New Administrator Says He's Talking to Companies about Taking over Operations of the International Space Station." *The Washington Post* (Washington, D.C.), June 5, 2018.

[21] Davenport, Christian. "The Trump Administration Wants to Turn the International Space Station into a Commercially Run Venture, NASA Document Shows." *The Washington Post*, February 11, 2018. Accessed June 27, 2018.

[22] Davis, Jason. "'Apollo on Steroids': The Rise and Fall of NASA's Constellation Moon Program." The Planetary Society. August 1, 2016. Accessed July 21, 2018. http://www.planetary.org/blogs/jason-davis/2016/20160801-horizon-goal-part-2.html.

[23] Dunbar, Brian. "Launches and Landings." National Aeronautics and Space Administration. Accessed July 16, 2018. https://www.nasa.gov/launchschedule/.

[24] "Economies of Scale." Investopedia. Accessed July 21, 2018. https://www.investopedia.com/terms/e/economiesofscale.asp.

[25] FAA Office of Commercial Space Transportation. "U.S. Spaceports Map Administration Active and Proposed Sites." Map. 2014.

[26] Federal Aviation Administration. *Fact Sheet - Commercial Space Transportation Activities*. Washington, DC: Government Publishing Office, 2017.

[27] United States. Executive Office of the President. Government Publishing Office. *Federal Register*. 239th ed. Vol. 82. Space Policy Directive-1 of December 11, 2017

[28] United States. Executive Office of the President. Government Publishing Office. *Federal Register*. 120th ed. Vol. 83. Space Policy Directive-3 of June 18, 2018

[29] United States. Executive Office of the President. Government Publishing Office. *Federal Register*. 104th ed. Vol. 83. Space Policy Directive-2 of May 24, 2018

[30] Foust, Jeff. "Charting a Path for the Space Industry's Growth." The Space Review. July 9, 2018. Accessed July 14, 2018. http://www.thespacereview.com/article/3530/1.

[31] Foust, Jeff. "Commerce Department to Create "Space Administration"." Commerce Department to Create "SPACE Administration". May 27, 2018. Accessed July 14, 2018. https://spacenews.com/commerce-department-to-create-space-administration/.

[32] Foust, Jeff. "A Step towards a "one-stop Shop" for Commercial Space Regulations." *The Space Review*, May 29, 2018. Accessed July 14, 2018. http://www.thespacereview.com/article/3501/1.

[33] United States. National Aeronautical and Space Administration. *FY 19 Budget Estimates*.

[34] Guthrie, Julian. *How to Make a Spaceship: A Band of Renegades, an Epic Race, and the Birth of Private Space Flight*. Black Swan, 2017.

[35] United States. Congressional Research Service. *The Commercial Space Industry and Launch Market*. By Glennon J. Harrison. 2012.

[36] Harrison, Todd, and Kaitlyn Johnson. "How Does Space Policy Directive 3 Affect Space Traffic Management?" CSIS: Critical Questions. June 19, 2018. Accessed July 14, 2018. https://www.csis.org/analysis/how-does-space-policy-directive-3-affect-space-traffic-management.

[37] Herridge, Linda. "NASA Commercial Crew Program Mission in Sight for 2018." National Aeronautics and Space Administration. January 5, 2018. Accessed July 14, 2018. https://www.nasa.gov/feature/nasa-commercial-crew-program-mission-in-sight-for-2018.

[38] National Transportation Safety Board. *Human Factors and Organizational Issues*. Washington, DC, 2018.

[39] Jamasmie, Cecilia. "Infographic: Why Asteroid Mining Can Create a Trillion-Dollar Industry." Mining.com. January 16, 2013. Accessed July 21, 2018. http://www.mining.com/infographic-why-asteroid-mining-can-create-a-trillion-dollar-industry-35009/.

[40] Johnson, Kent. "We Need an 'America First' Approach to Space." *The Hill*, June 18, 2018. Accessed June 25, 2018. http://thehill.com/opinion/technology/392772-we-need-an-america-first-approach-to-space.

[41] Jones, Andrew. "Commercial Chinese Companies Set Sights on Methalox Rockets, First Orbital Launches." *SpaceNews*, July 10, 2018. Accessed July 15, 2018. https://spacenews.com/commercial-chinese-companies-set-sights-on-methalox-rockets-first-orbital-launches/.

[42] Kisliuk, Erin. "COTS: Legacy." Commercial Space Transportation. August 3, 2017. Accessed July 20, 2018. https://www.nasa.gov/content/cots-legacy.

[43] Klimas, Jacqueline, and Brianna Gurciullo. "Exclusive: Apollo Astronaut on Space Launch System vs. Falcon Heavy." *POLITICO Space*, June 25, 2018.

[44] "Science and Technology in the Federal Budget." E-mail to Kei Koizumi. June 2018.

