Surborbital Space Tourism: A Case Study on Virgin Galactic and the Environmental Impacts of the Emerging Industry

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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

Background

Traveling to space was once a privilege reserved for the best of the best: highly trained test pilots and mission specialists were at the forefront of human space exploration through federal programs, such as Gemini, Apollo, and the Space Shuttle. The first astronauts were either hand-picked from military personnel or required to have a doctorate in medicine, engineering, or a natural science such as physics, chemistry, or biology. Even if one meets this requirement, NASA only selects "a small group of the most highly qualified candidates for interviews", and half of those make it to the second round (Bowman, n.d.). Finally, NASA selects the class of astronauts from those who made it past the second round, where they undergo rigorous training to get them prepared for space flight. Even then, it takes two years to complete astronaut training before they can become an astronaut allowed to fly to space. Combining the degree requirements, work experience, and training period, it takes nearly a whole decade for someone to fly to space under NASA. For several decades, going through the NASA pipeline was the only feasible way to go past the edge of Earth's atmosphere. However, a few new pathways and doors have opened to people interested in traveling to space.

Now, experiencing weightlessness, viewing the Earth from afar, and traveling to the moon is becoming more accessible through technological advancements. Many companies, ranging from startups to new leaders in the space industry, are offering different ways to travel beyond the Earth's atmosphere. Some companies employ a large rocket, while others utilize a spaceplane to travel in a parabolic path for a few minutes of weightlessness (Sampson, 2023). Regardless of the methodology, space doesn't seem so far away anymore. It's as simple as buying an expensive spot on a launch vehicle and waiting until the mission date. The accessibility of space stemmed from

an increased trend of space launches in the United States. US launches increased nearly 150 percent between 2018 and 2022, which is in part due to the larger presence that the commercial sector has in the space industry today (Semanik & Crotty, 2023). While all of this is exciting and paves a new path for humanity, an important consequence is commonly overlooked: The environment.

Considering the environmental effects of an increased trend in space launches spurred by the commercial sector is crucial because launch vehicle propulsion systems have a history of harming the Earth's atmosphere. Currently, the commercial space industry is investing much more capital than the federal sector. In 2021, an estimated $469 billion was spent in space-related activities globally. 48% of that spending was from commercial space products, 29% came from commercial infrastructure and support industries, while the rest of the 23% was from both US and non-US governments (Space Foundation, 2022). This trend highlights the significance of exploring the effects of these space launches. One consequence of a rapidly advancing space industry is the impact chemical propulsion has on climate change. Two main exhaust products are the contributors to the greenhouse effect: black carbon, a product of LOx/kerosene fuels, and alumina particles, a product of solid propellants. Black carbon, more commonly known as soot, is an extremely dangerous contributor to global warming because it traps more heat than CO2 and alumina particles. Having 1000 launches annually would cause the impact of the space industry on climate change to be comparable to the airline industry (Dallas et al., 2020). A combination of the rapidly increasing commercial space sector and, if left unchecked, the potentially dangerous effect on the environment underlines the importance of exploring the role and contribution of the emerging space tourism industry.

Scoping Through Science, Technology & Society

The rest of the paper will discuss the importance, history, and future of space tourism, highlight the potential environmental impact of this new industry, and provide recommendations on regulations to limit the harm on Earth without barring technological innovation and growth. For this paper, "space tourism" will be the suborbital, orbital, and interplanetary travel for leisure, recreation, or business purposes. Furthermore, a case study is conducted on Virgin Galactic, a leading company in the space tourism industry, while focusing on an overarching question: **What are the consequences of increased space activities spurred by the rise of space tourism on Earth's atmosphere and the global environment, and what are Virgin Galactic's contributions and mitigations of these environmental consequences?** Then, I use a Science, Technology & Society (STS) framework known as Technological Momentum to guide the research topic. Next, I explore the current state of the space tourism industry and how it evolved since its conception. After laying out the background information on space tourism, the section continues to describe the details and concept of operations of Virgin Galactic to prepare for a case study on the space tourism company. After, I review its launch vehicle under the Technological Momentum framework by introducing more key groups that influence the technology. Finally, I discuss the direction of the space tourism industry and recommendations for regulations enforced by commercial and federal entities. Through gathered data and thorough analyses, I show that the rise of space tourism is inevitable, especially with the involvement of the commercial sector, meaning that environmental regulations should be in place to reduce the harm that launch activities have on the Earth.

