HEDGE

(HYPERSONIC RE-ENTRY DEPLOYABLE GLIDER EXPERIMENT)

ANALYZING THE ETHICS OF THE UTILIZATION OF ACADEMIC RESEARCH ON THE MILITARIZATION OF HYPERSONIC WEAPONS

A Thesis Prospectus

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On my honor as a University of Virginia 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

The first manned, powered, heavier-than-air flight was achieved by the Wright brothers in Kitty Hawk, North Carolina, December 17, 1903; the bothers were propelled by the dream of the freedom that comes with soaring through the air. Just 10 years later in WW1, derivations of their original design were already an integral military unit.

Working in defense puts you in a unique position. On one hand you are working on the most cutting-edge technology, but on the other hand you are acutely aware of the potential lethality of the systems you are often intimately involved in. Defense, and specifically aerospace and space defense, has historically revolved around the eventual militarization of academia research.

Like many initial scientific endeavors, hypersonics was a topic first pursued by academia; the interesting aerodynamic and combustion effects that occur at such high speeds captured the attention of many aerospace engineers. In the decades following the cold war, technological advancements in propulsion and avionics saw the creation of several hypersonic programs, such as the NASP (National Aerospace Plane). Such programs have elevated hypersonic technologies and weapons to a sufficient militarized technological readiness level (TRD). But what role do, or should, universities and academia play in this development?

HEDGE

My Capstone is the Hypersonic Re-entry Deployable Glider Experiment (HEDGE) which is a concept experiment utilizing a CubeSat (cube satellite) for low-cost hypersonic flight experiments and data acquisition. For context, the hypersonic speed regime is anything greater than Mach 5+, however unlike the supersonic speed regime, there is no set fixed point where supersonic flow becomes hypersonic. Being a multi-year Capstone project, the CubeSat will most likely be payload aboard a NASA (National Aeronautics and Space Administration) launch vehicle, but private launch vehicles are also a possibility. The CubeSat will be jettisoned from the payload and orbit in LEO (Low Earth Orbit) for a period between 5 and 7 days, recording data and relaying back to ground control which will consist of a student-led communications team, as well as a network of ARO's (Amateur Radio Operators). Following this period, the CubeSat will de-orbit from LEO, deploy its hypersonic flight control surfaces, which will allow for some level of directivity control, and proceed with atmospheric reentry.

The speeds of reentry vehicles are significant, often reaching upwards of Mach 20+. At such speeds there are very interesting aerodynamic phenomena that occur, of which include: air dissociation and ionization thin boundary layers, and boundary and shock layer interaction to name a few. Air dissociation and ionization occurs when the temperature increase due to friction is so great, that it causes the air molecules to break their bonds, turning air molecules into free ion particles. At hypersonic speeds, the boundary layer and shock layer also begin to impinge on one another, causing large pressure concentration. The actual theory behind a hypersonic glide vehicle, however, is quite simple. Our CubeSat is a hypersonic glide vehicle, and being such, it utilizes the potential energy gained from the launch vehicle to, essentially, "glide" back down to obtain hypersonic speeds, rather than having an integrated propulsion system onboard. The CubeSat will then record and transmit data before burning up in the atmosphere, thus concluding the mission.

Specifically, my role concerned the power system of the spacecraft, as a part of the power, thermal and environment subsystem, a vital component to the operation of the spacecraft. The power system provides the generation and storage of electrical energy for use by other subsystems onboard the spacecraft. These subsystems include OBC (on-board computers), pressure transducers, motors and actuators, communications/radio systems, ADACS (Attitude Determination and Control), flight software, system health checks and redundancies. Without power, the spacecraft would lose functionality of most of the systems mentioned, and likely, also lose communication with ground control. These subsystems all depend on a reliable electrical source. Collaboration with the other subsystems will also be an important part achieving HEDGE's goals.

To power HEDGE, it is critical to know exactly the power budgeting constraints of the spacecraft. The power system must meet a minimum power supply (MPS), while being either storable within the spacecraft or generated throughout the duration of the mission. A power budget will be used to detail how much power to allocate to the CubeSat, and what margin of safety to include. A power budget is essentially the power generated subtracted by the average power to operate the spacecraft, ideally leaving a sufficient positive margin. Although a detailed layout of all other spacecraft systems would be needed to determine this budget, a preliminary power budget can be formulated using similar CubeSat designs. 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). Most power systems contain a dedicated Electrical Power System (EPS).

