Prospectus

Decelerating Hypersonic Flight Experiment Using a Cubesat Platform
(Technical Capstone Topic)

Hypersonic and Supersonic for Commercial Use
(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). Motivated by threats from China and Russia, the United States government and Department of Defense have recently begun expanding funding and research into hypersonic flight for use in weapons systems (Sayler, 2021). Hypersonic weapons systems' combination of speed and maneuverability make them extremely difficult to intercept before hitting their targets, and make hypersonic vehicles and weapons significantly more expensive to research and develop (Cronk, 2021). Some private companies also seek to build hypersonic passenger aircraft, which could connect LA to Tokyo in under two hours (Baggaley, 2019).

Hypersonic research has historically cost multiple billion dollars from the U.S. National Budget (Sayler, 2021). 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). Thus, lower cost and availability have bolstered its use in university funded projects for undergraduate study of spacecraft design, and would allow for attainable hypersonic research for college students.

In order to better understand the impact the affordable research CubeSatellites offer, we must analyze the effect of research and development on high-speed flight vehicles in the commercial market. The cost of research and development has proven to be a limiting factor in the design of many aircraft, and one such example is the concorde (Concorde SST, 2016). Through the analysis of the prospects of CubeSat technology, I am constructing a network of human and non-human actors in the development and long term success of high-speed flight vehicles

The world of Aerospace Engineering has much to gain from the affordable research and development offered through CubeSat technology. Research can then become attainable to young people at universities and small companies independent of the Department of Defense. Testing the hypersonic environment with a CubeSat significantly reduces the costs associated with ground testing and provides greater accuracy than model-based testing (Glenn Research Center, 2021).

This team seeks to assess the feasibility of using a CubeSat to study the deceleration of a spacecraft at hypersonic speeds and collect data that will be transmitted to engineers and scientists studying hypersonic flight. The success of this mission will allow greater understanding of the capabilities for CubeSats in hypersonic research endeavors, and their ability to provide a more cost effective, accurate, and accessible research medium.

Technical Problem

Air and Space travel have historically been a key interest in the eye of the American Public, from the first flight to the Space Race of the 60's. Flight has evolved over the years from basic gliders to turbojet planes, to supersonic, and ultimately hypersonic flight with many tangential developments appearing throughout the process. Hypersonic research is expensive, with an annual budget of 3.8 Billion, but has still become a priority due to a growing competition with countries such as Russia and China (Sayler, 2021).

Hypersonic research is typically funded by the government and comes with a high mission cost per launch cycle. Stone mentions that "the next generation of super-fast (hypersonic) missiles being developed currently cost tens of millions per unit," (Stone, 2021). This high price slows down development and makes hypersonic research much less desirable than the subsonic counterparts which cost around 5 million per unit (Stone, 2021). With these high costs, hypersonic research is out of reach of the average scientist. Universities and non DoD contracted scientists do not have the funding to conduct experimentation on hypersonic flight, despite the fact that hypersonic flight will greatly improve personal travel and shipping industries if it comes to fruition (Hermeus Corp., 2021). This team wishes to propose that the use of CubeSats, a compact and compartmentalized satellite that uses various modules to collect data, provides an affordable means to conduct hypersonic flight research. CubeSats allow for different modules to be attached to a standardized, compartmentalized body to collect a wide variety of data at a reduced cost. It does this by using parts and modules already in production, which reduces the cost of developing a highly capable test satellite.

To help clarify the basis of this mission, the team has generated the following mission operational requirements, functional requirements, and constraints. 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

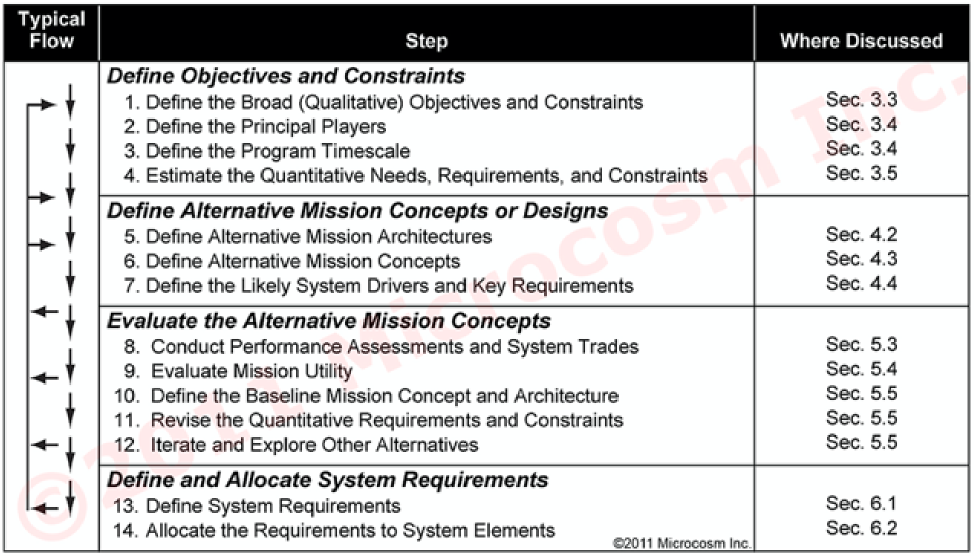
ID	Requirement
O1	Maintain stability of CubeSat at hypersonic velocity during atmospheric reentry
O2	Directly or indirectly transmit data throughout mission
O3	Minimize power consumption of avionics and sensors during operation while fulfilling requirements

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



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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Space Mission Engineering (SME) Process (Wertz et al, 2011)

The Space Mission Engineering (SME) was used to guide the development, and is meant to be a more efficient, near term, and cost effective method to conduct a space mission (Wertz et. al., 2011).

