Decelerating Hypersonic Flight Experiment Using a CubeSat Platform

(Technical Paper)

Examining the Failings of International Policy to Address the Space Debris Issue

(STS Paper)

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Aerospace Engineering

By
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Fall, 2021

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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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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.

The use of Cubesats in universities has risen dramatically as a result of recent developments in CubeSat technology in the form of commercial off-the-shelf components (COTS) and lowered launch costs (Nervold et al., 2016). 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.

The technical project 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 STS research is closely coupled with the technical project and will be applying actor-network theory to the issue of space debris in order to determine why international policy has failed thus far. This work will be accomplished during the Fall 2021 and Spring 2022 semesters, over the course of 28 weeks.

DECELERATING HYPERSONIC FLIGHT EXPERIMENT USING A CUBESAT PLATFORM

In order to design 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 the difficulties of conducting hypersonic flight tests (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.

As shown in figure 1, the primary objective for this project is 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. Additional primary objectives include delaying atmospheric burnup and collecting and transmitting sufficient and reliable data to the UVA ground station.

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. Figure 2 below shows the secondary mission objectives which are to promote Aerospace Engineering to the general public, in order to improve funding, resources, and general interest for future projects.

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

Figure 1: Primary Objectives. This figure shows the primary mission objectives determined in the space mission engineering process. (Boyles et al., 2021).

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

Figure 2: Secondary Objectives. This figure shows the secondary mission objectives determined in the space mission engineering process. (Boyles et al., 2021).

The primary objectives have a number of functional and operational requirements necessary for success, and must satisfy the mission constraints. The CubeSat must be able to survive extreme conditions 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 throughout the mission reduce the risk of component failure, data collection, and data transmission failure. 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, the CubeSat must be able to transmit the measured data to an accessible source. Finally, 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.

To achieve the objectives discussed in the previous section, the Space Mission Engineering (SME) process will be applied. 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. The broad qualitative objectives and constraints were defined above. 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.

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. 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) 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.

The design will use commercial off-the-shelf parts (COTS) which are available for purchase online. 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.

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.

EXAMINING THE FAILINGS OF INTERNATIONAL POLICY TO ADDRESS THE SPACE DEBRIS ISSUE

Proponents of Cubesats claim that they are a vital educational, scientific, and technological tool that allows for the democratization of space exploration. This technology, however, is not without consequences. As the number of small satellites launched into orbit increases the quantity of orbital debris in space is growing rapidly. Orbital debris is the term used to describe any object in space that no longer serves a useful function. Most small satellites are designed to stay in orbit for the project lifetime and then burn up upon re-entry into the atmosphere, however, in some cases they can stay in orbit long after the end of the mission and become orbital debris (Boggs, 2020). Figure 3 shows the increase in orbital debris accumulated since 1957. As of 2015, the U.S. Airforce was tracking more than 20,000 objects in space. Currently, CubeSats make up a small fraction of this debris, however, as their rate of deployment grows this fraction will increase (Clark, 2015). There is very little international regulation in place to prevent the pollution of the space environment (Haroun et al., 2021). Without proper regulation the growing issue of orbital debris could render space exploration inaccessible to future generations. Aside from the possible risk to the future of space exploration, “Space sustainability advocates argue that the environment of space has value itself and faces a much greater risk of harm than individuals on Earth.” (Aganabe, 2021) Though there are no clear victims or physical harm to living beings, sustainability advocates (Aganabe, 2021) believe that the space environment should still be protected from degradation caused by pollution. For these reasons it is essential that the failings of the policy landscape are addressed.

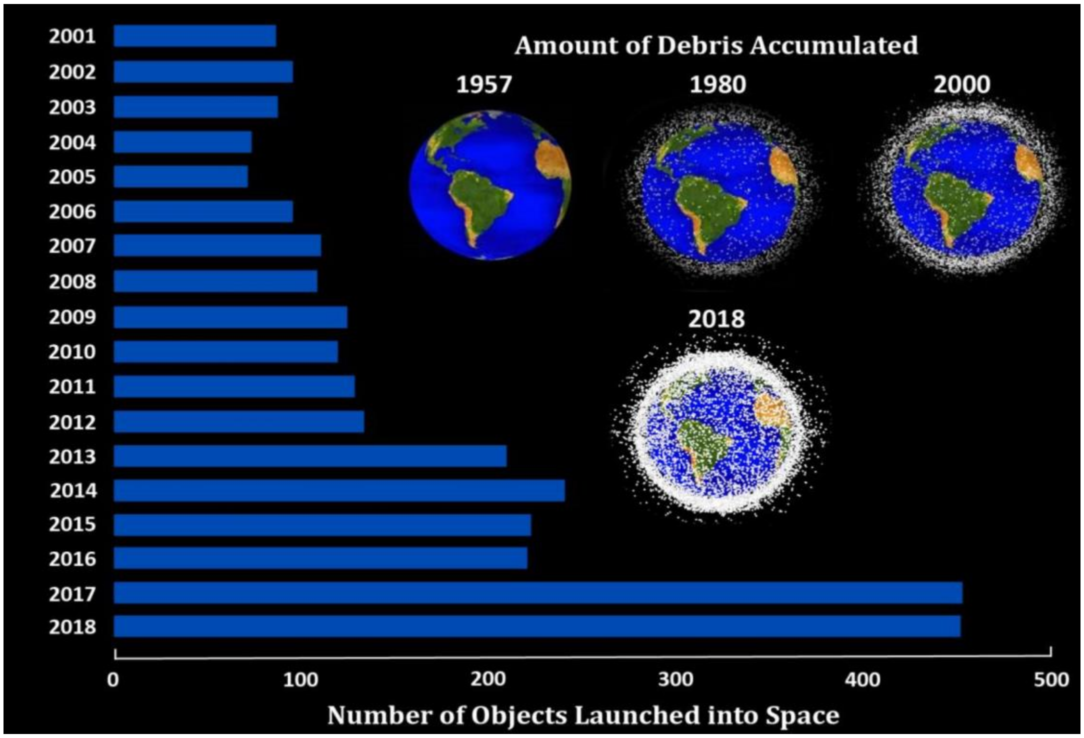

Figure 3: Orbital Debris in Space. Number of Objects Launched into Space Compared to the Accumulation of Debris (NASA, 2021)

