Flying Into the Future: How the Spaceflight Industry has Unfolded after the Decommissioning of the Space Shuttle

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Tucker Benton

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor

Kent Wayland, Department of Engineering and Society

Introduction

The space industry has exploded over the last decade, with companies launching rockets almost once a week, new developments of superheavy lift vehicles, satellite internet, space tourism, and other advancements. The spaceflight industry is still expanding, at a current market size of $13.6 billion, and an expected growth of 12.44% there will be more opportunities soon (Polaris Market Research, 2023). This is in stark contrast to the “drought” the U.S. had after the retirement of the Space Shuttle, with no human spaceflight capabilities, limited and expensive launch capabilities, and only a couple companies providing commercial or governmental launches at the time.

Today, there are now many companies working to reinstate these lost capabilities and beyond, such as SpaceX and Blue Origin reusing their rockets and designing reusable heavy lift vehicles larger than any rocket before, there are also various companies designing new space planes like Sierra Space, designing new space stations as the ISS is considered for retirement, and other companies to fill old capabilities and to provide brand new capabilities. These new developments open space from an extremely exclusive area, where only governments would be concerned, into a field that will affect the average person in numerous ways. For these developments to be useful and sustainable for a larger market, the safety, reliability, capabilities, frequency, and affordability must be improved to a level never seen before. With all this development, it begs the question: *Since the retirement of the Space Shuttle in 2011, how have private-sector companies competed to build confidence in spaceflight as both a business enterprise and a greater opportunity in general?*

With the trajectory that spaceflight is growing, it is arguably already an important part of people's everyday lives and will become even more so. Because of this, it is important to understand spaceflight development, and how it can develop in safe, responsible, and sustainable ways. Technological revolutions can greatly impact how society is shaped, but societies have just as much power to shape the development and use of this these technologies. By learning about the ways that the spaceflight market is growing shifting to privatization, we can help steer its growth so that we do not fall into the pitfalls of technological revolutions of the past.

Background and Context

Spaceflight has always been a massive undertaking, requiring the collaboration of governments, companies, scientific institutions, and many other organizations to ensure a safe, successful, and sustainable mission. For most of spaceflight history, it has been dominated by governments or closely related organizations. Spaceflight was seen then as a costly scientific and defense endeavor, not something where an independent private market would develop. The government led space race of the 1960's led to a very limited group that provided space launches, and they primarily were either operated or contracted out by the federal government. In the U.S. it was either NASA's Space Shuttle, which provided almost entirely government missions of some kind, or it was the United Launch Alliance (ULA) Atlas and Delta rockets, which mostly provided government services. While the public did benefit from some of these services, such as weather prediction, GPS, mapping, scientific knowledge, and the defense capabilities, space was not a market where private investment was the majority. After the Space Shuttle was retired for reasons including costs and safety concerns, ULA was the only primary option, and their launches were disposable and costly. The loss of the space shuttle caused the loss of many capabilities for the U.S. Including human spaceflight, satellite repair, spacewalks

other than the ISS, vehicle reusability, and large sample return. ULA did not provide the most important of these capabilities, human spaceflight, leaving Russia as the only option which was unfavorable due to political tensions. Picking up in 2012, companies started to fill these voids and lower costs, with the main player being SpaceX, achieving what many people thought to be practically impossible at the time, low-cost rapid reusability. This drastically decreased their launch costs, being about half of what ULA can provide today. Following this various other companies also provided new opportunities, such as small satellite launches, specializing in specific orbits, 3D printing rockets, space manufacturing, spaceplanes, space stations, and other promising fields. Spaceflight quickly transformed from a government only operation to a potentially profitable private opportunity.

Economics plays a key role in sociotechnical systems as one of the key motivators of developing and utilizing new technologies is the ability to generate value to maintain livelihoods. Aerospace has been a source of high paying jobs in both technical and non-technical fields. As much as aerospace needs highly specialized engineers, it also needs construction, mechanics, welders, shipping, infrastructure, metallurgy, and a variety of prosperous jobs. There are still the concerns of every industry with safety and sourcing, like rare earth metals, but exploratory and civilian aerospace jobs are currently highly exploitive or underpaid, and this new wave of space exploration is not focused on the creation of weapons. Frischauf et al., (2018) and Anderson (2018) discuss the economic effects of the emerging private spaceflight industry, and how the expanding industry is creating jobs and opportunities across the globe which can improve the lives of millions. However, as with all new industries, there are potential drawbacks that can arise from sudden influxes of money. Kim (2018) discusses the potential for the industry to experience a bubble effect like many tech industries. This could result in a bubble like the