[45] "Launch Manifest: Future Missions." SpaceX. Accessed July 16, 2018. http://www.spacex.com/missions.

[46] Leahy, Bart. "Blue Origin Conducts First Hot-Fire Test of BE-4 Engine." Spaceflight Insider. Accessed October 21, 2017. http://www.spaceflightinsider.com/organizations/blue-origin/blue-origin-conducts-first-hot-fire-test-be-4-engine/.

[47] Loff, Sarah. "Humans in Space Overview." Humans in Space. July 9, 2018. Accessed July 21, 2018. https://www.nasa.gov/topics/humans-in-space/overview.

[48] MacDonald, Alexander C. *The Long Space Age the Economic Origins of Space Exploration from Colonial America to the Cold War*. New Haven: Yale University Press., 2017.

[49] Malik, Tariq, and Denise Chow. "NASA Awards $1.1 Billion to Develop Three Commercial Space Taxis." CollectSPACE. August 3, 2012. Accessed July 22, 2018. http://www.collectspace.com/news/news-080312a.html.

[50] McCullough, Amy. "Pentagon Begins Planning for Space Force." Air Force Magazine. June 19, 2018. Accessed July 26, 2018. http://www.airforcemag.com/Features/Pages/2018/June 2018/Pentagon-Begins-Planning-for-Space-Force.aspx.

[51] Messier, Doug. "Mojave: The Once and Future Spaceport." *Parabolic Arc*, June 29, 2017. Accessed July 16, 2018. http://www.parabolicarc.com/2017/06/29/mojave-future-spaceport/.

[52] Mindell, David A. *Our Robots, Ourselves: Robotics and the Myths of Autonomy*. 2015.

[53] Mosher, Dave, and Andy Kiersz. "Elon Musk Has Job Openings for More than 500 People at SpaceX." Business Insider. June 7, 2018. Accessed June 21, 2018. http://www.businessinsider.com/spacex-jobs-elon-musk-hiring-open-positions-2018-6.

[54] Muir-Harmony, Teasel. "American Foreign Policy and the Space Race." *Oxford Research Encyclopedia of American History*, February 2017. Accessed July 14, 2018. doi:10.1093/acrefore/9780199329175.013.274.

[55] National Aeronautics and Space Administration. "New Space Policy Directive Calls for Human Expansion Across Solar System." News release, December 11, 2017. Accessed June 24, 2018.

[56] United States. National Oceanic and Atmospheric Administration. *NOAA Commercial Space Policy (January 2016)*.

[57] O'Connell, Cathal. "Launch, Land, Repeat - Reusable Rockets Explained." *Cosmos Magazine*, February 6, 2018.

[58] Obama, Barack. *National Space Policy of the United States of America*. Washington, D.C.: Executive Office of the President, 2010.

[59] Olson, Eric. "American-made BE-4 Rocket Engine Could End U.S. Dependence on Russian RD-180." *Engineering 360*, March 30, 2018. Accessed July 19, 2018. https://insights.globalspec.com/article/8391/american-made-be-4-rocket-engine-could-end-u-s-dependence-on-russian-rd-180.

[60] "Our Vehicles." Virgin Galactic. Accessed July 26, 2018. http://www.virgingalactic.com/learn/.

[61] Pappalardo, Joe. "Lockheed Martin Is 3D-Printing Giant Titanium Space Parts." Popular Mechanics. July 12, 2018. Accessed July 14, 2018. https://www.popularmechanics.com/space/satellites/a22129376/lockheed-martin-3d-printing-titanium-fuel-tanks/.

[62] Potter, Ned. "Crash Course: Florida's Economy Sinks as Space Shuttle Makes Final Flights." *ABC News*, November 1, 2010. Accessed July 15, 2018. https://abcnews.go.com/Technology/florida-unemployment-acute-space-coast-jobs-threatened-end/story?id=12019380.

[63] The White House. "President Donald J. Trump Is Achieving a Safe and Secure Future in Space." News release, June 18, 2018. Accessed June 27, 2018. https://www.whitehouse.gov/briefings-statements/president-donald-j-trump-achieving-safe-secure-future-space/.

[64] Public Law 111-267, § 2808 (Government Publishing Office 2010).

[65] Reasserting American Leadership in Space Act, H.R. 870, 115th Cong. (2017).

[66] Reimold, Di, and John Sloan. *Commercial Space Transportation Overview*. Proceedings of Twenty-Third Meeting of the Cross Polar Trans-East Air Traffic Management Providers' Working Group (CPWG/23), Virginia, Arlington. Accessed July 22, 2018.

[67] Roman, Jesse. "Primed for Lift-Off." NFPA Journal. March 1, 2018. Accessed July 21, 2018. https://www.nfpa.org/News-and-Research/Publications/NFPA-Journal/2018/March-April-2018/Features/Spaceports.