Methods

The overarching STS framework that will drive the rest of my research analysis is Technological Momentum introduced by Thomas Hughes in 1987. The framework states that

technologies “can be both causes and results of social change, but the bigger and more complex they become, the more inclined they are to form society” (Vermaas et al., 2011). The relationship between society and technology is time-dependent and reciprocal, meaning that they both influence each other at some point. Usually, either society influences technology or technology influences society. I prove that the public is currently molding the launch vehicle technology, specifically through the lens of space tourism. The STS research topic works greatly with the Technological Momentum theory because of the evolution of the space industry over several decades.

In my STS research paper, I examine the consequences of increased space activities from the rise of space tourism on Earth’s atmosphere and the global environment, with a specific focus on Virgin Galactic's contributions and mitigations of these environmental consequences. This relates to the research question proposed in the introduction which will guide the rest of this paper. I will use scientific data collection, an analysis of the data, a case study, and an environmental assessment before proposing recommendations for space tourism companies to answer the research question.

I collected data for this research through a comprehensive review of scholarly articles, research papers, industry reports, blogs, and news articles related to the space tourism industry, Virgin Galactic, and environmental impact assessments. Analyses of market researchers provided data on the past and present of the space tourism industry. A case study of Virgin Galactic explores its concept of operations and space technologies, which include current vehicles for space tourism, launch sites, and frequency of flights. Then, I gathered data from research papers analyzing the same or similar technologies that Virgin Galactic is employing. These sources provide multiple insights into various aspects of the space tourism industry, including market trends, technological

advancements, environmental implications, and business strategies. By combining information from several sources, I highlight the complex relationships between technology, society, and the environment in the context of space tourism.

After data collection, I used an analytical approach in this study by exploring historical trends, market dynamics, technological innovations, and environmental considerations within the space tourism industry. Furthermore, I analyzed the current standing of the launch vehicle within the Technological Momentum framework, signifying the relationship between space and society. The environmental data on similar technologies that Virgin Galactic uses is implemented in an environmental assessment of its current concept of operations. By gathering and analyzing currently available data, I provide a comprehensive assessment of the space tourism industry, the environmental impact of increased space activities, and Virgin Galactic's role in mitigating these consequences.

After a thorough analysis, I examine the potential future of the growing space tourism industry through market trends, highlighting the significance of this issue. Then, I provide recommendations for enhancing the sustainability of crewed launch vehicles and space tourism operations, specifically for Virgin Galactic and for the space industry. Many of these proposed regulations will come from the future of the space tourism industry and the scientific evidence of the environmental implications of launch vehicles. While environmental preservation is important, technological progress is significant as well, so the recommendations are tailored to spur competition and innovation within the industry. By offering reasonable laws and regulations, my STS thesis introduces updated space policy and industry practices. Ultimately, these recommendations will address environmental concerns, mitigate potential risks, and spur innovation in the design, deployment, and management of infrastructure in the space industry.

Results

Growth of Space Tourism

Space tourism as a concept has been around since the Space Shuttle missions with limited support from the federal sector and at a very high price, even for the most recent government-sponsored events. As early as the 1970s, Rockwell International, the prime contractor for the Space Shuttle program, studied a passenger cabin as the payload for the Space Shuttle with an expected cost of about $200-$300 million (Citron, 1985). Figure 1 displays early conceptual designs of an integration between the passenger cabin and the Space Shuttle.

