PAST AND FUTURE: AN ANALYSIS OF THE FAA COMMERCIAL SPACE TRANSPORTATION FORECASTS

International Science & Technology Policy Capstone Project
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May 8, 2017

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Abstract

The recent growth of the commercial space industry has significantly increased Congressional interest in the industry. Launch Forecasts help provide information to inform legislators in their authorization, appropriation, and oversight responsibilities related to the commercial space industry. Accurate commercial launch forecasting is integral to the success of planning for future businesses, expanding and maintaining support infrastructure, and in policy formulation. This study compiles key data for commercial space launch metrics from 1995-2017 and uses retrospective analysis to evaluate the accuracy and reliability of previous FAA Commercial Space Transportation Forecasts. This analysis finds that the commercial launch forecasts have overestimated the annual number of addressable launches across all orbital and payload segments. It proposes two corrective methods to determine a more accurate upper- and lower- bound estimate for the next year's commercial launch prediction. The aim of this study is to better inform the consumers of these Forecasts as well as contribute to the improvement of future attempts to project future activity of the commercial space launch industry. This study concludes with both short-term and long-term recommendations on how to improve both the development and use of the annual commercial Launch Forecasts.

Executive Summary

This report has been prepared as part of the George Washington University International Science and Technology Policy Capstone Course. The client for this report is the Congressional Research Service.

The commercial space industry is growing at a rapid pace and is reliant on the commercial launch market. Moreover, Congress, industry generally, and government agencies have a shared need to understand the trajectory of the commercial launch industry. This is especially true in light of recent legislation and policy initiatives meant to promote the growth of commercial space.

The commercial space industry is the subject of many government and non-government analyses. However, only one of these analyses is publicly available and offers future projections of the market, the *FAA AST Commercial Space Transportation Forecast*. This forecast has evolved since 1995 into an annual report that projects the total number of addressable commercial launches and payloads. The forecasts rely primarily on data voluntarily submitted by commercial space companies, which is used in conjunction with other variables affecting the commercial launch industry.

Although the Commercial Launch Forecasts have been produced for over two decades, a retrospective study on their accuracy has not been conducted prior to this report. To run this analysis, data was compiled from all available FAA Forecasts published from 1995-2017. These data were then compiled and compared using three main analytical techniques: aggregate mean analysis, annual launch rate analysis, and out-year prediction analysis. The primary findings of this report are that the *FAA Space Transportation Forecasts* are inherently over-optimistic in their prediction of future commercial launches. The sources of this error are not easy to identify because the methodology of the Forecasts is not transparent; however, the combination of self-reporting bias from industry as well as the overarching goals of the FAA AST likely encourage optimism in the formulation of the report.

Considering the error discovered in the FAA Forecasts, two attempts were made to develop an alternative predictive model. First, a correlation analysis of key variables using publicly available data was conducted to test for strong relationships with the actual number of annual commercial launches. The correlation analysis yielded null results, so a new launch realization factor was developed to provide a corrective adjustment that results in a more accurate range of launch prediction values.

Based on the culmination of this analysis, this report makes short-term and long-term recommendations to the Congressional Research Service regarding the FAA Forecasts. In the short-term, CRS should inform its congressional clients of the limited accuracy of the FAA Forecasts due to their inherent optimism when these forecasts appear as evidence in congressional testimony or in other mediums. In addition, the new launch realization factor should be tested in the following year to determine its validity as a corrective factor. In the long-term, steps should be taken to ensure that future FAA forecasts are accurate, rather than optimistic. These steps include: engaging with the contractor – who produces the reports – to develop ways to improve the forecast; encouraging the FAA to modify the contract language in order to implement consistent reporting requirements; and if necessary, urge Congress to mandate the report within the FAA's authorization and specify its contents, frequency, and potentially its methodology.

Section 1: Introduction

The past decade has witnessed a boom in both interest in and development of the commercial space launch industry. This increase in the commercial launch industry has sparked growth in a multitude of industries and business sectors. The FAA explains, "The commercial launch industry promotes developing businesses that build satellites, sell satellite communications services and satellite imagery, and manufacture ground equipment necessary to operate satellites and use satellite services."[1] These "enabled" industries rely on the commercial launch industry, and therefore need accurate information on its future trajectory to develop successful business plans.

Another key to the success of the commercial launch industry and its enabled industries is the development of a well-suited regulatory and policy framework. Since the U.S. space industry has both strategic, commercial, and security values, it is a unique policy area that must consider the effect on these various domains.[2] For lawmakers to draft and enact policy that will be able to foster the growth of the commercial launch industry, they need an accurate prediction of how the industry will grow over the coming years. Without accurate Launch Forecasts, legislators could drastically overestimate or underestimate the growth of the commercial launch market and its related industries. Either mistake brings a variety of consequences, particularly the creation of policy parameters that may constrain global commercial competitiveness.

The importance of the annual *FAA's Commercial Space Transportation Forecast* is that it provides industry, government agencies, and Congress with information on what to expect in

[1] The Federal Aviation Administration. (2007). The Economic Impact of Commercial Space Transportation on the U.S. Economy. *Journal of Magnetohydrodynamics, Plasma and Space Research, 16*(1/2), 43-74.
[2] Hertzfeld, H. R. (2007). Globalization, commercial space and spacepower in the USA. *Space Policy, 23*(4), 210-220. doi:10.1016/j.spacepol.2007.09.004

the commercial launch industry-segment in the coming years. Although the Commercial Launch Forecasts have been produced for over two decades, a retrospective study on their accuracy has not been previously conducted. An analysis of the accuracy of these Forecasts over time is integral to the improved development and production of these reports. Therefore, the goal of this study is to examine these Forecasts more closely and make recommendations on their improvement in the future.

This paper first provides a policy-focused overview of the U.S. commercial launch industry. Then, it outlines the history of the FAA Office of Commercial Space Transportation (AST) and the production of the *FAA Commercial Space Transportation Forecast* to provide context and relevant background information. The report then describes an historical analysis of the *FAA Commercial Space Transportation Forecasts* data, over time. This evaluation is organized into three main modes of analysis: the aggregate mean, the annual launch rate, and the out-year forecast. In the subsequent sections, this paper reports the null findings of a correlation analysis meant to identify variables strongly correlated with the actual number of commercial launches and presents a corrective model meant to improve the predictions of future Commercial Launch Forecasts. Finally, the paper concludes with a series of short-term and long-term recommendations for both the producers and consumers of the commercial Launch Forecasts.

Section 2: State of the Commercial Launch Industry and Policy Background

A) Overview of the Commercial Launch Industry

Within the United States, space exploration entities are typically categorized into one of three sectors: civil, security, or commercial space.[3] The civil space sector consists of government entities that directly undertake space activities for non-military purposes, such as the National Aeronautics and Space Administration (NASA) and the National Oceanic and

[3] Mutel, L., & Murray, D. (2018, February 18). Space Data Integrator: FAA's Innovative Platform for Launch and Reentry Operations. Retrieved from https://arc.aiaa.org/doi/abs/10.2514/6.2016-0218

Atmospheric Administration (NOAA).[4] The national security space sector consists of government entities that directly undertake space activities in support of national defense and intelligence operations, such as the Department of Defense (DoD) and the Intelligence Community (IC).[5] The commercial space sector consists of privately funded, owned, and operated entities that provide various space and satellite services to government and non-government clients, such as manufacturing, launch, communications, and data services.[6]

The commercial launch industry is a subset of the commercial space sector that provides orbital and suborbital launch services. The first U.S. commercial launch occurred in 1982 with the test flight of a Conestoga rocket by Space Services, Inc. of America (SSIA).[7] Seven years later, SSIA would go on to achieve the first commercial suborbital launch of a Starfire rocket, while McDonnell Douglas would quickly follow with the first successful commercial orbital launch of a Delta I launch vehicle, marking 1989 as the beginning of the U.S. commercial launch industry-segment.[8]

Today, commercial space sector analysts estimate that global space industry revenues grew to approximately $335 billion in 2015, the most recent year for which figures have been published.[9] This total represents an increase of 4% from 2014 (Figure 1). After accounting for all orbital launch contracts in which a financial transaction occurred, the global commercial launch industry represented $5.4 billion or 1.6 percent of the 2015 total.[10] While this amount is only a small fraction of total revenues, all other segments are wholly reliant on the launch segment for the deployment of assets to orbit, thus the continued health of the launch segment of the industry is crucial to the whole.

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[4] Seftas, R. (n.d.). The civil space sector. Retrieved from https://fas.org/spp/eprint/article07.html#1

[5] DOD. (n.d.). Space: Today and the Future. Retrieved from http://www.dod.gov/pubs/spacechapter2.pdf

[6] Haller, L., & Sakazaki, M. (n.d.). Commercial Space and United States National Security. Retrieved from https://fas.org/spp/eprint/article06.html#4

[7] SSI. (2014). Heritage- Space Services of America Inc. Retrieved from http://www.spaceservicesinc.com/company-heritage

[8] The FAA. (2015). Origins of the commercial space industry. Retrieved from https://www.faa.gov/about/history/milestones/media/Commercial_Space_Industry.pdf

[9] The Tauri Group. (2016). *State of the satellite industry report*. Retrieved from http://www.sia.org/wp-content/uploads/2016/06/SSIR16-Pdf-Copy-for-Website-Compressed.pdf

[10] The FAA. (2017). The Annual Compendium of Commercial Space Transportation: 2017. Retrieved from https://brycetech.com/downloads/FAA_Annual_Compendium_2017.pdf

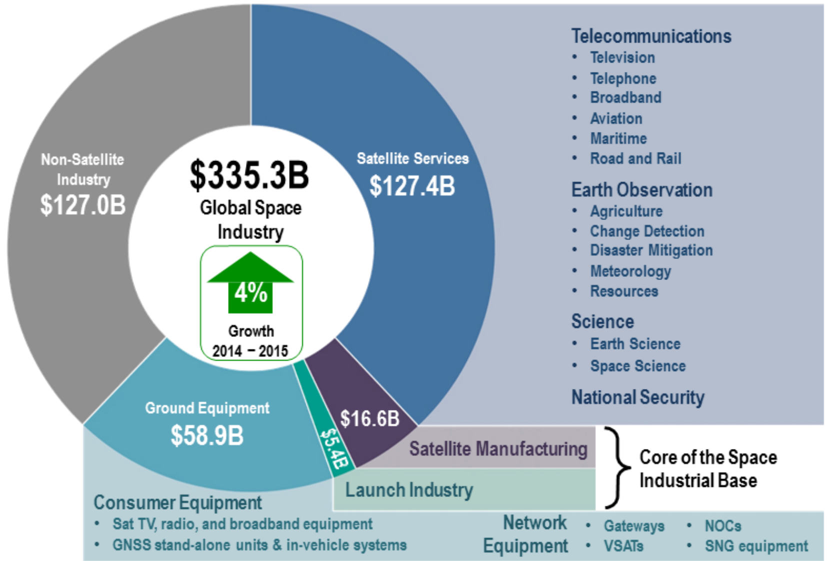

Figure 1- Global Space Industry Revenues for 2015, taken from the Satellite Industry Association "State of the Industry Report"[11]

From a total of 86 orbital launch events in 2015, the FAA AST classified 22 of those events as commercial launches, or 26 percent of the total.[12] For this tabulation, commercial launches are defined as having one or more of the following characteristics:

1. The launch is licensed by FAA AST
2. The launch contract for the primary payload was internationally competed
3. The launch is privately financed without government support

It is important to note that the total number of commercial launches is distinct from the number of addressable commercial launches projected in the FAA AST Forecasts, which is a subset of the total number of launches and accounts only for those that satisfy characteristic 2. Total global launches and total commercial launches have remained relatively constant since 2013 (Figure 2).

[11] 2016. State of the Satellite Industry Report. p. 7.
[12] 2017. The Annual Compendium of Commercial Space Transportation.

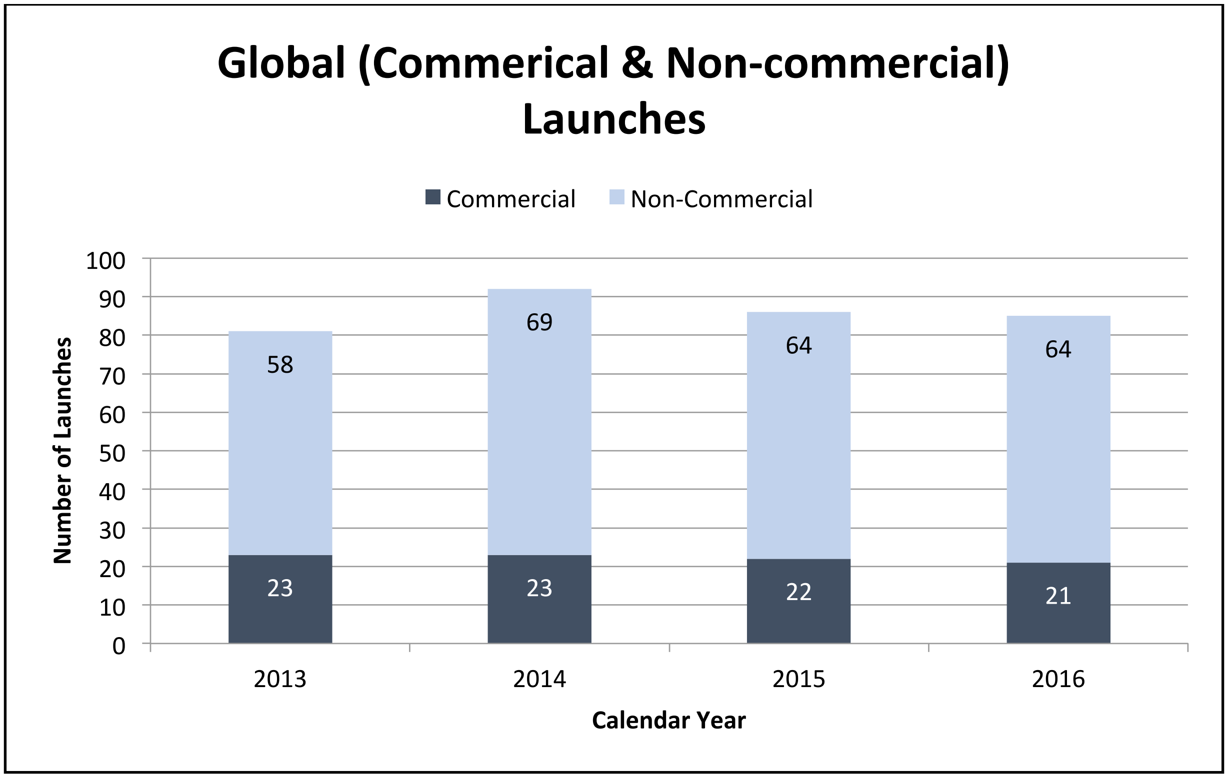

Figure 2- Global Launches in each calendar year, for selected years: 2013-2016. Data compiled from the FAA, analysis by authors.[13]

B) Overview of Congressional Action

Prior to 1982, U.S. manufacturers of launch vehicles only produced vehicles under contract to NASA or DoD, who also directly supervised their launch.[14] That year, President Reagan issued National Security Decision Directive (NSDD) 42, which first created the national goal of expanding private sector activities in space exploration.[15] Following this decision, the commercial launch industry began to develop along with additional U.S. policy and legislative interest in the sector.

