Undergraduate Thesis Prospectus

Designing a CubeSat for Decelerating Hypersonic Orbital Reentry
(Technical Research Project in Mechanical Engineering)

Space Skeptics: Critics of Space Missions in the United States
(Sociotechnical Research Project)

by

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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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General Research Problem

What is the motivation behind space exploration? It is well documented that since the dawn of mankind, we have been fascinated with space, wondering about "what's out there?" Whether it be the humans of 30,000 years ago using the moon as a timekeeping device (Aveni qtd. by Boyle…), to Jeff Bezos citing his 10-minute spaceflight as "the best day ever!" (Bezos qtd. by Dunn…), there is some inherently human itch for leaving Earth's atmosphere to understand what the void of space beholds. Why is this extraterrestrial curiosity so common among the human race when there is still so much we do not yet understand about the planet we currently inhabit?

Designing a CubeSat for Decelerating Hypersonic Orbital Reentry

How may the cost efficacy of a hypersonic flight experiment be optimized?

CubeSats are cube-shaped satellites comprised of "units" having dimensions of 10 cm. These units can be connected together to make 2U, 3U, 6U, etc. satellites. Chris Goyne, of the Mechanical and Aerospace Engineering department, serves as the technical advisor for this 30-person capstone class, MAE 4690, in which students work in two teams of 15 members, further divided into subsystem teams of approximately 3 students. Due to the scale of the experiment, this project will span over three years. While this year's deliverable is a project proposal to NASA, the technical prospectus will evaluate the entire lifecycle of the project.

Hypersonic flight, defined as flight with Mach numbers above 5, contains significant challenges with regards to thermal management, maneuverability, and communications (Ambrose & Greene, 2019). Limited by the financial cost of on-the-ground testing and motivated by the desire to reduce hypersonic research costs, a more economic solution is sought to collect hypersonic data.

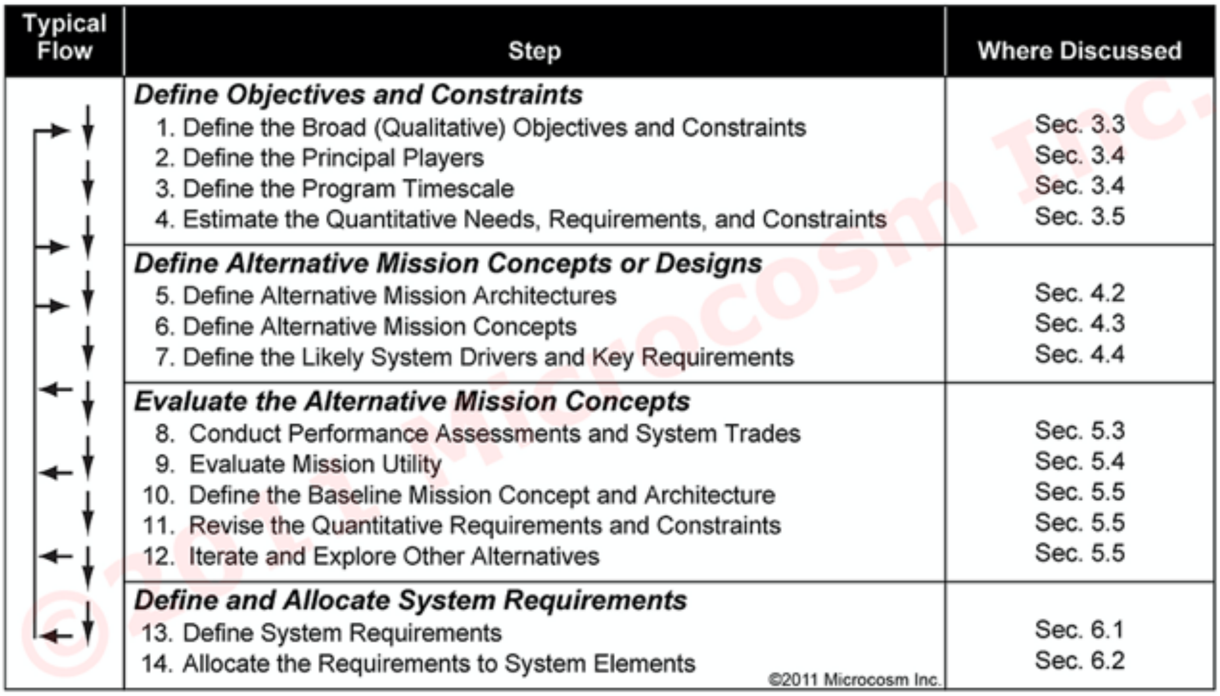
This project aims to design and implement a 3U CubeSat that will be launched into low Earth orbit and collect data as it reenters the atmosphere at hypersonic speeds. Project constraints are outlined in Table 1, below.

