Hypersonic ReEntry Deployable Glider Experiment (HEDGE): Power, Thermal, Environment Subsystem Product Development

How Hypersonics Are Being Taken into Consideration both Technically, Socially, and Environmentally

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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

Breaking down scientific barriers leads to new discoveries and new ways to think about current processes. For hypersonic research, this means how objects that travel above Mach five can be used for commercial travel, militaristic strategies, and educational purposes. 1949 marked the first time a human-made object reached hypersonic speeds. The first object to achieve this speed was the V-2 rocket and it was used for militaristic development (Bowersox, 2020). In the 21st century, the United States (US) and Russian militaries are still exploring hypersonic missiles that can out speed anti-missile turrets.

On the other hand, as hypersonics grew in popularity militaristically, a second wing of interest was created. This wing was created to mitigate the domestic and international travel times. Meaning hypersonics had branched out from the government and reached the public and private sectors of air travel. In 1976, the Concorde, the first and only supersonic (above Mach one) commercial aircraft was constructed. However, one of the major issues with hypersonics is cost. Due to the Concorde's cost, it touched down for the last time in 2003: "The Concorde was so expensive that private jets were actually deemed a much more affordable and practical option for anyone who needed a quick, direct, and private mode of travel" (Papadopoulos, 2022). This means that in the past hypersonics were classified as reserved for the government and high-class citizens in a society leading to hypersonic flight being unachievable for middle- and lower-class citizens. This is a trend when it comes to hypersonics and still exists in 2022. Their test flights are extremely expensive because on ground wind tunnels do not have the capabilities to simulate hypersonic flight meaning that a high-end supersonic aircraft or rocket will have to be used to perform these tests.

Regardless of these prices hypersonics are still being used and tested today. In 1999, the CubeSat was invented (Canadian Space Agency, 2022), giving the aerospace industry, universities, and other educational facilities the ability to test hypersonic vehicles at a fraction of the cost. A CubeSat is a cube that has the dimensions of 10 x 10 x 10 cm also known as a U. Stacking CubeSats on top of each other will result in a 2U or higher. They only cost $50,000 to produce and can be launched in conjunction with a mission to the International Space Station. A regular hypersonic missile test costs two to five million dollars meaning CubeSats are a fraction of the cost (Lofgen, 2022).

Using a CubeSat, the technical project is to develop a Hypersonic ReEntry Deployable Glider Experiment (HEDGE). Its goal is to demonstrate the feasibility of CubeSats as a platform for hypersonic glider flight research. To achieve this goal different subsystems have been developed with their own goals in mind to help HEDGE succeed. These subsystems include program management, communication, software and avionics, power, thermal, and environment, attitude determination and control system (ADACS) and orbits, and structures and integration. The focus of the technical section will be on the power, thermal, and environment subsystem. The goals of the power, thermal, and environment subsystem are to choose the right type of power source, thermal protection, and temperature and pressure sensors for HEDGE to be under the weight limit, under the power budget, and under the cost requirements. Building on this work, in my STS project, I will explore the viability of hypersonics based on social, environmental, and economic factors. The Concorde will serve as a primary case study for this. However, other hypersonics and CubeSats will aid in this discussion.

Technical Topic:

HEDGE is designed to be a 3U CubeSat. I am a part of the power, thermal, and environment subsystem which has multiple jobs that must be separated by parts. Power's job is to provide and distribute adequate electricity to every subsystem and sensor on HEDGE. It is thermal's job to keep spacecraft's component systems within acceptable temperature ranges. Lastly, it is the environment's job to deal with the environment beyond the sensible atmosphere of Earth. For HEDGE, this means to collect and transmit temperature and pressure data while in orbit and during reentry. To complete these jobs, our team must meet our research goals. The power team will create a power budget to determine the minimum necessary to power on-board computers (OBC), motors and actuators, communications/radio systems, ADACS, flight software, system health checks and redundancies. Georgia Tech noted that the maximum power usage of a 1U CubeSat was 1W, minimum power usage was 0.11W, and an idle power usage of 0.2W (Tadanki, 2020). To obtain this power, we must decide whether to store the power in the form of fuel cells or batteries or to generate it using solar panels or thermonuclear energy.

The thermal team's research goal is to pick the optimal heat shield and spacecraft structure materials so that the HEDGE platform can collect hypersonic data upon reentry and burn up in the atmosphere. Temperature increases rapidly as speed increases above Mach 5, typical hypersonic air temperatures can reach 3000 K. During reentry of the Earth's atmosphere from an orbit, some spacecraft's surface temperature can exceed the temperature of the sun's surface. This causes temperature to often be a limiting factor when researching hypersonic flight. Furthermore, when reaching hypersonic speeds, the shockwave around a spacecraft will envelop the body and create a hot shock layer that has the potential to damage the fuselage. Thermal effects across the entire spacecraft must be considered and not just on the leading surfaces (Urzay, 2020).

