STUDENT RESEARCHED AND DEVELOPED HIGH POWERED ROCKET

SUBORBITAL SPACE TOURISM: A CASE STUDY ON VIRGIN GALACTIC AND THE ENVIRONMENTAL IMPACTS OF THE EMERGING INDUSTRY

A Thesis Prospectus
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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

As space is becoming more accessible with revolutionary technologies, a new industry has started to emerge: space tourism. This prospectus introduces a scientific project and a Science, Technology, and Society (STS) paper that relate to space sciences and space tourism. First, the technical paper will explore the design, implementation, and testing of a student-researched and developed (SRAD) solid propulsion system to launch a rocket with a payload to 5,000 ft. above ground level (AGL). Additionally, it will dig deeper by exploring the project management aspect of turning a project objective into a tangible product while meeting requirements and mitigating risks associated with the manufacturing and testing of a rocket motor. Understanding the intricacies of a rocket engine and engineering project management will better contextualize the environmental effects of propulsion systems.

The prospects of space tourism, while exciting and revolutionary, raise urgent questions about the long-term consequences and sustainability of this industry. I will define space tourism as suborbital, orbital, and interplanetary travel for leisure, recreation, or business purposes. The STS investigation will hone in on the local and global environmental consequences of the rapidly growing space industry that is being accelerated by space tourism. To narrow the scope, I will do a case study on Virgin Galactic while focusing on the 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?** I chose Virgin Galactic for the case study due to its unique concept of operations and its role as the world's "first commercial spaceline" (Virgin Galactic, 2022). Through the research question, I am hoping to reveal overlooked

repercussions of the industry and challenge companies to balance technological advancements, company profits, and environmental sustainability.

Technical Project

Problem Statement

Rocketry has come a long way with multiple applications across several continents before eventually being used to launch humans into space. Now, many hobbyists around the globe compete with their own high-powered rockets and intricate propulsion systems to launch complex payloads several thousand feet into the air. Many of these payloads are in the form factor of a CubeSat, where 1U is a cube measuring 10cmx10cmx10cm (Caldwell, 2023). An example of a launch vehicle carrying a 1.5U boilerplate to a target altitude of 10,000 ft. using a commercial off-the-shelf motor is shown below in Figure 1.

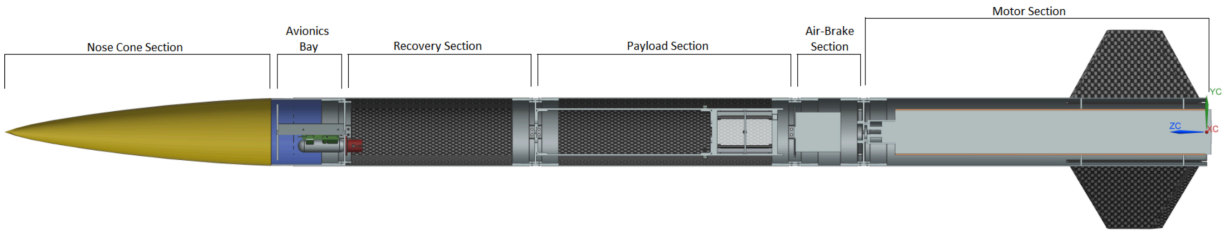

Fig. 1: Overview of the University of Maryland's rocket with a target altitude of 10,000 ft. (Hickman et al., 2021)

The design capstone is tasked with **safely designing, manufacturing, testing, and recovering a high-powered rocket carrying a 3U payload to a target altitude of 5,000 ft.** The class is split into 3 separate teams: Aerostructures, Propulsion, and Mechatronics. As the Propulsion Team Lead, I will be overseeing the development of an M-Class solid propulsion system to launch our rocket to a target altitude of 5,000 ft. Solid rocket motors are separated into several different classes using the alphabet with each letter being twice the impulse range of the

last one (National Association of Rocketry, 2014). A table of several motor classes is listed below in Table I with the M class motor highlighted.