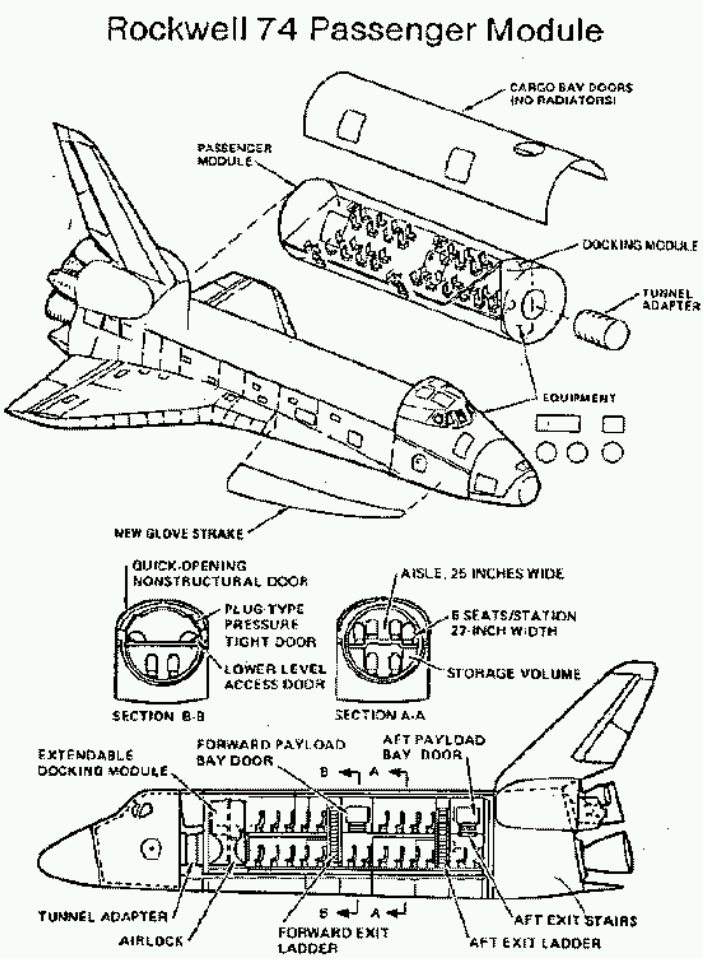

Figure 1: Conceptual Design of Space Shuttle Passenger Cabin

Although there has been interest in space tourism since the late 20th century, the first set of space tourists didn't come until the early 2000s. From 2001-2009, Denis Tito, Mark Shuttleworth, Gregory Olsen, and many other millionaires traveled to the ISS for upwards of $20 million for each trip, which consisted of several days (Seedhouse, 2024). Outside of a flight to the ISS in 2021, there haven't been other space tourism trips with an orbital trajectory past 2009, and suborbital ventures aren't available from a government body (Seedhouse, 2024). Still, the government is an important entity that influenced the reusability aspect of space tourism launch vehicles with the Space Shuttle, while also opening the doors for the commercial sector through legislation.

The current scene of space tourism traces back to inspirations from previous space tourism feats supported by the government and the introduction of the commercial sector in the space industry. After witnessing space tourists reaching the ISS, many companies attempted to make space tourism a profitable service by focusing on suborbital trajectories. The competition was further spurred by the Ansari X Prize that awarded $10 million to the first nongovernmental organization to launch a reusable crewed spacecraft into space within two weeks. In 2004, a launch vehicle designed under Virgin Galactic called SpaceShipOne won the X Prize, introducing a new era of space tourism (Seedhouse, 2024). The commercial sector had even more support from the government highlighted by the *U.S. Commercial Space Launch Amendments Act* (CSLAA), which provided guidelines for regulating the safety of commercial human spaceflight (Seedhouse, 2024). Another important act is the *U.S. Commercial Space Launch Competitiveness Act* which "promotes commercial space launches and reentries by the private sector" by "eliminating duplicative requirements and approvals for… operations" (U.S. Commercial Space Launch Competitiveness Act, 2015). This bill set the stage for many

commercial companies to grow ultimately leading to more space tourism opportunities. SpaceX's Inspiration4 mission in the Dragon capsule and Blue Origin's New Shepherd launch vehicle are both examples of orbital and suborbital missions for space tourism sponsored by companies benefitting from the *U.S. Commercial Space Launch Competitiveness Act* (Seedhouse, 2024). Many commercial companies, especially Virgin Galactic, have influenced and continue to influence the launch vehicle for space tourism purposes thanks to support from the government and wealthy adventurers.

Virgin Galactic's Role

The case study revolves around Virgin Galactic because of its focus on space tourism from its founding and the similarities of its launch vehicle to earlier concepts of space tourism. An annual report from Virgin Galactic to the U.S. Securities and Exchange Commission (SEC) describes its mission of "flying passengers to space as tourists" for an experience that includes several minutes of weightlessness (Virgin Galactic Holdings, Inc., 2021). The emphasis on "tourists" outlines its focus on space tourism, which is dissimilar to SpaceX, Blue Origin, and others that tend to have space tourism as a byproduct of their services and products. Furthermore, the description of several minutes of weightlessness points to the use of suborbital trajectories instead of orbital paths that usually have several days of weightlessness. Virgin Galactic's mission and current business model make it a viable option for a case study on the increasing space tourism industry.

