How Commercialization is Changing the Approach to Space Missions and Investments

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Taylor Chandler

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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

Bryn E. Seabrook, Department of Engineering and Society

STS Research Paper

An unprecedented amount of American space activity, once led for science, exploration, and national pride by NASA and its contractors, is now increasingly conducted by private corporations with wealthy backers that represent a growing four trillion-dollar industry (Koetsier, 2021). This change in operations will inevitably alter the landscape of the space industry, including motives, performance metrics, funding, and approach for space missions. The importance of space activity for science, technological development, and education demands skepticism and inquiry into any major changes in the way it is conducted. Here, this shift to private space flight presents many promising improvements in development speed and mission costs as well as concerns over how profit-motives might impact the field such as increased lobbying (Forrest, 2021) and is therefore worthy of study that may predict further change.

To provide needed research on the topic of space privatization, this paper will analyze the ongoing change in the space industry using the paradigm shift framework to characterize how the shift will alter the overall approach to space mission design and approval. The paradigm shift theory will be used in conjunction with the Actor-Network Theory which itself will examine the key players involved in the private space shift and their connections with each other for insight. To prevent an overly vague and bloated analysis, the scope will be limited to actors most representative of this paradigm shift such as NASA, the U.S government, and the largest players in the industry such as SpaceX and Blue Origin. These frameworks are the best tools to conduct this analysis and will lead to an answer for the following question: what is the sociotechnical impact of the shift from public to private companies in relation to the space industry and the future of space exploration?

A Changing Industry:

Breaking free from a centralized model of space operations has been and continues to be an economically prohibitive endeavor. From the beginnings of American investment in space flight that led to men on the moon, the incredibly high costs of space flight have restricted the viability of profitable private enterprise. For decades this meant that only centralized authorities such as the United States government or Soviet Union could afford to fund missions that had no hope of ever turning a direct profit. This aligned with early goals regardless; as Weinzierl says in his journal of economic perspectives, “The economic logic for the centralized model was clear, and for several decades it achieved its (remarkable) goals. Public goods such as national security, national pride, and basic science are typically underprovided if left to the market, and NASA was founded to provide them during the Cold War.” (p. 3). In essence, regardless of the prohibitive costs, the general use to the people for space flight was national pride and scientific research, things irrelevant to or often neglected by private enterprise.

However, political efforts were eventually made to reach an end goal of a traditional competitive free-market system for innovation in space operations. Policy such as the Communications Satellite Act of 1962 served to begin opening sectors that stood a chance at profitability (Weinzierl, 2018, p. 4). The removal of the space shuttle program, meanwhile, was an example of centralized operations that had missed budget targets scaling back to make room for industry. These acts by the government were also motivated by a lack of direction after the end of the apollo program, with even Buzz Aldrin stating: “After the Apollo lunar missions, America lost its love of space—there was no concentrated follow-up and we didn’t have any clear objectives.” something especially apparent when observing NASA budgets dropping to just .1% of the nation’s GDP after the space race (Weinzierl, 2018, p. 2, 4).

In modern times, the private space industry has progressed past just communications satellites and firmly into the territory of NASA as technology improvements have made profits feasible. The first notable private space company was Blue Origin, founded in 2000 by Jeff Bezos. Following Blue Origin soon after were SpaceX, founded in 2002 by Elon Musk, and Virgin Galactic, founded in 2004 by

Richard Branson. All three of these companies' founders and their respective companies are now worth billions, with each having highly public profiles and involvement (Grady, 2017). As of 2022, two of the three companies have successfully reached orbit (SpaceX and Virgin Galactic), all three have launched tourists in at least a suborbital spacecraft, and all three have roadmaps for human spaceflight going far into the future (Wattles, 2021). These accomplishments are very impressive and represent just a slice of over 10,000 companies (Koetsier, 2021). Also notable, however, is the increased number of legal battles as companies fight for government contracts and squabble over regulations; these costs continue to rise and have begun to hit the millions for the big three companies (Forrest, 2021).