Table 1: Primary Mission Constraints

ID	Constraint
C1	3U CubeSat weight and dimension specifications as specified by CalPoly: 100x100x340.5 mm, maximum mass of 4000 grams.
C2	The CubeSat must mate with the CubeSat dispenser by following constraints for exterior size/shape and connector rails (laid out in CDS)
C3	CubeSat must be compliant with federal regulations (FAA, NOAA, NASA)
C4	Material cost must stay under budget of $100,000

State of the art hypersonic flight is limited, and includes vehicles with brief flight times, and exorbitant costs. In 2003, NASA developed and tested the X-43, which reached peak speeds of Mach 9.8 for around 10 seconds, and was the last iteration of a series of flights totaling more than $230 million dollars (Dunbar 2009 & Antczak 2004). The current record for sustained hypersonic flight is held by the $300 million Boeing X-51, which sustained flight for just over six minutes, including 210 seconds of flight speeds greater than Mach 5 (U.S. Air Force, 2013).

To achieve the mission objectives, the Space Mission Engineering (SME) process will be applied, shown in Figure 1.



Typical Flow	Step	Where Discussed
	Define Objectives and Constraints	
	1. Define the Broad (Qualitative) Objectives and Constraints	Sec. 3.3
	2. Define the Principal Players	Sec. 3.4
	3. Define the Program Timescale	Sec. 3.4
	4. Estimate the Quantitative Needs, Requirements, and Constraints	Sec. 3.5
	Define Alternative Mission Concepts or Designs	
	5. Define Alternative Mission Architectures	Sec. 4.2
	6. Define Alternative Mission Concepts	Sec. 4.3
	7. Define the Likely System Drivers and Key Requirements	Sec. 4.4
	Evaluate the Alternative Mission Concepts	
	8. Conduct Performance Assessments and System Trades	Sec. 5.3
	9. Evaluate Mission Utility	Sec. 5.4
	10. Define the Baseline Mission Concept and Architecture	Sec. 5.5
	11. Revise the Quantitative Requirements and Constraints	Sec. 5.5
	12. Iterate and Explore Other Alternatives	Sec. 5.5
	Define and Allocate System Requirements	
	13. Define System Requirements	Sec. 6.1
	14. Allocate the Requirements to System Elements	Sec. 6.2

Figure 1: The Space Mission Engineering Process

To test and validate designs, simulation software such as finite element analysis, computational fluid dynamics, and thermal analyses will be applied.

A successful hypersonic reentry experiment will provide valuable data on hypersonic flight conditions such as pressure, temperature, forces, etc., that will help researchers in making hypersonic flight a viable tool for mankind.

For the full technical research prospectus, see Appendix A.

Space Skeptics: Critics of Space Missions Around the World

How do critics of space exploration organize and justify their opposition?