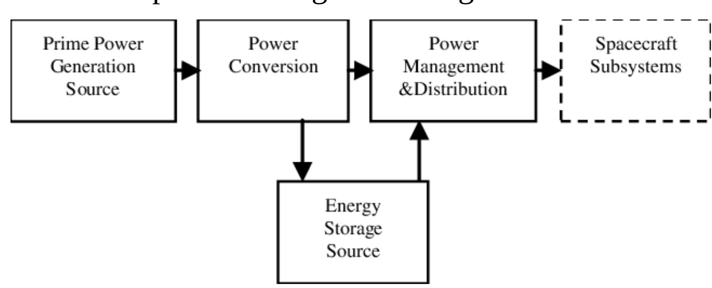

Figure 1: Power Circulation

Although some EPS's do come with a built-in battery, its main responsibility is the converting, conditioning, and distributing power to the other subsystems of the spacecraft. Additional components like the battery, wires, switches, and converters make up the remainder of the overall power system. Based on this information, research has been performed on potential batteries, electronic control units, and power generation systems which can meet these preliminary demands.

Being a multi-year project, our team is concerned with the preliminary to critical design development of the CubeSat. This encompasses the near final selection and prototyping of the EPS and power source. Our team considered a variety of power generation methods such as solar, battery, and thermonuclear. However, in the consideration of spacecraft missions, the most critical factors aren't maximal energy production, but rather the specific energy and the overall reliability of the system. Specific energy is defined as the energy per unit mass. Because the CubeSat is initially payload aboard a launch vehicle, weight savings in the power system are crucial to the overall cost of the mission. The near final selection of an EPS and power source are impacted by a multitude of factors, including but not limited to: the duration of mission, power distribution and conditioning, environmental conditions, weight and volume of hardware, and availability of resources (sun).

In terms of testing and evaluation, our team will perform rapid prototyping of several battery types such as Nickel Cadmium, Lithium Ion, and Lithium Sulfur to name a few, paired with different EPSs to determine the most optimal one, through a combination of destructive and non-destructive testing. The destructive testing serves the purpose of predicting, at what temperature maximums and minimums, do the battery and EPS fail to perform. It also serves the purpose of observing what effects do large temperature fluctuations have on the performance of the battery and EPS. This is important due to the CubeSat being subject to cycles of heat and cold during events such as the jettison from the launch vehicle and atmospheric reentry. The non-destructive testing will provide data on the battery charge duration and electrical data (power, current, etc.) of the set-up given an assumed, consistent load. As discussed earlier, and MPS and power budget will also be necessary. To do this, all components that require an electrical source will be accounted for. Their power requirements will be determined from their power modes and duty cycles, essentially, how much power they need for how long. This will allow us to determine the power budget, which will in turn tell us how much power we need given a safety margin. The data and observations gathered from the prototyping and testing phase, in addition to the power budget, are critical in the near final determination of the overall CubeSat power system.

Overall, it is anticipated that HEDGE will fulfill its main objective of demonstrating the feasibility of CubeSats as a platform for hypersonic research. To achieve this main objective, goals for each subsystem must be met. For the power system within the power, thermal, and environment subsystem, we must find an adequate way to generate, store, and distribute power throughout HEDGE

Academia In Hypersonics

Today, many schools like the University of Virginia are funded by NASA as well as other DOD (Department of Defense) organizations to conduct their own experiments in the hypersonic regime. Our CubeSat is being funded by NASA, and the Virginia Space Grant Consortium. The crux of the problem is that aerospace/space is by its very nature an expensive industry. It requires very significant funding in order to produce fruitful programs. Some of these expenditures include the acquisition of expensive/specialized materials, testing beds and sensors, integration of complex systems, and lots of human labor. This high entry cost to conduct aerospace/space missions results in many universities often depending on military funding for student research. For this CubeSat mission, although undoubtably a great and exciting project and learning opportunity, there comes the concern that students are supplying hypersonic flight data to the United States military that will someday be used for missions with questionable ethical origins.