[13] The FAA. (n.d.). The Annual Compendium of Commercial Space Transportation 2012-2016. Retrieved from https://www.faa.gov/c/commercial_space/annual_Compendium.html

[14] 2015. Origins of the Commercial Space Industry.

[15] USA, The Office of the President of the United States of America. (1982). *National Security Decision Directive Number 42, "National Space Policy,"*. Retrieved from https://www.hq.nasa.gov/office/pao/History/nsdd-42.html

Major Policy/Legislative Milestones:

1982

NSDD 42 – National Space Policy

- First declared the national goal of expanding private sector activities in space exploration. [16]

1983

NSDD 94 – Commercialization of Expendable Launch Vehicles

- Outlined the intention of the U.S. government to "encourage the private sector development of commercial launch operations." [17]

1984

Executive Order 12465 – Commercial Expendable Launch Vehicle Activities

- Formally designated DOT as the lead agency for encouraging, facilitating, and licensing commercial launch activities. [18]

H.R. 3942 – Commercial Space Launch Act

- Authorized DOT to license and regulate commercial launch activities, beginning in 1985.[19]

1988

Presidential Directive on National Space Policy

- Directed U.S. government agencies to purchase launch services from the private sector.[20]

1989

Starfire Rocket and Delta I Launch Vehicle

- First successful U.S.-licensed commercial suborbital and orbital launches[21]

1995

H.R. 2002 – Department of Transportation and Related Agencies Appropriations Act, 1996

- Officially moved the DOT Office of Commercial Space Transportation (AST) to the FAA.[22]

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[16] 1982. *National Security Decision Directive Number 42.*

[17] USA, The Office of the President of the United States of America. (1983). *National Security Decision Directive Number 94, "Commercialization of Expendable Launch Vehicles"*. Retrieved from https://reaganlibrary.archives.gov/archives/reference/Scanned%20NSDDS/NSDD94.pdf

[18] USA, The Office of the President of the United States of America. (1984). *Executive Order 12465--Commercial expendable launch vehicle activities*. Retrieved from https://www.archives.gov/federal-register/codification/executive-order/12465.html

[19] U.S.Cong., House - Science and Technology | Senate - Commerce, Science, and Transportation. (1983). *Commercial Space Launch Act* [Cong. 3942 from 98th Cong.]. Retrieved from https://www.congress.gov/bill/98th-congress/house-bill/3942

[20] USA, The Office of the President of the United States of America. (1988). *"Presidential Directive on National Space Policy"*. Retrieved from https://www.hq.nasa.gov/office/pao/History/policy88.html

[21] 2015. Origins of the Commercial Space Industry.

[22] U.S.Cong. (1996). *Department of Transportation and Related Agencies Appropriations Act* [Cong. Bill from 104th Cong.]. Retrieved from https://www.congress.gov/104/plaws/publ50/PLAW-104publ50.pdf

2009

H.R. 3237 – To enact certain laws relating to national and commercial space programs as title 51, United States Code, "National and Commercial Space Programs"

- Established Title 51 of the U.S. Code and consolidated most space-related provisions there.[23]

2015

H.R. 2262 – U.S. Commercial Space Launch Competitiveness Act (CSLCA)

- Initiated the study of major reforms to the commercial launch licensing and regulation regimes.[24]

C) Overview of Current Events Related to the Commercial Space Sector in the U.S.

Although the government has sustained an interest in the commercial space sector over the decades, there has been an increase in activity related to the promotion of both the public and private space sector. This activity has affected the predictions of more recent Forecasts, and will need to be considered in any analysis of their findings.

The first major development was President Trump's recent signing of the NASA Transition Authorization Act of 2017 in March of this year.[25] A NASA authorization bill has not been signed since 2010, making this bill of greater importance than if an authorization were made every year. The 2017 Authorization Act authorizes a NASA budget of $19.5 billion for FY 2017, an increase over the FY2016 level, and also reaffirms the federal government's commitment to space exploration and development. Interestingly, the Authorization Act also emphasizes the need for NASA to transfer some of its duties to the commercial sector, which shows the federal government's support for space commercialization efforts.[26] The authorized increase for NASA stands out in light of the Trump Administration's proposed cuts to other civil science agencies, such as the Environmental Protection Agency (EPA) and the National

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[23] U.S. House, House - Judiciary | Senate - Judiciary. (2009). *To enact certain laws relating to national and commercial space programs as title 51, United States Code, "National and Commercial Space Programs"* [H.R. 3237 from 111th Cong.]. Retrieved from https://www.congress.gov/bill/111th-congress/house-bill/3237?q=%7B%22search%22%3A%5B%22P.L.%2B111-314%22%5D%7D&r=1

[24] U.S. House, House - Science, Space, and Technology | Senate - Commerce, Science, and Transportation. (2015, November 25). [H.R. 2262 from 114th Cong.]. Retrieved from https://www.congress.gov/bill/114th-congress/house-bill/2262

[25] Committee on Science, Space, and Technology. (2017, April 06). So Far... Retrieved from https://science.house.gov/news/press-releases/so-far

[26] Cofield, C. (2017, March 21). President Trump Signs NASA Authorization Bill. Retrieved from http://www.space.com/36154-president-trump-signs-nasa-authorization-bill.html

Institutes of Health (NIH).[27] Federal government support for both NASA and the commercial space sector show that the market is on a growth trajectory that will require extensive development, planning, and coordination.

Along with signing the Authorization Act, the Trump administration has also emphasized its desire to reinstate the National Space Council (NSC) as a part of the Executive Office of the President. The NSC was used to coordinate government and commercial space activity from 1958 to 1973 and then from 1989 to 1993, but has not been a part of the Executive Office since then.[28] Although the utility of the NSC is debated, its recreation as a part of the Trump administration would, at the very least, symbolically affirm the government's support for space development. Since the NSC has a role in fostering public-private partnerships in space, it could help to push forward the current administration's goals for space outlined in the 2017 Authorization Act.

Recent federal government acts of support for both the public and private space sectors are important for development and growth. However, it is important that newly proposed legislation is supported by appropriate funding of key agencies and legislative bodies. Key commercial areas, such as space-based remote sensing, are gaining investment by new companies, but this interest is constrained within an antiquated regulatory framework. In this specific case, the most recently enacted legislation was the 1992 Land Remote Sensing Act.[29] Remote-sensing technology has changed significantly since then, making the outdated legislation an impediment to the competitive advantage of the U.S. industry.

The FAA AST Commercial Launch Forecasts are integral to the realization of the current administration's goals for space by providing an outlook for the future of the industry. Information conveyed in the report ideally can be used to prevent stagnant legislation in key areas, as well as to better equip agencies, Congress, and industry to handle the rapid changes inherent in the commercial space sector. Furthermore, because the FAA AST has the explicit

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[27] Duncan, D. E. (2017, January 30). President Trump's Wannabe Space Race Saves NASA's Funding-For Now. Retrieved from http://www.thedailybeast.com/articles/2017/04/03/president-trump-s-wannabe-space-race-saves-nasa-s-funding-for-now.html

[28] David, L. (2016, December 29). Playing the Space Trump Card: Relaunching a National Space Council. Retrieved from http://www.space.com/35163-trump-administration-national-space-council.html

[29] Babin, U. (2017, April 06). U.S. satellite rules out of focus; time for new vision. Retrieved from https://science.house.gov/news/in-the-news/us-satellite-rules-out-focus-time-new-vision

goal of encouraging, facilitating, and promoting the commercial launch industry, the office will need these reports for future planning. According to a recent document published by the U.S. House of Representatives Committee on Science, Space, and Technology, the FAA AST must, "focus and prioritize its resources in order to execute these statutory responsibilities".[30] The annual Launch Forecasts provide an important resource for the FAA AST in particular, because they give an estimate of the future demand for FAA commercial space licensing and regulation.

Section 3: History of the FAA AST and the Forecast Report

A) Other Industry Reports

Aside from the FAA Office of Commercial Space Transportation (AST) and the *Commercial Space Transportation Forecasts*, there are numerous other organizations that do annual space industry related forecasting. These reports focus on more than just commercial launches and act as important resources for actors wanting to assess the trajectory of the commercial space industry. These reports include but are not limited to:

- The Satellite Industry Association (SIA) State of the Satellite Industry Report (Prepared by Bryce Space and Technology)[31]
- The Space Foundation's Annual Space Report[32]
- The ASD Eurospace Annual Facts and Figures Publication[33]
- The SpaceWorks Small Satellite Report[34]
- The StratSpace Intelligence Report: Satellite and Launch Market Projections[35]

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[30]U.S. House, The Committee on Science, Space, and Technology. (2017). *The Views and Estimates of the Committee on Science, Space, and Technology U.S. House of Representative for FY 2018* (L. Smith, Author) [H.R. Doc.]. Retrieved from https://science.house.gov/sites/republicans.science.house.gov/files/documents/Views and Estimates FY 2018.pdf

[31] 2016. State of the Satellite Industry Report.

[32] The Space Foundation. (2016). *The Space Report: 2016*. Retrieved from https://www.spacefoundation.org/sites/default/files/downloads/The_Space_Report_2016_OVERVIEW.pdf

[33] ASD-Eurospace. (2015). The European Space Industry in 2014. Retrieved from http://www.eurospace.org/Data/Sites/1/pdf/eurospace_facts_and_figures_data2014.pdf

[34] SpaceWorks. (2017). SpaceWorks Forecast – Small Satellite Trends and Market Observations. Retrieved from http://spaceworksForecast.com/

There are many different commercial space reports, however, most of them rely on commercial launch industry data from the FAA. Furthermore, some of these reports cost thousands of dollars a year, which may make them inaccessible to researchers or start-up companies that do not have large budgets. Since the FAA Forecasts are available to the public free of charge, they are able to provide key information for all actors interested in the commercial space industry.

Bryce Space and Technology (formerly The Tauri Group) is currently responsible for preparing the FAA AST Forecasts, the *FAA Annual Compendium of Space Transportation*, as well as the SIA State of the Industry Report. Although these reports are produced by the same contractor and utilize the same data, the FAA Forecasts provide the only publicly available future projection of commercial launch activity. Because this product is free, comes from a reliable source, and has been produced consistently, it has become one of the most authoritative commercial space industry reports. The Forecast's common use by researchers, industry, and Congress makes it imperative to closely analyze its history and development.

B) Background on the FAA AST and the Commercial Space Transportation Forecast

U.S. Commercial Space Regulatory Structure

The U.S. commercial space industry is subject to three primary licensing authorities. The National Oceanic and Atmospheric Administration (NOAA) is responsible for issuing commercial remote sensing licenses to privately owned and operated satellites capable of observing Earth from orbit. The Federal Communications Commission (FCC) is responsible for issuing licenses to non-Federal satellites employing radio communications. The FAA AST is responsible for issuing licenses for commercial launch and reentry activities, as well as licenses for the operation of commercial launch and reentry sites, permits for suborbital launch activities, and safety approvals for equipment, processes, and personnel related to launch activities. Each of these licensing regimes must be coordinated through an interagency process that includes input from

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[35] StratSpace. (2017). StratSpace Announces its 2017 Space Intelligence Report & Market Forecast. Retrieved from http://www.stratspace.net/Forecasting/

NASA, the Department of Defense, the Department of State, members of the Intelligence Community, and other relevant agencies.

Overview

The Office of Commercial Space Transportation (AST) resides under the auspices of the Federal Aviation Administration (FAA) in the Department of Transportation (DOT). The mission of this office is to ensure protection of the public, property, and the national security and foreign policy interests of the United States during commercial launch or reentry activities, and to encourage, facilitate, and promote U.S. commercial space transportation development and public-private partnerships in the sector.[36] To fulfill this mission, the FAA AST is authorized to oversee, regulate, and issue licenses for the launch and reentry of vehicles and the operation of launch and reentry sites when these activities are undertaken within the territory of the United States, or when undertaken by a U.S. citizen or entity anywhere on Earth.[37] Furthermore, the FAA AST is authorized to issue regulations setting the requirements for human space flight participation and to determine the required levels of insurance for licensed commercial space activities.[38] The FAA AST Forecasts and Compendia have been published in support of these responsibilities.

