Using a CubeSat Platform as a Means for Conducting Hypersonic Glider Flight Research

Exorbitant Prices of Ambulances Rides: What Factors are Responsible for the Current Inefficiencies of Emergency Medical Transportation?

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 of the Degree
Bachelor of Science in Aerospace Engineering

By
Nicholas Lu

November 1, 2021

Technical Project Team Members

Brendan Angelotti	Ryan Jansen
Samantha Castro	Emma Jensen
Maggie Che	James Parker Johnson
Jonathan Cummins	Adam Obedin
Desmond DeVille	Eva Paleo
Michael Fogarty	Christina Rodriguez
Jashianette Fournier Jaiman	Joshua Willoughby

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.

ADVISORS

Bryn Seabrook, Department of Engineering and Society

Christopher Goyne, Department of Mechanical and Aerospace Engineering

Prospectus

Introduction

In the United States of America, the Federal Aviation Administration (FAA) is the chief governing body for all air and space traffic in the country and is responsible for regulating all civil aviation and commercial space travel (*Agencies - Federal Aviation Administration*, n.d.). A small, but critically important, subset of civil aviation is emergency medical air transportation, frequently called air ambulances. These aircraft and their crews provide life-saving services to critically injured patients, but they have recently come under scrutiny for their typically exorbitant prices. One of several justifications for these costs is the long-held belief in emergency medicine that a patient must get to a hospital within 60 minutes of being injured before their chances of survival or recovery drop off rapidly, a feat that in many cases is only possible via helicopter (MedEvac Foundation International, 2011). This claim has been contested in recent years, though (Wendover Productions, 2021), bringing into question the entire business model of air ambulances. Furthermore, recent research has suggested that a large number of emergency medical flights are unnecessary (Vercruysse et al., 2015), and most patients that are flown on them are unable to refuse consent, frequently resulting in huge unwanted or unexpected expenses. This raises the question of how the system got to this state, and what factors contributed to the inefficiencies that plague it. Research will be conducted and a report will be written and submitted attempting to answer this question.

Farther from home, commercial space flight accounts for all scientific, non-military space endeavors, including missions to the International Space Station (ISS) and test vehicles for hypersonic flight research. Hypersonics were researched intensely during the 1950s and 1960s, throughout the height of the Space Race, as spacecraft are fundamentally subjected to this regime during reentry; but in the following decades this research lulled (Anderson, 1984). In the last few years, however, the desire to continue hypersonic research has reemerged as jet propelled aircraft approach the possibility of flying hypersonically. Typically, this research is extremely expensive, as it requires a rocket launch to reach and maintain this speed, not to mention the cost of simply designing and preparing for such an experiment. One possible solution to this problem is to conduct hypersonic experiments by enclosing them in a CubeSat and launching them as an auxiliary payload on a preexisting rocket launch. The technical deliverable will be an explanation of a proposal for such a mission that will be used as an educational and research mission.

Using a CubeSat Platform as a Means of Conducting Hypersonic Glider Flight Research

Problem Statement

Hypersonic flight occurs at speeds exceeding five times the speed of sound and is an expanding research field in the aerospace industry with military and civil applications. Military applications include hypersonic missiles, both offensive and defensive, and high-speed aircraft. Civil applications include access to space and commercial air travel. A CubeSat is a small satellite flown in low earth orbit that is well suited for undergraduate education. As CubeSats orbit Earth, they fly at hypersonic speeds and re-enter the atmosphere in around five to seven days if launched into Extreme Low Earth Orbit (ELEO) (Panwar & Kennewell, 1999). Once objects re-enter the atmosphere, they can prolong hypersonic flight if measures are taken to reduce drag.

This technical project will assess the capability of a CubeSat to house a hypersonic glider flight experiment. These experiments are difficult to replicate in wind tunnels and expensive to achieve on rockets and aircrafts. By using a CubeSat, university students may be able to conduct these experiments at a lower cost, and with greater accessibility. The following discusses a mission proposal for a hypersonic glider CubeSat and outlines the significance, objectives, approach, resources available, and anticipated outcomes for the mission.

Significance of the Problem

Some current United States Weapons systems being developed include the Air-Launched Rapid Response Weapon (ARRW), Intermediate Range Conventional Prompt Strike (IRCPS), Long-Range Hypersonic Weapon (LRHW) and unmanned hypersonic aircraft. However, conducting these large-scale projects is expensive and time consuming (Bentley, 2021). By conducting this research experiment on a hypersonic glider utilizing a CubeSat, data collection will be cheaper, faster, and more accessible. Having undergraduate students conduct the research experiment will provide them with the knowledge base to directly enter the hypersonics workforce. Additionally, further understanding of hypersonic flight may lead to advancements in commercial aircraft and spacecraft. Hypersonic aircraft would greatly decrease travel time, while hypersonic spacecraft would provide greater accessibility to space travel. Flight data collected from CubeSat research will provide hypersonics researchers and professionals with information to help advance hypersonic flight, ultimately making it more accessible to the world.