A deeper dive into Virgin Galactic's concept of operations reveals the potential effect that space tourism could have on the environment. Currently, Virgin Galactic uses two main vehicles for its space tourism service. The first one is a rocket-propelled spaceplane called the VSS Unity

that uses a hybrid rocket engine, as shown in Figure 2. The solid fuel is hydroxyl-terminated polybutadiene (HTPB) while the oxidizer is nitrous oxide (N_2O) (Sampson, 2023).

Figure 2: VSS Unity During a Test Flight

Virgin Galactic manufactures another vehicle known as White Knight Two, which is a carrier aircraft. White Knight Two carries VSS Unity to an altitude of 15 km above sea level before releasing the spaceplane which then begins its flight to above the Karman line (100km above sea level). VSS Unity then glides down back to Earth before landing on a runway, similar to the Space Shuttle that inspired the very beginnings of space tourism (DeSisto, 2023). Virgin Galactic is an amazing choice for a case study due to its unique business model and execution of space tourism services. In the upcoming section, I examine Virgin Galactic's environmental impact, emphasizing its propulsion system while assessing government regulations and societal opinions that shape the space tourism industry within the Technological Momentum framework.

Analysis

Virgin Galactic's Sustainability

Virgin Galactic's current concept of operations negatively impacts the ozone layer and contributes to global warming but is less environmentally harmful than traditional expendable launch vehicles due to the company's reusable spaceplane and mothership. As mentioned before, the main components of the rocket engine are HTPB, a solid fuel & hydrocarbon, and N_2O, the liquid oxidizer. The leading environmental concern of launch vehicles is the local and global ozone depletion that stems from the propellant, which could lead to increased exposure to dangerous UV radiation. A study on solid propellants, including HTPB, revealed that there was nearly 100% local ozone depletion over an 8km exhaust plume 30-60 minutes after launch. After a few days, the ozone layer does approach normal rates, but pockets of depletion remained. Global atmospheric models for solid propellants unveiled a 0.25% annual ozone depletion based on 9 launches per year (Dallas et al., 2020). Furthermore, the nitrous oxide oxidizer used in VSS Unity can deplete the ozone layer. When excess N_2O diffuses in the stratosphere, it breaks down on a molecular level due to light and reacts with oxygen to produce nitric oxide (NO). This then contributes to the ozone (O_3) destruction cycle (Kramlich & Linak, 1994). Based on several studies, the hybrid fuel choice of the VSS Unity contributes to global warming, especially as the engine burns in the upper atmosphere.

Although Virgin Galactic's current concept of operations contributes to ozone depletion and climate change, the reusability aspect of VSS Unity and White Knight Two were heavily influenced by society, specifically through government and commercial programs. Currently, the engines on the White Knight Two motherships are "compatible with sustainable aviation fuel (SAF)… [and they] are currently assessing opportunities to integrate SAFs into future flight operations" (*Virgin Galactic - ESG*, 2024). According to the Department of Energy, SAFs are an alternative fuel made from non-petroleum sources, which is beneficial to the environment,

showing that Virgin Galactic's technologies are directly influenced by federal entities. Virgin Galactic is even taking advantage of incentives in the commercial sector through purchasing CO_2 offset credits through ClimateCare (*Virgin Galactic - ESG*, 2024). CO_2 offset credits are certificates provided by a profit-for-purpose company called ClimateCare representing the reduction of carbon dioxide emissions from the atmosphere through investments in environmental projects or activities (*Carbon Offsetting*, n.d.). This is another example of society influencing Virgin Galactic's operations as they must work around meeting carbon emission expectations. Virgin Galactic is obviously influenced by the government and commercial companies, highlighting the role that both entities have in influencing their launch vehicle under the Technological Momentum framework.