Paradigm Shift and Actor Network Theory:

Paradigm Shift Theory is an STS framework created to contextualize shifts in scientific understanding by Thomas Kuhn in his influential 1962 book *The Structure of Scientific Revolutions* (Bird, 2018). According to Kuhn, in normal science assumptions and models are static to allow for convenient problem solving. Eventually, scientific puzzles are regularly unable to fit within these parameters (model drift), leading to a model crisis. Finally, model revolution entrenches a new paradigm that accommodates these anomalies but isn't objectively better, often rising out of sociological or psychological reasons. This framework can be applied to the space industry, where privatization is fast becoming the new normal model for conducting operations as a result of new economic and operational puzzles that were not able to be solved under the previous public system.

The usefulness and applicability of Paradigm Shift Theory is debated. Its primary criticisms question Kuhn's belief that new models are not objective improvements, taking issue with the trivialization of massive scientific breakthroughs into the result of mob-psychology (McLeod, 2020). However, the addition of a social component to scientific change seems necessary for research conducted by humans subjected to the same pressures and groupthink as others. This is applicable to the privatization of spaceflight as well; sociopolitical factors have been very formative for modern space operations, leading to the development of the current model.

Actor-Network Theory (ANT) will serve as a supplementary framework. Actor-Network Theory is primarily associated with scholars Michel Callon, Bruno Latour, and John Law. ANT developed over time through the work of these scholars as a flexible framework for complex sociotechnical subjects. ANT works by defining a unique network of actors for a particular subject of research. In ANT, anything can be defined as an actor, a network, or both, as ANT considers that entities within a network are both confined by but also influence the network itself. Using this framework, a model can fully represent the subject with all its complexities and influences, allowing a more complete understanding of it.

As a result of its depth and flexibility, ANT's use-case is therefore seen by STS Scholar Darryl Cressman as for "exploring the questions of why and how we have the technologies that we do. ANT provides a research trajectory that can reveal complexities and contingencies that are too often overlooked in accounts of technology." (2009, p. 10). Scholars that praise ANT as a useful tool such as Cressman also admit that it is difficult to create a recognizable network given so many shifting actors; Cressman therefore says that ANT "looks to the network builders as the primary actors to follow and through whose eyes they attempt to interpret the process of network construction." (p. 3). As such, the best use of the tool for the topic of space privatization is to characterize the primary network builders such as government agencies and large companies with influence on the network through lobbying or otherwise.

Methods and Approach:

The research question "what is the sociotechnical impact of the shift from public to private companies in relation to the space industry and the future of space exploration?" is analyzed by exploring a variety of sources directly related to key actors in the industry. Keywords that guide this research includes space, industry, and private. Examples of key players include the U.S government, NASA, SpaceX, and even

NATO. Sources covering these entities are retrieved from political transcripts, books, and academic journals to establish multiple perspectives and therefore provide the best chance of a fair and comprehensive analysis of the impact aerospace corporations are having on the space industry. For example, congressional hearings and political doctrine will explain the system space corporations are forced to navigate and their influence within, while economic & scientific journals and news reports are used to outline the working operations of companies like SpaceX and Virgin Galactic. Taken together, these perspectives provide a fair overview of the impact these companies have on space activity. The sources were then organized thematically such that they appear during discussion of specific topics, such as cost reports when discussing economics.

The Present and Future of Space:

The results of this research highlight the difference between private and government space programs. Specifically, government programs more often take on exploratory and scientific endeavors as well as satellites that serve the nation’s interest such as through orbit of intelligence and GPS satellites. Private companies, meanwhile, are only able to approach long-term goals at the behest of wealthy donors, therefore more often choosing to seek profit by scaling up production and sale of rockets and communication satellites. This economical approach is due to a fundamental difference in paradigm. Government space programs are expected to provide net gain over decades to the public through development of technology and scientific discovery with no expectation of profit. Private companies must turn a profit eventually to justify their existence, however, thus resulting in a completely different approach to and language of space travel. This difference in paradigm manifests itself throughout the modern actor-network of space travel within treaties, the types of ventures taken, respect for space junk, human safety, and other facets. While these facets are explored in greater detail, in summary the result of this research is an understanding that if government entities continue to push for scientific discoveries and create policies that protect the future of space travel, transition to a competitive market will have positive impacts on the costs and possibilities of the field.

To assess the current landscape of space missions, 2021 orbital space missions are analyzed. 2021 had the largest amount of orbital space missions in history and the year is broken down into data shown in Figure one for analysis. Note that often launches carry many small payloads and thus achieve multiple objectives, placing it in multiple categories. In addition, the launches were placed based on the actors providing their funding, not the spacecraft constructor. Complete information available in Appendix A.

