Commercialization and the Future of Spaceflight

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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

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Introduction

To the average person, outer space is synonymous with distance. It's something vast and unattainable that doesn't outwardly seem to affect daily life all that much. Despite this, there are interactions between everyday society and space. If it weren't for the spaceflight industry, there would be no satellite communication or GPS, not to mention the long list of technologies developed by NASA that have been made available to the public. So-called "spinoff" technologies have been employed for prosthetic limbs, shock-absorbing helmets for athletes, and even things like memory foam (NASA—NASA Spinoff, n.d.). The spaceflight industry has had a tangible impact on society. This relationship is reciprocal, however. The current state of the industry is a result of demand for what it can provide, both to everyday consumers and to companies. Licensing data from the FAA shows an ever-increasing demand for access to space (FAA, 2023), but with that, there is a glaring issue. Access to space is very expensive, and it is challenging to achieve. This is where private spaceflight companies come in. Cost and time between construction and launch have always been important considerations for spaceflight, but now, they're more important than ever. Private companies aim to decrease the cost of launch and increase the number of launches, potentially by deviating from systems that were once the industry standard. Previously, expendable launch vehicles (ELVs) were the primary way to launch to space. Newfound emphasis on cost and launch frequency calls into question whether these systems are the best method for launch moving forward. The purpose of this paper is to investigate how the spaceflight industry has operated historically, how changing focus and values within the industry inform its operation, and finally, how the industry is seemingly moving away from use of ELVs in favor of newer reusable launch systems (RLVs), and whether that change is wise.

STS Framework

The framework for this analysis is the Social Construction of Technology (SCOT) framework. SCOT was introduced as an alternative to the Empirical Programme of Relativism (EPOR) by Wiebe Bijker and Trevor Pinch in 1987. EPOR approaches technological development from a fairly linear point of view focusing predominantly on the influence on and by scientists and researchers. SCOT, however, presents what Bijker and Pinch call a "multidirectional model," where this development can be viewed from a much wider perspective by considering a number of relevant social groups (Bijker et al., 1987). In addition to these social groups, SCOT explores interpretive flexibility, closure, and stabilization (Humphreys, 2005).

Within the SCOT framework, social groups are defined as people who view or interact with a piece of technology in the same way. In a 2005 article by Lee Humphreys which elaborates on the SCOT framework, four generic social groups are established. These groups can then interact with the technology either directly or indirectly, and can further be categorized as organized or individual. The four groups identified by Humphreys are producers, advocates, users, and bystanders. Producers are organized social groups with direct monetary stakes in the technology. Advocates are organized social groups with indirect or political stakes in the technology. Users are individuals who interact regularly with the technology, therefore creating a personal stake. Bystanders are individuals who do not directly interact with the technology, but whose opinions and values may drive the further development of technology (Humphreys, 2005). These groups influence and are influenced by technology, and their continued interaction determines how technological development proceeds.

Interpretive flexibility, closure, and stabilization are the remaining core aspects of SCOT, and they are closely related to one another. Flexibility is the idea that a specific technology may have different applications depending on the user. Humphreys uses the example of automobiles to demonstrate this–a sports car and a pickup truck have two fundamentally different purposes, but they both fall under the umbrella of automobiles. Closure is the process by which an artifact loses its interpretive flexibility. Using the automobile example, the broad category of automobile has lots of flexibility, but as different types of automobiles are defined, such as sports cars or pickup trucks, the increased specificity reduces the number of different ways to use the vehicles. Finally, stabilization is the process by which a particular design for a technology emerges as the predominant or defining design (Humphreys, 2005).

This framework is relevant to the future of spaceflight for several reasons. Rocket technology historically has provided a great example of interpretive flexibility and stabilization. Some of the first rockets in regular use were repurposed missiles, and systems derived from missiles coupled with multiple stages became the standard vehicle for spaceflight (Van Riper, 2004). Analyzing these processes occurring in the past may provide useful insight into the present and future status of the industry. Additionally, spaceflight is a field in which relevant social groups have significant bearing on technological development. For this analysis, relevant social groups will be identified as follows. Producers are contractors and companies such as Northrop Grumman and SpaceX who create ELVs and RLVs for use. These companies want their systems to be used so that they can continue to get funding for more projects and products. Users include those who wish to access space, whether it's a space agency like NASA, an academic research group, or even the producers themselves. Advocates are governmental entities such as the military or the National Oceanic and Atmospheric Administration (NOAA) who benefit from access to space. In this case, the bystander group is very extensive because of the far reaching effects of what spaceflight has to offer. This includes anyone from people who use satellite services such as satellite radio or GPS to people who use innocuous things such as memory foam pillows, which are made of a material invented for spaceflight. Given the influence of these social groups on the development of spaceflight technology, it is important to understand why these groups care, and what they hope to gain.