Virgin Galactic is meeting expectations to reduce emissions from a federal scope, but there is still room for improvement as shown by the studies on propellants mentioned earlier. Although Virgin Galactic follows federal regulations, it is difficult to quantify the detailed emissions that Virgin Galactic has because they are in the process of "disclos[ing] an emissions profile" (*Virgin Galactic - ESG*, 2024). The lack of data raises some questions regarding their impact on the environment that cannot directly be answered now: Does their current fuel source significantly impact the environment? Is the frequency of their flights negatively affecting the ozone layer? Moving on from these unanswered questions, I will explore how multiple factors and entities influence space tourism companies and their operations under the Technological Momentum framework.

Current Mitigation Efforts

Although many companies are making intelligent design choices for reusability, a lack of federal environmental regulations on commercial space activities and pushback from society

shows that the space tourism industry, if left untouched, could be an unnecessary risk to our environment. Currently, a mixture of outdated international treaties and ineffective national policies surrounding the commercial space industry requires updated legislation to protect the Earth. Many international agreements on space activities, including the Liability Convention of 1971, don't emphasize environmental protections for the Earth and beyond. Furthermore, U.S. federal entities fail to ensure that commercial companies involved in space tourism are doing everything they can to prevent irreversible effects on the environment. The 2001 Guidelines for Compliance with the National Environmental Policy Act and Related Environmental Review Statues for the Licensing of Commercial Launches and Launch Sites released by the Federal Aviation Administration (FAA) and the Associate Administration for Commercial Space Transportation (AST) simply requested companies to research their impact on the atmosphere and to mitigate these impacts. It is a step in the right direction, but it fails to incentivize commercial companies, who are simply trying to make a profit, to minimize the environmental consequences of their services (McCue, 2022). It's important to pass more policies and laws to be effective in regulating the environmental effects of a growing space tourism industry. The federal sector is incredibly influential in launch vehicle technologies through previous legislation along with potential future policies, further proving that society is currently molding this technology.

Outside of the government, several environmental organizations have already started to criticize space tourism which could influence launch vehicle technologies by legislation passed through lobbying efforts. There are several articles from the Sierra Club, the most historic grassroots environmental organization in the United States, that disapprove of space tourism companies' services and business models. Jeremy Miller from Sierra highlights that Virgin Galactic and Blue Origin are solely aiming to make money from their several hundred thousand

dollar launches targeting ultra-wealthy people looking for extravagant adventures (Miller, 2021). Additionally, Holly Haworth, another Sierra author, emphasizes the irony of the billionaire CEOs of Blue Origin and Virgin Galactic taking joyrides to space in 2021 while "Death Valley reached 130 degrees Fahrenheit, the hottest temperature on Earth ever recorded", that same year (Haworth, 2021). The environmental impact of the current space tourism industry from an individual's standpoint is even more devastating. Currently, a Virgin Galactic flight is equivalent to a ten-hour trans-Atlantic commercial air flight in terms of carbon emissions. With a maximum capacity of six people, that equates to 4.5 tons of carbon per person (Moore, 2023). Although environmental organizations are condemning space tourism, their protests have only amounted to increased discussions on the topic instead of effective regulatory legislation, but they could influence what the launch vehicle for space tourism looks like with more momentum.

The most important question that arises under the Technological Momentum framework is whether a technology is *influenced by* or *influencing* society. A diagram showing all the actors within the framework is shown in Figure 3. An arrow pointing from A to B signifies that A is *influencing* B, and bi-directional arrows show a mutual relationship. Text is provided to show how each actor is influenced.