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[36] USA, The House of Representatives. (n.d.). *U.S.C. 50903. General authority*. Retrieved from http://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title51-chapter509&saved=L3ByZWxpbUB0aXRsZTUxL3N1YnRpdGxlNS9jaGFwdGVyNTA5|Z3JhbnVsZWlkOlVTQy1wcmVsaW0tdGl0bGU1MS1jaGFwdGVyNTA5|||0|false|prelim&edition=prelim

[37] USA, The House of Representatives. (n.d.). *U.S.C. 50904. Restrictions on launches, operations, and reentries*. Retrieved from http://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title51-chapter509&saved=L3ByZWxpbUB0aXRsZTUxL3N1YnRpdGxlNS9jaGFwdGVyNTA5|Z3JhbnVsZWlkOlVTQy1wcmVsaW0tdGl0bGU1MS1jaGFwdGVyNTA5|||0|false|prelim&edition=prelim

[38] USA, The House of Representatives. (n.d.). *U.S.C. 50905. License applications and requirements*. Retrieved from http://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title51-chapter509&saved=L3ByZWxpbUB0aXRsZTUxL3N1YnRpdGxlNS9jaGFwdGVyNTA5|Z3JhbnVsZWlkOlVTQy1wcmVsaW0tdGl0bGU1MS1jaGFwdGVyNTA5|||0|false|prelim&edition=prelim; USA, The House of Representatives. (n.d.).

Authorization and Appropriation

The FAA AST was established in the Commercial Space Launch Act of 1984, as amended and re-codified at 51 U.S.C. 50901-50923.[39] This section of the U.S.C.:

- Defines general authorities and relevant terminology
- Specifies commercial space activities that require commercial space transportation licensing
- Outlines the processes by which the FAA AST may develop its licensing requirements
- Provides the interagency cooperation, administrative hearings and judicial review requirements for the FAA launch licensing regime
- Establishes the disclosure, enforcement and reporting obligations of the FAA AST

The FAA AST has seen incremental budget growth over the past decade (Figure 3). AST was appropriated $17.8 million in FY2016 and the FAA's FY2017 budget request included an increase of $2 million for AST to "keep pace with the continued growth of the commercial space transportation industry."[40,41] After operating through April 2017 at slightly below the 2016 appropriation level under the first 2017 continuing resolution, as amended, FAA was appropriated a total of $19.8 million for the 2017 fiscal year in May 2017.[42, 43, 44]

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[39] See 51 U.S.C. 50901-50923, P.L. 98-575 Commercial Space Launch Act of 1984, P.L. 100-657 Commercial Space Launch Act Amendments of 1988, P.L. 105-303 Commercial Space Act of 1998, P.L. 106-405 Commercial Space Transportation Competitiveness Act of 2000, P.L. 107-248 Title IX Commercial Reusable In-Space Transportation Act of 2002, P.L. 108-428 To extend the liability indemnification regime for the commercial space transportation industry [2004], P.L. 108-492 Commercial Space Launch Amendments Act of 2004, Executive Order 12465 Commercial expendable launch vehicle activities, P.L. 111-125 To extend the commercial space transportation liability regime [2009], P.L. 111-314 Enactment of Title 51—National and Commercial Space Programs [2010]. Full citation information is provided in the bibliography.

[40] U.S. House, House - Appropriations | Senate - Appropriations. (2015). *Consolidated Appropriations Act, 2016* [H.R. 2029 from 114th Cong.]. Retrieved from https://www.congress.gov/bill/114th-congress/house-bill/2029/text

[41] The U.S. Department of Transportation. (2016). Budget Estimates: FY 2017. *Federal Aviation Administration FY 2017 President's Budget Submission*. Retrieved from https://cms.dot.gov/sites/dot.gov/files/docs/FAA-FY-2017-CJ.pdf

[42] U.S. House. (2016). *Public Law 114-223* [H.R. 5325 from 114th Cong.]. Retrieved from https://www.congress.gov/bill/114th-congress/house-bill/5325/text/pl?overview=closed

[43] U.S. House, House - Appropriations | Senate - Appropriations. (2015-16). *Further Continuing and Security Assistance Appropriations Act, 2017* [H.R. 2028 from 114th Cong.]. Retrieved from https://www.congress.gov/bill/114th-congress/house-bill/2028/text

[44] U.S. House, House - Veterans' Affairs | Senate - Health, Education, Labor, and Pensions. (2017). *Consolidated Appropriations Act, 2017* [H.R. 244 from 115th Cong.]. Retrieved from https://www.congress.gov/bill/115th-congress/house-bill/244/text

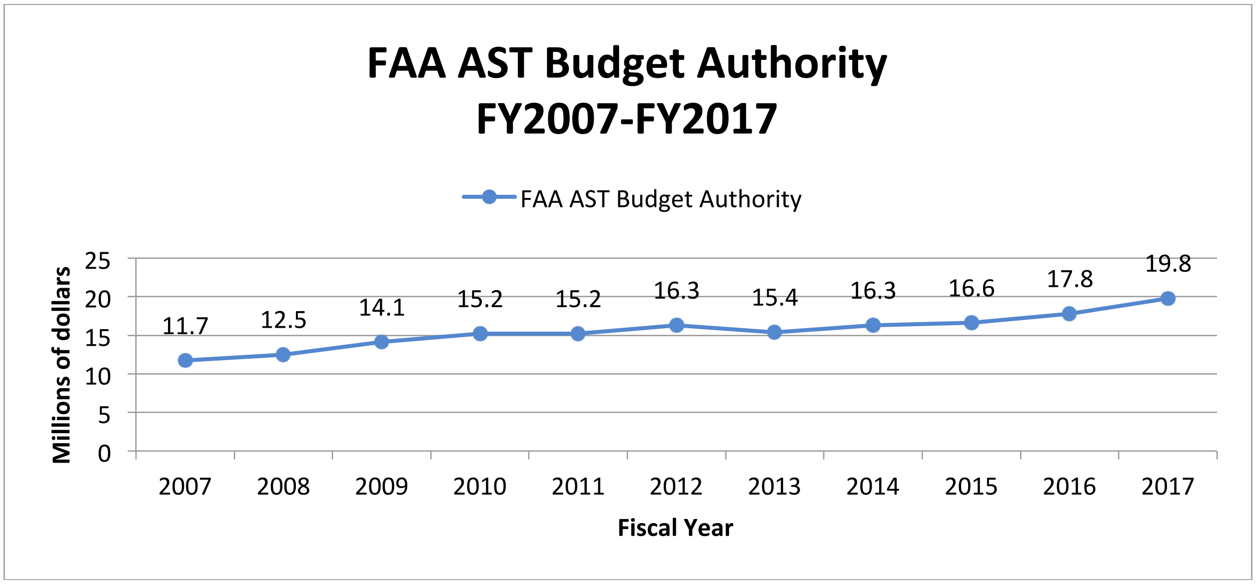

Figure 3- The FAA AST budget authority in millions of then-year dollars, by fiscal year: 2007-2017. Data are from the FAA's budget requests.[45]

Licenses, Permits, and Regulations

The general and permanent rules established by the FAA AST are codified in CFR Title 14 Chapter III. These rules include the organizational and procedural structure of the FAA AST, as well as detailed descriptions of the licenses and permits issued by the office. Since 1989, the FAA AST has licensed 254 orbital commercial launches, averaging approximately nine per year (Figure 4).

[45] The U.S. Department of Transportation. (n.d.). FAA Budget Estimates: FY 2008-2017. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/aba/budgets_brief/

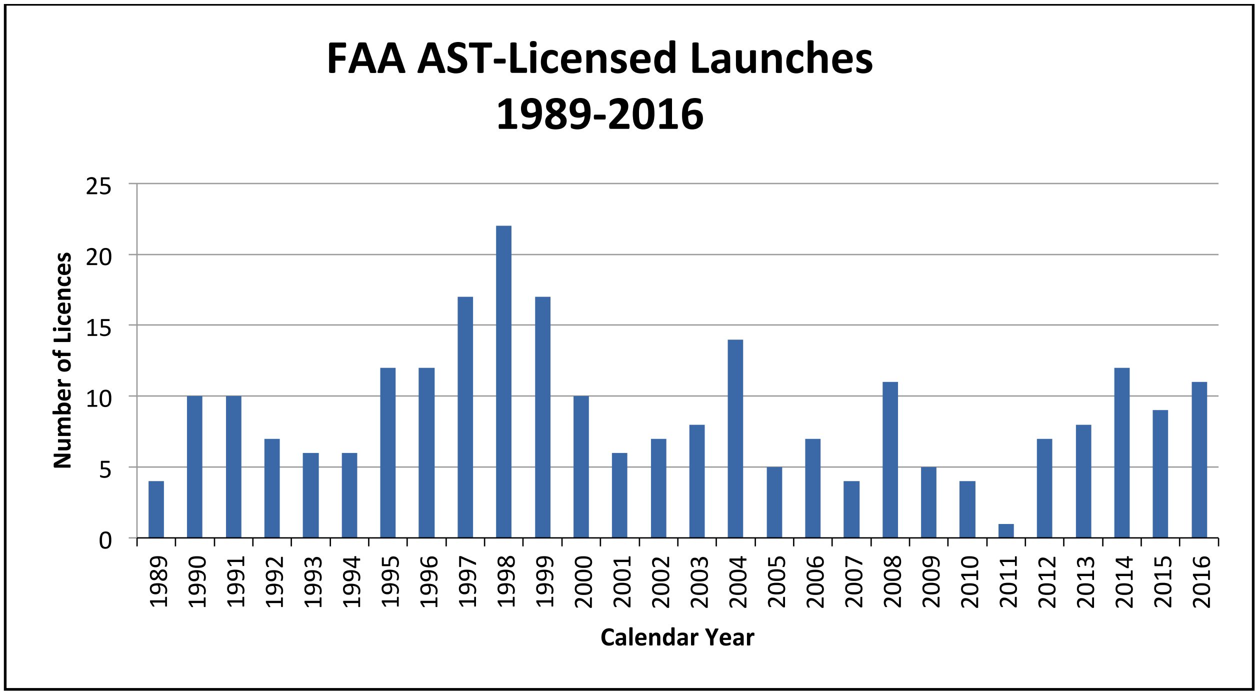

Figure 4- The total number of commercial launch licenses issued by FAA AST in each calendar year.[46]

C) History of the FAA AST Commercial Space Transportation Forecasts

In order to better understand and analyze the *FAA AST Commercial Space Transportation Forecasts*, it is important to first look at the history and development of the report. The Forecast itself began as two separate reports that were later merged into a single document. The first half of the Forecast began in 1993, when the Department of Transportation put in a request with the Commercial Space Transportation Advisory Committee (COMSTAC) to create an annual GSO satellite launch forecast. COMSTAC worked with launch providers to produce the forecast, which was titled the *Commercial Spacecraft Mission Model Update*. After the first edition of the report was published, satellite manufacturers and service providers began to provide information for the forecast. By 1995, the FAA AST gave COMSTAC an official charter to produce this forecast under the same title. In 1995, the FAA AST also began to recognize the growth of the commercial Low Earth Orbit (LEO) market and began to publish a

[46] The FAA AST. (n.d.). FAA AST Licensed Launches Data. Retrieved from https://www.faa.gov/data_research/commercial_space_data/launches/?type=license

separate annual forecast report of this sector of the industry entitled *The LEO Commercial Market Project*.[47]

The two separate forecasts for the GSO and LEO market were produced until 1999 when they were combined into a single *Commercial Space Transportation Forecast*.[48] The two forecasts were likely combined for convenience and improved consistency in the methodology. In the following year, the LEO Forecast was renamed the non-geostationary orbit (NGSO) forecast to include all orbital parameters not addressed by the GSO forecast. Since the combination of the reports in 1999 and the subsequent renaming of the LEO forecast in 2000, the information conveyed and methodology used has been mostly consistent. Commercial launch providers and the satellite industry have contributed data to the production of the Forecast each year.

In addition to the production of the *Commercial Space Transportation Forecast*, the FAA AST began to publish *The Annual Compendium of Commercial Space Transportation* in 2013.[49] The Compendium reports include the *Commercial Space Transportation Forecast*, but provide further information on global regulations, legislation, and activity related to the commercial space sector. Although the Compendium continues to be published annually, the 2016 edition of the report did not include a commercial space launch forecast. In addition, there was no *FAA Commercial Space Transportation Forecast* published separately, likely due to contract negotiations with the producers of the report.

Since the Compendium provides extra information on the space industry, starting in 2017 the *Commercial Space Transportation Forecast* will no longer be published separately from the Compendium. It will provide the same information as it did in the past, but will be published inside of *The Annual Compendium of Commercial Space Transportation,* most likely for convenience. Although the FAA AST is not mandated to produce the annual Compendium or the Commercial Launch Forecasts, it will continue to produce the Compendium with the Commercial Launch Forecast as a subsection in the coming years.

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[47] The FAA. (2012). History of the Forecast Reports. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/Forecasts/

[48] 2012. History of the Forecast report.

[49] Bryce Space and Technology. (2013). The Annual Compendium of Commercial Space Transportation: 2012. Retrieved from https://brycetech.com/downloads/FAA_Annual_Compendium_2012.pdf

D) Methodology of the FAA Commercial Launch Forecast

The FAA Commercial Space Transportation Forecast has used a consistent methodology since its initial publication in 1999. Its data is primarily collected from voluntary industry submissions and its analysis relies on mixed methods techniques, which incorporate both quantitative and qualitative analyses. An example of the commercial Launch Forecast provided in the 2017 Compendium is shown below:

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	Total	Avg.
Payloads												
GSO Forecast (COMSTAC)	25	25	26	21	22	22	22	22	22	22	229	22.9
NGSO Forecast (FAA)	242	300	300	244	256	249	206	252	206	135	2,390	239.0
Total Payloads	***267***	***325***	***326***	***265***	***278***	***271***	***228***	***274***	***228***	***157***	***2,619***	***261.9***
Launches												
GSO Medium-to-Heavy	19	21	24	19	20	18	20	18	19	20	198	19.8
NGSO Medium-to-Heavy	16	25	15	17	16	16	11	15	11	9	151	15.1
NGSO Small	5	10	13	11	5	4	5	4	5	1	63	6.3
Total Launches	***40***	***56***	***52***	***47***	***41***	***38***	***36***	***37***	***35***	***30***	***412***	***41.2***

Table 1- This figure is the 10-year projection of payloads and launches reproduced from the FAA AST 2017 Compendium.[50]

The number of launches projected in each category is from a subset called "addressable launches" of the total commercial launches in a given year. Addressable launches are defined as: "commercial satellite launches that are open to an internationally competitive (including U.S.) launch service procurement process".[51] The remainder of commercial launches, called unadressable launches, are therefore launches that are not competed on the international market.

