Prospectus

Decelerating Hypersonic Flight Experiment Using a CubeSat Platform
(Technical Topic)

Analysis of the Failure of the Space Shuttle Challenger
(STS Topic)

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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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 ~~to Mach 10~~ (Glenn Research Center, 2021). Modeling these flows is important in order to understand both the pressure and heating distributions on reentry spacecraft. 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 Los Angeles and Tokyo in under two hours (Baggaley, 2019). Although hypersonic flight presents several technical challenges, collecting flight data is invaluable as it garners interest from both government and commercial industries.

In order to design these hypersonic flight systems, engineers need to obtain accurate flow data within the hypersonic regime. However, 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. 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).

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). According to NASA, “CubeSats are a class of research spacecraft that are built to standard dimensions and typically weigh less than 1.33 kg per unit (a 10cm x 10cm 10cm cube" (Loff, 2018). 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.~~

The aim for this project is 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. However, this prospectus aims to not only describe the difficulties of flight while leaving and reentering the Earth's atmosphere, but also during the design and build stages of spacecraft design.

A CubeSat will be used to collect data while moving at speeds greater than that of Mach 5 to tackle the problems associated with hypersonic flight. To deal with the other factors associated with spacecraft design, the explosion of the Space Shuttle Challenger of 1986 will be analyzed. Most people know that the explosion was caused by an O-ring malfunction. However, there were many other reasons behind the shuttle's failure. There were calculations overlooked, difficult management decisions made, and misinformed employees that could all be seen as other problems that led to the failure of the launch. If these other factors are not looked into, nobody would understand the impact that each of them has on the shuttle's explosion. Through the use of Actor-Network Theory, it will be shown how each category of factors has an equally important role in the Challenger explosion. The Presidential Commission on the Space Shuttle Challenger Accident from 1986 will be primarily used alongside other sources to support my argument.

Technical Problem

(This portion was written collaboratively in order to comply with the direct and specific requirements of the Technical Advisor, Christopher Goyne.)

The primary objective for this project is to design and implement a 3U CubeSat that will be launched into extreme 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 that is cost effective and short term. Proving the feasibility of CubeSats for hypersonic flight experiments has the potential to promote aerospace engineering to the general public that may improve funding, resources, and general interest for future projects. The primary objective requires a number of functional and operational requirements necessary for success, and must satisfy the mission constraints (Tables 1-3).

Table 1. 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)

The CubeSat must be able to survive extreme conditions (F1, Table 1) so that the electronics and sensors necessary for control, data collection and transmission do not fail due to the extreme temperatures and high forces. This is also essential so that the CubeSat gathers and transmits sufficient data to the University. Extreme condition survival and full power (F4, Table 1) throughout the mission reduces the risk of component failure, data collection, and data transmission failure.

Table 2. Primary Operational Requirements for Mission Success

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

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, operational requirement 2 from Table 2 highlights the importance of the CubeSat’s ability to transmit the measured data to an accessible source. The ability to minimize power consumption will stem from the construction of an efficient CubeSat which properly addresses changing flight conditions. As displayed in Table 3, 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 used for this project.

Table 3. 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 Space Mission Engineering (SME) process will be applied to achieve the objectives previously discussed. As shown in Table 4, the SME process can be loosely divided into four main sections: Objectives and Constraints, Alternative Mission Concepts or Designs, Alternative Mission Concepts, and System Requirements.

Table 4: The Space Mission Engineering (SME) Process

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

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The 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, a preliminary design review, and a critical design review before product manufacturing can occur, culminating in the actual launch of the satellite after a nearly three-year process.

With respect to program management, the team was divided into six subgroups: project management; communications; software and avionics; power, thermal, and environment; attitude determination and control system and orbits; and Structures and Integration. At the subsystem level, SME steps 5-14 will be explored by each sub-team to develop more concentrated mission elements such as particular drivers, constraints, and requirements.

Available resources for the 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 Professor Christopher Goyne and a communications advisor, Michael McPherson. Subject matter experts are also available through NASA, the DoD, University 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 to be sourced online through various websites, such as *Cubesatkit.com* or *Cubesatshop.com*. These websites offer ready to install CubeSat parts at a wide variety of prices, some of which are conducive to an educational environment. Additionally, the University of Virginia has extensive 3-D printing capabilities which can compensate for parts which 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.