It's been often argued that the United States needs to develop their own hypersonic weapons in order to defend against future threats (Sherman 2018). Nations like Russia and China currently have functioning hypersonic glide vehicle weapons and cruise missiles. For example, the Russian "Kinzhai" or dagger was reported to have been used against the Ukrainian forces in the Russo-Ukrainian War. Today's climate surrounding hypersonic weapons is reminiscent of the race to develop nuclear weapons in the decades following WWII between Russia and the United States. It was a classic arms race between the emergent technological superpowers at the time, justifying the development of nuclear weapons against the opposing nation under the intentions of "national defense" and rarely of "first use" policies (Russell 2021). According to the 2018 Nuclear Posture Review (NPR), the United States will only utilize nuclear weapons "to defend the vital interests of the United States, its allies, and partners. Extreme circumstances could include significant non-nuclear strategic attacks." (Russell 2021).

As Russell points out, the adoption of nuclear weapons as a deterrent strategy is an all-or-nothing strategy. It will not work as a deterrent for most military threat situations because of the seriousness of the intentions behind it. Since 2010, the NPR has cited the adoption of non-nuclear deterrent strategies using high speed weapons (HSW) (Russell 2010). This is where hypersonics show their strategic edge. The capability to precision-strike strategic targets at a speed that would compromise most missile defense systems is a huge strategic advantage, and makes for a much more useful and believable deterrent. However, truthfully, hypersonic weapons have been around for some time. Most missiles that follow a ballistic trajectory will reach near hypersonic velocities. The German V2 missile during WWII is often credited with being the first hypersonic weapon. What makes modern hypersonic weapons different is their directability and maneuverability mid-trajectory which makes them so effective (Terry 2020).

It's clear that the current focus of aerospace/space defense is not about building weapons of mass destruction (WMD). The overall climate of the industry highlights the necessity for precision-strike weapons in order to reduce the number of civilian casualties, not the other way around. Despite this however, it's also true that hypersonic weapons are still potentially lethal and devastating not just to a nation's peoples but the infrastructure that those people depend on to live.

Consider the humble undergraduate engineering student, where it all begins. Undergraduate engineering students are the major pipeline feeding into private defense contractors who are tasked with the design, test, and fielding of hypersonic weapons and other conventional weapons. In the study performed by Hersh, which looked to examine the ethics of engineers and scientists involved in military work, it was found that while some participants of the study had a "traditional approach" towards defense, most participants were quite self-aware of the impact of their work, and it was important to them that their work be consistent with their idea of social progress (Hersh 2021). It is true that university students are legal adults, and that they have the means and ability to choose what profession to pursue and to embrace everything that is associated with it. However, for a student who wishes to pursue a field like aerospace engineering, avoiding military backed projects is very difficult. It can be argued that the great difficulty in pursuing this field without sacrificing one’s morals, if one should feel strongly against the militarization of their work, is a real problem. It can also be argued there should be a productive way for those who have no intention of having their work associated with the development of hypersonic and conventional weapons to contribute to aerospace engineering research. In my STS project, I will be discussing these issues in more detail.

For my STS project, I will be analyzing senior capstone projects from several top undergraduate aerospace engineering programs, ideally ones that also are related to hypersonics, in order to analyze what percentage of funding comes from the military, or a defense point of view. This will help to gain a better understanding of where the work of undergraduate students is going towards. To clarify, I am by no means taking a claim as to whether military funding is inherently a good or bad thing. What I wish to explore, is to what extent exactly, is the field of undergraduate aerospace research swayed by military interest. This is a difficult issue to quantize, thus my findings will be anecdotal from the faculty and students from different universities, in addition to monetary values that I can research.

I believe that there should be more transparency in the defense and aerospace/space defense sector about the mission statement of the projects that students are involved in, as well as greater transparency on the expected utilization of the end products of the project, so that students can make their own informed decision as to whether or not they wish to be a part of it, based on their own ethical ideologies.

Conclusion

Hypersonic weapons, despite their long history, are still a developing weapon system. They hypersonic flight regime is a hostile environment, and lots of research is still ongoing into the development of these systems. The HEDGE project is just one of many ongoing hypersonic projects with the shared goal of better understanding the intricacies of flight in a hypersonic environment. Through my STS project, I hope to gain a better understanding of how the field of aerospace and the military work together, and how involved academia currently is in the fielding of new hypersonic technologies. It will most likely be several years before the United States fields its own hypersonic vehicles and useable hypersonic weapons. However, it's more critical now than ever that the new generations of engineers be aware and conscious of the implications their actions have on the safety and security of the nation, as well as that of the rest of the world.

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