Within the table, the predictions for the first three years of the Forecast (2017-2019) are derived directly from the data voluntarily submitted by industry, with little adjustment. These are termed the short-term predictions. The predictions for the remaining years (2020-2026) are based on projections of satellite fleet replenishment and manufacturer estimates of industry growth. These are termed the long-term predictions.

[50] 2017. The annual Compendium of commercial space transportation. p. 45.
[51] The FAA AST, & COMSTAC. (2015). 2015 Commercial Space Transportation Forecasts. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/Commercial_Space_Transportation_Forecasts_2015.pdf. p. 7.

For the more qualitative portion of its analysis, the FAA takes several factors that affect the commercial launch market into account. The factors listed in the Forecasts include:

COMSTAC	AST
1. Publicly-announced satellite and launch contracts	1. Satellite technical issues
2. Projected planned and replenishment missions	2. Launch vehicle technical issues
3. Growth in demand from new and existing services and applications	3. Weather
4. Availability of financing and insurance	4. Range availability issues
5. Potential consolidation among operators	5. Dual-manifesting
6. New launch vehicle capabilities	6. Business issues
7. Hosted payload opportunities	7. Regulatory issues
	8. Geopolitical Issues

Table 2- FAA's report of factors affecting estimates for commercial launches. Reproduced from select passages in the 2015 Commercial Space Transportation Forecast.[52]

Since their start in 1999, the Launch Forecasts have been consistently optimistic in their predictions for both the GSO and NGSO markets. In the earlier days of the Forecast, the creators introduced a corrective factor identified as the "launch realization factor". The 2015 Forecast explains,

> "Over the history of this Report, the Forecast demand for satellites and launches has almost always exceeded the number of satellites and launches actually accomplished in each of the first three years of a Forecast period… This factor is derived by comparing Forecast satellite launches with actual satellites launched in the five years prior to the current Report." [53]

[52] 2015 Commercial Space Transportation Forecast. p. 6; p. 18.
[53] 2015 Commercial Space Transportation Forecast. p. 19.

The launch realization factor was included in the *Commercial Space Transportation Forecasts* from 2002-2015. It was intended to provide a more accurate range for the number of annual commercial launches predicted, given by submissions mentioned above. However, the realization factor stopped being presented for the annual number of launches with the switch from the Forecast to *The Annual Compendium of Commercial Space Transportation*. The 2017 Compendium does not provide adjusted annual predictions using the launch realization factor and, instead, only provides a single prediction number for each given year.

Section 4: The Commercial Space Transportation Forecast Data Accuracy and Analysis

A) Data Collection and Methodology

Data for the analyses used in this report were compiled from the Federal Aviation Administration's Launch Forecasts. Each datum represents a launch figure estimated by the FAA for successive years. As mentioned earlier, figures from forecasts prior to 2000 include a division between geosynchronous orbit (GSO) and low Earth orbit (LEO) and subsequent data include a division between GSO and non-geosynchronous orbit (NGSO). Within the NGSO division there is a further division for large and medium payload launches and small payload launches, classified as NGSO (M-L) and NGSO (S) respectively.[54]

The Forecasts were initially set to 2010 as the last out-year for the Forecasts, although this arbitrary terminus was abandoned after the late 1990s in favor of 10-year forecasts. For example, the 1998 Forecast gave predictions for 13 years while later Forecasts would only give predictions for 10 years. In each case, the launch figures are presented within forecast tables located within each Forecast (see Table 1 for an example). Historical data for the actual number of recorded launches were found in the historical tables located in the appendices of the Forecasts produced prior to 2015. Starting with the 2016 Compendium, these historical tables

[54] In this context launch refers to a commercially addressable launch and for convenience, wherever a launch is identified here it is meant to be a commercially addressable launch. Occasions where this is not the case in this report are indicated specifically.

were no longer included. Thus, the numbers for total addressable launches for 2014, 2015, and 2016 were estimated from a graph in the 2017 Compendia.

Once the Launch Forecast figures were compiled in an array in Microsoft Excel, it was feasible to assess both the average number of launches forecasted for a particular year and the average values forecasted by out-year. The tables produced from both efforts form the basis for the two quantitative approaches found in this report. One example of the launches forecast for chronological years would be 2012. The earliest Forecast for 2012 was the 9th out-year from the 2003 Forecast, which predicted 20, 3, and 2 for GSO, NGSO (M-L), and NGSO (S) respectively for 2012. Using only total figures for this example, the sum of 25 in that case forms the first value for the chronological average or aggregate mean.

The last value for the chronological average are the figures reported for 2012 in the 2012 report. To help limit confusion this value – in out-year terms – it is designated the 0-year (zero-year). In chronological years, it is just the expected number of launches for the next year, when the data are complied. Thus, for the 2012 report the 2012 estimated launches were compiled and reported in 2011, although the report is not published until 2012, which is why these figures are identified as 0-year Forecasts.

Returning to the example of 2012, the 0-year Forecast figures are: 19, 10, and 1 for GSO, NGSO (M-L), and NGSO (S) respectively. The sum, of course, is 30 and forms the last value in the chronological average. The chronological average in this case is 26. However, the launches recorded only show 15. Here, by examining the orbit averages that comprise the total, it is possible to say where the difference originates. For GSO, NGSO (M-L), NGSO (S) the averages are 18, 6, and 2 respectively and all just for 2012. The actual recorded give 12, 3, 0 for a total of 15, again for GSO, NGSO (M-L), and NGSO (S) respectively. Here it is possible to see the optimism that tends to exist for each Forecast datum. The Forecast values are usually above the actual recorded, which creates an optimism in the averages as well.

The average for these values is found for each division (GSO, NGSO (M-L), NGSO (S)) and the total for each year. This process was performed from the earliest data available in 1995 through the most recent available in 2017. The process used for chronological average was also performed for the out-year values. So, instead of a chronological average there is a 0-year average up to a 9-year average, with each value representing a point from near-term to long-term.

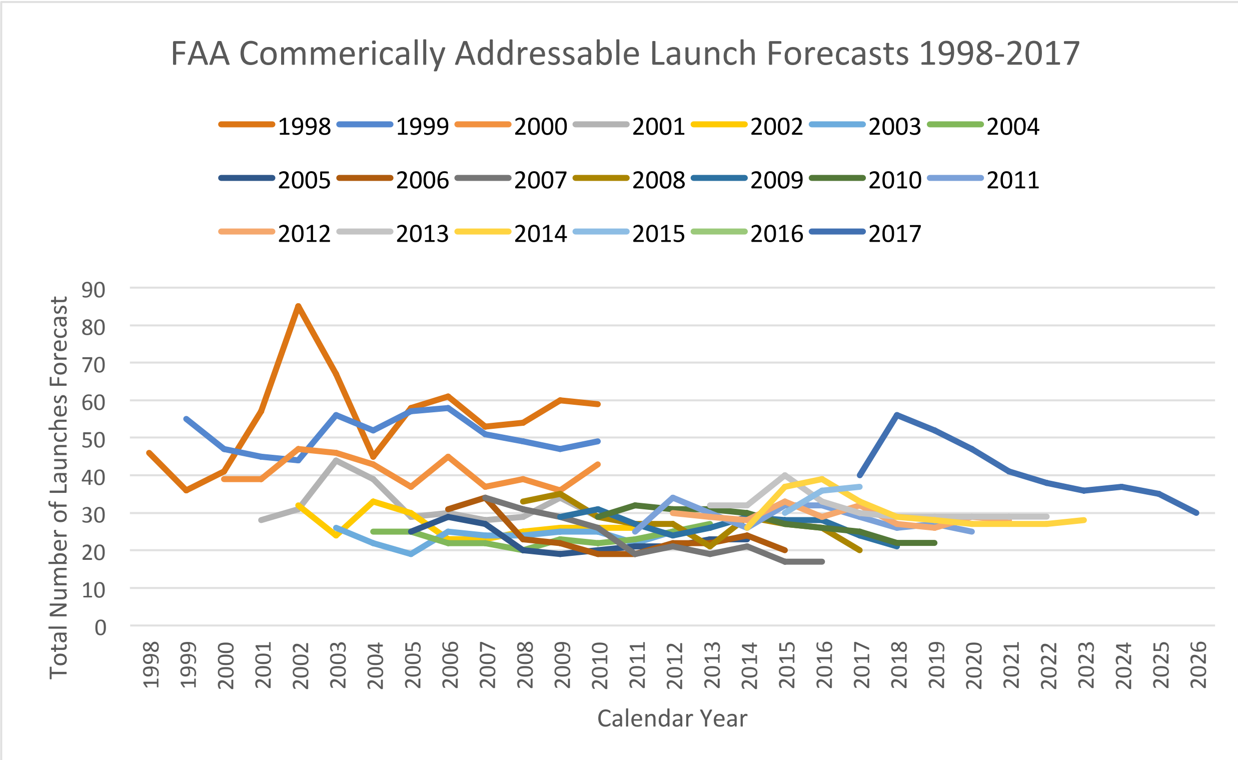

Figure 5- Compilation of all data points for the aggregate number of launches projected in each calendar year by each individual FAA AST Forecast, 1998-2017. Note that the latest Forecast from 2017 (in blue, furthest right) represents a departure from recent previous Forecasts, and projects rapid increases in launches for 2017 and 2018. Data compiled from the FAA, analysis performed by the authors.

After compiling the Forecast data into multiple datasets and calculating the averages, the second step of our data collection involved the calculation of net and absolute difference values for the number of actual commercial launches versus the predicted number of launches. Along with the Launch Forecast data, there are also other data that were compiled for a correlation analysis that is presented in section 5A of this report. Some examples of these data are launch industry-segment revenue, satellite industry revenue, U.S. government space spending, and global (non-commercial and commercial) launches.

B) Aggregate Mean Analysis

Mean by Orbit and Payload Segment

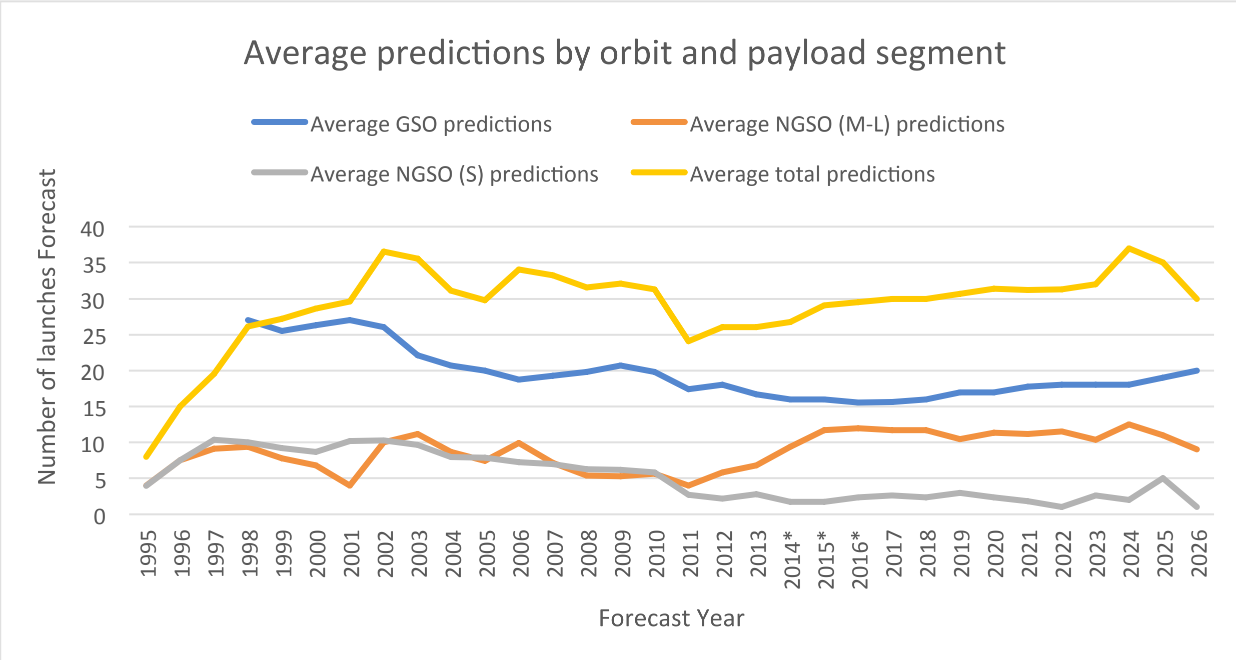

Figure 6- Average predictions by orbit and payload segment. Data compiled from the FAA, analysis performed by the authors.

Over time, the trend for the Forecast averages for GSO and NGSO (S) have remained mostly consistent and decreasing from 1998 through 2026 which is the final year for the current set of predictions. The years denoted with an asterisk indicate years where actual launches were estimated from graphs, rather than taken directly from tables. After 2016, there are no actual launch figures available.

Reproduced below is the annual average prediction for GSO from 2003 to 2014 as it has been organized in this report's larger dataset.[55] It shows that the average number of predicted launches does not swing wildly over this period. The 99 percent confidence interval, as shown below, indicates that over time the Forecast average has tended to be less volatile the further in the future it goes.

[55] The selection of 2003-2014 is partly an arbitrary restriction, made solely due to the constraint of space.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Total	133	145	160	169	193	218	248	258	174	180	167	160
Average	22	21	20	19	19	20	21	20	17	18	17	16
Median	22	20	20	18	20	21	21	19	17	18	16	15
Standard Deviation	3	4	3	3	3	4	4	5	3	2	2	2
Count	6	7	8	9	10	11	12	13	10	10	10	10
99% Confidence	5	5	4	4	3	4	4	4	3	2	2	2
	17	15	16	15	17	16	17	16	14	16	15	14
	28	26	24	22	22	24	25	24	20	20	19	18

Table 3- GSO Forecast average, statistics: 2003-2014

This analysis was also produced for NGSO (M-L) and NGSO (S), although it is not presented in the body of this report. However, this analysis showed that over the same period of prediction that at 99 percent confidence the most volatile predictions are the NGSO (M-L) launch predictions. There the average swings from a high of 11 to a low of 4 and considering that these are average values, suggests that predictions for this orbit and payload tend to be either the most difficult or perhaps the most speculative in terms of growth over time.