Why do space exploration critics feel the way that they do, and how, if at all, do they organize themselves based on their criticisms? In 2004, when president Bush announced his Vision for Space Exploration, the main concern expressed by Congress was the sheer cost of the proposal (Smith 2006). While critics within the government have mostly been concerned with budget allotment, civil rights movements such as The Poor People's Campaign have accused the government of a "distorted sense of national priorities," and that they want "NASA scientists and engineers and technicians to find ways to use their skills to tackle the problems we face in society," (Abernathy, qtd. in Maher 2019). In fact, civil rights activists have been critical of federal budgeting dating as far back as the early 1870s, engaging in, what Shugerman (2014) calls, an "uphill battle," following the post-Reconstruction creation of the DOJ. Aside from financially centered criticisms, there has also been concern over the logistical efforts required for international cooperation on space missions (Finarelli and Pryke, 2005). While the aforementioned groups tend to be critical of the motivation for space exploration, there exist fringe conspiracy theorists that are critical of the proof of space exploration. At first, civil rights groups and "flat-earthers" may seem categorically different in their criticisms of space exploration, but they share a common sentiment: the government has failed them. Whether it be a failure to deliver meaningful financial commitment or factual information, these groups feel that the government has not fulfilled its role in serving its people. Citing "anti-God, theoretical astronomy," and "early youth…indoctrination" as justification of his criticisms, Samuel Shenton, founder of the International Flat Earth Research Society (IFERS) makes the case that governments in the space age have mandated a certain way of thinking (Shenton 1963). In fact, the anti-science sentiments seem to be the main draw for prospective members of IFERS. In a correspondence between hopeful member, Francis McGrath, and Samuel Shenton, McGrath explains that he "holds steadfastly to the well-known fact that the Earth is flat in spite of the brain washing of so-called scientists" (McGrath 1969). The strong language used by both Shenton and McGrath provides some insight into the feelings that foster the cohesion within organized conspiracy groups such as the IFERS.

Anti-science rhetoric is not uncommon, and is often used by people in positions of power, such as U.S. politicians, especially in the Republican party (Hsu 2021). Hsu (2021) posits that "crusades against science can be appealing to voters that have little in common with scientists, perhaps materially much less than scientists, and perhaps have a poor understanding of science," making the connection between anti-science ideology and how it used as both ethos and pathos to garner public support and maintain control. Furthermore, the Trump Administration was known to criticize science for economic gain. Trump's campaign was backed by industries that most contribute to climate change, such as coal, mining, fossil fuels, and other chemical industries. To maintain these cash inflows, Trump frequently discredited scientific findings that directly linked these industries to the climate crisis (Hsu 2021). Trump was unique in that, prior to being elected president, he already had significant public influence as a celebrity, which, many would argue, won him the election. In tandem with his political pull, Trump used the "celebrity effect" to amplify his opposition to science. In his STS research paper for the University of Virginia, titled *The Influence of Celebrities in the Spread of Anti-Science Beliefs*, Badrish (2016) explains that "by circulating [anti-science] ideas, and constantly forcing the media to talk about them, celebrities can potentially change individual opinions into believing these false statements," concisely summing up how the celebrity effect can perpetuate anti-science ideology.

One of the participants are civil rights groups, particularly those in the 1960s who were competing against the space race for public support and validation (Smith 2019). The student activist group known as Students for a Democratic Society (SDS), were known to organize anti-NASA demonstrations on the grounds that they are just a "weapon of the military establishment which is draining our resources" (Maher 2019). Participants also include congressmen who oppose space exploration on the basis of financial commitment alone, which manifests itself in recent trends of congressional approval of NASA's budget allotment (Chatzky et al., 2021). Finally, there exist highly organized conspiracy theorist groups such as the IFERS (Shenton 1956), and less organized fringe conspiracy theorists, like moon landing deniers (Sibrel 2021). Even pop-culture celebrities, like NBA point guard, Kyrie Irving, have expressed doubt on terrestrial roundness, asking if "you can openly admit that you know the Earth is constitutionally round? … Like I don't know" (Irving qtd. in Deb 2018). Netflix star, Millie Bobby Brown, has also loosely aligned herself with "Flat-Earthers" in a livestream on her social media, stating "I think I am a…what do they call it? Um…a flat — I think they call it a flat-earther." (Brown qtd. in Young Celebrity World 2018). While their opinions are far less formalized than those of the other mentioned participants, social phenomena like the "celebrity effect" have far reaching effects on public opinion when it comes to celebrities expressing their perspectives (Badrish 2016).

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Appendix A

Prospectus

Decelerating Hypersonic Flight Experiment Using a CubeSat Platform

(Technical Capstone Topic)

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10/26/2021

Introduction

Hypersonic flight, defined as flight with Mach numbers above 5, contains significant challenges with regards to thermal management, maneuverability, and communications

(Ambrose & Greene, 2019). Hypersonic flows are most often encountered during atmospheric reentry, where the spacecraft is constantly decelerating from speeds as high as Mach 25(Glenn Research Center, 2021). Modeling these flows is important in order to understand pressure and heat distributions for spacecraft during reentry, both of which will affect the design of its heat shielding and aerodynamic components. In addition, motivated by threats from China and Russia, the United States military and Department of Defense have recently begun expanding funding and research into hypersonic flight for use in weapons systems (Sayler, 2021). Some private companies also seek to build hypersonic passenger aircraft, which could connect LA to Tokyo in under two hours (Baggaley, 2019). With hypersonic flight presenting several technical challenges, collecting flight data is invaluable and it garners interest from both government and commercial industries.