Table I: Motor Classes and Impulse Ranges

Motor Class	Impulse Range (N*s)
I	320.1 - 640
J	640.1 - 1,280
K	1,280.1 - 2,560
L	2,560 - 5120
M	5120.1 – 10,240
N	10,240.1 – 20,480
O	20,480.1 – 40,960

The solid propulsion system that is being developed will be using an Ammonium Perchlorate Composite Propellant (APCP) formula that was slightly altered from MIT's formula known as Cherry Limeade (Fallen, 2021). The capstone project represents a significant leap in rocketry capabilities at the institution. Beyond offering invaluable hands-on experience for undergraduate students, this project has the potential to fill crucial gaps, laying the groundwork for future advancements and enhancing the university's standing in the field of undergraduate aerospace engineering.

Significance of the Project

Historically, the University of Virginia students have not had an extensive history in rocketry research or extracurricular activities, particularly in comparison to established aerospace programs at other institutions. Even the UVA Rocketry Club, founded in 2016, has primarily only participated in local competitions with target altitudes under 4,000 feet. The capstone project, with its objective to launch a glider to a minimum target altitude of 5,000 feet using an SRAD solid propulsion motor, fills an important gap. It not only provides undergraduate students with valuable

hands-on experience in the field of rocketry but also allows the exploration of complex and ambitious projects that were previously beyond the scope of available resources within the UVA Rocketry Club or other courses available at the university. Furthermore, the SRAD solid motor designs, reports, and analyses could be provided to the club for their use in national competitions or as preliminary findings for researchers. As UVA makes progress in this area, it enhances the credibility and status of the university's engineering program.

STS Project

Framework & Outline

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?

Four major topics stem from the question: The rapid growth of the space tourism industry, Virgin Galactic's role in the private sector, the potential local and global environmental effects of their concept of operations, and any pushback and regulations from the government or other entities. I will look at each of these research areas through the lens of the Social Construction of Technology (SCOT) framework while highlighting key sources and recognizing several important social groups. The social groups & key stakeholders are on the following page, along with a graph visualizing the relationships. Starting from the center, Virgin Galactic and its space tourism ventures will be the root of the case study due to their direct contribution in catering to the demand of space tourists. Branching off, space tourists will have a bi-directional connection to Virgin Galactic because the space tourists rely on the company to travel, while Virgin Galactic will rely on the demand to increase its profits. Then, advocacy groups are involved with Virgin Galactic through the environmental consequences of space tourism companies.