Aggregate Mean

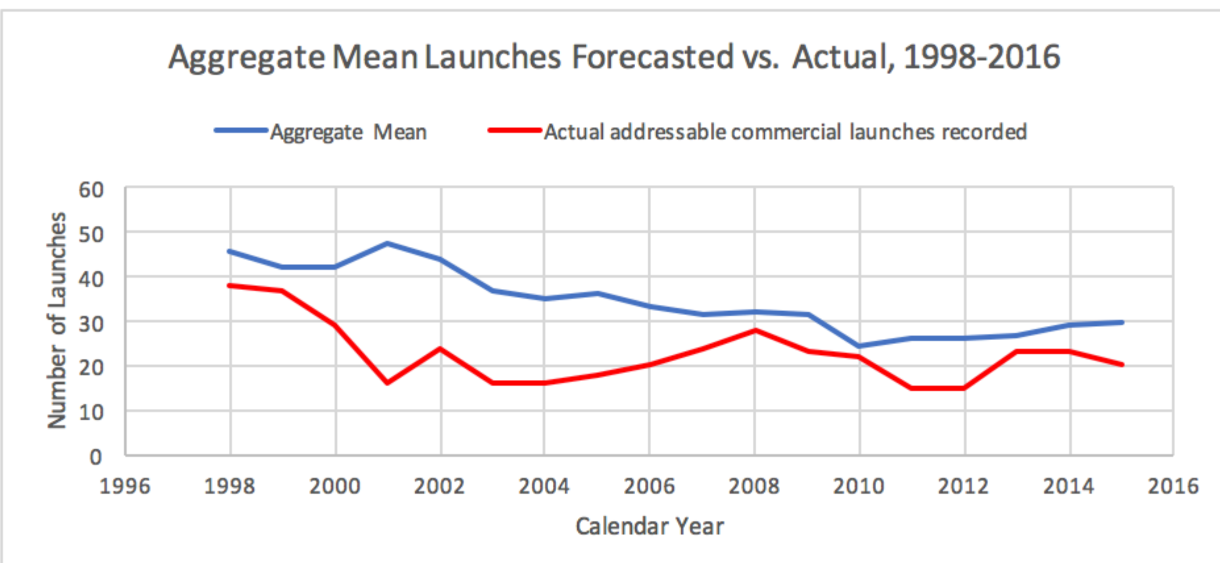

Figure 7- Aggregate mean of total launches predicted across all Forecasts in each calendar year compared to the total number of recorded addressable commercial launches.

The sum of predicted GSO and NGSO launches gives the aggregate number of predicted launches for a given year by a given Forecast, as illustrated in Figure 5. Finding the mean value across all aggregate Forecast predictions in a given year gives the aggregate mean. The aggregate mean value for each calendar year is observed to be higher than the actual number of addressable commercial launches recorded each year, for calendar years 1998-2015 (Figure 7). The over-prediction for this period, on average, represented approximately 30% error from the actual number of recorded addressable launches, with a variance of 22.4.

C) Annual Launch Rate Analysis

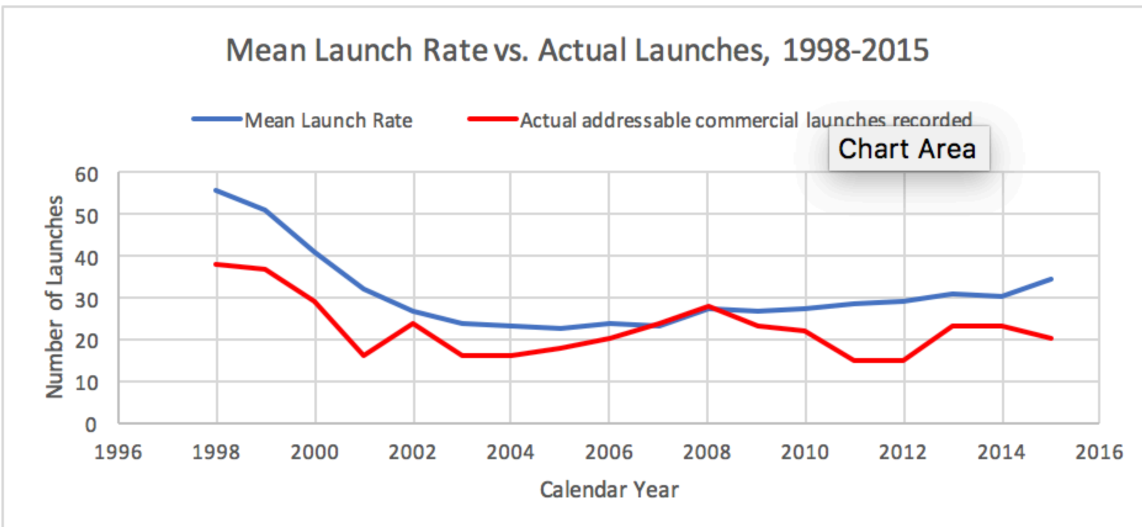

Figure 8- Mean launch rate from each Forecast compared to the total number of recorded addressable commercial launches.

In addition to annual predictions, each Forecast also includes a projected mean launch rate, equal to the mean number of total launches per year. For example, the annual launch rate from the 2017 Compendium is reported in the lower right hand corner of Table 1 as 41.2 launches per year. When compiled, the mean launch rate for each calendar year, as reported from that year's Forecast, is observed to be most often higher than the actual number of addressable commercial launches recorded that year, for calendar years 1998-2015 (Figure 8). The absolute value of the difference between the mean launch rate and the actual number of addressable commercial launches recorded for this period represented approximately 42% error, on average, with a variance of 28.5.

D) Out-Year Prediction Analysis

The final mode of analysis compares the accuracy and consistency of predictions based on the number of years into the future, called the out-year. For this analysis, near-term is defined as 0, 1, 2 in terms of out-year, while long-term is 4-9 in out-year terms. This division is not arbitrary; it reflects the basis for the FAA's data. Near-term data are mainly provided from the launch companies and some satellite manufacturers through surveys or in the COMSTAC industry panel. In either case, the near-term forecasts are chiefly the industry-reported launch manifests for the first three out-years.

The forecast trend for the out-years cannot be interpreted in quite the same way as the chronological year. It is worth noting that with the out-year forecast table it is possible to distinguish between near-term and long-term forecasts. The long-term forecasts represent more speculative estimates. Specifically, the long-term forecasts, or out-years 4-9, are expectations about satellite fleet replenishment and manufacturer estimates based on expected industry growth. The GSO out-year averages are reproduced in Table 4.

	0	1	2	3	4	5	6	7	8	9
Total	375	376	376	333	321	318	322	324	329	332
Average	20	20	20	19	18	18	18	18	18	18
Median	19	19	18	17	16	17	18	18	19	20
Standard Deviation	4	3	6	5	4	3	3	3	3	4
Count	19	19	19	18	18	18	18	18	18	18
99% Confidence	3	2	4	3	3	2	2	2	2	3
	17	18	16	15	15	16	16	16	16	16
	23	22	24	22	20	20	20	20	21	21

Table 4- GSO, out-year forecast statistics: 1998-2017.

As shown above, using the average and confidence intervals as indicators, the GSO segment was stable over the available forecast years, which includes 1998 through 2017, with the omission of a forecast from 2016 and a three-year forecast in 2015.

As was true with the chronological forecasts, the most volatile segment is NGSO (M-L) with a high of 10 and a low of 6 as forecast values, in years 1 and 9 respectively. The statistics table for NGSO (M-L) is reproduced in Table 5.

	0	1	2	3	4	5	6	7	8	9
Total	183	211	194	191	200	183	177	193	163	131
Average	8	10	9	9	9	8	8	9	7	6
Median	9	8	8	8	7	5	10	10	7	5
Standard Deviation	5	6	4	5	10	9	6	7	6	4
Count	22	22	22	22	22	22	22	22	22	22
99% Confidence	3	3	2	3	6	5	4	4	4	2
	5	6	6	6	3	3	4	5	4	4
	11	13	11	11	15	14	12	13	11	8

Table 5- NGSO (M-L) out-year forecast statistics: 1995-2017

By combining the GSO and NGSO analyses, it was possible to observe the accuracy and variability of the total number of launches predicted in each out-year. The data was down-selected to include only Forecasts from the consolidated reports that were issued between 1999 and 2015, for their consistency of methodology.

For each out-year, the mean value of differences between predicted values and actual addressable launches was calculated (Figure 9). It was observed that the zero-year predictions were the most consistent, demonstrating an average difference of 10 with a variance of 13. The zero-year predictions were then selected for further analysis.

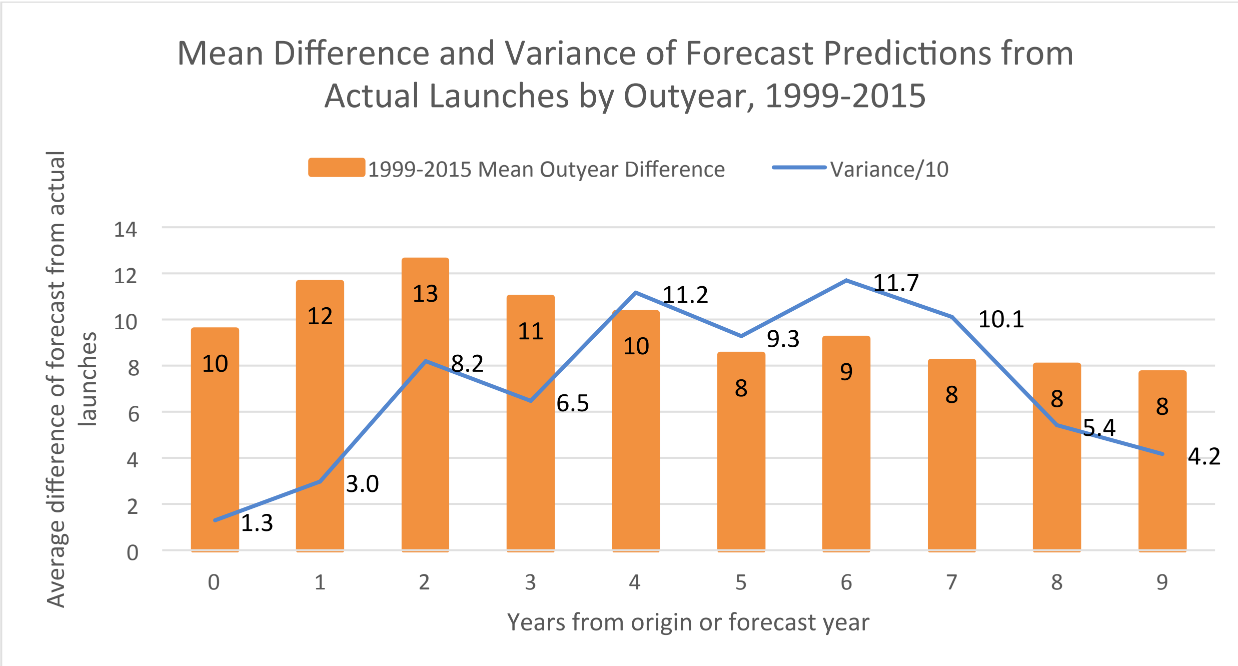

Figure 9- Forecasts compared by out-year prediction mean and variance. The variance figures shown have been multiplied by 10^{-1} in order to scale to the visualization range. For example, the data point 1.3 for zero-year predictions represents a variance of 13.

Reintroducing the distinction made above, the first column of values in any given Forecast is called the zero-year prediction, which refers to the calendar year within which the Forecast is published. For example, the first column value of the *Total Launches* row in Table 1 indicates the 2017 Compendium's prediction for the total number of addressable launches in 2017, the year the data was published. When compiled, the zero-year predictions are observed to be higher than the actual number of addressable commercial launches recorded each year, for calendar years 1998-2015 (Figure 10). The over-prediction for this period, on average, represented approximately 40% error from the actual number of recorded addressable launches, with a variance of 12.4.

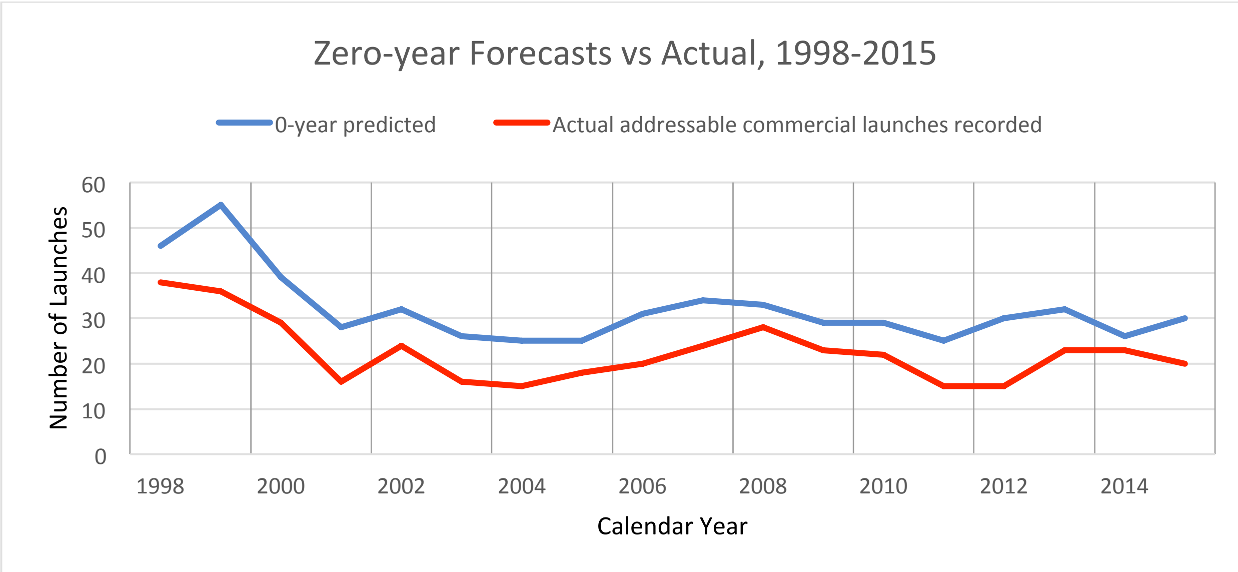

Figure 10 – Zero-year predictions from each Forecast compared to the total number of recorded addressable commercial launches.