Objective of the Research Work

As previously described, the aim of this research work is to perform a hypersonic experiment using a test article deployed from a CubeSat in Extreme Low Earth Orbit (ELEO). As can be seen in Table 1, this goal has been discretized into three primary objectives, which are motivated by a combination of technical and educational considerations. These have been further subdivided into supporting objectives intended to facilitate the completion of these larger goals. Upon project completion, the fulfillment of these objectives will be used to gauge mission success.

Table 1. Labeled Research Objectives

O1	**Demonstrate the feasibility of CubeSats as a platform for hypersonic glider flight research.**
1.1	Design a CubeSat-based system that can survive the environment of launch and insertion into extreme low earth orbit (ELEO)
1.2	Deploy gliding hypersonic test article from the system
1.3	Maintain stable flight at hypersonic speed for maximum possible duration
1.4	Collect/transmit mission data from test article during hypersonic flight
1.5	Prevent any large fragments from reaching Earth's surface
O2	**Show that undergraduate students can conduct hypersonic glider flight experiments at lower cost and with greater accessibility.**
2.1	Minimize cost by using commercially sourced components and a student workforce
2.2	Deploy a successful experiment designed by undergraduate researchers
O3	**Provide an opportunity for undergraduates to gain hands-on experience and generate interest in the spaceflight industry.**

Approach to the Problem

The process of planning for and designing the hypersonic glider space mission will be completed within the Mechanical and Aerospace Engineering department's Spacecraft Design course advised by Professor Christopher P. Goyne at the University of Virginia (UVA) over the course of the next two years. The students in this course are divided into two groups of fifteen members. This document is the prospectus of one of these teams, which is tasked with designing a hypersonic glider using the CubeSat platform. Each team is subdivided into five functional teams: Communications; Software and Analysis; Power, Thermal, and Environment; Attitude Determination and Control System (ADACS) and Orbits; and Structures and Integration. These component teams are all together led by one project manager.

Table 2. Brief Timeline

Phase		**End Defined By**	**Duration**
Concept Exploration		Finalized Prospectus End of Semester Presentation	Fall 2021
Detailed Development	Risk Reduction/Technology Development	Initial Design Proposal Submission	Spring 2022
	Detailed Design	Finalized Design Proposal Grant Proposals Submitted	Fall 2022
Production and Deployment	Production	Final CubeSat Testing Ship to Launch Site	Spring 2023
	Launch	Lift-Off and Arrival in VLEO	Summer 2023
	On-Orbit Check-Out and Transfer to Operational Orbit	Start of operations	~ 1 week of orbit
Operations and Support	Operations and Disposal	Re-entry	~ 1 week

Over the course of the fall and spring semesters of the first year, the class will go through conceptual and preliminary design. Each phase will be concluded with a design review. The design will be finalized in the fall of the second year, after which system manufacturing and integration will occur, followed by subsystem testing. The anticipated mission launch date is the Summer of 2023. The flight during the mission will be monitored, and after the mission is concluded, there will be post-flight analysis of the data collected. This timeline is summarized in Table 2.

It is anticipated that this CubeSat system will be launched onboard a Northrop Grumman (NG) Antares rocket and deployed from its second stage into Extreme Low-Earth Orbit (ELEO).

Technical solutions will be developed by the subsystem teams to meet functional and technical constraints and requirements developed during the Space Mission Engineering Process.

Available Resources

For the design and construction of the project, the team is provided with resources such as industry experts, sponsors, and available facilities. Team advisor, Chris Goyne, alongside additional faculty support from University of Virginia provides invaluable knowledge and guidance to the team during the conceptual design of the project. The Federal Communications Commission (FCC) will also be consulted for additional guidance on requirements and regulations on communication with the CubeSat. Two key sponsors for the team include the National Aeronautics and Space Administration (NASA) for funding of the fabrication and testing of the team design as well as providing the launch site, Wallops Flight Facility, and Northrop Grumman for providing the Antares launch vehicle (Clark, 2021). The launch profile will be dependent upon Antares concept of operations as shown in Figure 1. The profile is important to consider as the CubeSat is attached to the NG Antares Rocket. Lift off, separation, frame deployment, and reentry into orbit are its main stages. As shown in the figure, around nine minutes after lift-off the CubeSat will be released into orbit for five to seven days after which it will reenter the atmosphere.