In order to design these hypersonic flight systems, engineers need to obtain accurate flow data from the hypersonic regime, which poses several challenges. Testing of ground-based hypersonic experiments is limited by the size and expense of new systems and the insufficient technology of many existing test facilities (National Research Council, 1994). Obtaining flight data from a prototype hypersonic aircraft is generally an even more costly solution. Additionally, modeling software poses issues due to a lack of technical understanding for concepts such as boundary layer transition at higher Mach numbers (National Research Council, 1994). From 2021 to 2022 alone, the FY Pentagon requested a budget increase for hypersonic research from 3.2 to 3.8 billion dollars to attempt to overcome these difficulties (Stone, 2021). Limited by the financial cost of ground testing and motivated by the desire to lower hypersonic research costs, , a more cost-effective solution is sought to collect hypersonic data.

Recent developments in CubeSat technology in the form of commercial off-the-shelf components (COTS) and lowered launch costs have improved accessibility for spacecraft missions (Nervold et al., 2016). As a result, the use of CubeSats in university funded projects has risen dramatically. Testing the hypersonic environment with a CubeSat undergoing atmospheric reentry could significantly reduce the costs associated with ground testing and provide greater accuracy than model-based testing. CubeSat reentry also presents an opportunity to study hypersonic deceleration at the undergraduate level.

This project team seeks to assess the feasibility of using a CubeSat to study the deceleration of the spacecraft at hypersonic speeds and collect data that will be transmitted to engineers and scientists studying hypersonic flight. At the end of this year, the technical thesis will be completed in proposal format for potential submission to NASA for funding of the fabrication and testing of the 3U CubeSat design. The purpose of this document is to outline the plan that this project team will follow to solve the technical problem presented. The document will discuss the technical problem and its objectives, the technical approach, program management, the resources available to the team, and desired outcomes.

Technical Problem

Research Objectives

The primary objective for this project is to design and implement a 3U CubeSat that will be launched into low Earth orbit (P1, Table1) and collect data as it reenters the atmosphere at hypersonic speeds (P2, Table 1). Additional primary objectives include delaying atmospheric burnup (P3, Table 1) and collecting and transmitting sufficient and reliable data to the UVA ground station (P2, Table 1). The use of CubeSats offers undergraduate students the opportunity to be involved in the space mission engineering process in a cost effective manner over a short term (S2, Table 2). Proving the feasibility of CubeSats for hypersonic flight experiments has the potential to promote Aerospace Engineering to the general public (S1, Table 2), which may improve funding, resources, and general interest for future projects.

Table 1: Primary Objectives

ID	Primary Objectives
P1	Successfully launch a 3U CubeSat bus into extreme low Earth orbit
P2	Collect and relay decelerating hypersonic flight data upon atmospheric entry
P3	Delay atmospheric burnup to maximize the quantity of collected data

Table 2: Secondary Objectives

ID	Secondary Objectives
S1	Promote Mechanical and Aerospace Engineering to the public
S2	Provide the opportunity for students to engage in cost-effective educational space mission engineering and design

The primary objectives have a number of functional (Table 3) and operational (Table 4) requirements necessary for success, and must satisfy the mission constraints (Table 5).

The CubeSat must be able to survive extreme conditions (F1, Table 3) so that the electronics and sensors necessary for control, data collection, and transmission do not fail when exposed to extreme temperatures and high forces, and so that the CubeSat can gather and transmit sufficient data to the University. Extreme condition survival and full power (F4, Table 3) throughout the mission reduce the risk of component failure, data collection, and data transmission failure.