internet in 2008, which saw the loss of thousands of jobs and uncertainty if the internet would ever truly be a profitable and stable domain. However, these experiences and observations can be used to prevent bubbles, in the emerging space industry. While it is beneficial for most people to create jobs and value from spaceflight, it is important to not be blinded by profit as so many have and keep in mind the people involved and ethical considerations of spaceflight. Galliot (2015) discusses both economic developments, and the development and application of ethics for spaceflight. Spaceflight has a long history of ethics, or lack thereof, depending on the period and the country. This includes space launch capabilities originally designed for nuclear warfare, various levels of safety thresholds and accidents, exclusive and often sexist and racist astronaut and engineer requirements, and many others. While the ethical considerations have improved over time, with the increase of both number of launches, and the increase of human spaceflight, there will be many more ethical situations to discuss. Spaceflight is still rapidly expanding and if used responsibly can bring more prosperity and opportunity to wide sections of society, not just wealthy governments as in the past.

With the advent of cheaper and more numerous spaceflights, and the expansion of human spaceflight, it is imperative that safety be ensured to people that go to space, especially the untrained. As higher numbers of people can go to space, for there to be any value or opportunity safety must be ensured. Griko et al., (2022), discusses the many risks associated with spaceflight for even short durations with current technology, and many companies are working on ways to improve radiation shielding and counteract the effects of microgravity. There is a long history of safety in spaceflight as shown by Chatimoff and Vadali (2021), there have been many lessons to learn about safety, management, and responsibility. Many of the organizations that traditionally produce spacecraft are older and have versed history with the practices that came out of these

mistakes, while newer companies may be unfamiliar with why some practices exist and may try to cut corners. To gain the trust of the public and become a widespread opportunity, risks must be lowered to acceptable levels for civilian usage, and we have yet to reach at level of reliability. There are even risks that don't stem from the difficulty of spaceflight or the harsh conditions of space, but risks of our own making that will only get worse if we are not responsible with spaceflight. Behrens & Lal (2019) discuss the factors that affect the satellite ecosystem, and the importance of keeping Low Earth Orbit (LEO) clean to maintain access to space. The scenario where space is so filled with junk that it becomes impossible to safely launch, known as Kessler syndrome, is a real threat to spaceflight. There are already companies and governments that are developing ways to keep space clean, which could become an economic opportunity in and of itself. To keep expanding, all these risks must be dealt with and managed, or there may be no opportunity in space for anyone.

To enforce companies to keep spaceflight a safe, reliable, and sustainable practice, legal systems must be considered. The development and implementation of laws and their enforcement is core to any sociotechnical system, as without proper regulation or oversight, selfish or unaware actors in the system can cause harm to themselves or others reducing opportunity for all. von der Dunk (2011) discusses the legal aspects of regulation and potential models from previous law including those of traffic, corporate liability, and private competition. Laws regarding space in the U.S. and abroad are incomplete and complicated, and currently land can't be owned in space, which will have to change when bases and colonies that have already been planned are made. How these laws are made and who is making the decisions has and will drastically affect how spaceflight is conducted in the future. United States Congress Senate Committee on Commerce (2012) highlights how laws and spaceflight have often been

overlooked in the past, despite being vital to missions in governmental interest, let alone private interests at the time. In the Senate meeting, the future of spaceflight is discussed, and the lack of current viable options for many necessary services that should have been accounted for is brought to light as well as lack of procedures for the situation. This oversight by the federal government led to a lapse of service, forcing the U.S. to rely on a foreign adversary for human spaceflight at the time, Russia. While the private market has less concerns about working with international partners, this shows that support of spaceflight and laws regarding it have been overlooked and this hurt the standing of the U.S. for a considerable amount of time. While there are improvements being made, there is still a lot of work to do to ensure that spaceflight is properly regulated so that the public and enterprise will have the trust needed to pursue opportunity. The complicated world of space law is further exemplified by Dunk and Tronchetti (2015), who highlight how current laws are not sufficient to cover a variety of continuous and upcoming issues, including nuclear power in space, ownership in space, cleaning up space crashes, and a wide variety of other laws that will need to either change or be discussed. While we have come a long way, for space to be a prosperous enterprise for both businesses and society there must be strong, effective regulation before issues arise.

This paper addresses the balance between new technologies created because of demand from social organizations like the government and private business, and how these technologies have made new opportunities for social groups, such as start-ups and the U.S. Government to implement socially demanded technologies such as worldwide internet, weather tracking, accurate mapping, enhanced GPS, scientific laboratories, and other possible technologies. There would be no reason to go to space or develop these technologies if not for the social demand to do so, and none of these opportunities would exist without the technology preceding them.