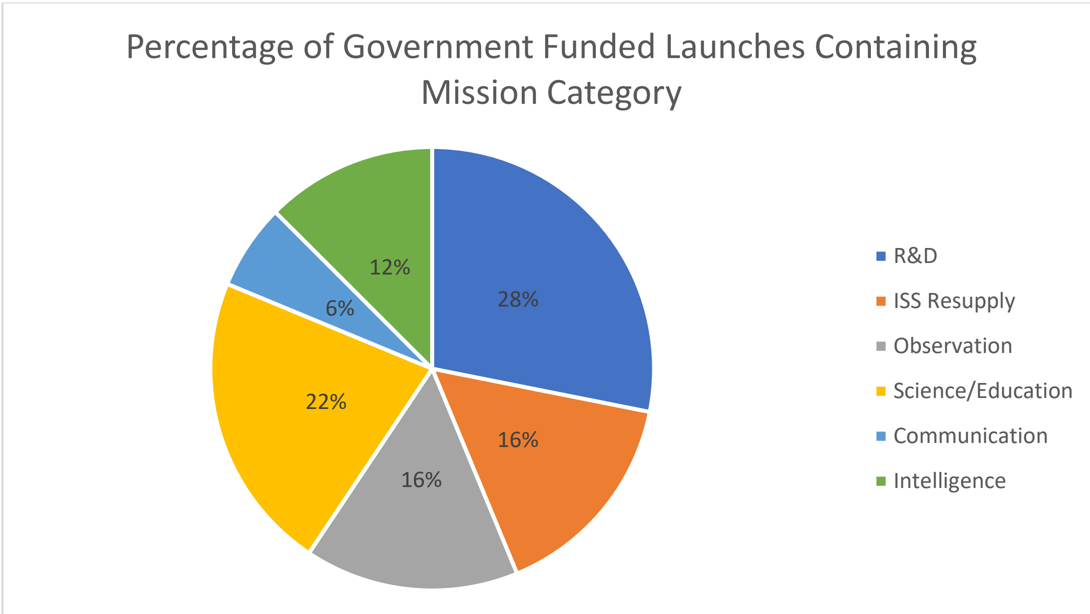

Figure 1: Pie chart showing the types of missions approved by government funding (Chandler, 2022)

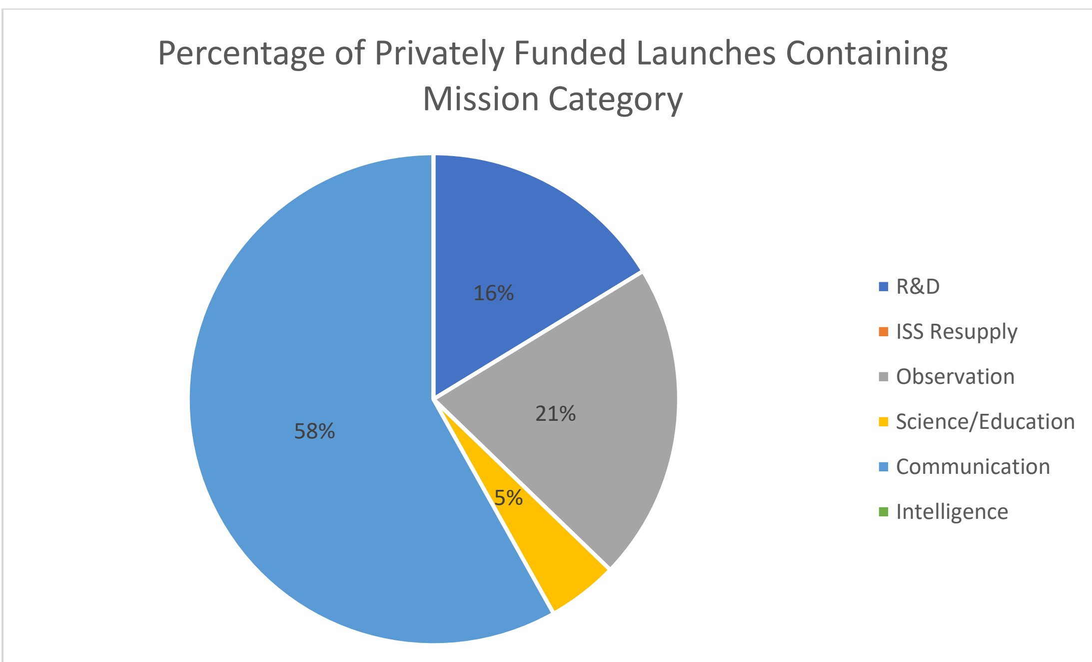

Figure 2: Pie chart showing the types of missions approved by Private funding (Chandler, 2022)

