Hypersonic ReEntry Deployable Glider Experiment (HEDGE) Power, Thermal and Environmental Systems

Understanding the Effect of Anti-Satellite Weapons (ASAT) Development on the US National Defense Strategy and Foreign Relations

A Thesis Prospectus
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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

For the past century, the world has viewed space as ‘the final frontier’. Many nations have expanded their capabilities in this frontier, launching networks of satellites that have both commercial and strategic applications (Brinksman, 2009). Unfortunately, many competing nations seeking to utilize a shared space can lead to increased tensions and the threat of armed conflict (Gruenwald, Oskar, 2023). It is this threat that has led many global superpowers to focus research on developing anti-satellite weapons, known as ASATs, with the hopes of securing their place in the space domain by remaining technologically competent in military space operations (Saunders & Lutes, 2007). My research will focus on how the development of these ASATs has affected the United States’ National Defense Strategy and relations with the United States’ adversaries.

For my technical project, I will be working with a team to design and manufacture a CubeSat capable of collecting data on hypersonic reentry conditions. CubeSats are a relatively new form of small, cube shaped satellites which are typically developed by universities and can be used for a variety of research applications (Canadian Space Agency, 2017). While the main purpose of the mission is to collect data, this project also provides valuable insight into the process of planning and executing a mission to space. Due to the CubeSat’s hypersonic re-entry, the project gives an opportunity to study and predict the effects of hypersonic flight on a vehicle with an emphasis on the thermal loading on the craft. Launching an ASAT is a space based mission that can sometimes use missiles traveling at hypersonic speeds, so this technical project will lay the groundwork for the knowledge I will need to effectively analyze ASAT development. (Smith, 2022)

To complement my technical project, I will be researching ASATs to determine the global political effects of their development. This will entail summarizing the history of ASAT development, how different nations have responded to ASAT testing, and how this technology has had an impact on domestic policies. I will also discuss the current threat posed by near peer ASAT technologies and how the US military is prepared to deal with such threats, which will be reflected in the current National Defense Strategy.

This prospectus will serve as a detailed outline of the research I plan to conduct, including the framework I will use, what aspects of my topic I will primarily focus on, and how I will acquire sources. I will also attempt to convey the importance of this topic and why it must be considered as we continue to advance our space operations.

Technical Project

Introduction/Significance of the Problem

CubeSats were developed in 1999 by professors at California Polytechnic State University and Stanford University, enabling students to design and execute satellite missions. They're classified by number of units (1U, 2U, or 3U), with a 1U CubeSat having a volume of 10 cm^3 (Canadian Space Agency, 2017). Size limits operational ability but allows CubeSats to be integrated into the payloads of larger missions (Woellert et al., 2011). Our capstone project, *Hypersonic ReEntry Deployable Glide Experiment* (HEDGE), aims to demonstrate the viability of CubeSats as an affordable platform for conducting hypersonic glider research, using the Iridium satellite network for communications.

A rocket will launch our 3U CubeSat into low earth orbit (LEO). HEDGE will deploy fins after release, morphing into a hypersonic glide vehicle, and remain in LEO until naturally

deorbiting (Goyne, 2023). To simulate a real mission planning scenario, the capstone is split into various sub-teams: program management; communications; software and avionics; attitude determination; power, thermal, and environment (PTE); and structures and integration. Our group has been assigned to the PTE team.

Objectives

The power subsystem has the main objective of supplying electrical power to all other subsystems in the CubeSat, and it must produce more power than what is required by the satellite. The thermal subsystem's objective is to tailor the design of HEDGE to the thermal conditions expected throughout the mission. Considerations include thermal protection in both LEO and reentry, and a complete burnup of the CubeSat after necessary data collection. The environment team's objective is to calculate the mechanical loads experienced by the spacecraft during launch and reentry, as well as to determine the potential space debris or radiation HEDGE will encounter based on the timing and location of its launch.

Methods

The power team will combine previous work with information from industry to estimate power generation while also collaborating with other sub-teams to determine system requirements and optimal components. The thermal team will run tests and simulations to examine previously selected structures and materials. We will use computational fluid dynamics (CFD) and finite element analysis (FEA) software to analyze reentry conditions and thermal loads, ensuring that HEDGE can collect data before burnup. The environment team will conduct research to find values needed for load calculations as well as debris and radiation trajectories.