Societies and technologies are so deeply intertwined that the two cannot progress without each other. When the space shuttle program ended, the government still needed heavy launch capabilities, and human spaceflight capabilities, which is where companies like SpaceX took the opportunity to fill these voids, and with launch costs cut to under ½, new companies could emerge to fill market gaps, or to support developing space infrastructure (Flyvbjerg, 2022). This demonstrates how mutual shaping is a major factor in spaceflight, and that societies and technology rely on each other.

Methods

There are three main arguments that need to be supported. First, that the space industry is larger than ever before. Second, that the spaceflight industry is more privatized than any time in the past. Third, how these private companies have built confidence to fuel this growth. This paper uses both primary and secondary sources to support the main arguments. The primary data is either direct statements from stakeholders, such as governments, companies, or other associated organizations, or it is data of launches and costs collected directly from the providers or from other unbiased record keeping sources such as the FAA or NASA. This data was collected by searching on scholarly websites such as google scholar, web of science, or the UVA library for terms related to the information in the paper. The data collected will be used to support the main three arguments made in this paper, and how they relate to the main question.

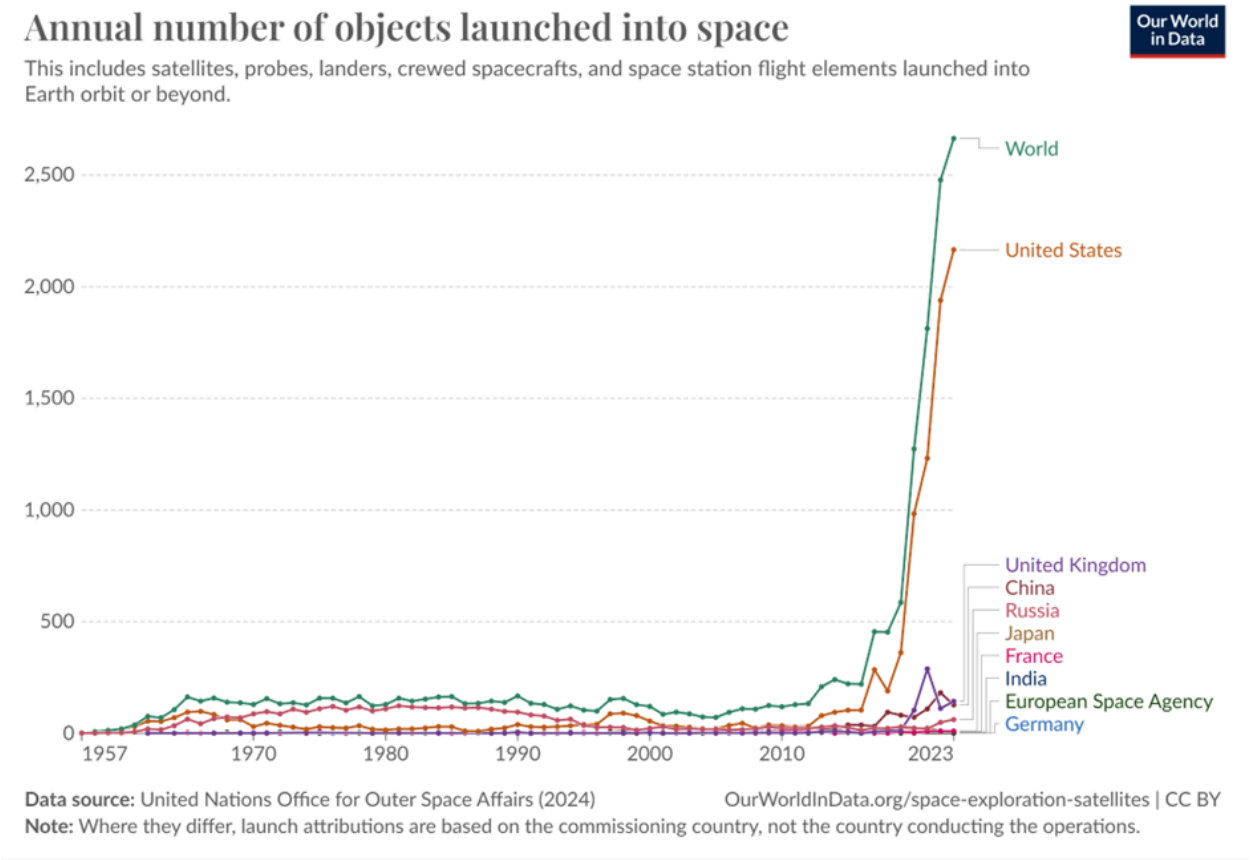
The other kind of data that will be collected is secondary sources that are able to provide insights on the development of spaceflight over time or have other information that can aid in the study of how companies have managed to expand and improve spaceflight, and if this growth can be sustained. Such sources include Maidenberg, Driebusch, and Jin (2023) that describe how

SpaceX, despite its success, still operates at a loss, and other sources that show how private companies operate.