STS Problem

On January 28, 1986 at 11:38 EST and temperatures hovering around 36°F, the Space Shuttle Challenger was launched from the Kennedy Space Center in Merritt Island, Florida. The plan was to deploy a large communications satellite, deploy and retrieve an astronomy payload to study Halley's Comet, and to conduct lessons for school children while in orbit (Uri, 2021). This mission was abruptly stopped because after approximately 73 seconds after liftoff, the entire shuttle broke apart, killing all seven members of the crew on board.

This explosion was due to the failure of two O-ring seals used in the joint of the solid rocket booster (SRB), as shown in Figure 1 (Presidential Commission, 1986, p. 58). The aforementioned failure led to the burning gas from inside the SRB to escape, reach the external fuel tank, and cause the fuel tank to explode. However, there were many other factors leading up to this moment that could have stopped this disaster from ever happening.

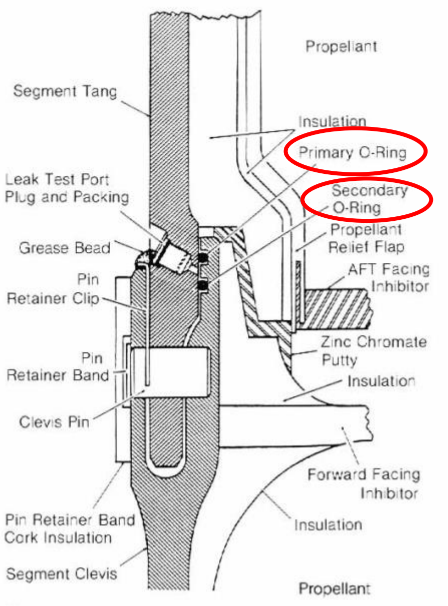

Figure 1. Diagram of SRB Joint

According to a test conducted in 1977, engineers from Thiokol (the company mainly producing the booster rockets for the Space Shuttle Challenger) performed a test to simulate a motor firing to test that the casing was structurally sound. These tests contradicted the expected outcome when the "joint tang and inside clevis (shown in Figure 1 above) bent away from each other instead of toward each other" which caused a rotation in the SRB joint. At the time, Thiokol engineers did not see this rotation as a major issue and moved forward with further testing (Presidential Commission, 1986, p. 123-124).

There was another decision made by Thiokol that could have also stopped the Challenger from exploding the night before liftoff. During a series of teleconferences between Thiokol and NASA engineers, the Thiokol engineers brought up that there was no data collected for using the O-rings in the SRB in temperatures below 53°F (Presidential Commission, 1986, p. 100). Due to this concern, it was recommended by Thiokol that the launch did not move forward with the near freezing predicted weather. However, NASA management was appalled by this recommendation and, according to Roger Boisjoly (one of the lead engineers for Thiokol), pressured him and the other engineers to move forward with the launch (Berkes, 2012). The final result of these teleconferences was that “Thiokol had reassessed; temperature effects are a concern, but data is inconclusive.” (Presidential Commission, 1986, p. 109).

The morning of the launch, there was ice found on the SRB and the temperatures for each of the two SRBs were 25°F and 8°F. This raised no concerns for the ice crew since there were no *Launch Commit Criteria* for surface temperatures. They decided to report that that were “patches of ice on lower segment and skirt of left SRB,” (Presidential Commission, 1986, p. 111) but did not report the surface temperatures to their superiors.

While the O-rings were the actual failure of the Space Shuttle Challenger, there are many other things that led up to this moment. Actor-Network Theory (ANT) attempts to consider human and non-human elements equally as actors within a heterogeneous network (Cressman, 2009). As previously stated, the tests done almost a decade earlier, Thiokol engineers not standing up to NASA administration, the extreme temperatures, and lack of information given to the smaller, less important crews all could have been used to predict the explosion that happened, yet nobody did anything about it in the end. Using ANT, it can be seen that each of the social and technical events are equally important to the failure of the Space Shuttle Challenger. If any of them were left out, then the entire story behind the explosion would not be complete.

Conclusion

The primary outcome of the technical project will be the assessment of the feasibility and capability of future hypersonic decelerating CubeSat experiments. The data collected and returned 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 or evidence of either premature spacecraft incineration or slowdown to sub-hypersonic speeds.

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.

Factors other than the technical aspects of the project must be looked into to have a positive outcome. It was shown that there are many factors that contribute to a mission's success or failure by studying the Space Shuttle Challenger's explosion through the use of Actor-Network Theory. This analysis will help the project team along the design path and lead to a successful CubeSat launch in the near future.

Word count: 2,111

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