Hypersonic Atmospheric Reentry Deceleration Experiment (HARD-E)
(Technical Report)

The Commercial Space Industry: How High-Speed Broadband Satellite Internet Will Affect Rural Consumers
(STS Research Paper)

A Thesis Prospectus
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Prospectus

Introduction

Hypersonic flight, defined as flight with Mach numbers above five, 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 expanded 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 Los Angeles 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 the 2021 to 2022 fiscal year alone, the 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.

The rise of CubeSats is partly driving the growing commercial space industry. In the past decade, the global space economy has increased in size by 55%, to an estimated $447 billion USD in 2020 (Space Foundation, 2021). Of that economy, an estimated 80% is now commercial space activity (Space Foundation, 2021), meaning for-revenue commercial activities, as opposed to non-revenue missions such as a NASA launch to the moon. Almost all of that commercial activity, 95%, is in the space-for-earth economy - goods or services produced in space for use on earth (Weinzeirl & Sarang, 2021). The growing space economy, and the new technologies arriving with it, have implications for consumers around the globe. Those implications have the potential to change society by changing the relationships and power balance between different societal groups.

Technical Topic

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

The technical deliverable 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.

STS Topic

The growing economy in space is producing many new technologies. One of the new technologies being implemented is faster satellite internet, driven by large “mega-constellations” of low-cost satellites that stay in low-Earth orbit (LEO). Although satellite internet already exists, it uses relay stations that sit in geostationary orbit - an orbit that stays in a fixed position relative to the ground. This orbit is quite far away from Earth compared to LEO, leading to large lag times of up to half a second, making voice and video calls difficult, and multiplayer gaming and high-speed financial training impossible (Harris, 2019). By placing satellites in LEO, the issues with lag time can be remedied, allowing high speed broadband and low latency times. However, in LEO, satellites cross the horizon in 10 minutes, meaning large, globe-encircling constellations need to be maintained in order to ensure continuous coverage. Multiple major companies have announced plans to deploy these types of constellations, and if those plans hold, there could be 50,000 active satellites orbiting within 10 years (Daehnick et al, 2021).

High speed, low latency internet has the potential to fix America’s, and the world’s, broadband internet problem (defined as 25Mbps download speeds or higher). Despite the internet being crucial to modern life, many Americans still do not have reliable internet access. At the onset of the COVID-19 pandemic, one in five 13- to 17-year-olds reported being unable to do their homework “often” or “sometimes” because of poor internet access (Chakravorti, 2021).

Rural areas especially struggle with internet access. Rural residents are less likely to have broadband internet access, and current internet infrastructure is not supportive of consistent broadband access (Vogels, 2021). Internet access has been shown to have significant economic impact, with a Deloitte study finding that a 10% increase in broadband access in 2016 would have resulted in an additional 806,000 jobs in 2019 (Deloitte, 2021). Other studies have shown the internet having a positive impact on household income in rural areas (Ma et al, 2020), as well as a positive impact on the arts in rural areas, which in turn brings economic growth (Townsend et al, 2017). Through analyzing past trends and outcomes of broadband connectivity, insights on the societal effects of improved satellite internet can be obtained.

Framework and Methodology

The commercialization of space brings up an important question: What are the sociotechnical factors arising from the commercialization of space that will impact the average consumer? In order to analyze the research question, Actor-Network Theory (ANT) will be utilized. As explained by Cressman (2009), ANT analyzes "networks", or relationships, among a group of "actors", or stakeholders within the actor-network. Importantly, human and non-human elements are considered actors within an actor-network. Thus, using actor-network theory, the relationships between the satellite companies, consumers, regulators, and the actual technology can be considered equally. One of the criticisms of ANT is that it is overly broad, and therefore almost everything can be considered a part of an actor-network (Cresswell et al, 2010). In order to limit the scope of the actor-network, only the major actors within the network will be considered.

To answer the research question posed, two research methods will be used. Primarily, historical case study will be utilized. The historical cases investigated will be twofold: first, investigating the impact of other previous efforts to expand broadband access, and second, investigating the impacts of other transformative technologies on rural consumers, such as electricity and telephones. Documentary research will also be used, in order to gather data on the current state of satellite internet technology, and to create and define an actor-network.

Conclusion

The technical 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.

The research paper covers the sociotechnical impact of commercial space on consumers, especially focusing on the impact of high speed, low latency internet on rural consumers. Rural residents are less likely to have broadband internet access and the associated economic benefits than urban consumers, a key deficit that new satellite internet addresses. However, recent technological advancements within the commercial space industry are making cheap broadband access possible for millions of consumers that still lack it. The potential impacts of the new technology will be explored by investigating the impacts of previous emerging technologies on the same rural consumers, such as electricity, phone, and wired broadband internet.

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