The charts highlight difference in approach between private companies and governments. Particularly noteworthy is the dominance of communication satellites such as SpaceX's 1600+ Starlink satellites within commercial launches (Mohanta, 2021). There are some areas that private space companies are not very active; intelligence, International Space Station (ISS) missions, and science/education related operations are almost entirely handled by government programs. However, many of these government missions are launched using rockets made by private companies. SpaceX's Falcon nine launching two Crew Dragon missions to the ISS carrying NASA astronauts for the government serves as an example of this cooperation (Potter, 2021)(Margetta, 2021). It seems, then, that the private space paradigm is well-suited to refining repeatable, versatile tasks such as sales of SpaceX's reusable rockets or launch of satellites. This communication dominance is particularly evident when looking at satellite launches in 2020, where SpaceX launched 83% of communications satellites for Starlink (*The Space Report*, 2020).

Another point of comparison between paradigms is the cost to launch rockets. Below is a table comparing the cost per kg of rockets commonly launched within the last decade. The cost varies greatly between rockets of different sizes, so these three were chosen due to their similarity; however, note that industry secrets and the many different versions of one class of rocket makes it difficult to compare R&D costs.

Category	**Company**	**Rocket**	**Cost per kg**
Government Contractor	ULA	Atlas V	$8,100.00
	Northrop Grumman	Antares	$13,600.00
Private Enterprise	SpaceX	Falcon 9	$2,350.00

Figure 3: cost per kg for various common medium sized rockets to Low Earth Orbit (Chandler, 2022)

From the figure, it is apparent that Falcon nine has reduced the cost of space launches. The U.S government has also recognized this reality, with the president of the Commercial Spaceflight Federation Eric Stallmer stating, "the commercial sector is making space affordable and accessible." (The Commercial Space Landscape: Innovation, Market, and Policy, 2019). The private space paradigm has resulted in much cheaper launches overall, with Falcon nine serving as the flagship example. This cheaper cost can likely be attributed to many aspects of the paradigm such as competition, the priority of cost, lack of political motives, and designing almost everything in-house.

NATO's 2018 report on the space industry has many insights into the expectations and fears of western government for the industry's future. The report cites many unexplained space activities; for example, "In March 2018, a Californian company was accused of launching satellites without government approval." (Bockel, 2018). The report attributes these activities to lowered costs, stating "ever lower entry barriers could also potentially engender problems of corporate negligence and misuse and might eventually open the space domain to malicious actors, including hackers and terrorist organizations." (Bockel, 2018). The report goes on to say that regardless, "its members' economic livelihood increasingly relies on unimpeded access to space and on its capacity to ensure the safety and survivability of space assets. The Alliance has an interest in preserving this economic capacity while deterring any threats that might make use of the space domain." (Bockel, 2018). That statement on economy suggests that NATO doesn't plan on restricting or moderating space activity from actors within its own sphere of influence, which is mostly corroborated by NATO's most recent policy. As of January 17, 2022, NATO has updated its overarching space policy to reflect that the body wants free and open access to space and protection for NATO countries' space activity, with itself acting as a military and communication coordinator (2022).

U.S space companies may not be particularly concerned with NATO as an actor, but the U.S has also updated its space policy framework as of December 2021. This new policy, much like NATO's report, sees space as a growing and important commercial sector but here commits to "provide clarity and certainty for the authorization and continuing supervision of non-governmental space activities, including for novel activities such as on-orbit servicing, orbital debris removal, space-based manufacturing, commercial human spaceflight, and recovery and use of space resources" (The White House, 2022). Space debris is highlighted as a major safety topic, and so it will also be discussed in relation to private enterprise.