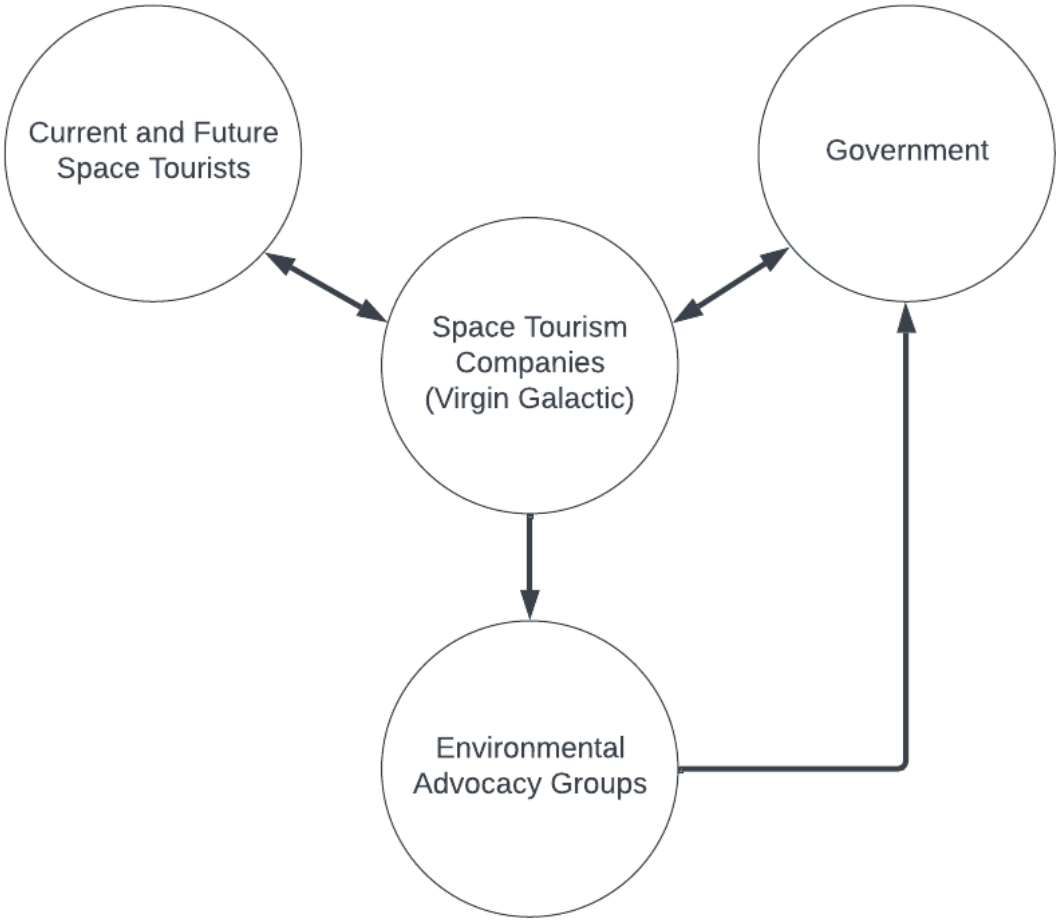

Fig. 2: Relationships influencing the activities of space tourism companies.

These groups are also connected to the government as they push for policies that protect the ecosystem by regulating space tourism companies. Lastly, the government is bi-directionally related to Virgin Galactic due to the regulations that the government may create stemming from environmental advocacy groups or space tourism companies themselves. These aren't the only stakeholders involved in this complex industry. The prospectus will be focusing on the main entities that contribute to space tourism in an environmental context, while purposefully overlooking engineers, scientists, pilots, etc. This will aid in developing a detailed, focused case

study of Virgin Galactic and key social groups in a SCOT framework while leaving room for the exploration of unexplored groups to others.

Growth of Space Tourism

The rapid, continuous increase of the space tourism industry is evident based on several reports and analyses on the market. The expected growth rate of the industry is 40.2% from 2023 to 2030 due to increasing technological advancements, demand from space enthusiasts, and investments from high-income individuals (*Space Tourism Market Size*, 2017). Figure 3 below shows the anticipated increase in the space tourism market size with depictions between suborbital, orbital, and other trajectories.