Motivations of Social Groups

As spaceflight technology has developed, entities within the respective relevant social groups mentioned previously have changed. Some have remained constant, such as NASA and the general public, while some have come into existence more recently. These newer additions to the field of aerospace technology have had a disruptive impact on goals and development. This section will be exploring the changes in the goals and behaviors of relevant social groups since the advent of spaceflight technology, and how these changes may affect the future of spaceflight. The purpose of this is to use historical examples of social groups relevant to spaceflight to establish that there is a link between the priorities of such groups and development of the technology.

The early days of spaceflight were largely defined by the geopolitical climate after the second World War. Missile technology was transformed into early rockets, and the United States and the Soviet Union who had access to them found themselves competing for dominance in what is now referred to as the Space Race (Van Riper, 2004). This competition spurred the United States to pass the National Aeronautics and Space Act of 1958, thus creating the National Aeronautics and Space Administration, NASA, who was and is still a major stakeholder in the field of spaceflight. In the early days of NASA, their goals emphasized the advancement of knowledge about space and the development of more spacefaring vehicles. Collaboration between other agencies within the United States government is mentioned specifically with the purpose of avoiding the creation of redundant infrastructure and efforts (NASA, 1958). At its inception, the goals of NASA as both producers and users of spaceflight technology aligned directly with the goals of the advocates, who have been identified primarily as the United States government.

As for bystanders, which here have been defined as the general American public, there was a notable shift in attitude in the first decade of spaceflight. Within a year of NASA's formation, the agency was the target of some scrutiny because it was generally thought that the United States was falling behind the Soviet Union when it came to spaceflight. In an article published by *Newsweek*, one author mentioned that the general lack of direction within NASA was disappointing, and that there was "insufficient appreciation of the international prestige that goes with dramatic 'firsts' in space" (Lindley, 1959). A few years later, *The New York Times* published an article about a launch that was part of Project Mercury. It provided details of the launch and the mission to be carried out, citing then administrator of NASA, James Webb, as saying that they aimed to collect data on stresses that an astronaut would undergo. Quite a few comparisons were made to the flight made by Soviet cosmonaut, Yuri Gagarin, which was longer and more strenuous than the planned Mercury mission, though it was also emphasized that Gagarin's mission had been controlled from the ground, while the NASA mission would be controlled by the astronaut on board (Witkin, 1961). Overall, in the very early days of the American space program, it was evident that novelty was an important factor in engaging the general public. This is further emphasized by the notable shift in tone surrounding spaceflight after the success of the Apollo 11 mission. Another article published in *The New York Times* detailing accounts from people all across the United States celebrating the moon landing, stopping in the middle of the workday to watch history being made on television. Notably, towards the end of the article, there were accounts of a few people who believed the landing had been faked, but the general attitude surrounding spaceflight was one of optimism and excitement (Van Gelder, 1969). From these accounts, it is evident just how important first accomplishments in spaceflight were in order to keep attention on the topic. Even at the end of the Apollo 11 article, one person who was interviewed expressed boredom with spaceflight because of how much it was publicized. Even today, novelty and excitement are a crucial factor in continued interest in spaceflight and advancements in the field. It is worth noting here that the assumption made in this paragraph is that the selected newspaper and magazine articles are indicative of the feelings of the entire American public. Treating the entire group as a monolith that shares the opinions of the selected authors, while reductive, was necessary for this analysis. Since newspapers and magazines were a source of information that much of the public engaged with and based opinions on, they have been deemed an appropriate resource.

As it stands, today's spaceflight is heavily centered around regularly scheduled resupply missions to the International Space Station. After the cancellation of the Space Shuttle program, it was no longer a reasonable financial decision for NASA to be entirely in charge of all aspects of resupply missions, which is where the Commercial Cargo Program comes in. Through this program, NASA is able to send supplies up to astronauts on the ISS through partners like Northrop Grumman and SpaceX, the companies that create the Cygnus and Dragon resupply capsules (NASA—Commercial Cargo Spacecraft, 2023). While the core mission of NASA has remained the same throughout the years, there is a notable difference in the nature of some of their goals. In the 2022 NASA Strategic Plan, it is stated that they aim to "Develop a human spaceflight economy enabled by a commercial market," (NASA—NASA Strategic Plan, 2023) while at its inception, only collaboration between government agencies was mentioned. Because resupply is such a regular occurrence, it has lost the interest of the general public. Other possible activities that could be facilitated by spaceflight, such as tourism, mining, advanced manufacturing, and improved communication, do more to capture attention (Kotkin et al., 2021). Ultimately, those are the goals of private spaceflight companies such as SpaceX and Blue Origin.