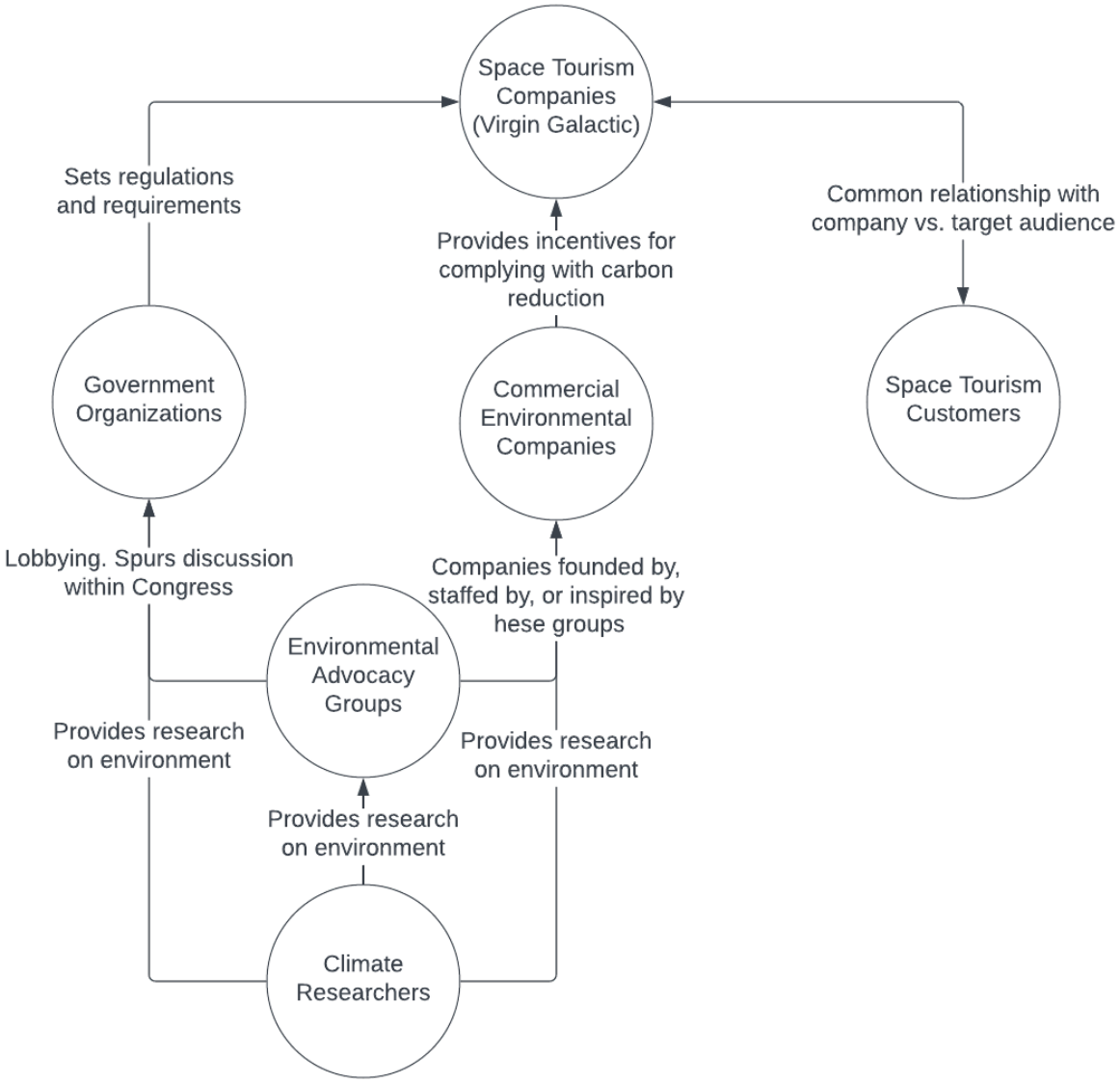

Figure 3: Relationships of Each Entity Involved in Space Tourism

As shown in the figure, there are plenty of groups that influence space tourism companies and their technologies & concept of operations. Under the lens of Technological Momentum, launch vehicles for space tourism are currently being *influenced by* society, showing that it is a relatively young technology. Now, it is important to look ahead and see what the future may hold for space tourism launch vehicles.

Discussion

Future of Space Tourism

Technological innovation and a viable end-user base push the space tourism industry to grow with suborbital tourism services leading the path while regulations could affect the market the most. A market analysis report done by Grand View Research, a reputable business consulting firm, highlights the significant projected growth of space tourism. In 2023, the global space tourism market had a value of $851.4 million, and Grand View Research predicts an increase at a compound annual growth rate (CAGR) of 49.9% from 2024-2030. A combination of innovative launch services, ultra-wealthy individuals interested in space travel, and investments from government and private entities has been the driving factor in this growth (Grand View Research, 2023). Figure 4 shows the estimated growth of space tourism separated by sub-orbital, orbital, and other flight trajectories.