Table 3: Primary Functional Requirements

ID	Requirement
F1	Survive extreme conditions of deorbit and reentry for as long as is necessary to obtain data (extreme high and low temperatures, forces up to 7.8g)
F2	CubeSat sensors collect effective and purposeful data that proves mission success or failure
F3	Have capability to return mission data to the University for study
F4	Remain powered through entire mission (5-7 Days)

An unstable CubeSat upon atmospheric reentry will not be able to provide credible data and would likely cause an early burnup of the system. Prior to this burnup, O2 from Table 4 highlights the importance of the CubeSat's ability to transmit the measured data to an accessible source.

Table 4: Primary Operational Requirements

ID	Requirement
O1	Maintain stability of CubeSat at hypersonic velocity during atmospheric reentry
O2	Directly or indirectly transmit data throughout mission
O3	Minimize power consumption of avionics and sensors during operation while fulfilling requirements

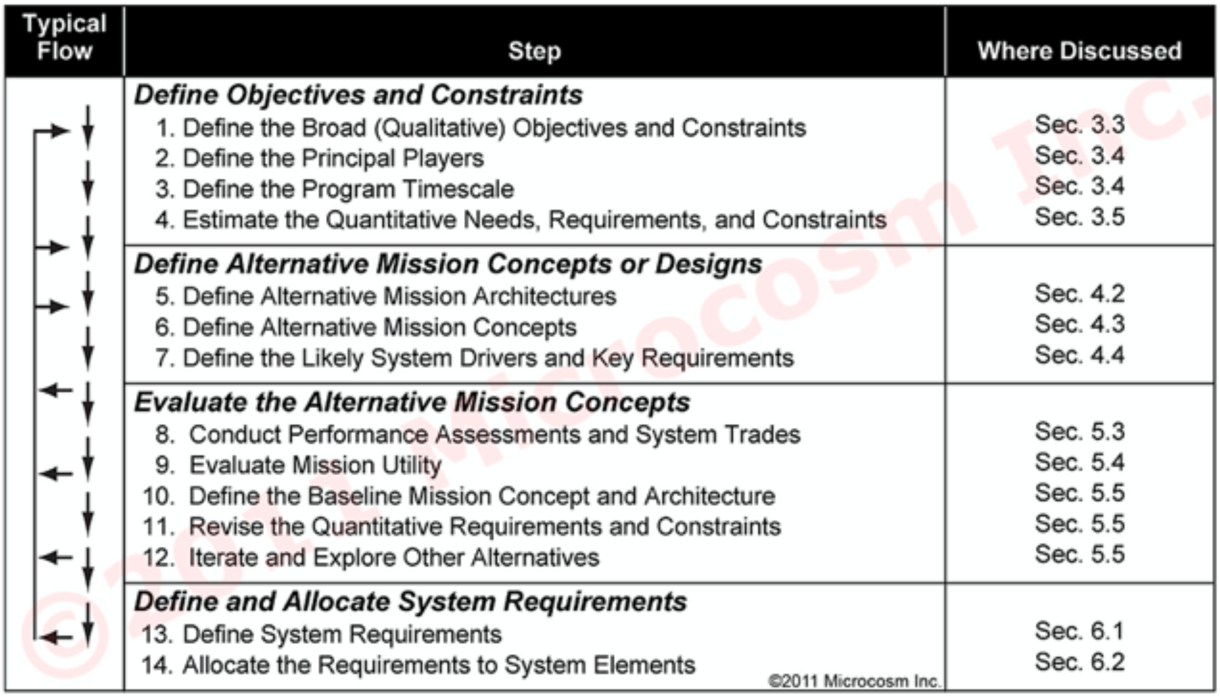
The ability to minimize power consumption will stem from the construction of an efficient CubeSat that properly addresses changing flight conditions. As displayed in Table 5, the CubeSat will need to adhere to dimensional and budget constraints, as well as federal regulations, which will affect manufacturing techniques and potential commercial products.

Table 5: Primary Mission Constraints

ID	Constraint
C1	3U CubeSat weight and dimension specifications as specified by CalPoly: 100x100x340.5 mm, maximum mass of 4000 grams.
C2	The CubeSat must mate with the CubeSat dispenser by following constraints for exterior size/shape and connector rails (laid out in CDS)
C3	CubeSat must be compliant with federal regulations (FAA, NOAA, NASA)
C4	Material cost must stay under budget of $100,000
C5	Availability of manufacturing techniques and commercial products for mission components

Technical Approach

To achieve the objectives discussed in the previous section, the Space Mission Engineering (SME) process will be applied. As shown in Figure 1, the SME process can be loosely divided into four main sections: Define Objectives and Constraints, Define Alternative Mission Concepts or Designs, Evaluate the Alternative Mission Concepts, Define and Allocate System Requirements.