Figure 1. Diagram of Concept of Operations for CubeSat Launch to Reentry (Adapted from Clark, 2021)

Additional resources provided by the University of Virginia include lab spaces and testing equipment in the School of Engineering as well as student experimental facilities providing mechanical manufacturing capabilities and machinery for construction of future prototypes. Available labs include Lacy Hall, the mechanical engineering building basement, and the Architecture School Fabrication Lab. Group project grant funding from the University of Virginia is under consideration for additional funding of the project.

Anticipated Outcomes

Secured government funding and sponsors (UVA, NASA, etc.) will enable the construction of a CubeSat which utilizes the Space Mission Engineering (SME) process to satisfy mission objectives. By demonstrating the feasibility of CubeSats as a platform for hypersonic glider flight, this project will introduce a new method for conducting low-cost hypersonics research in conditions unachievable on the ground. The project will rely on several mission-critical events occurring: the successful deployment of the CubeSat and hypersonic glider, the stability of the glider during flight, and data being relayed during reentry. Ideally, the data will show a longer time in orbit than a typical CubeSat design due to the decreased drag on the test article with stable hypersonic flight conditions. The collected flight data will be transmitted to partner organizations.

Drafting for the funding proposal, designing the CubeSat and deployable glider, and working with government organizations will result in an optimal learning environment for all undergraduate students involved. Such an environment, which requires substantial writing, design, and communication skills will lead to increased knowledge and improved abilities of participating students. Professional relationships will be established with University of Virginia faculty and government organizations for future collaboration. Additionally, through demonstrating undergraduate students' capabilities of conducting these experiments, it is hoped that prospective students take ongoing interest in future aerospace research.

Type of Technical Paper

The final paper will be a mission proposal to the project coordinators, Professor Goyne and the University of Virginia detailing our plan for a hypersonic glider vehicle experiment using a CubeSat for submission to NASA and the DoD for funding.

Conclusion

Through this project, the turbulent conditions of hypersonic flight will be captured at a low cost providing important and limited information to the aerospace industry. Within this industry, the captured data has considerable implications for military and commercial aircraft and spacecraft. The team will finish the Concept Exploration phase of the project this semester and continue with the Detailed Development phase next semester. The project team is well-prepared, knowledgeable, and enthusiastic for the design process and continued application of space engineering principles.

Factors Contributing to Inefficient Emergency Medical Transportation

Undisputedly an important and life-saving service, ambulances both on the ground and in the air provide rapid transportation to hospitals for critically injured patients. The first use of a helicopter to transport a trauma patient was on 23 April, 1944, when USAAF Lt. Carter Harman flew a few injured men in Burma at the end of WWII (Martin, 2006). This event set the precedent for helicopter-based aeromedical transportation, but it was not until the Vietnam War that it became widely used. Through this conflict and the Korean War, aeromedical helicopters were thrown into the public eye; and with the benefits of the rapidity of service and the ability to reach remote areas, it was not long before civilian versions were adopted.

Today, air ambulances are very widespread, but they are typically extraordinarily expensive. In a study performed by Chhabra et al., it was found that the median cost for one emergency helicopter flight was around $49,000 (Chhabra et al., 2020). This cost can place a huge financial strain on patients or their families, especially if they are members of a lower socioeconomic class. Patients that are flown on air ambulances are almost always unconscious or otherwise unable to refuse consent, and it is rarely considered whether a service provider is actually in-network of a patient’s insurance when choosing to use an air ambulance. This fact can result in “surprise bills” in the range of tens of thousands of dollars more than the patient was expecting to pay for service (Chhabra et al., 2020).

Furthermore, a multi-year study analyzing the ground and air emergency transportation to the University of Arizona Level 1 trauma center found that nearly one-third of all patients transported by helicopter were “minimally injured.” They also found that there was no difference in mortality rate between patients transported by ground or helicopter, and that there was no difference in length of stay at the hospital for minimally injured patients, regardless of how they arrived at the hospital (Vercruysse et al., 2015). As such, a large number of flights were unnecessary, needlessly placing many patients in potentially life-crippling debt. Over the course of the study, several million dollars could have been saved by patients if they had been transferred by ground.

All of this is indicative of a major market failure. Patients often have little say in how they are transported (or if they are transported at all), resulting in constant demand, regardless of the prices set by air ambulance service providers (Turrini et al., 2021). There have been many proposed solutions to this problem, however none of them have been able to be applied (Maryland Health Care Commission, 2006). This inability to adopt a solution is often attributed to the Airline Deregulation Act of 1978. Simply put, this act prohibits the government from regulating any part of the way airlines conduct business, including: the rates they set, the routes they take, and the services they provide (Peterson, 2018).