Results and Discussion

As will be shown in this section, the space launch market is much larger, more private, and more viable as a business and societal enterprise than ever before.

Figure 1

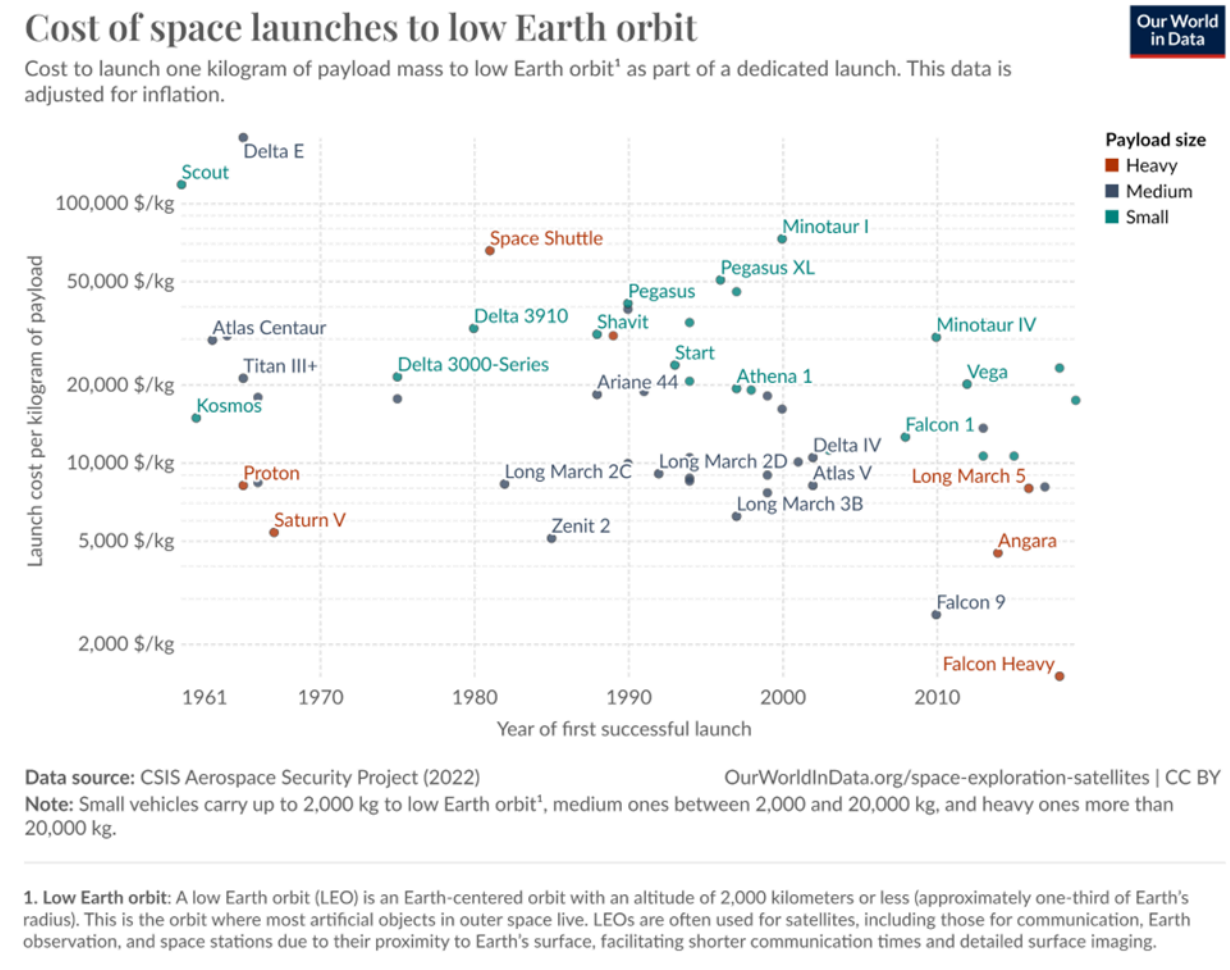


Mattheiu and Roser (2022) (n.p)

The above graph shows the number of launches, particularly from the U.S., has exploded in recent years, having hundreds of objects launched into space per year compared to any other time in spaceflight history. This shows that the spaceflight industry in the U.S. is growing at an exponential rate, and much of this progress is after the decommissioning of the Space Shuttle.

This is also supported by the growing market size as reported by the Polaris Market Research (2023).