E) Summary of Findings

In each mode of analysis, the compiled data from the FAA Forecasts were observed to predict more addressable launches than were actually recorded, across all orbital and payload segments. Of the three primary comparisons between aggregate means, mean launch rates, and out-year predictions, the following observations were made:

- Mean launch rates were observed to have the highest average error with the highest variance, spanning values between 2% error in 1998 and 100% error in 2001.
- Aggregate means were observed to have the lowest average error with the second highest variance.
- Zero-year predictions were observed to have the second highest average error, but a very low variance, by comparison to the others.

F) Potential Sources of Error

Sources of error were difficult to identify through statistical analysis due to a lack of transparency in the data and methodology of the report. Although the FAA Forecast reports some of the main variables considered by its prediction (see Table 2), it does not explain how exactly these variables are measured or weighted in their analysis. For example, the Forecast reports the variable "geopolitical issues" as weighing into the prediction, however it does not explain what factors determine this variable or how it affects annual commercial launches. Due to a lack of transparency in the calculation of the prediction itself, a full analysis of the FAA model is not possible for external analysts.

Since the FAA Forecast relies on self-reporting of launch information from commercial companies, there is an incentive for them to over-report their future launch figures. Early Forecasts did not include proprietary information, however current reports include a list of payloads scheduled to launch in the first three years following the report. This may give industry an incentive to list flights that are unlikely to take place in order to appear more active or successful. In addition to industry, the FAA AST also has an incentive for the Forecast to be optimistic in its assessment of the commercial launch industry as it has a mission to encourage, facilitate, and promote the industry. High Forecast predictions showing a healthy commercial launch industry indicate that the FAA AST is fulfilling its mission statement. The combination of self-reporting bias from industry as well as the overarching goals of the FAA AST likely encourages optimism in the formulation of the report.

During the process of compiling the data for the retrospective analysis, multiple inconsistencies were observed within and among the FAA AST documents that may contribute to the identified error rates, as well. For example, the 2017 Compendium reports that 21 total commercial launches occurred in 2016, 20 of which were addressable.[56, 57] Within the appendix of that same Compendium, a launch manifest also lists every global launch reported in 2016 and designates those which were commercial launches.[58] This manifest identifies only 19 total commercial launches, which is inconsistent with the previously reported totals.

Furthermore, the 2017 Compendium also reports that 20 addressable commercial launches occurred in 2015.[59] In the prior launch manifest of the 2016 Compendium, however, 22 total commercial launches are noted, three of which are identified as SpaceX cargo flights to

56 2017 Compendium, p. 39.
57 Ibid. p. 46.
58 Ibid. p. 95-99.
59 Ibid. p. 39.

the International Space Station, which are not internationally competed contracts and, thus, not addressable launches.[60] The remainder of 19 launches is inconsistent with the reported total in 2017.

Due to the comparatively small number of annual commercially addressable launches, the erroneous omission or inclusion of even one or two launches can greatly impact the accuracy of the Forecast.

Section 5: Improving the FAA Model

A) Correlation Analysis

In addition to the Forecast data accuracy analysis, our team also attempted to develop a regression model that would predict next year's number of commercial launch figures using a publicly available data set. Some of the main variables we included in this dataset are a launch industry-segment revenue, predicted global (commercial and non-commercial) launches, and actual launch figures. Data on satellite industry revenue was collected from the Space Industry Association annual report.[61] Global launch figures were obtained from an appendix in the Aeronautics and Space Report of the President, as was U.S.G. space spending.[62] As mentioned above the figures on commercially addressable launches were obtained from the FAA's Launch Forecasts and later Compendia.[63]

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[60] 2016 Compendium, p. 65-69.

[61] The Satellite Industry Association. (n.d.). SIA State of Satellite Industry Reports 2002-2016. Retrieved from http://www.sia.org/annual-state-of-the-satellite-industry-reports/2014-sia-state-of-satellite-industry-report/

[62] The Office of the President of the United States of America. (2015). Aeronautics and Space Report of the President: FY 2015. Retrieved from https://history.nasa.gov/presrep2015.pdf

[63] The Commercial Space Transportation Forecasts 1999-2005; The Annual Compendium of Commercial Space Transportation 2012-2017. Full citations included in the bibliography.

	Mean	Variance	Observations	Hypothesized Mean Difference	df	t Stat	P(T<=t) one-tail	t Critical one-tail	P(T<=t) two-tail	t Critical two-tail
Variable 1 (Actual)	20.57	23.49	14	14	23	-12.23	7.56E-12	2.50	1.51E-11	2.81
Variable 2 (Forecasted average)	34.90	51.60	14							

Table 6- Results of a T-test assuming unequal variances, testing whether there is a statistically significant difference between the actual commercially addressable launches recorded and the Forecasted average.

Variable 2 (Forecasted average)

A series of ANOVA tests were performed to analyze the variance between the predicted launch numbers. Each ANOVA test performed showed that there was a statistically significant difference among the predicted values by Forecast year. In other terms, the expected number of commercially addressable launches varies from year to year. The series of ANOVAs are not reproduced here, although a T-test assuming unequal variances was also performed to evaluate the difference between the Forecast averages and the actual number of recorded launches. The finding of this T-test supports the findings of the earlier data accuracy analysis, as it shows that there is a statistically significant difference between the annual average number of predicted commercial launches and the actual number of commercial launches.[64]

As the next step of the analysis, we ran a correlation analysis of variables in order to identify the salient ones to include in the regression model predicting the number of global commercial launches in a given year. The theory was that variables such as total satellite industry revenue and U.S. space spending would have a strong relationship to the annual number of commercial launches, however, the correlation analysis yielded predominantly null results. The results of the last correlation analysis performed are reproduced below.

[64] With the implicit assumption that if the forecasts were accurate each year, the forecast average would not differ significantly from the actual recorded, by the central limit theorem.

	Actual Commercial Launches Recorded	Actual, (backward shift)	Mean of predictions	Mean of predictions minus 5	Satellite Services Revenue	Satellite Launch Revenue	Total Satellite Industry Revenue	Total, Global Launches	U.S. Space Spending	0-year Forecast	0-year - 9
Actual Commercial Launches Recorded	1	.618**	-0.119	-0.119	-0.433	-0.115	-0.134	0.430	-0.367	.556**	.556**
Actual, (backward shift)	.618**	1	-.468*	-.468*	-.485*	-0.007	-0.011	0.271	-0.413	0.062	0.062
Mean of predictions	-0.119	-.468*	1	1.000**	0.141	-.686**	-.664**	-0.425	0.405	.507*	.507*
Mean of predictions minus 5	-0.119	-.468*	1.000**	1	0.141	-.686**	-.664**	-0.425	0.405	.507*	.507*
Satellite Services Revenue	-0.433	-.485*	0.141	0.141	1	.501*	.999**	0.130	0.143	-0.112	-0.112
Satellite Launch Revenue	-0.115	-0.007	-.686**	-.686**	.501*	1	.998**	0.153	-0.217	-.492*	-.492*
Total Satellite Industry Revenue	-0.134	-0.011	-.664**	-.664**	.999**	.998**	1	0.112	-0.190	-.499*	-.499*
Total, Global Launches	0.430	0.271	-0.425	-0.425	0.130	0.153	0.112	1	-0.180	0.047	0.047
U.S. Space Spending	-0.367	-0.413	0.405	0.405	0.143	-0.217	-0.190	-0.180	1	-0.016	-0.016
0-year Forecast	.556**	0.062	.507*	.507*	-0.112	-.492*	-.499*	0.047	-0.016	1	1.000**
0-year - 9	.556**	0.062	.507*	.507*	-0.112	-.492*	-.499*	0.047	-0.016	1.000**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 7- Correlation analysis of select factors assumed to affect the commercially addressable launches in each year. Sources for data are noted in the text, analysis original.

The correlation analysis shows that the actual number of commercially addressable launches are not correlated to most explanatory variables included in our dataset, aside from the 0-year predictions. As a final test, the researchers ran a simplified regression model with the dependent variable being the actual number of commercial launches, and the independent variables being the 0-year predictions and the actual number of launches in the year prior to the prediction year. This regression model did not produce statistically significant relationships and had a fairly low adjusted R^2 value of 0.614.

The null findings of this analysis showed that a predictive regression model relying on a publicly available dataset would not be very robust or informative. So, although this statistical analysis yielded predominantly null results, it did show that the FAA Forecast's mixed methodology is required to produce an accurate annual launch prediction. Furthermore, the correlation found between the 0-year predictions and the actual number of commercial launches helped to inform this report's next phase of analysis.

B) Introducing a New Launch Realization Factor

The launch realization factor analysis that first appeared in 2002 has been discontinued in the latest versions of the FAA Forecast during the transition to the Compendium structure. Using the two most accurate and consistent measures as determined by the retrospective analysis, the aggregate means and the zero-year predictions, a new version of the realization factor is proposed that predicts adjusted lower and upper bounds of the 2017 zero-year prediction.

Lower Bound: Aggregate Mean Adjustment

During the retrospective analysis, the aggregate means were determined to have the lowest average difference from the actual recorded number of launches. Focusing on the Forecast data produced since 2002 (when the original launch realization factor was introduced), the mean difference was determined to be 10, with an average percent difference of 54% above the number of actual addressable launches (65% below the aggregate mean), since all mean values predicted more launches than were subsequently recorded. Figure 11 demonstrates the reduction of the aggregate mean by the average percent difference.

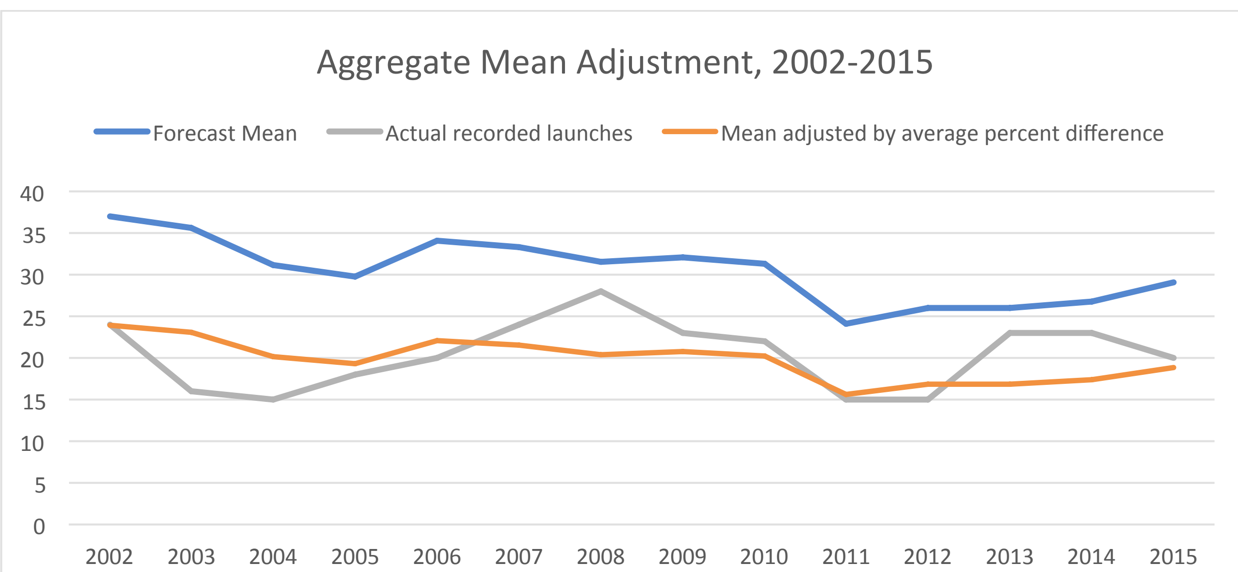

Figure 11- Aggregate mean adjustment, which shows the difference of the forecast average from the actual recorded commercially addressable launches.

Upper Bound: Zero-Year

The retrospective analysis also determined that the zero-year predictions had the lowest variance. Focusing on the Forecast data produced since 2002 when the original launch realization factor was introduced, the mean difference was determined to be 9, with an average percent difference of 47% above the number of actual addressable launches (68% below the prediction), since all zero-year values predicted more launches than were subsequently recorded. Figure 12 demonstrates the reduction of the zero-year predictions by the average percent difference.