As mentioned in The White House safety policy, one major safety issue is the collective problem of orbital space debris. The NATO report states "The number of satellites in orbit is rapidly increasing as states and commercial actors expand their capabilities. These new satellites are, in turn, orbiting in an environment increasingly crowded with defunct or damaged satellites.” (Bockel, 2018). The problem will be compounded when collisions begin to occur more frequently, as collisions split two orbital bodies into thousands of new and deadly projectiles. This can lead to a phenomenon called Kessler Syndrome, a worst-case scenario where orbital debris render space inaccessible for generations (Bockel, 2018). As of 2022, businesses are already responsible for a significant portion of these satellites, with Starlink’s 1900 Satellites making up over 25% of all satellites in orbit as of March 2022 despite the program beginning launches in just 2019 (Foust, 2022). It is notable that these satellites have collision avoidance capabilities; however, with Starlink approved for over 4000 satellites already and around 400 already inoperable due to events such as solar flares, space debris will continue to be a concern (Foust, 2022). The situation will only become worse if Amazon, SpaceX, and additional foreign actors release their planned communications satellites, increasing their combined satellites to at least 96,655 in Low Earth Orbit (LEO) according to The Space Report (2020). Though, the fact that these satellites are in LEOs does alleviate some concern for long term issues, as they fall out of orbit relatively quickly.

Space debris isn’t the only issue with an overpopulated orbital environment; observation of space is also negatively impacted and has become a relevant topic due to Starlink’s relatively bright satellites, all of which sit just under the threshold brightness magnitude of seven set by astronomers (Foust, 2022). One study of an observatory in California found “a sharp increase in the number of images taken near dawn and dusk that had streaks from satellites,” but also found “little evidence that the satellite streaks were interfering with the science being done by the observatory,” suggesting that, for now, the impact is mainly impacting photography (Foust, 2022). However, if satellites in LEO increase to levels estimated by The Space Report (96,955), the light pollution will impact observation more severely and may begin to impact astronomy research (2020).

Space debris and orbital light pollution are both quite indirect and long-term problems. The more direct issues of launch success rates and human safety must also be considered and will be analyzed here. In figure three, the success rates of various common rockets since 2010 are shown.

Category	Company	Rocket	Successes	Failures	Percent	Overall
Government Contractor	ULA	Atlas V	72	0	100.00%	95.35%
	Northrop Grumman	Minotaur Series	13	1	92.31%	
		Antares	16	1	93.75%	
Private Enterprise	SpaceX	Falcon Series	142	3	97.89%	91.80%
	Rocket Lab	Electron	21	3	85.71%	

Figure 4: Success rates of private enterprise and government contractors since 2010 (Chandler, 2022)

This data reveals little difference in mission success rate between government contractors and private rocket launches. The reality is that in modern times, most rockets are quite safe, and reliability will continue to improve due to reusable rockets. Human space flight is especially safe: no humans have died during an orbital flight in the last 12 years, with only one death occurring during a suborbital flight on SpaceShipTwo by Virgin Galactic (Malik, 2015). This highlights a convergence in paradigms, suggesting that both private and government affiliated contractors value safety for monetary public relations, and/or other reasons.

The final point of analysis is something that only the private space paradigm has ventured into. Space Tourism serves as a key part of the industry for popular private businesses such as Blue Origin, SpaceX, and Virgin Galactic due to the scalability of the product if the launch price decreases. 2021 Was a landmark year for the prospect, with Virgin Galactic's founder Richard Branson and five others embarking on a zero g journey on July 11, 2022, and Blue Origin embarking on a similar mission with Jeff Bezos and three others just nine days later (Howell, 2021). Other journeys included William Shatner on another Blue Origin flight and Jared Isaccmans's privately chartered flight on SpaceX's Inspiration4, the first civilian orbital flight. These examples all occurring in the same year seem to mark a turning point where the rich and famous can begin to consider space tourism as a real option (Howell, 2021). At its current costs, however, the average person couldn't dream of hitching a ride to orbit. Criticisms aimed at the new segment of the industry express anger at the wastefulness of these programs, as millions are thrown at space not for scientific advancement but instead as a once-in-a-lifetime thrill ride. Regardless of feelings, this sort of activity would likely never exist under a public space paradigm.