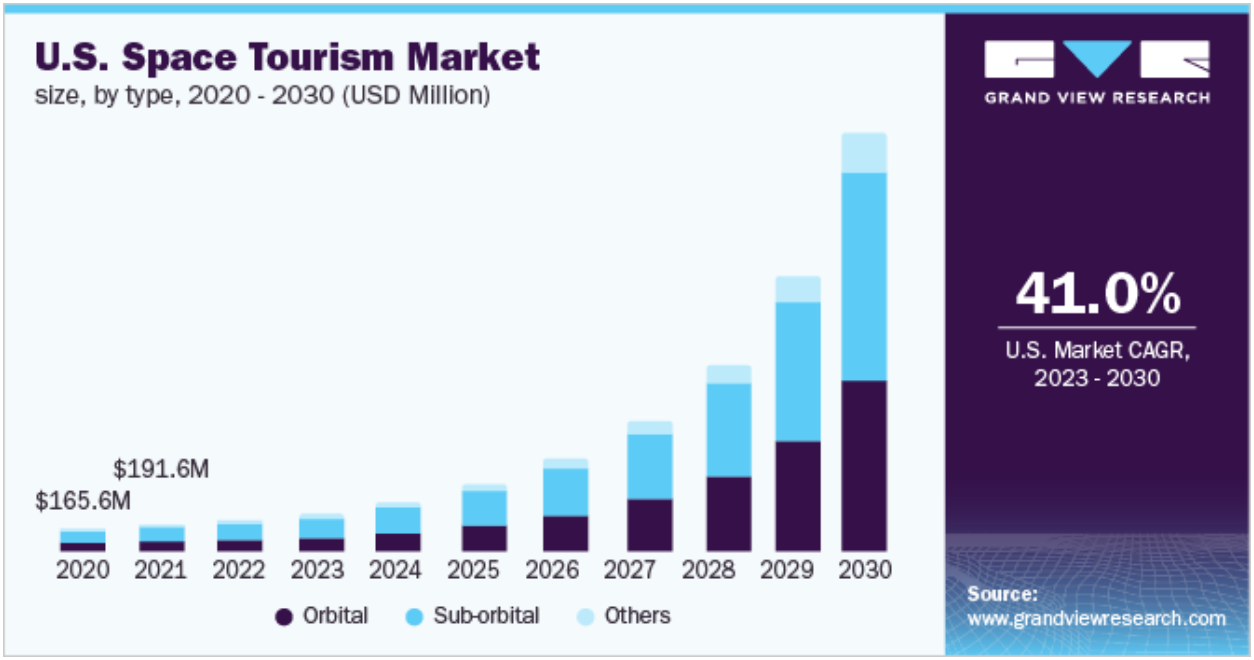

Fig. 3: U.S. Space Tourism's current and predicted market size for the next decade.

My STS project must highlight the eventual expansion of the space tourism industry, which emphasizes the importance of analyzing its positive and negative effects.

Virgin Galactic's Role

Virgin Galactic has a significant position in the space tourism field because of its unique mission statement and concept of operations. Virgin Galactic's mission is to transform access to space for more people than ever before, which is different than other companies involved in space tourism (*Virgin Galactic Holdings, Inc.*, 2021). Virgin Galactic focuses on bringing civilians to space, while SpaceX, Blue Origin, and others tend to have space tourism as a byproduct of their technological advancements. Furthermore, Virgin Galactic has a distinctive concept of operations to get its customers to space. A mothership carries its hybrid engine spaceplane near the Karman line, the edge of space, before detaching and landing. Then, the spaceplane reaches a suborbital path to allow the customers to experience microgravity (Sampson, 2023). An image of the spaceplane's flight path is shown below in Figure 4. Exploring a company whose tackling space tourism head-on with an uncommon solution will enhance the quality and significance of my STS paper.