Available resources

To determine the power budget, we will use the documented hardware specifications for the required components as well as previous calculations. For thermal analysis, we will use Ansys Fluent and Mechanical to carry out CFD and FEA on an existing computer aided design (CAD) model of HEDGE. Prior teams identified niobium alloys as the best high temperature material and Teflon as the best ablative material for the hypersonic nose cone, and we will work to predict performance. The environment team will use loads and testing parameters found within the NASA Sounding Rockets User Handbook and the SpaceX's Falcon User Guide to perform structural tests using the aforementioned resources. Online databases will be used to track orbital debris and radiation.

Objectives for Spring Semester

The primary task facing the power team is to recalculate the power budget and power flow chart with new EnduroSat components (Figure 1).

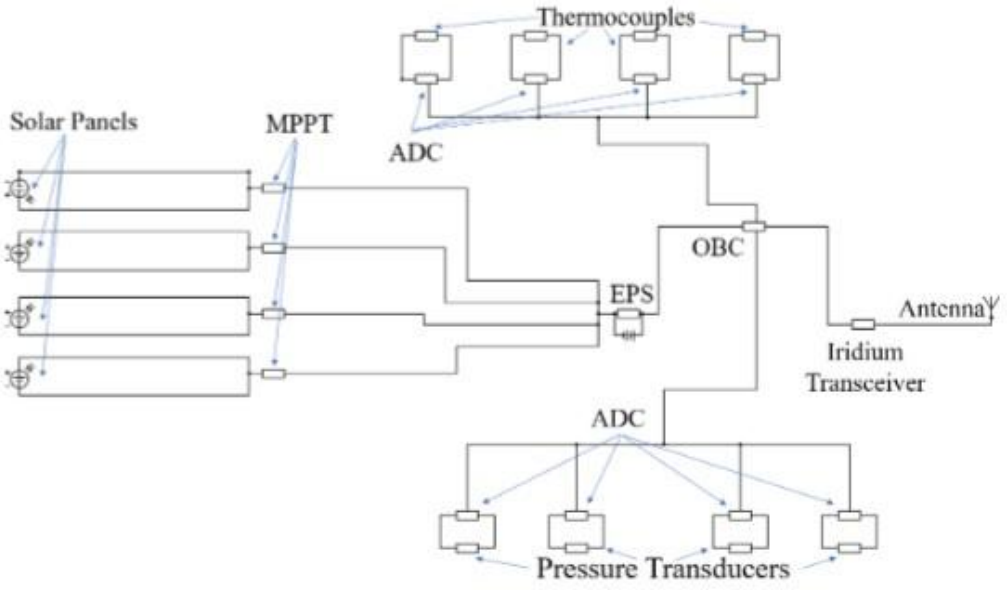

Fig. 1. HEDGE Power subsystem circuit diagram (Goyne et al., 2023)

Components must generate and store more power than the maximum power draw (MPD). The final task is configuring a battery pack that will fit in the nose cone to operate the CubeSat when the solar panels aren't producing power. The primary goal of the thermal team is to analyze the performance of HEDGE under a variety of expected conditions. We will review completed CFD analysis, modify the CAD model and CFD parameters to meet current objectives, and run several iterations of CFD and FEA testing. Part of our work will include predicting the reentry burnup time for the final design to minimize uncertainty. The environment team aims to find the mechanical and vibrational loads during launch and reentry and determine any protections against radiation or space debris.

The fall semester of MAE 4690 will conclude with a Technical Interchange Meeting (TIM), where sub-teams will merge work into one Critical Design Review (CDR) and present completed research and future design plans.

STS Project

My STS research question will sharply pivot from a technical analysis of a CubeSat to how satellite related technology has had an effect on the world. I will be investigating how ASAT development has influenced international relations between military superpowers with a special focus on the United States' response in the National Defense Plan. I believe this topic is worth exploring due to the massive ramifications ASATs may have on our future. The development of ASATs opens up a new domain of warfare, one that jeopardizes future space related operations for all nations and will have effects that will trickle down to the civilian population (Secure World Foundation, 2022). Therefore, I think it is important to have a solid understanding of the

history of ASAT development, the threats that are posed, and current international policies so that we can be well equipped to tackle ASAT related issues in the future.

I will begin my research by looking at the history of ASAT development, from their inception to the current state of the art. ASATs are a classification of weapons systems, so they come in many forms and are being developed by many countries across the globe (Smith, 2022). It will be beneficial to understand what ASATs are, their objectives, and how they operate before looking into their political implications. Once this has been accomplished, I will begin investigating the various social groups which have been and will continue to be impacted by ASAT technology. The three groups I have identified are the citizens of nations with space capabilities, the governments of foreign military powers, and the United States' government (to include the military). Given that our society is dependent on satellites for things such as GPS technology and the internet, the average person will be greatly affected if ASAT weapons are ever deployed (Steer & Hersch, 2021). Satellite warfare may render all of space uninhabitable for commercial satellites if it causes the amount of space debris to exponentially increase, crippling our infrastructure and complicating the lives of billions of people (Santamaría, 2022). Additionally, citizens will be the ones electing the officials in charge of creating policies surrounding these weapons. The link between ASATs and both foreign and domestic governments is far more obvious; the governments are the ones dictating policy, forming international agreements, and testing the systems. Looking at how these three groups interact regarding the issue of ASATs will provide insight into the social aspects of their development.