Originally instituted as a result of academic pressure on the government, deregulation aimed to allow the airline industry to grow and prosper. For roughly a decade after the act was passed, the industry was quite volatile while it found a new equilibrium (A. R. Goetz & Dempsey, 1989); several new airlines were formed and others went out of business; new business models were adopted in the pursuit of finding the optimal one. After this time of volatility had passed, though, the act was considered a resounding success based off of its intended results. The prices of fares dropped significantly, drastically increasing the accessibility of air travel, especially for those that previously struggled to afford it. Better service to popular destinations further increased the appeal of flying. As a result, the volume of passengers increased markedly and the total number of flights soared, ushering in a golden age of flying (A. Goetz & Vowles, 2009).

These results of airline deregulation have generally been very good for the aviation industry, but after several decades, certain unintended consequences have arisen. Because most emergency medical air transportation systems are privately owned companies, they are by definition airlines. As a result, principal among these unintended consequences is that a ceiling cannot be placed on the price of a ride in an air ambulance. With this fact, it becomes apparent why all previously proposed solutions to the problem of this market failure have been unsuccessful: as prices continue to rise, there are no market forces to drive the price down, since most patients are unable to refuse the service, but the government cannot intervene because it would break the precedent of deregulation and invite a host of other problems for the rest of the aviation industry.

Research Methodologies

Research Question: What factors are responsible for the current inefficiencies of emergency medical transportation in the United States?

This research question will be approached through the Actor-Network Theory (ANT) framework and Wicked Problem Framing. Despite the “Theory” in its name, ANT is more accurately described as a framework for conducting and organizing research. Principally attributed to Bruno Latour, Michel Callon, and John Law, this framework is used to describe the relationships between both the human and non-human actants[1] within a system, as well as how these actants affect the system (Cressman, 2009). Through this framework, the market failure of the emergency medical air transportation industry will be examined to determine potential actants that influence it, which will each be analyzed via a network analysis to determine their effects on the system and each other.

One of the chief limitations of ANT is that it is exclusively reliant on case studies and empirical observations, overlooking "elements like values and norms" (Cressman, 2009). Similarly, pure ANT does not consider social factors such as race, class, and gender in its analysis (Banks, 2011). To alleviate this limitation, analysis of these factors' contributions to the network will be specifically included, as a recent study has identified a disparity in the usage of emergency medicine based on age, gender, and race (Sarkar et al., 2020).

Sources for this information will be gathered via searches using keywords such as: air ambulance, emergency medical air transportation, market failure, and aeromedical. These keywords will likely initially lead to broad information regarding this industry, which can then be used to inform future searches as other factors surface, allowing for focusing in on those factors. While academic or scientific papers will be the chief target of this research, other sources, such as newspapers or blogs, might be found to help inform further searches. Additionally, the personnel working for the emergency medical transportation service based at the University of Virginia's hospital, Pegasus, will be asked for interviews to gather insider perspectives. Finally, past proposed solutions to the problem will be researched.

The term "wicked problem" was first coined in 1973 by Horst Rittel and Melvin Webber to describe policy problems that are fundamentally unsolvable by their nature. In their paper,

[1] "Actant" is the preferred term, as "actor" is primarily used for human roles (Banks, 2011)

they define several characteristics common to all wicked problems, including: having an innumerable set of potential solutions, solutions cannot be tested by trial-and-error, and the problem can be seen as simply a symptom of another underlying problem (Rittel & Webber, 1973). By framing the inefficiencies of emergency medical transportation as a wicked problem, past proposed solutions will be analyzed through policy analysis to determine why they either failed or were not adopted. Combined with ANT, wicked problem framing will also help to identify root causes or source problems of the inefficiencies and determine prerequisite requirements for future solutions to be successful.

Conclusion

Hypersonics is a reemergent and important field of current aerospace and aerodynamic research, but conducting experiments for it can be extremely expensive. The proposed project will describe the technical details of an innovative way to conduct hypersonics research at comparatively low cost by using the CubeSat platform as ride-along payload of an International Space Station resupply mission onboard a Northrop Grumman Antares rocket. This will lay the groundwork for next year's spacecraft design capstone class to finish designing the module and execute the experiment, thereby demonstrating the feasibility of such a mission.