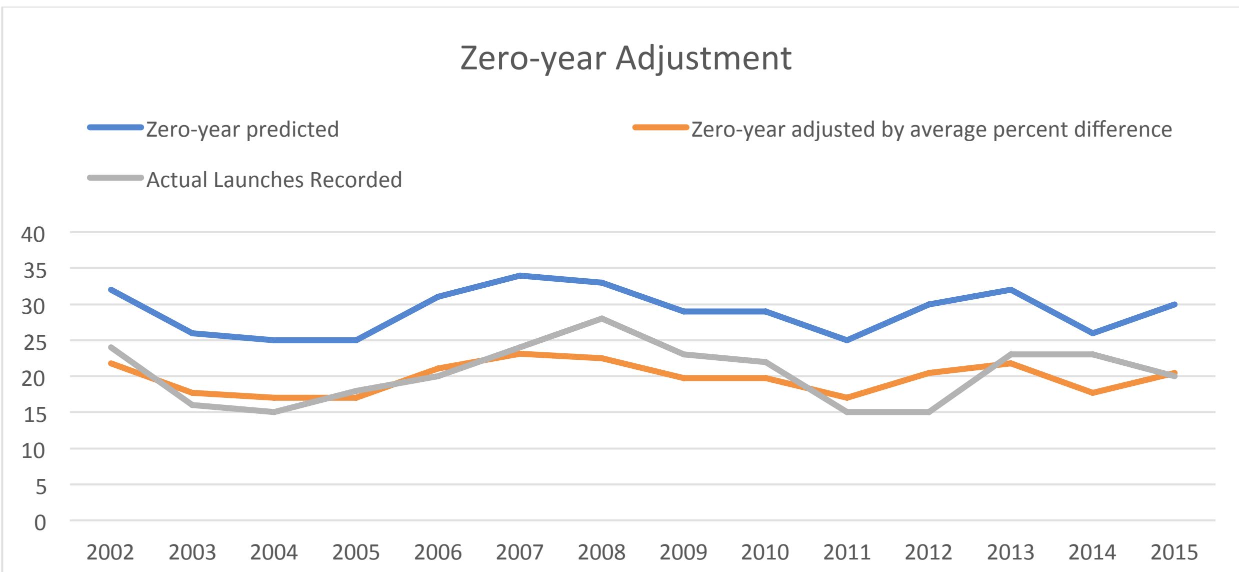

Figure 12- Zero-year prediction adjustment, which shows the adjustment of 0-year predictions from actual commercially addressable launches recorded.

Application of Adjustments to 2017 Forecast

Applying the adjustments described above to the 2017 zero-year prediction yields an expected range of 20 to 27 addressable launches in 2017 (Table 8). At the lower bound, 20 launches represent no change from the reported total in 2016. At the upper bound, 27 launches represent an increase of 35%, or 7 more total addressable launches than in 2016. These values were calculated as follows:

1. The 2017 Compendium's zero-year prediction for total addressable launches is 40 (See Table 1). Including all previous predictions for that calendar year, the aggregate mean prediction for 2017 is found to be 30. Adjusting the aggregate mean by the average percent difference determined above gives a prediction of 19.5 launches, which is rounded to 20 and will serve as a lower bound for the launch realization factor.
2. Once again, the 2017 Compendium's zero-year prediction for total addressable launches is 40. Adjusting this prediction by the average percent difference determined above gives a prediction of 27.2 launches, which is rounded to 27 and will serve as an upper bound for the launch realization factor.

	Aggregate Mean Adjustment	Zero-year adjustment
2017 Zero-year Prediction	40	40
2017 Aggregate Mean	30	N/A
Reduction Factor	65%	68%
Adjusted Forecast	20	27

Table 8- Launch realization calculations for the 2017 zero-year prediction and aggregate mean.

C) Limitations

The main limitation of the upper-bound and lower-bound model is that it relies upon an analysis of the historical trends of the Forecast predictions. Therefore, the predictive power of this model is only valid if the methodology being used in the FAA Forecasts remains consistent over the coming years. Since it is only an adjustment factor for the assumptions being made in the FAA Forecast model, the insight it provides is fully dependent upon the current methodology being used in these annual Forecasts. Therefore, any major changes in the prediction methodology over the coming years will require an adjustment in the factors put forth in the upper- and lower-bound models. Since Bryce Aerospace has the contract to create the annual Compendium until 2020, it is unlikely that there will be a drastic change in methodology until that year. If the contract to produce the Compendia is given to another firm or new methodological requirements are introduced, a large adjustment in the reported analysis will be required.

The second limitation of this analysis is the potential for slight errors in the dataset for the actual number of addressable launches. For example, in the Forecast reports and Compendia for 2014, 2015, and 2016, the figures for the actual number of addressable versus unadressable commercial launches were not provided in a table, but were instead reported in a chart. There was a need to estimate these numbers based on the chart, which was fairly clear to interpret, however, they may be off by a value of one or two depending on the accuracy of interpretation. In an attempt to remedy this problem, all three members of the team needed to agree upon the value to use in the analysis. Another issue lies in the data that shows the distinction between launch predictions based on orbit. Data stemming from the reports prior to 1999 were divided into GSO and LEO, which sorted the data based on different parameters than the Forecasts made post-1999. This may have resulted in some discrepancies within the datasets that sort launches by orbit, however, it does not affect the dataset for the total number of launches. This discrepancy in the data is part of the motivation for this analysis to focus on the total number of commercial launches rather than the number of launches per orbit.

Section 6: Policy Recommendations and Conclusions

A) Short-Term Recommendations

Recommendation One: Inform Forecast Consumers of Over-Optimism

The primary finding of this analysis is that the FAA Commercial Transportation Forecasts are consistently over-optimistic in their annual commercial launch predictions. The Congressional Research Service should be aware of this inherent over-optimism and advise consumers of the report, such as Congress, of this trend in the prediction. The Forecast reports are used in multiple settings, such as in hearing testimony for Congress or in private sector planning. There are a variety of consequences of reliance on overly optimistic figures for industry, government agencies, and Congress, which makes the accuracy of the Forecasts very important.

Overestimations in commercial space Launch Forecasts may lead to wasted investments in support infrastructure like spaceports. Millions of dollars have been invested in the construction of spaceports in states such as Alaska, Oklahoma, and Texas in anticipation of an increase in demand for commercial space launches.[65] Most of these spaceports are not currently in use and the money spent on infrastructure and maintenance could go to waste if commercial demand for use of these launch sites is not high enough. More accurate Forecasts will make space-related spending better suited to the future commercial industry. Since the space industry and government are so closely linked and the commercial space market is rapidly changing, it is important for policy to both handle and foster the growth of the industry. Therefore, this report recommends to CRS that when commercial space Launch Forecasts appear before Congress in conjunction with any of these activities or interests, that CRS inform Congress of the inherent optimism of these reports so that they may accurately interpret their value as evidence.

Recommendation Two: Test the New Launch Realization Factor

Previously, the FAA has applied a Launch Realization Factor to compensate for some of the optimism that is built into the Forecast. However, starting in the 2016 Compendium this corrective factor has been left out. The second main finding of this report is that a range of values can be calculated using time-trend analysis in order to correct for the optimism of the prediction. This finding has been presented as a new launch realization factor that can be used by readers of the report to supplement the Forecast projections being published in future version of the Compendium.

This report recommends that CRS should monitor the actual number of commercial launches in 2017 to evaluate the proposed new launch realization factor methodology. Using this methodology, the report predicts that the actual number of addressable commercial launches will fall within the range of 20 to 27. If the actual number of commercially addressable launches for 2017 does lie within this range, then the efficacy of this methodology holds.

[65] Sloan, J. (2017, February 23). *Introduction to FAA Office of Commercial Space Transportation and State of the Industry*. Lecture presented at Presentation to the GW SPI Course IAFF 6158.10, Washington, D.C.

Therefore, it is recommended that the users of the Forecast numbers use this new launch realization factor to adjust for the over-optimism in this report. The contract for the production of the Compendium runs until 2020, which indicates that the current methodology and reporting style will not undergo any drastic changes until this date. Therefore, the new launch realization factor should be used as an adjustment tool until the contract expires or major methodology changes are introduced into the Forecasts.

B) Long-Term Recommendations

The authors believe that the FAA Forecast is beneficial to the commercial space industry and helps to fulfill the mission of the FAA AST to support, facilitate, and promote commercial space. However, after conducting a thorough analysis of the FAA Forecasts, the authors also argue that the consumers of the Forecasts need a realistic prediction of commercial launches rather than an optimistic one. In order to bring about the necessary changes to the FAA Forecasts, this report recommends a three-tiered strategy.[66]

The first step is to have the contractor of the FAA Forecast acknowledge the over-optimism of the commercial launch predictions. Since the contractor (currently Bryce Space and Technology) has knowledge of the data collection processes and methodologies that are unknown externally, they can conduct a more thorough analysis of where this error is stemming from. The contractor can then make recommendations to FAA AST on how the accuracy and utility of the Forecast can be improved.

The second step is that once the FAA receives these recommendations, they should implement permanent changes to the contracting structure in future Forecast contracts. These changes should mandate the specific requirements of future reports so that they remain consistent and comparable from year-to-year. This report recommends that the main requirement firstly should be parameters to remove inconsistencies both within and across the reports. The second requirement should be to either change the overall methodology of the report to make the Forecast predictions more accurate or to reintroduce the launch realization

[66] Special thanks to Dr. Scott Pace of the George Washington University Space Policy Institute who helped develop this idea in a conversation held on May 2, 2017.

factor to provide adjusted predictions. Either of these options would result in a more accurate and usable commercial Launch Forecast.

If the first two tiers are unsuccessful in implementing the necessary changes, Congress should introduce legislation that would mandate the preparation of the Forecast by the FAA as part of its authorization. The Forecasts are not a required document for the FAA to produce, although similar reports are already mandated of the FAA and the Department of Transportation. Making the Forecast a congressionally mandated report would allow Congress to stipulate the contents of the report, the frequency of the report, and to some extent, the methodology used in the report. In addition, it would directly contribute to the oversight duties of Congress in its interest in promoting commercial space. Congress would then be able to outline what they require in the Forecast, which this analysis argues should be a more accurate prediction of the future commercial launch market.

The combination of these short-term and long-term recommendations will help to improve the production of the FAA Commercial Space Transportation Forecast, which is an important resource for multiple actors. Furthermore, these recommendations will help to remedy some of the issues that stem from the current inaccuracy of the Forecast.

References

ASD-Eurospace. (2015). The European Space Industry in 2014. Retrieved from http://www.eurospace.org/Data/Sites/1/pdf/eurospace_facts_and_figures_data2014.pdf

Babin, U. (2017, April 06). U.S. satellite rules out of focus; time for new vision. Retrieved from https://science.house.gov/news/in-the-news/us-satellite-rules-out-focus-time-new-vision

Cofield, C. (2017, March 21). President Trump Signs NASA Authorization Bill. Retrieved from http://www.space.com/36154-president-trump-signs-nasa-authorization-bill.html

Committee on Science, Space, and Technology. (2017, April 06). So Far... Retrieved from https://science.house.gov/news/press-releases/so-far

COMSTAC. (1994). 1994 Commercial Spacecraft Mission Model Update. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/1994_geo_launch_forecast.pdf

COMSTAC. (1995). 1995 Commercial Spacecraft Mission Model Update. Retrieved from http://commercialspace.pbworks.com/w/file/fetch/55097048/1995%20COMSTAC%20GEO%20Launch%20Forecast.pdf

COMSTAC. (1996). 1996 Commercial Spacecraft Mission Model Update. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/1996_geo_launch_forecast.pdf

COMSTAC. (1997). 1997 Commercial Spacecraft Mission Model Update. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/geo.pdf

COMSTAC. (1998). *1998 Commercial Spacecraft Mission Model Update*. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/comstac.pdf

David, L. (2016, December 29). Playing the Space Trump Card: Relaunching a National Space Council. Retrieved from http://www.space.com/35163-trump-administration-national-space-council.html

DOD. (n.d.). Space: Today and the Future. Retrieved from http://www.dod.gov/pubs/spacechapter2.pdf

Duncan, D. E. (2017, January 30). President Trump's Wannabe Space Race Saves NASA's Funding-For Now. Retrieved from http://www.thedailybeast.com/articles/2017/04/03/president-trump-s-wannabe-space-race-saves-nasa-s-funding-for-now.html

The FAA. (n.d.). The Annual Compendium of Commercial Space Transportation 2012-2016. Retrieved from https://www.faa.gov/c/commercial_space/annual_compendium.html

The FAA. (2012). History of the Forecast Reports. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/forecasts/

The FAA. (2013). The Annual Compendium of Commercial Space Transportation: 2013. Retrieved from https://www.faa.gov/c/content/dam/faa/office-content/ast/documents/FAA_2013_Compendium.pdf

The FAA. (2014). The Annual Compendium of Commercial Space Transportation: 2014. Retrieved from https://www.faa.gov/c/content/dam/faa/office-content/ast/documents/FAA_Annual_Compendium_2014.pdf

The FAA. (2015). Origins of the commercial space industry. Retrieved from https://www.faa.gov/about/history/milestones/media/Commercial_Space_Industry.pdf

The FAA. (2016). The Annual Compendium of Commercial Space Transportation: 2016. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/2016_Compendium.pdf

The FAA. (2017). The Annual Compendium of Commercial Space Transportation: 2017. Retrieved from https://brycetech.com/downloads/FAA_Annual_Compendium_2017.pdf

The FAA AST. (1995). 1995 LEO Commercial Market Projections. Retrieved from http://commercialspace.pbworks.com/w/file/fetch/84014746/1995%20LEO%20Forecast.pdf

The FAA AST. (1996). *1996 LEO Commercial Market Projections*. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/leo-b.pdf

The FAA AST. (1997). 1997 LEO Commercial Market Projections. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/leo-c.pdf

The FAA AST. (1998). 1998 LEO Commercial Market Projections. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/leo-d.pdf

The FAA AST. (n.d.). FAA AST Licensed Launches Data. Retrieved from https://www.faa.gov/data_research/commercial_space_data/launches/?type=license

The FAA AST, & COMSTAC. (1999). 1999 Commercial Space Transportation Forecasts. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/leo-99.pdf

The FAA AST, & COMSTAC. (2000). 2000 Commercial Space Transportation Forecasts. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/AST2000.PDF

The FAA AST, & COMSTAC. (2001). 2001 Commercial Space Transportation Forecasts. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/0501forcast.pdf

The FAA AST, & COMSTAC. (2002). 2002 Commercial Space Transportation Forecasts. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/ForecastMay2k2GSO_NGSO.pdf

The FAA AST, & COMSTAC. (2003). 2003 Commercial Space Transportation Forecasts. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/Forecast_05-19-03.pdf

The FAA AST, & COMSTAC. (2004). 2004 Commercial Space Transportation Forecasts. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/2004_CST_Forecasts.pdf

The FAA AST, & COMSTAC. (2005). 2005 Commercial Space Transportation Forecasts. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/Forecast_05-05_GSO_NGSO_Comm_Launch.pdf

The FAA AST, & COMSTAC. (2006). 2006 Commercial Space Transportation Forecasts. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/2006_Forecast_GSO_NGSO_May_24.pdf

The FAA AST, & COMSTAC. (2007). 2007 Commercial Space Transportation Forecasts. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/Forecast_2007_COMSTAC.pdf

The FAA AST, & COMSTAC. (2008). 2008 Commercial Space Transportation Forecasts. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/2008%20Forecasts%20NGSO%20GSO%20Commercial%20Space%20Transportation%20May%202008%20website.pdf

The FAA AST, & COMSTAC. (2009). 2009 Commercial Space Transportation Forecasts. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/NGSO%20GSO%20Forecast%20June%203%202009%20lowres.pdf

The FAA AST, & COMSTAC. (2010). 2010 Commercial Space Transportation Forecasts. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/2010_launch_forecast_report.pdf

The FAA AST, & COMSTAC. (2011). 2011 Commercial Space Transportation Forecasts. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/2011%20Forecast%20Report.pdf

The FAA AST, & COMSTAC. (2012). 2012 Commercial Space Transportation Forecasts. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/2012_Forecasts.pdf

The FAA AST, & COMSTAC. (2013). 2013 Commercial Space Transportation Forecasts. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/2013_GSO_NGSO_Forecast_Report_June.pdf

The FAA AST, & COMSTAC. (2014). 2014 Commercial Space Transportation Forecasts. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/2014_GSO_NGSO_Forecast_Report_FAA_COMSTAC_July_15_2014.pdf

The FAA AST, & COMSTAC. (2015). 2015 Commercial Space Transportation Forecasts. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/ast/media/Commercial_Space_Transportation_Forecasts_2015.pdf

The Federal Aviation Administration. (2007). The Economic Impact of Commercial Space Transportation on the U.S. Economy. *Journal of Magnetohydrodynamics, Plasma and Space Research, 16*(1/2), 43-74.

