HEDGE: Hypersonic ReEntry Deployable Glider Experiment
(Technical Paper)

Souvenirs from the Stars: Examining International Political Impacts of Space Mining
(STS Paper)

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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

In 1969, the Apollo program landed the first human beings on the surface of the moon using state-of-the-art guidance computers. In 2021, an iPhone 6 can process instructions approximately 120,000,000 times faster, and could guide 120,000,000 of the same Apollo spacecraft to the moon at once (Puiu, 2021). Since the conclusion of the Space Race in the 20th century, possibilities and capabilities revolving around spaceflight have grown substantially. Among novel 21st century concepts of space travel, development and utilization of both small-scale, affordable satellites – or “CubeSats” - and extraterrestrial resource collection – or “space mining” technology are deserving of closer research and examination, due to their potential to impact the future of human knowledge and affairs, on earth and beyond. In recent years, CubeSat and space mining technology have even overlapped, with a commercial CubeSat-based satellite containing equipment to prospect water content on asteroids successfully completing all of its specified mission goals in April 2018 (Wall, 2018).

CubeSats are miniature block-shaped satellites weighing between 1 and 10 kilograms and of dimensions 10 x 10 x 10 cm, of which up to 6 can be joined together. This small size and weight allow CubeSats to efficiently and cost-effectively launch as secondary payloads on larger space launches. CubeSats also present an opportunity to conduct scientific research at previously unattainable frequency and resource expenditure levels (Goyne, 2021). Despite growing interest in its application, sustained hypersonic flight (flight maintained at 5 times the speed of sound) research is infrequent and expensive due to difficulties of both operating hypersonic wind tunnels and accelerating test objects to – and maintaining – hypersonic velocity (Bentle, 2021). CubeSats possess the potential to improve the cost-effectiveness and regularity of this research. Extraterrestrial resource collection, or “space mining,” refers to extraction of a variety of resources for human consumption from sources including meteors, asteroids, and the moon via manned or unmanned missions (May, 2021; Keszthelyi, 2017). A variety of useful resources exist on these bodies, for usage both back on earth and in equipment remaining in outer space. Given prior international agreements barring claims of extraterrestrial bodies (See Outer Space Treaty, 1967) and inevitable sustainability concerns accompanying resource mining, there are a number of aspects and viewpoints to be considered surrounding future space mining systems and their commercial and international implementation, along with critiques of more recent perspectives (See Outer Space Treaty, 2015; Artemis Accords, 2020).

The contents of the following research will include first a technical analysis of the applicability of a CubeSat platform for sustained hypersonic flight research, involving deployment of an aerodynamically designed hypersonic glider from the initial CubeSat platform. This analysis will go over mission goals and objectives for a proposed deployment of the CubeSat platform from the Northrop Grumman *Antares* launch, scheduled for 2023. The subsequent section will consist of a literary analysis and discussion of space mining systems, with focus in international political ramifications and comparisons to impacts of current terrestrial resource acquisition practices.

Hypersonic Glider Research

Problem Statement

Hypersonic flight occurs at speeds exceeding five times the speed of sound and is an expanding research field in the aerospace industry with military and civil applications. Military applications include hypersonic missiles, both offensive and defensive, and high-speed aircraft. Civil applications include access to space and commercial air travel. A CubeSat is a small satellite flown in low earth orbit that is well suited for undergraduate education. As CubeSats orbit Earth, they fly at hypersonic speeds and re-enter the atmosphere in around five to seven days if launched into Extreme Low Earth Orbit (ELEO) (Panwar & Kennewell, 1999). Once objects re-enter the atmosphere, they can prolong hypersonic flight if measures are taken to reduce drag.

This technical project will assess the capability of a CubeSat to house a hypersonic glider flight experiment. These experiments are difficult to replicate in wind tunnels and expensive to achieve on rockets and aircrafts. By using a CubeSat, university students may be able to conduct these experiments at a lower cost, and with greater accessibility. The following discusses a mission proposal for a hypersonic glider CubeSat and outlines the significance, objectives, approach, resources available, and anticipated outcomes for the mission.

Significance of the Problem

Some current United States Weapons systems being developed include the Air-Launched Rapid Response Weapon (ARRW), Intermediate Range Conventional Prompt Strike (IRCPS), Long-Range Hypersonic Weapon (LRHW) and unmanned hypersonic aircraft. However, conducting these large-scale projects is expensive and time consuming (Bentle, 2021). By conducting this research experiment on a hypersonic glider utilizing a CubeSat, data collection will be cheaper, faster, and more accessible. Having undergraduate students conduct the research experiment will provide them with the knowledge base to directly enter the hypersonics workforce. Additionally, further understanding of hypersonic flight may lead to advancements in commercial aircraft and spacecraft. Hypersonic aircraft would greatly decrease travel time, while hypersonic spacecraft would provide greater accessibility to space travel. Flight data collected from CubeSat research will provide hypersonics researchers and professionals with information to help advance hypersonic flight, ultimately making it more accessible to the world.