This paper will use Actor Network Theory (ANT) to analyze why the existing legal regime and international treaties regarding space debris mitigation is limited and fails to address contemporary issues associated with the increase in small satellites. Currently the only international agreement in place governing the post-operational lifetime of objects in space is the 25-year rule. The 25-year rule is an international agreement under which countries are not supposed to launch objects with a lifespan beyond 25 years after the project conclusion, however, compliance is not mandatory (David, 2017). While the U.S. does not approve any projects that will exceed this limit this policy has not been rigorously enforced. As many as one in five of the Cubesats launched between 2000 and 2014 will remain in orbit for more than 25 years after their useful lifespan (Clark, 2015). Aside from the 25-year rule there is little mention of space pollution in any international policy. Significantly, space debris is not mentioned in any U.N. agreement and the only instruments that directly address the issue do not create binding agreements (Haroun et al., 2021). The policy that does exist is mainly focused on the issue of space debris falling to earth and the possibility of damage to property or human beings. However, risks to life and property are not the only concerns about space pollution and debris that is unlikely to crash to earth still poses significant threats to the space environment (Aganabe, 2021).

One of the challenges of creating effective policy to address the issue of orbital debris is the large number of human and nonhuman actors involved. Thus far, international policy to mitigate pollution of the space environment has failed in part because of the challenges of regulating spacecrafts on a global scale. Figure 4 shows the complex network of actors involved in the development of CubeSat projects. The presence of a wide array of actors, from members of industry to national and international regulatory bodies, has made it difficult to develop and enforce international guidelines. Additionally, the nearest regions of space are themselves an important actor that are often overlooked due to the lack of human presence (Rand, 2019). Actor Network Theory is an approach to studying technology, posited by Latour, Callon, and Law, that addresses the hybrid socio-technical problems occurring in an increasingly connected world where global and local actors are intertwined (Jolivet, 2010). By applying ANT this paper aims to examine the complex human and non-human actors involved in international policy governing space debris in order to analyze why policy has failed thus far.

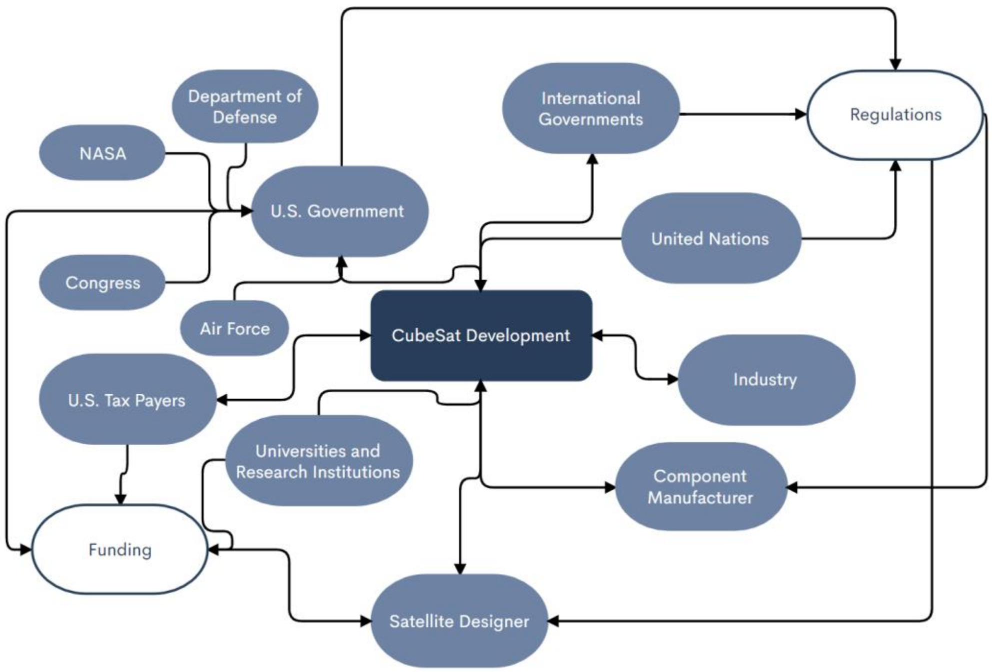

Figure 4: Mapping the Actors. Human and Nonhuman Actors Involved in Cubesat Development (Boyles, 2021)

ARE CUBESATS WORTH IT?

CubeSats are an important technological advancement that has allowed for increase democratization of access to space. Space exploration is no longer limited to just government and industry. The low-cost and ease of launch has made it possible for students at all levels of education to get involved. The technical project takes advantage of these advancements and design a 3U Cubesat for conducting decelerating hypersonic research. 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. However, like with all new technologies it is important to consider the unexpected consequences. The increased adoption of small satellites is contributing to the growing problem of orbital debris. While the impact of Cubesats on orbital debris is currently fairly limited, Cubesats are one of the only space exploration technologies for which the pace of deployment is expected to increase. It is essential that international governing bodies work to develop stringent and enforceable legislation before this issue becomes too large to manage.

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