Limitations and Future Revisions:

This project encountered several limitations that impacted its depth. The first is the

the high cost of The Space Report by The Space Foundation, preventing access to recent 2021 data. However, the 2020 Q4 version was available and was used instead. The space report isn't the only example of out-of-date information; in general, many sources and articles are outdated or limited in scope or authenticity, complicating the writing process. Often, desired information isn't compounded in one place, forcing the creation of figures with many sources or from websites such as Wikipedia. Private companies and even some contractors also do not release detailed data on the development of rocket platforms until they've reached end of service. The scope also could have included more social topics such as gender inequality, working conditions, pay, and public opinion. Finally, a greater focus on private Companies besides SpaceX

A future revision of this paper would include interviews and surveys from workers and the public on their opinion about NASA, SpaceX, and other actors. These surveys would also be used to differentiate working conditions and workers' reasons and passions for joining their companies. The report may also assess inequalities and other issues that may be endemic to a specific industry paradigm or to specific actors.

Conclusion:

The overall goal of this research is to characterize the fundamental differences between private and public space operations as private enterprise continues to see larger investment. The significance of this goal is that it assesses the pros and cons of different approaches and can help predict future activity. Based on the findings herein, the answer seems to be that private space as a paradigm is more adept at specific tasks. Private space is concerned primarily with profit, leading to scalability as a chief consideration in any endeavor. The results of this paradigm are impressive: costs for common operations such as satellite launches have fallen drastically, LEO satellite networking is a new possibility, and new but controversial space tourism launches are becoming more common. However, the paradigm does not lend itself to activities that are not obviously profitable but might improve humanities progress. For example, scientific and exploratory launches are very rare for private enterprise, while government funded launches often include GPS satellites, Surveillance for security, and missions to the ISS. In addition, the paradigm is beholden to ultra-rich investors that ultimately have a lot of sway in the agenda. Finally, private space is less likely to consider long term issues such as space debris and light pollution, meaning that without regulatory actors further investment in private enterprise could cause huge problems. Given these shortcomings, it's important that the private and public paradigms both operate in cooperation, with public actors such as NASA continuing to fund scientific endeavors and push towards the Moon and Mars while regulatory actors such as the FAA provide clear regulations that prevent long term issues. If both paradigms exist in harmony, the public can expect new industries, dropping costs, and continual discovery.

Appendix A: Data on government funded space launches

Entity Type	Funding	Date	Rocket	Category					
				R&D	ISS Resupply/Crew	Observation	Science/Education	Communication	Intelligence
Gov. Entity	NASA	20-Feb	Antares						
		23-Apr	Falcon 9						
		3-Jun	Falcon 9						
		17-Jun	Falcon 9						
		29-Aug	Falcon 9						
		16-Sep	Falcon 9						
		27-Sep	ULA Atlas V						
		16-Oct	ULA Atlas V						
		11-Nov	Falcon 9						
		24-Nov	Falcon 9						
		9-Dec	Falcon 9						
Gov. Entity	NRO	26-Apr	Delta IV Heavy						
			Minotaur 1						
Gov. Entity	Space Force	18-May	ULA Atlas V						
		13-Jun	Pegasus XL						
		17-Jun	Falcon 9						
		29-Jul	Electron						
		28-Aug	Rocket 3.3						
		20-Nov	Astra						
		7-Dec	Atlas V						

Appendix B: Data on privately funded space launches

Entity Type	Funding	Date	Rocket	Category					
				R&D	ISS Resupply/Crew	Observation	Science/Education	Communication	Intelligence
Private Company	SpaceX	8-Jan	Falcon 9						
		20-Jan	Falcon 9						
		24-Jan	Falcon 9						
		4-Feb	Falcon 9						
		16-Feb	Falcon 9						
		4-Mar	Falcon 9						
		11-Mar	Falcon 9						
		14-Mar	Falcon 9						
		24-Mar	Falcon 9						
		7-Apr	Falcon 9						
		29-Apr	Falcon 9						
		4-May	Falcon 9						
		9-May	Falcon 9						
		15-May	Falcon 9						
		26-May	Falcon 9						
		6-Jun	Falcon 9						
		30-Jun	Falcon 9						
		14-Sep	Falcon 9						
		13-Nov	Falcon 9						
		2-Dec	Falcon 9						
		18-Dec	Falcon 9						
		19-Dec	Falcon 9						
		21-Dec	Falcon 9						
Private Company	Rocket Lab	20-Jan	Electron						
		22-Mar	Electron						
		15-May	Electron						
		18-Nov	Electron						
		9-Dec	Electron						
Private Company	Virgin Group	17-Jan	LauncherOne						
		30-Jun	LauncherOne						
Private Company	Firefly	3-Sep	Firefly Alpha						

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