Objective of the Research Work

As previously described, the aim of this research work is to perform a hypersonic experiment using a test article deployed from a CubeSat in Extreme Low Earth Orbit (ELEO). As can be seen in Table 1, this goal has been discretized into three primary objectives, which are motivated by a combination of technical and educational considerations. These have been further subdivided into supporting objectives intended to facilitate the completion of these larger goals. Upon project completion, the fulfillment of these objectives will be used to gauge mission success.

Table 1. Labeled Research Objectives

O1	**Demonstrate the feasibility of CubeSats as a platform for hypersonic glider flight research.**
1.1	Design a CubeSat-based system that can survive the environment of launch and insertion into extreme low earth orbit (ELEO)
1.2	Deploy gliding hypersonic test article from the system
1.3	Maintain stable flight at hypersonic speed for maximum possible duration
1.4	Collect/transmit mission data from test article during hypersonic flight
1.5	Prevent any large fragments from reaching Earth's surface
O2	**Show that undergraduate students can conduct hypersonic glider flight experiments at lower cost and with greater accessibility.**
2.1	Minimize cost by using commercially sourced components and a student workforce
2.2	Deploy a successful experiment designed by undergraduate researchers
O3	**Provide an opportunity for undergraduates to gain hands-on experience and generate interest in the spaceflight industry.**

Approach to the Problem

The process of planning for and designing the hypersonic glider space mission will be completed within the Mechanical and Aerospace Engineering department's Spacecraft Design course advised by Professor Christopher P. Goyne at the University of Virginia (UVA) over the course of the next two years. The students in this course are divided into two groups of fifteen members. This proposal articulates the objectives of one of these teams, which is tasked with designing a hypersonic glider using the CubeSat platform. Each team is subdivided into five functional teams: Communications; Software and Analysis; Power, Thermal, and Environment; Attitude Determination and Control System (ADACS) and Orbits; and Structures and Integration. These component teams are all together led by one project manager.

Table 2. Brief Timeline

Phase		**End Defined By**	**Duration**
Concept Exploration		Finalized Prospectus End of Semester Presentation	Fall 2021
Detailed Development	Risk Reduction/Technology Development	Initial Design Proposal Submission	Spring 2022
	Detailed Design	Finalized Design Proposal Grant Proposals Submitted	Fall 2022
Production and Deployment	Production	Final CubeSat Testing Ship to Launch Site	Spring 2023
	Launch	Lift-Off and Arrival in VLEO	Summer 2023
	On-Orbit Check-Out and Transfer to Operational Orbit	Start of operations	~ 1 week of orbit
Operations and Support	Operations and Disposal	Re-entry	~ 1 week

Over the course of the fall and spring semesters of the first year, the class will go through conceptual and preliminary design. Each phase will be concluded with a design review. The design will be finalized in the fall of the second year, after which system manufacturing and integration will occur, followed by subsystem testing. The anticipated mission launch date is the Summer of 2023. The flight during the mission will be monitored, and after the mission is concluded, there will be post-flight analysis of the data collected. This timeline is summarized in Table 2.

It is anticipated that this CubeSat system will be launched onboard a Northrop Grumman (NG) Antares rocket and deployed from its second stage into Extreme Low-Earth Orbit (ELEO). Technical solutions will be developed by the subsystem teams to meet functional and technical constraints and requirements developed during the Space Mission Engineering Process.

Available Resources

For the design and construction of the project, the team is provided with resources such as industry experts, sponsors, and available facilities. Team advisor, Chris Goyne, alongside additional faculty support from University of Virginia provides invaluable knowledge and guidance to the team during the conceptual design of the project. The Federal Communications Commission (FCC) will also be consulted for additional guidance on requirements and regulations on communication with the CubeSat. Two key sponsors for the team include the National Aeronautics and Space Administration (NASA) for funding of the fabrication and testing of the team design as well as providing the launch site, Wallops Flight Facility, and Northrop Grumman for providing the Antares launch vehicle (Clark, 2021). The launch profile will be dependent upon Antares concept of operations as shown in Figure 1. The profile is important to consider as the CubeSat is attached to the NG Antares Rocket. Lift off, separation, frame deployment, and reentry into orbit are its main stages. As shown in the figure, around nine minutes after lift off the CubeSat will be released into orbit for five to seven days after which it will reenter the atmosphere.