Haller, L., & Sakazaki, M. (n.d.). Commercial Space and United States National Security. Retrieved from https://fas.org/spp/eprint/article06.html#4

Hertzfeld, H. R. (2007). Globalization, commercial space and spacepower in the USA. *Space Policy, 23*(4), 210-220. doi:10.1016/j.spacepol.2007.09.004

Mutel, L., & Murray, D. (2018, February 18). Space Data Integrator: FAA's Innovative Platform for Launch and Reentry Operations. Retrieved from https://arc.aiaa.org/doi/abs/10.2514/6.2016-0218

The Office of the President of the United States of America. (2015). Aeronautics and Space Report of the President: FY 2015. Retrieved from https://history.nasa.gov/presrep2015.pdf

The Satellite Industry Association. (n.d.). SIA State of Satellite Industry Reports 2002-2016. Retrieved from http://www.sia.org/annual-state-of-the-satellite-industry-reports/2014-sia-state-of-satellite-industry-report/

Seftas, R. (n.d.). The civil space sector. Retrieved from https://fas.org/spp/eprint/article07.html#1

Sloan, J. (2017, February 23). *Introduction to FAA Office of Commercial Space Transportation and State of the Industry*. Lecture presented at Presentation to the GW SPI Course IAFF 6158.10, Washington, D.C.

Smith, P. (2017, March 20). Interview with Bryce Technology's Phil Smith [Telephone interview].

The Space Foundation. (2016). *The Space Report: 2016*. Retrieved from https://www.spacefoundation.org/sites/default/files/downloads/The_Space_Report_2016_OVERVIEW.pdf

SpaceWorks. (2017). SpaceWorks Forecast – Small Satellite Trends and Market Observations. Retrieved from http://spaceworksforecast.com/

SSI. (2014). Heritage- Space Services of America Inc. Retrieved from http://www.spaceservicesinc.com/company-heritage

StratSpace. (2017). StratSpace Announces its 2017 Space Intelligence Report & Market Forecast. Retrieved from http://www.stratspace.net/forecasting/

The Tauri Group. (2016). *State of the satellite industry report*. Retrieved from http://www.sia.org/wp-content/uploads/2016/06/SSIR16-Pdf-Copy-for-Website-Compressed.pdf

The U.S. Department of Transportation. (n.d.). FAA Budget Estimates: FY 2008-2017. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/aba/budgets_brief/

The U.S. Department of Transportation. (2007). Budget in Brief: FY 2008. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/aba/budgets_brief/media/bib2008.pdf

The U.S. Department of Transportation. (2008). The FAA Budget in Brief: FY 2009. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/aba/budgets_brief/media/bib2009.pdf

The U.S. Department of Transportation. (2009). Budget Estimates: FY 2010. *Submitted for Use of the Committees on Appropriations*. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/aba/budgets_brief/media/FY%202010%20President's%20Budget%20Submission.pdf

U.S. Department of Transportation. (2010). Budget Estimates: FY 2011. *Federal Aviation Administration FY 2011 President's Budget Submission*. Retrieved from https://www.transportation.gov/sites/dot.gov/files/docs/faa_fy_2011_budget_estimate.pdf

The U.S. Department of Transportation. (2011). Budget Estimates: FY 2012. *Federal Aviation Administration FY 2012 President's Budget Submission*. Retrieved from https://www.transportation.gov/sites/dot.gov/files/docs/faa_%20fy_%202012_budget_estimate.pdf

The U.S. Department of Transportation. (2012). Budget Estimates: FY 2013. *Https://www.transportation.gov/sites/dot.dev/files/docs/faa_%20fy_%202013_budget_estimate.pdf*. Retrieved from https://www.transportation.gov/sites/dot.dev/files/docs/faa_%20fy_%202013_budget_estimate.pdf

The U.S. Department of Transportation. (2013). Budget Estimates: FY 2014. *Federal Aviation Administration FY 2014 President's Budget Submission*. Retrieved from https://www.transportation.gov/sites/dot.gov/files/docs/FAA_FY2014_Budget_Estimates.pdf

The U.S. Department of Transportation. (2014). Budget Estimates: FY 2015. *Federal Aviation Administration FY 2015 President's Budget Submission*. Retrieved from https://www.transportation.gov/sites/dot.gov/files/docs/FAA-FY2015-Budget-Estimates.pdf

The U.S. Department of Transportation. (2015). Budget Estimates: FY 2016. *Federal Aviation Administration FY 2016 President's Budget Submission*. Retrieved from https://www.transportation.gov/sites/dot.gov/files/docs/FY2016-BudgetEstimate-FAA.pdf

The U.S. Department of Transportation. (2016). Budget Estimates: FY 2017. *Federal Aviation Administration FY 2017 President's Budget Submission*. Retrieved from https://cms.dot.gov/sites/dot.gov/files/docs/FAA-FY-2017-CJ.pdf

U.S. House. (2016). *Public Law 114-223* [H.R. 5325 from 114th Cong.]. Retrieved from https://www.congress.gov/bill/114th-congress/house-bill/5325/text/pl?overview=closed

U.S. House, House - Appropriations | Senate - Appropriations. (2002). *Department of Defense Appropriations Act* [H.R. 5010 from 107th Cong.]. Retrieved from https://www.congress.gov/bill/107th-congress/house-bill/5010?q=%7B%22search%22%3A%5B%22%5C%22Commercial%2BReusable%2BIn-Space%2BTransportation%2BAct%5C%22%22%5D%7D&r=1

U.S. House, House - Appropriations | Senate - Appropriations. (2015). *Consolidated Appropriations Act, 2016* [H.R. 2029 from 114th Cong.]. Retrieved from https://www.congress.gov/bill/114th-congress/house-bill/2029/text

U.S. House, House - Appropriations | Senate - Appropriations. (2015-16). *Further Continuing and Security Assistance Appropriations Act, 2017* [H.R. 2028 from 114th Cong.]. Retrieved from https://www.congress.gov/bill/114th-congress/house-bill/2028/text

U.S. House, House - Judiciary | Senate - Judiciary. (2009). *To enact certain laws relating to national and commercial space programs as title 51, United States Code, "National and Commercial Space Programs"* [H.R. 3237 from 111th Cong.]. Retrieved from https://www.congress.gov/bill/111th-congress/house-bill/3237?q=%7B%22search%22%3A%5B%22P.L.%2B111-314%22%5D%7D&r=1

U.S. House, House - Science | Senate - Commerce, Science, and Transportation. (1999). *Commercial Space Transportation Competitiveness Act of 2000* [H.R. 2607 from 106th Cong.]. Retrieved from https://www.congress.gov/bill/106th-congress/house-bill/2607?q=%7B%22search%22%3A%5B%22P.L.%2B106-405%22%5D%7D&r=1

U.S. House, House - Science. (2004). *Commercial Space Launch Amendments Act of 2004* [H.R. 5382 from 108th Cong.]. Retrieved from https://www.congress.gov/bill/108th-congress/house-bill/5382?q=%7B%22search%22%3A%5B%22P.L.%2B108-492%22%5D%7D&r=1

U.S. House, House - Science. (2004). *To extend the liability indemnification regime for the commercial space transportation industry* [H.R. 5245 from 108th Cong.]. Retrieved from https://www.congress.gov/bill/108th-congress/house-bill/5245?q=%7B%22search%22%3A%5B%22P.L.%2B108-428%22%5D%7D&r=1

U.S. House, House - Science and Technology | Senate - Commerce, Science, and Transportation. (1984, October 30). (D. Akaka, Author) [H.R. 3942 from 98th Cong.]. Retrieved from https://www.congress.gov/bill/98th-congress/house-bill/3942/actions

U.S. House, House - Science and Technology | Senate - Commerce, Science, and Transportation. (2009). *To extend the commercial space transportation liability regime* [H.R. 3819 from 111th Cong.]. Retrieved from https://www.congress.gov/bill/111th-congress/house-bill/3819?q=%7B%22search%22%3A%5B%22P.L.%2B111-125%22%5D%7D&r=1

U.S. House, House - Science, Space, and Technology | Senate - Commerce, Science, and Transportation. (2015, November 25). [H.R. 2262 from 114th Cong.]. Retrieved from https://www.congress.gov/bill/114th-congress/house-bill/2262

U.S. House, House - Veterans' Affairs | Senate - Health, Education, Labor, and Pensions. (2017). *Consolidated Appropriations Act, 2017* [H.R. 244 from 115th Cong.]. Retrieved from https://www.congress.gov/bill/115th-congress/house-bill/244/text

U.S. House, The Committee on Science, Space, and Technology. (2017). *The Views and Estimates of the Committee on Science, Space, and Technology U.S. House of Representative for FY 2018* (L. Smith, Author) [H.R. Doc.]. Retrieved from https://science.house.gov/sites/republicans.science.house.gov/files/documents/Views and Estimates FY 2018.pdf

USA, The House of Representatives. (n.d.). *Chapter 509- Commercial Space Launch Activities- U.S.C 50901-50914*. Retrieved from http://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title51-chapter509&saved=L3ByZWxpbUB0aXRsZTUxL3N1YnRpdGxlNS9jaGFwdGVyNTA5|Z3JhbnVsZWlkOlVTQy1wcmVsaW0tdGl0bGU1MS1jaGFwdGVyNTA5|||0|false|prelim&edition=prelim

USA, The House of Representatives. (n.d.). *U.S.C. 50903. General authority*. Retrieved from http://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title51-chapter509&saved=L3ByZWxpbUB0aXRsZTUxL3N1YnRpdGxlNS9jaGFwdGVyNTA5|Z3JhbnVsZWlkOlVTQy1wcmVsaW0tdGl0bGU1MS1jaGFwdGVyNTA5|||0|false|prelim&edition=prelim

USA, The House of Representatives. (n.d.). *U.S.C. 50904. Restrictions on launches, operations, and reentries*. Retrieved from http://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title51-chapter509&saved=L3ByZWxpbUB0aXRsZTUxL3N1YnRpdGxlNS9jaGFwdGVyNTA5|Z3JhbnVsZWlkOlVTQy1wcmVsaW0tdGl0bGU1MS1jaGFwdGVyNTA5|||0|false|prelim&edition=prelim

USA, The House of Representatives. (n.d.). *U.S.C. 50905. License applications and requirements*. Retrieved from http://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title51-chapter509&saved=L3ByZWxpbUB0aXRsZTUxL3N1YnRpdGxlNS9jaGFwdGVyNTA5|Z3JhbnVsZWlkOlVTQy1wcmVsaW0tdGl0bGU1MS1jaGFwdGVyNTA5|||0|false|prelim&edition=prelim

USA, The Office of the President of the United States of America. (1982). *National Security Decision Directive Number 42, "National Space Policy,"*. Retrieved from https://www.hq.nasa.gov/office/pao/History/nsdd-42.html

USA, The Office of the President of the United States of America. (1983). *National Security Decision Directive Number 94, "Commercialization of Expendable Launch Vehicles"*. Retrieved from https://reaganlibrary.archives.gov/archives/reference/Scanned%20NSDDS/NSDD94.pdf

USA, The Office of the President of the United States of America. (1984). *Executive Order 12465--Commercial expendable launch vehicle activities*. Retrieved from https://www.archives.gov/federal-register/codification/executive-order/12465.html

USA, The Office of the President of the United States of America. (1988). *"Presidential Directive on National Space Policy"*. Retrieved from https://www.hq.nasa.gov/office/pao/History/policy88.html

U.S.Cong. (1996). *Department of Transportation and Related Agencies Appropriations Act.* [Cong. Bill from 104th Cong.]. Retrieved from https://www.congress.gov/104/plaws/publ50/PLAW-104publ50.pdf

U.S.Cong., House - Science and Technology | Senate - Commerce, Science, and Transportation. (1983). *Commercial Space Launch Act* [Cong. 3942 from 98th Cong.]. Retrieved from https://www.congress.gov/bill/98th-congress/house-bill/3942

U.S.Cong., House - Science, Space and Technology | Senate - Commerce, Science, and Transportation. (1988). *Commercial Space Launch Act Amendments of 1988* [Cong. Bill from 100th Cong.]. Retrieved from https://www.congress.gov/bill/100th-congress/house-bill/4399?q=%7B%22search%22%3A%5B%22pl100-657%22%5D%7D&r=1