Typical Flow	Step	Where Discussed
	Define Objectives and Constraints	
	1. Define the Broad (Qualitative) Objectives and Constraints	Sec. 3.3
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	13. Define System Requirements	Sec. 6.1
	14. Allocate the Requirements to System Elements	Sec. 6.2

Figure 1: The Space Mission Engineering Process

The broad qualitative objectives and constraints were defined in the previous section. Principal players, including the Primary and Secondary Customers, Sponsors, Operators, and End Users, need to be identified in order to assess particular agendas and understand each player's needs. Deadlines set by principal players additionally allow for the creation of a more rigid project timeline. For the purpose of this project, and with the goal of approval and funding from NASA, there will be a Conceptual Design Review, Preliminary Design Review, and Critical Design Review before product manufacturing can occur, culminating in the actual launch of the satellite after a nearly three year process.

Program Management

With respect to task delegation, the team was divided into six subgroups: the Project Management team, Communications team, Software and Avionics team, Power, Thermal, and Environment team, Attitude Determination and Control System and Orbits team, and Structures and Integration team. At the subsystem level, SME steps 5-14 will be explored by each subteam to develop more concentrated mission elements such as particular drivers, constraints, and requirements. This will be facilitated by each subteam's preliminary research of literature in their relevant fields of expertise.

Available Resources

Available resources for the 3U CubeSat include personnel and information resources, monetary funding, parts sourcing, and systems/communications support. Personnel and information resources are available through university professors and databases, which have ample information from previous space missions. Previous spacecraft design projects provide an excellent structure for the basis of the hypersonic deceleration design project. The project is supervised by Christopher Goyne and UVA has access to a volunteer communications advisor, Michael McPherson. Subject matter experts are also available through NASA, the DoD, UVA faculty, and industry experts.

The NASA CubeSat Launch Initiative (National Aeronautics and Space Administration, 2020) is an available resource that allows for a free ride into space for promising satellite projects. Funding for development is available through the NASA Space Grant Project, which provides funding to college programs intending to strengthen the bond between the public and engineering communities (National Aeronautics and Space Administration, 2021), as well as the DoD, military contractors, non-profit organizations, and other aerospace-centric companies.

Parts and assemblies can be independently designed and fabricated, though this process can be costly both in time and money. A better alternative is to use commercial off-the-shelf parts (COTS) which are available online through various websites. Some examples include *Cubesatkit.com* and *Cubesatshop.com*. These websites offer ready-to-install CubeSat parts and assemblies at a wide range of prices, many of which are conducive to an educational environment. Additionally, UVA has extensive 3-D Printing capabilities, which can compensate for parts that cannot be purchased or sourced online.

Systems and communications support for the CubeSat is available through the University in the form of a ground station that has satellite communications capabilities. Other college Aerospace Engineering programs and commercial providers of satellite constellations, such as Iridium or Starlink, are also available for system support and to use as communications ground stations.

Conclusion

The project is expected to produce several outcomes. The primary outcome of the project will be the assessment of the feasibility and capability of future hypersonic decelerating CubeSat experiments. The data collected and returned to the University of Virginia, including position, velocity, acceleration, temperature, pressure, and orientation, will provide the means to perform this analysis. Assuming successful collection of intelligible data, possible results of study include complete validation of mission goals and predictions, evidence of premature spacecraft incineration, or evidence of premature slowdown to sub-hypersonic speeds. The results of student and professional assessment of the mission may lead to further exploration and study by UVA or other entities. Students involved in this or future missions will gain experience in engineering design and project management while exposing the public to mechanical and aerospace engineering.

Achieving the expected mission outcomes could prove vital for developing future spacecraft concepts. If the data collected confirms expected results, development of decelerating hypersonic spacecraft, such as modules meant to return astronauts to Earth, would have a cost-effective method to confirm results of simulations and test aircraft components. The UVA Decelerating Spacecraft Design Team will therefore use its collective knowledge and available resources, such as guidance from experts in space mission design, to progress the project in the direction necessary to achieve its goals.

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