Figure 1. Diagram of Concept of Operations for CubeSat Launch to Reentry (Adapted from Clark, 2021)

Additional resources provided by the University of Virginia include lab spaces and testing equipment in the School of Engineering as well as student experimental facilities providing mechanical manufacturing capabilities and machinery for construction of future prototypes. Available labs include Lacy Hall, the mechanical engineering building basement, and the Architecture School Fabrication Lab. Group project grant funding from the University of Virginia is under consideration for additional funding of the project.

Anticipated Outcomes

Secured government funding and sponsors (UVA, NASA, etc.) will enable the construction of a CubeSat which utilizes the Space Mission Engineering (SME) process to satisfy mission objectives. By demonstrating the feasibility of CubeSats as a platform for hypersonic glider flight, this project will introduce a new method for conducting low-cost hypersonics research in conditions unachievable on the ground. The project will rely on several mission-critical events occurring: the successful deployment of the CubeSat and hypersonic glider, the stability of the glider during flight, and data being relayed during reentry. Ideally, the data will show a longer time in orbit than a typical CubeSat design due to the decreased drag on the test article with stable hypersonic flight conditions. The collected flight data will be transmitted to partner organizations.

Drafting for the funding proposal, designing the CubeSat and deployable glider, and working with government organizations will result in an optimal learning environment for all undergraduate students involved. Such an environment, which requires substantial writing, design, and communication skills will lead to increased knowledge and improved abilities of participating students. Professional relationships will be established with University of Virginia faculty and government organizations for future collaboration. Additionally, through demonstrating undergraduate students' capabilities of conducting these experiments, it is hoped that prospective students take ongoing interest in future aerospace research.

Type of Technical Paper

The final paper will be a mission proposal to the project coordinators, Professor Goyne and the University of Virginia detailing our plan for a hypersonic glider vehicle experiment using a CubeSat for submission to NASA and the DoD for funding.

Conclusion

Through this project, the turbulent conditions of hypersonic flight will be captured at a low cost providing important and limited information to the aerospace industry. Within this industry, the captured data has considerable implications for military and commercial aircraft and spacecraft. The team will finish the Concept Exploration phase of the project this semester and continue with the Detailed Development phase next semester. The project team is wellprepared, knowledgeable, and enthusiastic for the design process and continued application of space engineering principles.

Extraterrestrial Mining Analysis

Introduction

In the near future, highly valuable natural resources could be collected from celestial bodies. While a relatively new concept, extraterrestrial mining has undergone a significant amount of early-stage development, analysis, and discussion of future potential. In a general sense, these discussions are split into two categories: overall viability of proposed applications and international political/legal impacts. This research will include an analysis of both categories, constituting an ethical comparison between practices on earth and in outer space, along with an investigation of international political impacts of space mining systems.

Concept Background

In terms of near-future applications, space mining refers to activities on the moon and nearby meteors and asteroids due to the limitations of current space faring technology. More specifically, these limitations center around the transit time of spacecraft to and from bodies further out in the solar system, which outright prevents manned missions, and is not economically viable for unmanned missions (May, 2021). While there are a number of resources to be collected from these bodies for a variety of applications, current developments focus primarily on commercial resources to be brought back to earth, and resources to be collected and used in outer space. One of the main resources to be used in outer space is water, as this molecule can be split into hydrogen and oxygen, from which hydrogen can be used as a major component of rocket fuel, allowing for refueling of spacecraft thrusters without returning to earth (Gilbert, 2021). Keeping the water molecules intact or utilizing the extracted oxygen molecules on a terrestrial body or in low earth orbit could prove useful as well in reducing the mass of rocket launches (May, 2021). In terms of resources to be brought back to earth's surface, “rare earth” metals and helium-3 isotope are current targets for commercial use (Gilbert, 2021). Rare earth metals such as lanthanum, neodymium, and yttrium are required for many electronic technologies, such as a smartphone or an electric car, and are, hence the name, scarce on earth. Current practices for retrieving these elements on earth are highly hazardous to both the environment and those involved in their retrieval, who consist of primarily impoverished and underpaid miners (Lima et al., 2016). Helium-3 isotope is an element that has been theorized to be a highly efficient fuel for nuclear fusion and subsequent energy production, without emission of harmful radioactivity. While present in lunar regolith, or soil on the surface of the Moon, the specific isotope does not exist here on earth (May, 2021).