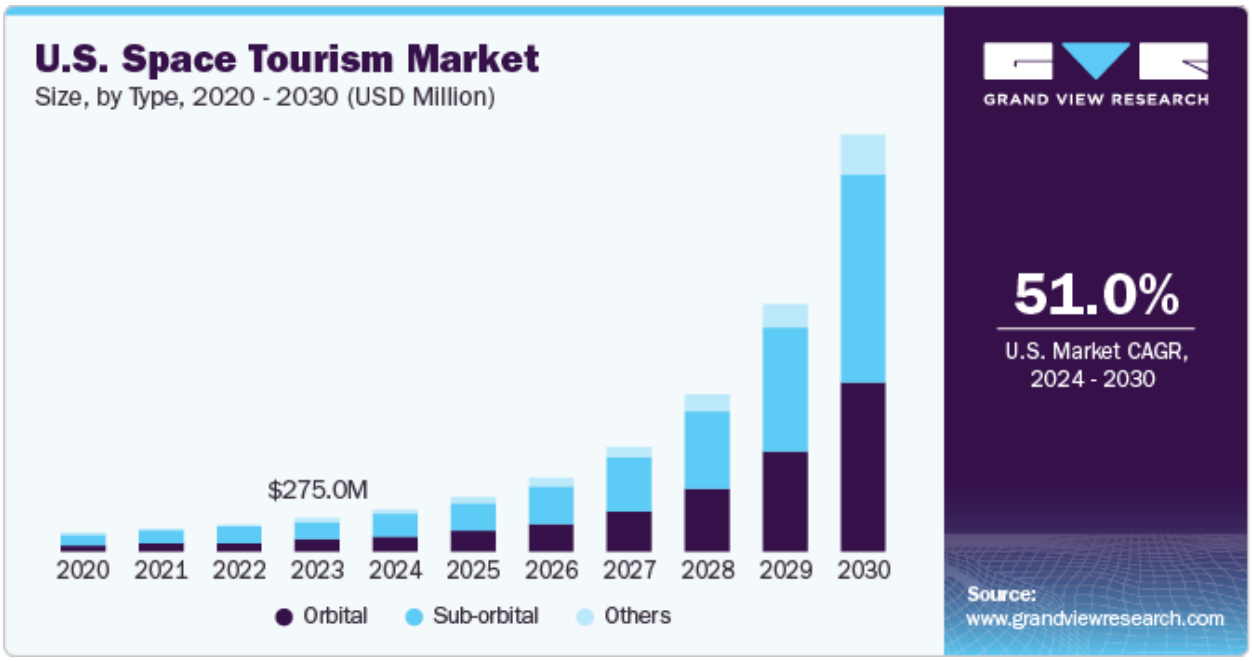

Figure 4: Project Market Trends for Space Tourism by Category

The space tourism industry is not a temporary venture signifying the importance of understanding possible venues to prevent launch activities' adverse effects on the environment. The most effective way to mitigate the environmental consequences of an unrestricted space tourism industry is to implement balanced federal regulations. Currently, the U.S. government is attempting to apply effective legal frameworks that can protect the public interest while promoting innovation (Grand View Research, 2023). The Grand View Research market analysis emphasized the impact of regulations on the space tourism market, shown below in Figure 5.