Figure 2



CSIS (2022) (n.p)

This graph shows the cost to launch to orbit and the times that the rockets first debut. As can be seen the Falcon 9 and Falcon 9 Heavy made by SpaceX have by far the lowest cost to orbit per kilogram compared to any rocket in history, even somewhat more modern rockets. SpaceX also has Medium and Heavy payload capacity options, high flexibility in orbit options with a cheaper

LEO service, a more expensive expendable service, and ride sharing. The rapid reusability of the Falcon series allows for SpaceX to have cheaper flights more frequently and is a much more sustainable model than any other rocket before.

Figure 3

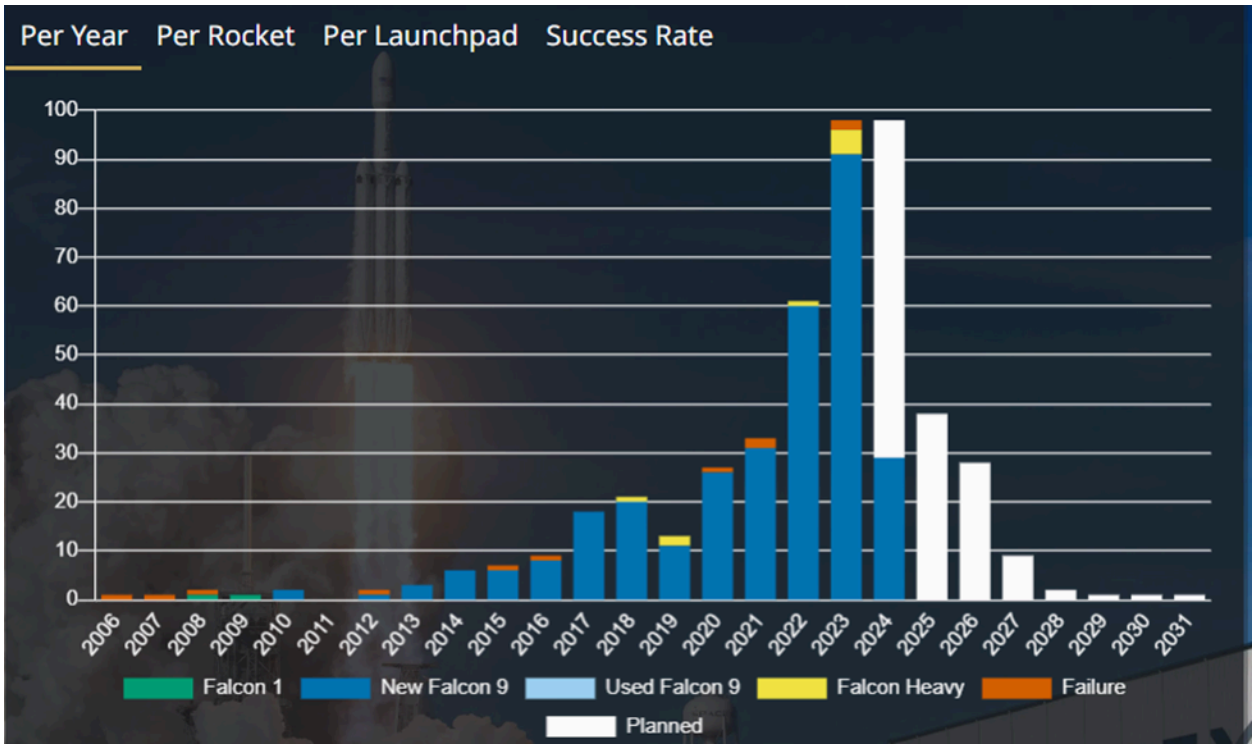
Berger (2018)

This graph shows the market share of SpaceX compared to other countries around the world, and even compared to the U.S. As can be seen, even in 2018 which had nowhere near as many launches as today, SpaceX dominates the market, and that Russia's market share has decreased drastically. While there are numerous reasons for this trend, the low cost, medium and heavy payload capacity, fast turnaround time, and the only U.S. option capable of launching humans

into space again means that there are far fewer reasons to use foreign services or ULA, however there are newer companies such as RocketLab that are able to cut a share of their own market through catering to small payloads that require specific orbits or launch windows and reusability (Brock, 2024).