Despite growing interest in their application, space mining systems carry with them a difficult dilemma relating to international law. In 1967, the “Outer Space Treaty” was entered into force by the United Nations with signatures from 199 countries, including current space-powers the United States, Russia (formerly the Soviet Union), China, India, and nearly all of Europe (Arms Control Association, n.d.). Along with strictly prohibiting military activity in outer space, the Outer Space Treaty goes on to explicitly state that celestial bodies are “not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means” (1967). While likely not considered at the time, this verbiage could be interpreted as prohibiting any private company or individual from owning an object in outer space, which is an obvious obstacle for any space mining system (May, 2021). In 2015, the United States sought to remove this barrier, with the legislation of the U.S. Commercial Space Launch Competitiveness Act, or “Space Act.” Within the Space Act, United States citizens and industries are encouraged to engage in “commercial recovery of space resources” and are “entitled to any asteroid resource or space resource obtained” (2015). In 2020, the United States went on to draft the “Artemis Accords,” currently signed by 12 nations, with the intent of promoting “peaceful exploration of deep space.” Within the Artemis Accords, collection of space resources is explicitly stated to be acceptable within the Outer Space Treaty of 1967 (2020). Despite the presence of these documents, there is a distinct lack of international discourse or agreement on the specifics of how this resource collection will be carried out.

STS Frameworks

Each of the above topics will be analyzed separately using established science, technology, and society (STS) theories and analytical frameworks. The first framework utilized will be the concept of the “technological fix,” established by American nuclear physicist Alvin M. Weinberg and elaborated upon by Baylor University mechanical engineering professor Byron P. Newberry in the Encyclopedia of Science, Technology, and Ethics in 2005. Put simply by Newberry, a technological fix involves the development and implementation of technological systems to solve “social problems that are traditionally addressed via … social processes.” In most literature, a technological fix is ascribed a negative connotation, however sociologist Amitai Etzioni has critiqued this perspective by suggesting that these pessimistic views are “based on conjecture rather than hard evidence” (Newberry, 2005). For the purposes of this research, this framework will be expanded to problems that are currently addressed by technological as well as social processes. In particular, the usage of space mining for orbital fuel resupplying, collection of rare earth metal and ores, along with collection of helium-3 for increased nuclear power capability will be considered as a technological fix for present-day processes intended for the same goals. The second framework utilized will be the concept of "political technologies." Established by political theorist and Science and Technology Studies Chair at Rensselaer Polytechnic Institute Langdon Winner in 1980, the theory of political technology encompasses the idea that "certain technologies in themselves have political properties." One method of possessing political properties given by Winner is being "strongly compatible with … political relationships" or correlating with particular kinds of political relationships. Critiques of this theory often contend that any political weight held by a technology is entirely within the control of society, and can be just as easily given as taken away (Winner, 1980). For this analysis, space mining systems from different industries and nations will be viewed through the lens of political technology, due to their inherent influence on domestic and, more drastically, international political relationships.

Research Methodology

This research will focus on investigating both the relation between extraterrestrial mining applications and current societal practices it is poised to disrupt, along with the inherent international political influence of space mining systems. The methodologies utilized in researching these topics will include documentary research of space mining developments and capabilities, along with current terrestrial practices for gathering similar resources. Additionally, this examination will include a policy analysis of both international law (See Outer Space Treaty, 1967; Artemis Accords, 2020) and United States domestic law (See Space Act, 2015). Finally, this research will include a discourse analysis involving educated perspectives on space and terrestrial resource acquisition practices along with policy critiques and opinions. Data collection for this research is primarily digital, courtesy of the University of Virginia Virgo online database and accompanying databases with access provided courtesy of the University of Virginia, along with the University of Virginia Law Library online database. More generalized information and data has been provided via lecture courtesy of University of Virginia Professors Bryn Seabrook and Christopher Goyne in the Science, Technology and Society and Mechanical and Aerospace Engineering departments, respectively. Sources utilized in this research will include both primary sources such as original research in academic journals and government publications regarding mining data, along with digitalized original publications of policy documents. Secondary analysis of topics including space mining trends and policy (See Bennett, 2021; Sutherland, 2021) will also be included in the development of this research. Subsequent research will be organized into the two themes described in the introduction to this section. Keywords for use in online databases include "space mining," "space law," "rare earth metals," "nuclear power hazards," "rocket launch resources."

Conclusion

Upon conclusion of this research, two final products will be presented, one technical and one based in science, technology, and society (STS) studies. The technical deliverable will include an assessment of the feasibility of utilizing CubeSat technology for sustained hypersonic flight experimentation. This technical research will conclude with submission of a proposal to NASA to fund the fabrication and test of a designed hypersonic experiment. The STS deliverable will entail an analysis of extraterrestrial mining systems and likely impacts through the lens of established theories including Alvin Weinberg's "technological fix" and Langdon Winner's "political technology." The topic of space mining will be thoroughly explored as both a viable, or unviable, substitute for terrestrial resource gathering and usage practices, and as an impactful technology on international political relationships. The overall products of this research will contribute to technological advancement of hypersonic flight systems and societal comprehension of extraterrestrial mining systems.

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