[68] Ross, Wilbur. "President Trump Wants My Department to Keep Space Safe. We're Ready." *The Washington Post*, June 19, 2018. Accessed July 14, 2018. https://www.washingtonpost.com/opinions/president-trump-wants-my-department-to-keep-space-safe-were-ready/2018/06/19/a3aa96f6-73f8-11e8-9780-b1dd6a09b549_story.html?utm_term=.339ee3ea1835.

[69] Scaled Composites. "SpaceShipOne and White Knight Mothership." Smithsonian National Air and Space Museum. Accessed July 20, 2018. https://airandspace.si.edu/multimedia-gallery/spaceshipone-and-white-knightnasm-9a03260jpg.

[70] Schmitt, Harrison. "The Right Rocket for the Moon and Mars." *POLITICO*, June 15, 2018. Accessed June 25, 2018. https://www.politico.com/story/2018/06/15/mars-moon-rocket-jack-schmitt-636632.

[71] Seedhouse, Erik. *SpaceX : Making Commercial Spaceflight a Reality*. Springer/Praxis., 2013.

[72] Sheetz, Michael. "Space Companies Received $3.9 Billion in Private Investment during 'the Year of Commercial Launch': Report." CNBC. January 18, 2018. Accessed July 22, 2018. https://www.cnbc.com/2018/01/18/space-companies-got-3-point-9-billion-in-venture-capital-last-year-report.html.

[73] Smith, Marcia. "Senate Appropriators Join House in Boosting Funding For FAA Space Office." *Space Policy Online*, June 8, 2018. Accessed June 27, 2018.

https://spacepolicyonline.com/news/senate-appropriators-join-house-in-boosting-funding-for-faa-space-office/.

[74] Smith, Marcia. "Senate Appropriations Joins House in Boosting Funding for FAA Space Office." Space Policy Online. June 8, 2018. Accessed July 14, 2018. https://spacepolicyonline.com/news/senate-appropriators-join-house-in-boosting-funding-for-faa-space-office/.

[75] Smith, Yvette. "Celebrating the Tenth Anniversary of the COTS Program." National Aeronautics and Space Administration. August 6, 2017. Accessed July 14, 2018. https://www.nasa.gov/feature/celebrating-the-tenth-anniversary-of-the-cots-program.

[76] National Aeronautics and Space Administration. *Space Launch System Fact Sheet*. Washington, DC: Government Publishing Office, 2018.

[77] Hogan Lovells. "Space Policy Directive - 2, Streamlining Regulations on Commercial Use of Space." News release, June 21, 2018. Accessed July 14, 2018.

[78] Stephens, Marric. "Space Debris Threat to Geosynchronous Satellites Has Been Drastically Underestimated." Physics World: Telescopes and Space Missions. December 12, 2017. Accessed July 21, 2018. https://physicsworld.com/a/space-debris-threat-to-geosynchronous-satellites-has-been-drastically-underestimated/.

[79] Todd Harrison, Todd, and Kaitlyn Johnson. "Back to the Moon? Understanding Trump's Space Policy Directive 1." Center for Strategic & International Studies. December 14, 2017. Accessed July 21, 2018. https://www.csis.org/analysis/back-moon-understanding-trumps-space-policy-directive-1.

[80] United States. Department of Commerce. *U.S. Department of Commerce Strategic Plan: 2018-2022*. Washington, D.C.: Dept. of Commerce. 4.

[81] "Vector Space Systems: About Us." Vector Launch. 2017. Accessed June 27, 2018. https://vector-launch.com/about/.

[82] Wall, Mike. "Trump's New Space Policy Directive 2 Could Make Life Easier for SpaceX and Others." Space.com. May 25, 2018. Accessed July 14, 2018. https://www.space.com/40700-trump-space-policy-private-spaceflight-deregulation.html

[83] "Werner, Debra. "Lockheed Martin Prepares to Turn on U.S. Air Force Space Fence on Kwajalein Atoll." SpaceNews. May 3, 2018. Accessed July 26, 2018. Https://spacenews.com/lockheed-martin-prepares-to-turn-on-u-s-air-force-space-fence-on-kwajalein-atoll/."

[84] "Who Owns What in Outer Space." *The Economist*, June 12, 2018.

[85] *Who's Winning the Commercial Space Race?* 2018. Statistica.

[86] Wichner, David. "Tucson-based Vector Launch Busy Ramping up for Orbital Launches." *Arizona Daily Star*, June 9, 2018. Accessed June 25, 2018. https://tucson.com/business/tucson-based-vector-launch-busy-ramping-up-for-orbital-launches/article_75a7ea36-ef63-5058-bd20-d059f669ff57.html.

[87] Zapata, Edgar. *An Assessment of Cost Improvements in the NASA COTS/CRS Program and Implications for Future NASA Missions*. Report. Kennedy Space Center, National Aeronautics and Space Administration.

[88] Proceedings of Future Space Leaders 2018, Washington, D.C.