According to NASA, the commercialization of space is the way forward, and as such the values of the predominant companies in the industry will shape future developments. This means that the mission statements of companies at the forefront of spaceflight innovation are strong indicators for the future of the field. For example, the SpaceX mission statement is "to revolutionize space technology, with the ultimate goal of enabling people to live on other planets" (Pereira, 2023). Part of this mission is to facilitate more cost effective spaceflight, which they aim to accomplish in several ways. Primarily, they place a heavy emphasis on vehicle reusability which in turn allows for more launches to happen in a shorter period of time. This supports the company's goal of "Making Humanity Multiplanetary" because interplanetary colonization would require an immense amount of resources and launches (SpaceX, n.d.). While ambitious, the promise of interplanetary travel is novel and exciting, and it's how SpaceX is able to capture the attention of the American public. Blue Origin takes a somewhat similar approach, stating that their mission is to "reduce the cost of access to space, harness in space resources, and inspire the next generation to enable millions of people to live and work in space for the benefit of Earth" (Blue Origin—Blue Origin Work Culture, n.d.). The primary difference between the companies is that Blue Origin appeals more directly to those who are interested in participating in space tourism, which is another novel and exciting idea for many. Sustainability and reusability of vehicles is also heavily emphasized by both SpaceX and Blue Origin (Blue Origin—About Blue, n.d.). Reusable systems have been considered and successfully implemented in the past, but there are specific challenges with reusable systems that are absent from traditional expendable systems. The switch in focus to reusable systems by private companies combined with NASA's current heavy reliance on such companies indicates that reusable launch vehicles will become much more prevalent as spaceflight technology continues to progress. This is significant because it shows that spaceflight technology is moving towards possible stabilization in favor of reusable systems, which have not historically been the industry standard. A shift towards new technology presents new concerns, however, and the spaceflight industry must be equipped to address them.

Design Considerations

The changing nature of spaceflight in response to social group demands has resulted in a shift in perception of important system qualities. For example, if a company wants to complete several launches in a short amount of time, it is important for the chosen launch vehicle to have a short build to launch period. Similarly, if the goal is to launch humans into space, safety and reliability become more important. It is up to the social groups, particularly the users and producers, to decide what features of a launch system are the most important for a given mission. As such, systems that already exist have their own strengths and weaknesses. For the sake of this analysis, space launch systems will be separated into two categories mentioned previously: expendable launch systems (ELVs) and reusable launch systems (RLVs). While the development and use of RLVs brings excitement to the field, there is still work to be done to ensure the safety and reliability of such systems.

In order to contextualize the choices that need to be made by various social groups, it is important to understand the difference between the types of launch systems. ELVs are a family of launch vehicles which are single use, as the name implies. They typically consist of different stages that allow for sections of the craft to be discarded during launch as a method of saving fuel. In most cases, ELVs are developed from some form of ballistic missile, and compared to RLVs, are cheap to produce (NASA, 2013). Generally, ELV designs are fairly simple, which is an important factor in reliability. They make up most of the rockets that NASA has used throughout its history of operation, with applications ranging from the moon landing to regularly scheduled ISS resupply. RLVs such as the Space Shuttles, despite the name, are not entirely comprised of reusable parts. Rather, they typically include some pieces that are recovered after launch and refurbished to be used again, though there are some components that are discarded, much like with ELVs. The Space Shuttles consisted of a reusable orbiter and solid rocket boosters, but had an expendable external propellant tank (NASA, 1976). Booster stages are the most commonly reused parts of modern RLVs. For example, in the Falcon 9 produced by SpaceX, the booster can reportedly be used over 10 times (Brown, 2023). Such is the case with other systems as well, such as the EU funded MESO launcher, which also reports a first stage with similar reusability (Trifa et al., 2023). Because these systems do not have to be built entirely from scratch every time, RLVs are an attractive option for cheaper launches with relatively fast turnaround times.