To gauge the success of this mission, we will first analyze the abilities of the cubesat to successfully collect and transmit data from hypersonic speeds. We have found online CubeSat initiatives which will aid in the development of a CubeSat. NASA's online forum includes ample information on constructing, hosted payloads, financing, and licensing information for practical use of CubeSats (NASA, 2021). The CubeSat must successfully launch, enter into orbit, decelerate, and burn up upon reentry while transmitting data for as long as possible. Secondary measures of effectiveness include any measure of increased interest in aerospace programs at the University of Virginia or other academic institutions where this mission is cited, and any consumers who purchase and use this experimental data for hypersonic flight development.

STS Problem

The concorde jet was once the epitome of luxurious and futuristic flight, and instantly encapsulated the public when the concept was released. In an independent review, Sam Chui describes his flight as "worth every cent, there is no better way to fly than on Concorde," (Chui, 2003). Despite the praise, the last supersonic commercial flight was on October 24th, 2003 when the remaining Concorde jets were grounded (History).

The Concorde was deemed unprofitable and unviable to fly due to the immense fuel consumption of the engines and noise pollution during both subsonic and supersonic flight. Those mitigating factors along with a notable accident are typically attributed to grounding the Concorde for good (Museum of Flight).

While these factors did contribute to the Concorde and commercial supersonic flight failing in the long term, it overlooks the fact that much of the research on supersonic flight to that point was defense centric and did not focus on the commercial possibilities. The Concorde had no commercial basis to work from and started their development from the ground up, and were venturing "into areas not hitherto explored by commercial aircraft designers," (Concorde SST, 2016). This ultimately led to the high cost of production and design compromises due to research and development budget. By analyzing the environmental factors and shortcomings of the final Concorde product along with the inherent disadvantages from the start of development, we can more completely analyze the failure of the Concorde as a commercial means for supersonic flight.

I propose that by looking through the scope of Actor-Network Theory it becomes apparent that the pollution, efficiency, and cost of operations acted in conjunction with the lack of development for commercial supersonic flight, ultimately leading to the failure of the Concorde. The development was especially problematic because it led to extensive costs and compromise in the aircrafts design such as the materials science and wing design, for example (Concorde SST, 2016). A network builder, namely the French and British governments, were attempting to solve the “problem” of creating a sustainable supersonic transport aircraft by creating a network of human and environmental factors. The network included actors such as engineers, corporate investors, the flight environment in which the plane would fly, and the scientific research and development which had already occurred.

Actor-Network Theory (ANT) is a framework that classifies certain developments as “black box” networks with a heterogeneous set of actors influencing the development of an artifact. The heterogeneity comes from the fact that actors can be human or non-human, so long as they have an effect on the development of the artifact. In this framework, a network builder assembles a network of actors that is meant to solve a problem (Cressman, 2009). In this case, the problem being solved was that of commercial supersonic flight. Another key tenant of ANT to the proposed claim is that if certain primary actors are not considered in the development process of an artifact the artifact may not succeed in a general consumer market.

To support my claim I will analyze evidence from the firsthand accounts of developers from that time period both of military and commercial supersonic aircraft, along with the historical development trends of aircraft. These sources will provide insight into the development of the Concorde and the general lack of adjacent and preliminary development which resulted in the permanent grounding of the Concorde SST jet.

Conclusion

The project is expected to produce several outcomes. One such 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 on the effectiveness of the CubeSat technology for hypersonic applications. The results of student and professional assessment of the mission may have the secondary effect of promoting Aerospace Engineering at the collegiate level to the public and encouraging further development.

The socio-technical analysis of the Concorde SST will help identify the underlying reasons for the failure in the consumer market. It will also help illustrate the importance of research and development focus on commercial supersonic and hypersonic flight vehicles. A network of many factors caused the Concorde SST to fail in the market, but the physical and environmental factors alone were not the downfall of the aircraft. It was a network of human and non-human faults which ultimately led the Concorde SST and similar aircraft to be unsuccessful.

The combination of these technical and STS research objectives has the potential to steer the industry towards more affordable research opportunities which allow greater freedom of research for developing high-speed flight vehicle industries. More accessible research in this field will allow for greater industry success of future supersonic and hypersonic aircraft, separate from a solely military application of the technology. This research will have a profound impact on the rate and quality of production on future aircraft and spacecraft, and allow our society to continue to progress towards efficient and sustainable high-speed flight vehicle development.

Word Count: 2292

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