Perhaps the largest section of my research will be discovering how the most influential governments around the globe have interacted with each other over the issue of ASAT development. International relations can be a delicate matter, especially when extraordinarily

destructive military technologies are involved (Department of Defense, 2023). I will be looking at the ASAT tests each global superpower has conducted and how other nations responded to such tests. This will include researching international treaties regarding ASAT testing and how each nation has either respected or disregarded these treaties. I also plan to investigate whether or not ASAT development has sparked an arms race similar to when nuclear weapons were first created and see how they can be used as part of the United States' deterrence strategy. I will conclude with research into how the United States' National Defense Plan has evolved to address ASATs, which will include an analysis of the threat posed to national security by near-peer adversaries being in possession of such weapons. To do this, I will compare and contrast the 2023 National Defense Policy with those from previous years.

I will be conducting my research over the next few months, with the intention of being finished when it is time to write my thesis paper in the spring. Collecting sources for this topic might be a challenge since the technology I am investigating is still being developed, meaning all current information may still be classified and I will have to work with outdated, unclassified sources. However, I have already begun collecting sources and am confident that enough information has been released to the public for me to write a detailed thesis. I also plan on using my connections within my Reserve Officer Training Corps (ROTC) detachment to secure interviews with active duty members of the US Space Force. I already have a few interview candidates who have been tasked with working on Space Operations, so they might be able to offer a unique perspective on this issue. I will be reaching out to them soon to request interviews and establish meeting times. Through the use of published research articles, declassified military documents, and interviews with Guardians actively involved in these projects, I will be able to

synthesize information from a wide range of sources and compose a comprehensive thesis on the effects of ASAT development.

Key Texts

Space Policy Review and Strategy on Protection of Satellites. (2023). United States Department of Defense. https://media.defense.gov/2023/Sep/14/2003301146/-1/-1/0/COMPREHENSIVE-REPORT-FOR-RELEASE.PDF

- This report "provides a review of space policy and describes the Department of Defense's approach to protecting and defending space systems and protecting the Joint Force from adversary hostile use of space."
- Includes information about the state of Russia's and China's ASAT development and policy
- Discusses information regarding the space strategy in the 2022, 2021, and 2020 National Defense Strategies
- Provides an overview of the United States' policy on using ASAT weapons as a deterrence measure, as well as policy changes and funding around such operations

Karas, T. H., Callaham, M., DalBello, R., & Epstein, G. (1995). Anti-Satellite Weapons, Countermeasures, and Arms Control. *US Congress Office of Technology Assessment*. https://aerospace.csis.org/wp-content/uploads/2018/09/OTA-Report-on-ASAT-Weapons-and-Countermeasures-1985.pdf

- Contains a summary of the history of ASAT development

- Discusses ASAT capabilities, countermeasures, and arms control
- Presents options for how to handle ASAT development in the future. This is a very old source so this information will no longer be relevant, but it will be useful to see the policies in place 30 years ago and how ASAT development was viewed compared to today. I can also evaluate whether or not the options presented we actually implemented.

Krepon, M., & Thompson, J. (n.d.). *Anti-Satellite Weapons, Deterrence, and Sino-American Space Relations* (pp. 15–41). Stimson Center. https://www.stimson.org/wp-content/files/file-attachments/Anti-satellite%20Weapons%20-The%20Stimson%20Center.pdf

- Another source discussing the current state of ASAT weapons and the policy of using such weapons for deterrence.
- Draws parallels to when the nuclear bombs were first created
- Provides an in depth look at how the United States and China have interacted regarding the topic of ASAT development. It discusses how the two nations have been competing, cooperating, and options for future interactions

Steer, C., & Hersch, M. H. (Eds.). (2021). *War and peace in outer space: Law, policy, and ethics* (First edition). Oxford University Press. https://academic.oup.com/book/33444

- Considers the ethical and legal aspects of ASAT weapons, not just the military and strategic benefits
- Argues that preventing a space war is imperative and will benefit all of mankind

- Discusses future risks that may prevent space from remaining a secure environment and provides options for actions that should be taken now

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