Within the current and future states of spaceflight technology, there are many specific features and constraints that are being demanded by social groups. In a technical report published by NASA in 2000, cost and risk were both identified as significant design parameters that should hold a similar amount of weight as technical design requirements. Despite the age of this report, the introductory information holds, as it comments on the most fundamental parts of the design process rather than any specific technology that was available at the time. In general, any new launch system would need to reduce the cost of access to space in order to be a viable option, and the level of risk that comes with launch should either be maintained or decreased (Christenson et al., 2000). From the perspective of users, the lower per-launch cost of RLVs is significant because of this desire. To quantify the difference between ELVs and RLVs in this space, launching one RLV (Falcon 9) rocket costs between $51-65 million, while a comparable ELV (the Antares) costs between $86-92 million per launch (Roberts, 2022). However, the economic viability of an RLV is contingent on whether or not the reusable parts can be recovered and refurbished. If an RLV is unable to fulfill its purpose of being reused, the ultimate goal of reducing the cost to access space is not met.

With more demand for launches and more excitement surrounding human spaceflight, RLVs may seem like an obvious frontrunner for launches because of their cost and time effectiveness. On the more technical side, however, due to the strenuous conditions of spaceflight, there are many other design considerations that need to be made. Namely, the craft needs to have robust thermal and propulsion systems, and the reusable parts need to remain intact upon landing. During reentry, vehicles are prone to extreme degradation due to heat. There are various ways that degradation can occur, including pyrolysis and ablation, in which a material loses mass through carbonization, and the carbonized material is removed from the surface to reveal more material underneath (Lachaud et al., 2011). In any case, material is being removed. This can sometimes be a conscious design choice, as is the case with ablative thermal protection systems. Another consideration is propulsion systems. With reusable systems, cyclic loading becomes a concern. Some amount of stress is applied to the engine each time, causing creep and fatigue that can lead to failure (Qi et al., 2022). Additionally, reusable parts need to be able to make soft landings. This technology has been successfully demonstrated by both SpaceX and Blue Origin (SpaceX Returns, 2015). It is absolutely critical that these effects are tested thoroughly and well understood because of just how catastrophic spaceflight accidents can be. Because critical designs such as thermal protection systems and propulsion systems are subject to further degradation with each successive launch, there needs to be a rigorous refurbishment process that thoroughly checks each system for wear. There also needs to be a limit set for how much wear is too much, but at least in the cases of the Falcon 9 and the MESO launcher, it appears that that limit has been established. From the perspective of designers, there is still lots of work to be done before RLVs become the most widely used technology. At a material level, technology is not quite where it needs to be in order to facilitate reliable and safe spaceflight on reusable systems. Reliability issues will only become worse as the launch systems increase in size, which will be necessary for ventures such as interplanetary travel. Progress is being made, but according to MIT professor Zack Cordero, “there is a real, underappreciated risk that these new heavy lift launch vehicles will continue to fail unless there are fundamental advances in materials technology” (Brown, 2023).

In summary, stakeholders have lots of different considerations to make when designing or using spaceflight systems. Given the goals of companies, such as SpaceX and Blue Origin, to provide more frequent and less expensive access to space, it makes sense that they would prioritize the development of reusable systems (SpaceX, n.d.) (About Blue, n.d.). The tradeoffs that come with frequent and less expensive launches, however, need to be mitigated to ensure acceptable safety and reliability, especially within the realm of human spaceflight.

Conclusion

The spaceflight industry is seeing an ever increasing trend away from the use of ELVs, which have been the types of systems traditionally used for launch. Using SCOT to investigate this situation, this change makes sense. Since the inception of the spaceflight industry, the relevant social groups have seen significant change. The user base for such systems expanded from government entities like NASA to other producers–commercial companies such as SpaceX and Blue Origin. While NASA's primary goal has been and continues to be furthering human capability of conducting science in space, the inclusion of commercial entities has initiated a slow shift in focus from solely scientific endeavors to decreasing the barrier for entry to space, both in terms of cost and time. This is beneficial for several reasons, such as the facilitation of new and exciting missions to places like the moon or Mars, but could also set a dangerous precedent. Concerns about safety and reliability of reusable systems have been expressed by experts, such as the previously mentioned Doctor Cordero at MIT (Brown, 2023). Spaceflight is and always has been a dangerous endeavor, and when human lives are on the line, even more special care should be taken to ensure safety and success. One recommendation to mitigate this would be to use RLVs for uncrewed missions and ELVs for crewed missions. That way, users can still benefit from the lower cost and build to launch time while still having the reliability necessary to safely send people into space. A potential downside of this method would be that human spaceflight would more or less go at the same pace as it has in the past, but that is a small price to pay for human life.

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