For the environment team, the goal is to collect pressure and temperature data points while in orbit and through the re-entry process. Different types of sensors will be tested to ensure that they can withstand the heat and get an accurate measurement. Testing will be done using a kiln because their temperature range is between 982℃ and 1316℃. The maximum temperature during re-entry according to the Federal Aviation Administration (FAA) is 1477℃. We will compare H-series platinum sensors, thermocouples, and infrared IR thermometers to see which one will be the most accurate and most cost-effective for the thermal sensors. For pressure sensors, we will be testing PVC 1000 and MEMS MicroPirani sensors. We will be collaborating with the structures and integration team to place these sensors on HEDGE. Additionally, heavy testing will be done on each part of HEDGE to ensure a successful mission. Also, since HEDGE is a multiyear project, last year's conceptual design review will be used as a backbone and as a starting point to develop a research plan. This plan will start with a broad selection of power sources and protective thermal materials and end with testing and the final selection for HEDGE. Overall, it is anticipated that HEDGE will fulfill its main objective of demonstrating the feasibility of CubeSats as a platform for hypersonic research while fulfilling each goal of the power, thermal, and environment subsystem.

Science, Technology, and Society

HEDGE is intended for a university class, however hypersonics reach beyond the classroom and affect society and the environment. To analyze hypersonics, the reason for investment, the cost of the investment, and the result of the investment must be explored. Since the 1950's, government agencies and the aerospace industry have been producing hypersonic missiles and vehicles (Bowersox, 2020). In 2018, John Harper wrote, "[defense] industry executives see hypersonic weapons as an increasingly lucrative business opportunity as the

Pentagon pumps more funding into its initiatives" (13). This means that even after 60 years, the desire to pursue hypersonic objects has not gone away and is still being heavily funded by the government. However, these productions and tests are not free; they host a variety of drawbacks. Noise pollution "will continue to increase in magnitude and severity because of population growth, urbanization, and the associated growth in the use of increasingly powerful, varied, and highly mobile sources of noise" (Goines, 2007, 287). As the popularity of hypersonics continues to increase, the amount of noise pollution created will also increase. Emissions are also of large concern when it comes to hypersonics. Since climate change has become an omnipresent issue, hypersonics are faced with the task of limiting the amount of greenhouse gasses (GHG) emissions they produce. One keyway that society has been involved in this process is by legislation. To "curb the growth of GHG emissions from air travel, the U.S. Federal Aviation Administration (FAA) has created a policy to achieve carbon neutral growth by 2020 relative to the 2005 baseline" (Arul, 2014). Additionally, certain studies have shown the impact of placing a carbon tax on air traffic and on automobiles. Lastly, as climate change awareness has increased some studies have revisited "the previous debate surrounding Concorde to explore the potential for current initiatives to overcome the public's anxiety of further environmental degradation" (Drake, 2001, 501).

To further examine why hypersonics are in use, Diffusion of Innovation by Katz, will be used as the primary framework. This framework states "the process of diffusion may be characterized as the (1) acceptance, (2) over time, (3) of some specific item-an idea or practice, (4) by individuals, groups or other adopting units, linked (5) to specific channels of communication, (6) to a social structure, and (7) to a given system of values, or culture" (Katz, 1963, 237). This is supported by the author explaining that very few studies have incorporated all the elements. Most of them “favor” certain elements (Katz, 1963). By being selective of different parts of this framework, different case studies of hypersonics can be analyzed to show their impact. In tandem with diffusion of innovation, a sunk-cost effect study will also be performed on hypersonics. This hypothesizes that “(a) because humans are social animals, the tendency to keep investing should be stronger in social than non-social context… (b) if it is indeed an adaptive heuristic, the decision to keep investing should require less cognitive effort than the decision to terminate further investments” (Hromatko, 2018, 258). Primarily these frameworks will use the Concorde as a case study, but they will also be used in a broader context.

Research Question and Methods

Creating this background on why and how humans interact with hypersonics will aid in answering the question, what do we gain from hypersonics and why are we still investing in them? Additionally, to answer this question, both the science, technology, and society and the technical section must be used. Although some of these studies have concrete evidence and results, the technical section is an experimental mission. For the science, technology, and society side, a case study on the Concorde will be done. I plan on doing a historical analysis to provide more context on why the Concorde was invented as well as see how it changed the hypersonic field. Understanding the downfall of the Concorde and the impact of the Concorde will shape the way society views hypersonics. Additionally, I plan on doing a literature review on different hypersonic missiles and planes that did not gain publicity to better understand the entire field of study. Lastly, an interview with a hypersonics professional will be performed. They will hopefully give me their thoughts on hypersonics not just in the technical aspect but also on the societal side. Additionally, I plan to use them to branch out into the hypersonic field to obtain other interviews to get multiple perspectives.

Conclusion

CubeSats are the way forward when it comes to hypersonic testing. Overall, it is anticipated that HEDGE will fulfill its main objective of demonstrating the feasibility of CubeSats as a platform for hypersonic research. For my team (power, thermal, and environment), it is anticipated that there must be an adequate way to generate, store, and distribute power throughout HEDGE. To do this, we must determine a power source, find the minimum power necessary, and create a power budget. On the thermal side, we must choose an optimal heat shield and structural material. Lastly, for the environment, choosing the right temperature and pressure sensors will allow for the collection and transmission of data points while in orbit and through re-entry. I anticipate that at the end of the science, technology, and society research I will show the importance of investing in hypersonics, have a general layout of the social structure both publicly and privately for hypersonics, and determine the environmental impact of hypersonics. Hopefully this research will find alternative methods to cut cost and peak market investment into alternative forms of hypersonics. In the future, having companies investing time and resources into CubeSat will allow for a faster transition to hypersonic capabilities.

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