Figure 4

Number of SpaceX Launches by Year

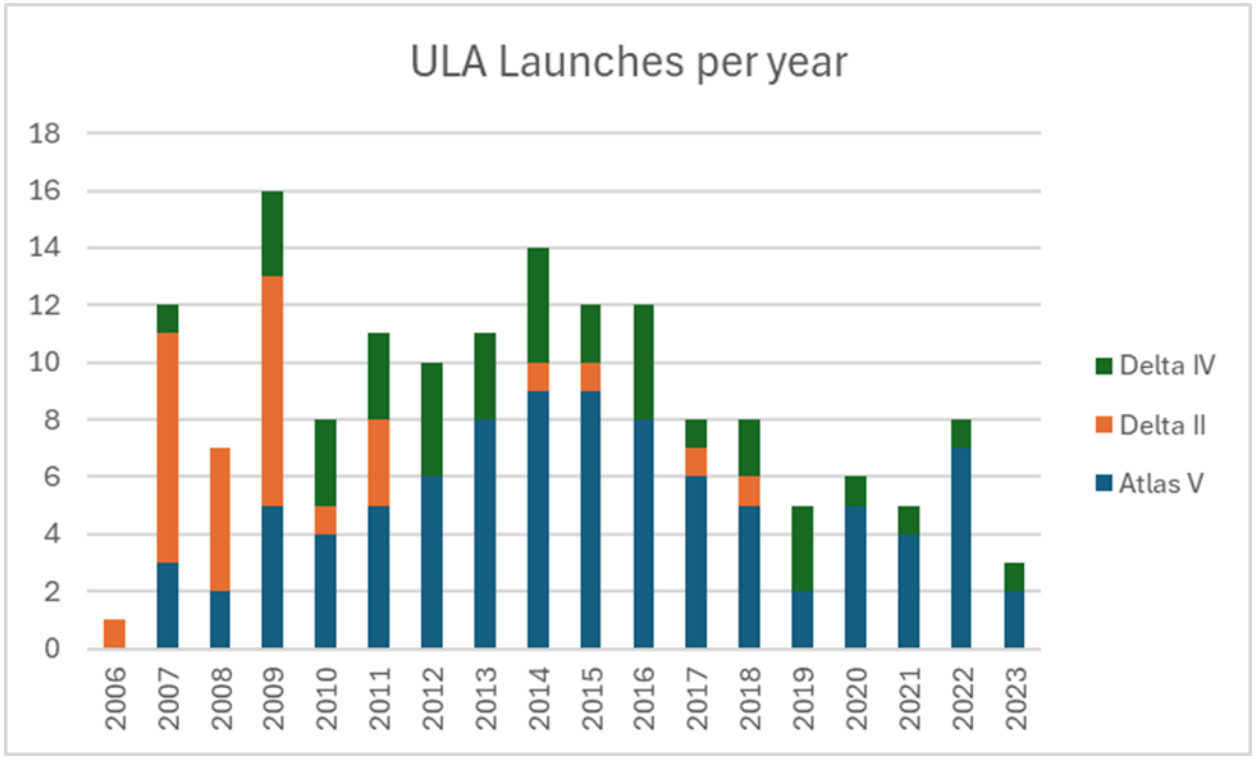


SpaceXStats (2024) (n.p.)

This chart shows the massive number of launches that SpaceX has performed in recent years, and how the trend will continue to match or exceed the current pace of development. This shows that

the low cost reusable strategy of SpaceX has made them the largest spaceflight company in the world extremely quickly.

Figure 5



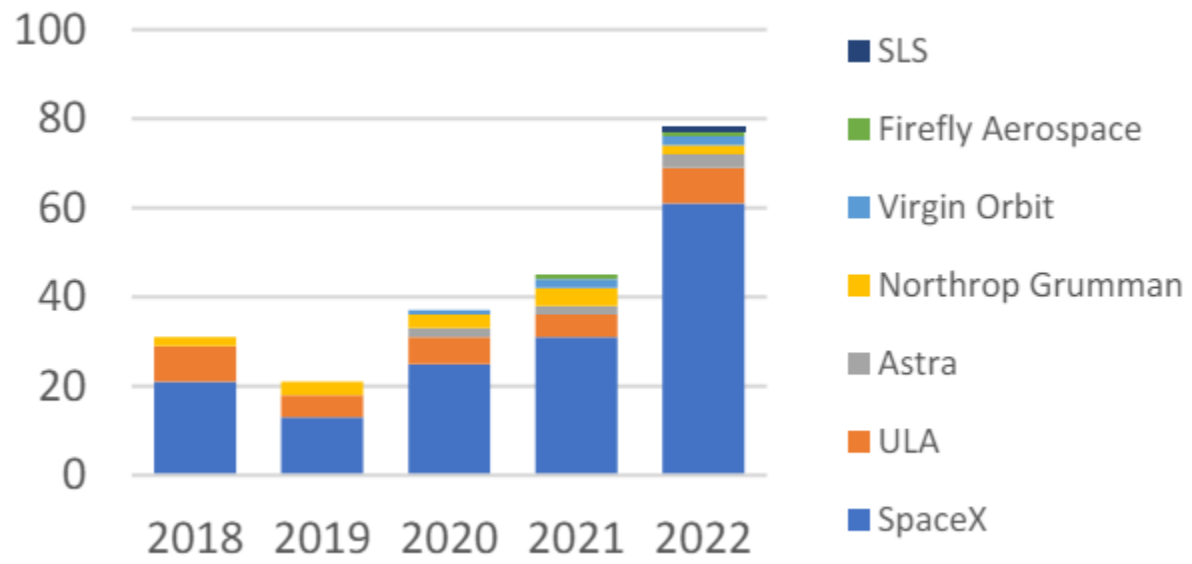
ULA (2024) (n.p.)