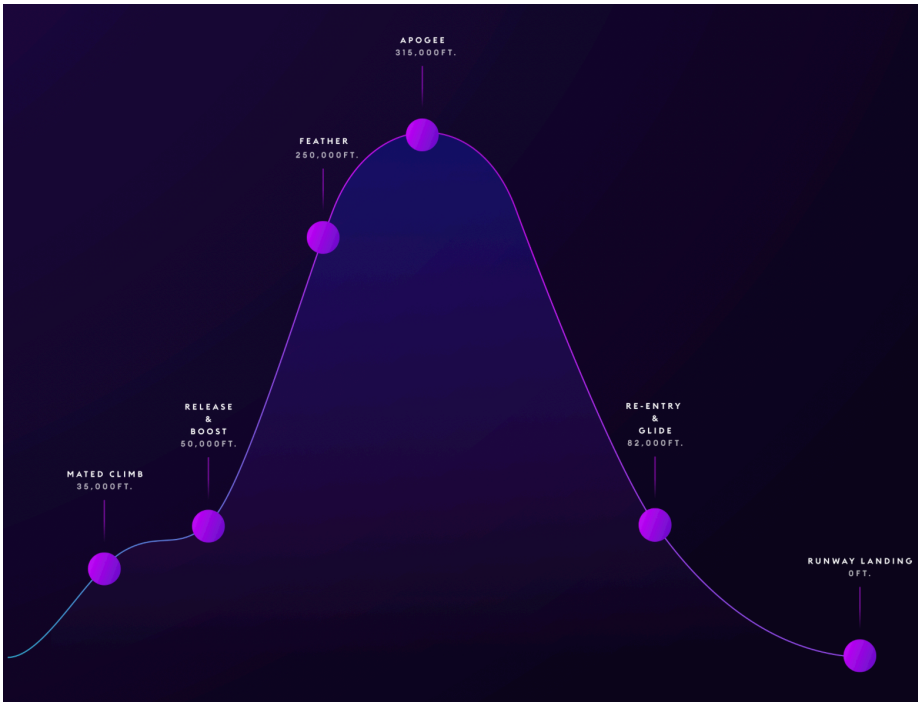

Fig. 4: A simplified overview of Virgin Galactic's space tourism flight path

Environmental Consequences & Advocacy Groups

The growth of space travel and Virgin Galactic's activities have environmental consequences both locally and globally, which are being recognized by environmental advocacy groups. Hydroxyl-terminated polybutadiene (HTPB), the main fuel source of Virgin Galactic's spaceplane, has a relatively large impact on ozone depletion, climate change, and acid rain in the vicinity of a launch (Dallas et al., 2020). These negative effects have garnered the attention of environmental advocacy groups, such as the Secure World Foundation, an organization aiming to "achieve the secure, sustainable, and peaceful uses of outer space benefitting Earth and all its people" (2021). After Virgin Galactic founder Richard Branson experienced weightlessness for the first time, a writer from Sierra Club, a grassroots environmental organization, criticized this achievement by claiming that "traveling in rockets is arguably the most carbon-spewing thing an individual can do" (Haworth, 2021). These environmental advocacy groups play a pivotal role in regulating space activities, including space tourism.

Significance of the Case Study

It is becoming increasingly important to explore the potential outcomes Virgin Galactic as a space tourism company may have for the environment and other stakeholders. Virgin Galactic will be the first of many companies solely focusing on space tourism, so it's necessary to weigh the risks and rewards of space tourism to determine whether the services outweigh the environmental harm. If the benefits of the service outweigh the impact it has on Earth, then these companies must minimize the damages they cause. The case study will reveal important information on the risks of space tourism and raise awareness of important policies that could prevent a hasty, harmful race to space contributing to increasing carbon emissions & ozone depletion.

Key Texts & Timeline

US Commercial Space Launch Competitiveness Act of 2015

The US Commercial Space Launch Competitiveness Act of 2015 highlights the shift of the space industry from the federal sector to the private sector where space tourism was born (U.S. COMMERCIAL SPACE LAUNCH COMPETITIVENESS ACT, 2015). This will be pivotal in setting the stage for the birth of space tourism.

Virgin Galactic Holdings, Inc's Annual Reports

Another useful text an the annual report that Virgin Galactic sent to the Security and Exchange Commission (SEC) which describes their mission "to offer [their] customers a unique, multi-day experience culminating in a spaceflight that includes several minutes of weightlessness and views of Earth from space" (*Virgin Galactic Holdings, Inc.*, 2021). Using this shows the company's involvement in the space tourism industry.

SpaceShipTwo Bounces Back to Rubber Fuel

Another important text is the description of Virgin Galactic's current motor by Chief Executive George Whitesides (Foust, 2015). Learning more about the technical details of Virgin Galactic's technologies deepens the impact that they have on the environment.

Environmental Impact of Emissions From Space Launches: A Comprehensive Review

Lastly, a research paper that dives into the environmental consequences of space launches is key in depicting the potential harm of the increased space activity caused by space tourism (Dallas et al., 2020). Many researchers come together to study of several ways that space activity could harm the environment. Each of these sources are imperative in tackling the STS research question.

I will thoroughly read and analyze many resources, including the four mentioned, throughout Fall 2023 and early Spring 2024 to create a solid foundation for my research paper. First, I will develop an understanding of the growth of space tourism and Virgin Galactic by looking through government policies and company history. Then, I will research the intricacies in the concept of operations of Virgin Galactic to further understand how they execute space tourism. Finally, I will compile the environmental impacts of their concept of operations by linking studies done on similar technologies' effects on the local and global ecosystems. After gaining all the necessary knowledge, I will draft, revise, edit, and finalize a research paper before the end of the Spring semester.

Conclusion

This prospectus lays the foundation for an in-depth exploration of the intersection of space tourism and environmental responsibility within the framework of the Social Construction of Technology (SCOT). The research 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?"** serves as a guide to my research paper. With the aid of the SCOT framework, I can do a deeper analysis into the complex relationships between several social groups, the ethical obligation to protect our planet, and the case study of Virgin Galactic as a representative of the emerging space tourism industry. This research endeavor hopes to provide valuable insights into the environmental consequences of space tourism and the measures taken by key actors within this sector to address these challenges. The prospectus sets the stage for a comprehensive study that will shed light on the evolving landscape of space tourism and its

environmental impacts, building a deeper understanding of the profound connection between science, technology, and society.

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