Additionally, emergency medical air transportation is inefficiently employed and excessively expensive, leaving many helpless patients with needlessly large bills on top of already high medical bills. This system is illustrative of a market failure, and this research project seeks to explore the factors that have contributed to this problem. Despite many solutions having been proposed, none of them have ever been successful. This research will also identify why these solutions failed and what was common to all of them. Furthermore, it will seek to identify avenues by which a permanent solution may be found, and what characteristics said solution must have.

References

Agencies—Federal Aviation Administration. (n.d.). Federal Register. Retrieved October 21, 2021, from https://www.federalregister.gov/agencies/federal-aviation-administration

Anderson, Jr. J. D. (1984). A survey of modern research in hypersonic aerodynamics. *17th Fluid Dynamics, Plasma Dynamics, and Lasers Conference*. https://doi.org/10.2514/6.1984-1578

Banks, D. (2011, November 2). A Brief Summary of Actor Network Theory—Cyborgology. *Cyborgology*. https://thesocietypages.org/cyborgology/2011/12/02/a-brief-summary-of-actor-network-theory/

Bentley, R. (2021, September). *Strategy at Mach 5: Hypersonic Weapons in Chinese Military Strategy*. Retrieved from Air University: https://www.airuniversity.af.edu/Wild-Blue-Yonder/Article-Display/Article/2771133/strategy-at-mach-5-hypersonic-weapons-in-chinese-military-strategy/

Chhabra, K. R., McGuire, K., Sheetz, K. H., Scott, J. W., Nuliyalu, U., & Ryan, A. M. (2020). Most patients undergoing ground and air ambulance transportation receive sizable out-of-network bills: An analysis of the prevalence and financial impact of out-of-network billing for ground and air ambulance transportation. *Health Affairs*, *39*(5), 777–782. https://doi.org/10.1377/hlthaff.2019.01484

Clark, S. (2021, February 20). *Antares launch timeline on the NG-15 mission*. Spaceflight Now. Retrieved October 19, 2021, from https://spaceflightnow.com/2021/02/20/antares-launch-timeline-on-the-ng-15-mission/.

Cressman, D. (2009). A Brief Overview of Actor-Network Theory: Punctualization, Heterogeneous Engineering & Translation. https://summit.sfu.ca/item/13593

Goetz, A. R., & Dempsey, P. S. (1989). Airline Deregulation Ten Years After: Something Foul in the Air. *Journal of Air Law and Commerce*, *54*(4).

Goetz, A., & Vowles, T. (2009). The Good, the Bad, and the Ugly: 30 Years of US Airline Deregulation. *Journal of Transport Geography*, *17*, 251–263. https://doi.org/10.1016/j.jtrangeo.2009.02.012

Martin, T. (2006). Chapter 1: History of Aeromedical Transportation. In *Aeromedical Transportation: A Clinical Guide* (2nd ed.). Taylor & Francis.

Maryland Health Care Commission. (2006). *Air Ambulance Study: Required Under Senate Bill 770*.

MedEvac Foundation International. (2011). *Air Medical Services: Critical Components of Modern Healthcare Systems*.

Panwar, R., & Kennewell, J. (1999). *Satellite Orbital Decay Calculations*. Australian Government: Bureau of Meteorology. Retrieved October 19, 2021, from https://www.sws.bom.gov.au/Category/Educational/Space%20Weather/Space%20Weather%20Effects/guide-to-space-radiation.pdf.

Peterson, R. (2018). Impacts of Airline Deregulation. *TR News*, *315*(May-June 2018), 8.

Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, *4*(2), 155–169. https://doi.org/10.1007/BF01405730

Sarkar, S. N., DeVito, A. F., Lespinasse, E., & Khosa, F. (2020). Gender and racial disparity for hospital emergency service usage in USA: A quantitative analysis for various age groups during 2010–2017. *Journal of Public Health and Emergency*, *4*(0), Article 0. https://doi.org/10.21037/jphe-20-47

Turrini, G., Ruhter, J., Chappel, A. R., & Lew, N. D. (2021). *Air Ambulance Use and Surprise Billing*. 14.

Vercruysse, G. A., Friese, R. S., Khalil, M., Ibrahim-Zada, I., Zangbar, B., Hashmi, A., Tang, A., O'Keeffe, T., Kulvatunyou, N., Green, D. J., Gries, L., Joseph, B., & Rhee, P. M. (2015). Overuse of helicopter transport in the minimally injured: A health care system problem that should be corrected. *Journal of Trauma and Acute Care Surgery*, *78*(3), 510–515. https://doi.org/10.1097/TA.0000000000000553

Wendover Productions. (2021, January 26). *How Air Ambulances (Don't) Work*. https://www.youtube.com/watch?v=3gdCH1XUIlE