In comparison to the SpaceX graph, this shows that ULA has only launched as much as 16 times in one year, and their launch counts are declining as of late. While this may turn around with the Vulcan Centaur, a new rocket ULA has begun using, it is unlikely without major development that they will be able to catch up to SpaceX. This is significant because ULA comprises the major launch providers from decades past, including Lockheed, Boeing, Rocketdyne, and other traditional launch companies, showing that the methods and technologies of these established

launch providers are struggling to keep up without innovation in a market with increasing private options, indicating rising competition in a market that used to be a near monopoly.

Figure 6

U.S. Lauches by Company



Semanik & Crotty (2023) (p.2.)

This chart shows the number of launches from U.S. companies in recent years. As can be seen there are many new players in the space launch scene, but SpaceX is by far the dominant force in the space launch industry. However the growing diversity of the industry shows that there is still room for growth and new ideas, and the market is shifting away from having a low number of competitors, which can mean room for healthy competition and growth in the industry. Semanik & Crotty (2023) also describe how the investment for many launches is shifting away from government contracts to private purchases with a 362 billion dollar investment from private

companies vs a 107 billion dollar investment from the public sector. They also discuss the growing variety in launch providers, with companies such as Firefly, Astra, Rocket lab, Relativity, ABL space systems, and the first launch of NASA's Space Launch System designed for the Artemis lunar missions.

While much of this evidence is positive for spaceflight industries becoming successful private enterprises, it is not a mature market yet. Despite very high recent success rates, SpaceX has had launch failures earlier that included payloads, calling into question the reliability of newer start ups (SpaceX Stats, 2024). SpaceX also operates on a loss, while much of this is due to the rapid research and development of the new technologies that allows them to gain a competitive edge, it's difficult to trust in the market viability of launch services when the most successful company operates in the negative (Maidenberg, Driebusch, and Jin, 2023). Many other companies still operate on start-up investment without profit, and Virgin Galactic, a promising spaceplane startup, recently went bankrupt (Semanik & Crotty 2023). Even with these doubts, the spaceflight industry is still growing at a rapid rate, and shows no evidence of slowing down any time soon, and reliability, capability, and safety have been improving for all of these companies as they learn from their mistakes, and SpaceX's Falcon now has a 99.08% success rates despite early failures due to the volume of launches (SpaceX Stats, 2024).

The evidence shows that, for a fact, the space industry has both grown exponentially and become far more private than purely government-funded. There are numerous companies that no longer rely on solely government contracts to stay afloat; although, it is still a large part of the market. There are far more specializations in the launch-provider market, such as focusing on launching small satellites to specific orbits including RocketLab and Firefly, ridesharing of microsats, launching constellation of satellites for internet and communications, specializing in

specific orbits as done by Astra, launch location flexibility, and many other services that never had a market before. All of these services are primarily funded by private investment, showing that there is both enough need for diversification and capital that private industry is driving development without government funding. There is also a plethora of new of companies arising, small sat companies, space internet, imaging and data gathering of all kinds, space tugs, tourism, and many other services being provided or developed. This is partly due to the lowered launch costs due to reusability, manufacturing techniques, or specialization for specific services. The biggest player in the market by far is SpaceX. Lower cost is the largest factor for more spaceflight, and rapid reusability means that not only are launches cheaper, but also more plentiful, having a twofold factor in decreasing the cost of launches. With companies like Blue Origin and SpaceX developing even larger reusable launch vehicles with cost to orbit even lower than it is now, it is to be expected that the market will be completely dominated by private competitors, and that soon we could see the market shift from high government dependancy, to a mostly private enterprise with more options. Compared to after the end of the Space Shuttle program, private companies have expanded the capabilities of spaceflight and will continue to do so.