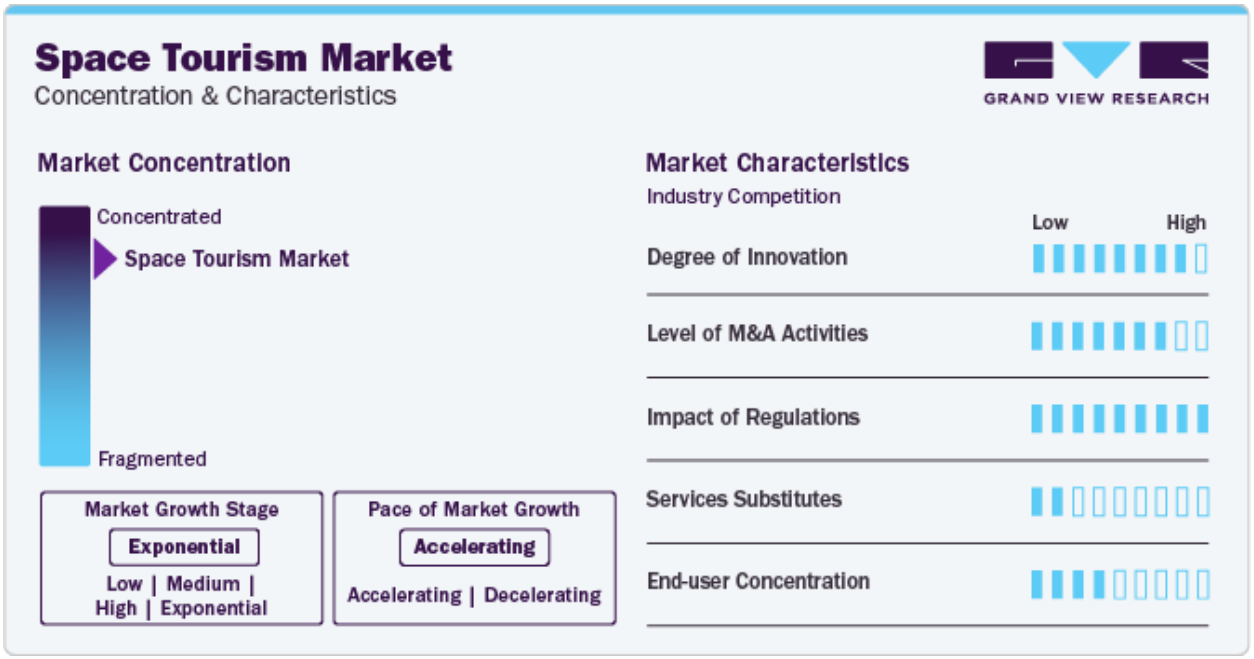

Figure 5: Concentrations & Characteristics of the Space Tourism Industry

The following section recommends some possible legislation or regulations to incentivize protecting the environment without hindering technological innovation.

Potential Future Regulations

All the potential environmental consequences of the rapidly growing space tourism industry spur the need for both direct and indirect regulation of propellants and launches. First, taxing the

use of solid propellants and propellants with heavy soot emissions that directly cause severe ozone depletion and contribute to climate change would protect the environment (Novikov et al., 2019). Next, incentivizing companies that use green hydrogen fuel (hydrogen sourced from electrolysis) through capital would push the industry in the right direction. Green hydrogen fuel with liquid oxygen as the oxidizer has the least environmental impact due to the exhaust being water vapor (Dallas et al., 2020). Regulating harmful chemical propellants and encouraging the use of sustainable fuels will prevent space tourism from negatively impacting the Earth. Outside of the fuels, the structure of the launch vehicles themselves must meet certain expectations before launching. Having a concentrated drop zone for stage separations will prevent widespread ecological toxicity and make clean-up easier. Currently, there are little to no restrictions on the size of the drop zone (Novikov et al., 2019). With these restrictions, certain stakeholders are bound to rely on creativity and innovation to work around the regulations. Regulations on the end-user base weren't recommended because it doesn't seem realistic enough to garner proper support within Congress. Barring ultra-wealthy individuals from space while only allowing scientific/research ventures would be extremely effective in reducing unnecessary harm to the environment, but it would be difficult to propose to profit-prioritizing companies. Although regulations may be restricting, they are necessary to prevent the space industry from becoming a bigger environmental problem in the future, and these restrictions could even spur innovative technologies.

The regulations above are not meant to be all-encompassing whatsoever, and more conversations between commercial space companies, environmental organizations, and the U.S. government are necessary to implement long-lasting, effective legislation. The environmental consequences of space tourism, specifically ozone depletion and global warming, signify the need

for mitigation strategies. While the commercial space sector expands through innovative systems and government & public support, the lack of updated environmental guidelines poses significant risks to the Earth's atmosphere. Virgin Galactic reflects the excitement and significance of the new market as a leading player in the space tourism industry. Its unique, reusable approach to space travel is a step in the right direction for sustainable space tourism. However, VSS Unity's propulsion system contributes to ozone depletion and climate change, highlighting the urgent need for programs that incentivize environmental protection. Under Technological Momentum, launch vehicles, such as the VSS Unity, are being morphed significantly by society in a triangular manner as the public pressures the government through environmental organizations, Congress passes legislation that affects the commercial sector, and private companies conform to the regulations while appealing to their target audience. By embracing sustainability, humanity can enjoy accessible spaceflight without harming the one planet we call home.

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