Conclusion

There has been massive growth in the spaceflight industry despite the lack of governmentally developed and launched vehicles with the Space Shuttle gone for several years and the Space Launch System not providing launches for the Artemis Moon missions yet. This is due to the fast-paced innovation of newer companies and new technologies, such as the reusability of SpaceX and Rocket Lab, unique manufacturing techniques and new designs, and a growing market for smaller satellites that can be launched from a rideshare, or by specialized

smaller rockets. Spaceflight is bigger than it has ever been before and is predicted to keep growing as the capabilities improve and as spaceflight moves from a limited expensive service to an ample opportunity for both governments, enterprise, and people alike. Spaceflight and society will continue to become more intertwined as launches improve their services and lower their costs, and it is important to keep track of this development, so that we do not fall into the same pitfalls of other technological revolutions in history. More research is needed to determine the exact internal methods these companies use to develop so quickly compared to traditional companies, however that information may be difficult to obtain as companies are normally secretive with their development methods.

References

Anderson, Chad (2023). The Space Economy: Capitalize on the Greatest Business Opportunity of Our Lifetime. Hoboken, New Jersey: John Wiley & Sons, Inc.

Behrens, J. R., & Lal, B. (2019). Exploring trends in the Global Small Satellite Ecosystem. New Space, 7(3), 126–136. doi.org/10.1089/space.2018.0017

Brock, J. (2024, April 25). *Rocket lab takes a specialized approach*. Rocket Lab Tkaes A Specialized Approach. https://labusinessjournal.com/special-reports/rocket-lab-takes-a-specialized-approach/

Chamitoff, G. E., Vadali, S. R. (2021). Human Spaceflight Operations: Lessons Learned From 60 Years in Space. Reston, VA: American Institute of Aeronautics and Astronautics, Inc.

Dunk, F. G. d., & Tronchetti, F. (Eds.) (2015). Handbook of Space Law. Cheltenham, England: Edward Elgar Publishing.

Edouard Mathieu and Max Roser (2022) - Space Exploration and Satellites. Published online at OurWorldInData.org. https://ourworldindata.org/space-exploration-satellites

Eric Berger - Jul 20, 2018 12:15 pm UTC. (2018, July 20). *As the SpaceX Steamroller Surges, European rocket industry vows to resist*. Ars Technica. https://arstechnica.com/science/2018/07/as-the-spacex-steamroller-surges-european-rocket-industry-vows-to-resist/

Frischauf, N., Horn, R., Kauerhoff, T., Wittig, M., Baumann, I., Pellander, E., & Koudelka, O. (2018). NewSpace: New business models at the interface of space and Digital Economy: Chances in an Interconnected World. New Space, 6(2), 135–146. https://doi.org/10.1089/space.2017.0028 Web of Science

Flyvbjerg, B. (2022, July 29). *SpaceX vs. NASA: Cost*. Medium. https://medium.com/geekculture/spacex-vs-nasa-cost-4fae454823ac

Galliott, J. (Ed.) (2015). Commercial Space Exploration: Ethics, Policy and Governance. Surrey, England: Ashgate.

Kim, M. J. (2018). The potential speculative bubble in the U.S. commercial space launch industry and the implications to the United States. New Space, 6(2), 156–183. doi.org/10.1089/space.2017.0029

Maidenberg, M., Driebusch, C., & Jin, B. (20203, August 17). *WSJ News Exclusive| A rare look into the finances of Elon Musk's Secretive SpaceX.*

https://www.wsj.com/tech/behind-the-curtain-of-elon-musks-secretive-spacex-revenue-growth-and-rising-costs-2c828e2b

Polaris Market Research. (2023, March). *Space launch services market size & share global analysis report, 2022-2030*. Space Launch Services Market Size & Share Global Analysis Report, 2022-2030. https://www.polarismarketresearch.com/industry-analysis/space-launch-services-market

Semanik, M., & Crotty, P. (2023, November). *U.S. private space launch industry is out of this world*. U.S. Private Space Launch Industry is Out of this World. https://www.usitc.gov/sites/default/files/publications/332/executive_briefings/ebot_us_private_space_launch_industry_is_out_of_this_world.pdf

Trancart, A. (2024). *SpaceX stats*. SpaceX Stats. https://www.spacexstats.xyz/#launchhistory-per-year

United Launch Alliance (ULA),. (2024). Missions. https://www.ulalaunch.com/missions/-in-category/categories/rocket/vulcan

United States Congress Senate Committee on Commerce, S., T. S. S., A., R. S., & United States Congress Senate (2012). Issues Facing the U.S. Space Program After Retirement of the Space Shuttle: Hearing Before the Subcommittee on Space, Aeronautics, and Related Sciences of the Committee on Commerce, Science, and Transportation, United States Senate, One Hundred Tenth Congress, First Session, November 15, 2007. Washington: U.S. G.P.O..

von der Dunk, F. G. (2011). Space tourism, Private spaceflight and the law: Key aspects. Space Policy, 27(3), 146–152. doi.org/10.1016/j.spacepol.2011.04.015