STRUCTURES AND INTEGRATION SUBSYSTEM FOR THE HYPERSONIC REENTRY DEPLOYABLE GLIDER EXPERIMENT (HEDGE)
(Technical Paper)

Global Effects of Hypersonic Weapons
(STS Paper)

A Thesis Prospectus Submitted to the

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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

As tension between the United States of America and Russia rises, the need for new technologies grows exponentially. Many countries are shifting their focus to hypersonic capability. Hypersonic flight is defined by the ability to travel at or faster than five times the speed of sound. Russia displayed the Kh-47M2 Kinzhal in the Ukrainian war, the first sighting of a hypersonic missile used in active warfare (Neuman, 2023). The United States will soon deploy two hypersonic missiles: the Army's Long Range Hypersonic Missile (LRHM) and the Navy's Intermediate-Range Conventional Prompt Strike Missile (Jones, 2023). With the world shifting its attention away from nuclear missiles and toward hypersonic weapons, effective research must be conducted to bring advances in the hypersonic field. However, analyzing hypersonic flight's effects on objects is problematic because it is difficult to replicate in laboratories. Wind tunnels commonly used in aerodynamic experiments cannot reproduce all aspects of hypersonic atmospheric flight (Jewill, 2022). The next-best alternative is to have actual flight testing. Thus, the University of Virginia is creating its own hypersonic glide body through CubeSats. CubeSats are nanosatellites that fly in Low-Earth Orbit (LEO) and are used mainly in undergraduate research due to their lower relative costs.

The project code-named HEDGE (Hypersonic ReEntry Deployable Glider Experiment) aims to have a glide-body be released in Low-Earth Orbit, glide in the atmosphere at hypersonic speeds, and ultimately burn up during reentry. The mission objectives are to show the feasibility of CubeSats in hypersonic flight and to transmit flight data observed from the glide-body back to ground stations. HEDGE consists of six subsystems: Program Management, Communications (ground and space segments), Software and Avionics, Power Thermal & Environmental, Altitude Determination and Control Systems (ADACS) and Orbits, and Structures and Integration (S&I).

HEDGE also utilizes the help of four rising Electrical Engineering majors. The following prospectus outlines the significance, objectives, resources, and future of this design, specifically related to the S&I subteam of the HEDGE CubeSat design.

Technical Topic

The S&I subteam is tasked with providing the overall mechanical integrity of the spacecraft, ensuring that all components are securely enclosed and protected, and guaranteeing that inner components can withstand the loads endured in handling, launch, and flight in freefall (Garino, 2009). The team must also collaborate with other subsystems within HEDGE to ensure the most efficient and effective configuration of the spacecraft is achieved.

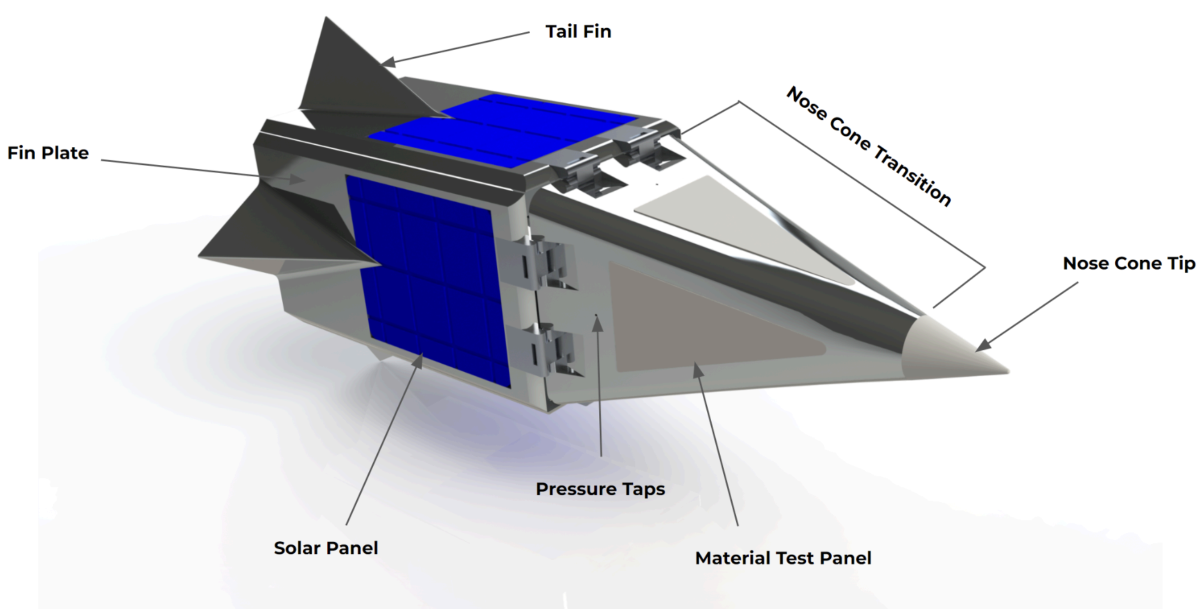

Figure 1. 3D modeled design of HEDGE that lists each major component (2022)

Methods

HEDGE will be receiving new components from each subteam this year. This changes the design laid out by previous S&I teams. Components must be placed in a method that allows a large enough static margin. Having the correct static margin is important because it ensures the stability of the spacecraft during reentry (Coleman and Faruqi, 2009). Thus, effective communication between the subteams is crucial to the spacecraft's longevity. We will employ a method to ensure proper and clear communication with other teams by delegating a specific teammate or group of teammates to collaborate with a specific team. Our team must work closely with the Software and Avionics team to determine the placement, wiring, and logistics of the solar panels on the spacecraft. In determining the spacecraft's static margin, we must work with the ADACS and Orbits team, the Software and Avionics team, and the Communications team. Each team is responsible for hardware that will affect the spacecraft's center of gravity, in which we will determine orientation.

We plan to use CAD and FEA software (SolidWorks and ANSYS) to alleviate current structural designs such as solar panel location, cable management, location of internal components, hinge design, and transceiver and thermocouple layout. CAD (Computer-Aided Design) allows users to create 2D and 3D models of their product before manufacturing. FEA (Finite Element Analysis) is a numerical simulation that predicts how the product will react to real-world conditions (Autodesk). These softwares will also aid in the risk management of the structural integrity and capabilities of the spacecraft.

Available resources

Many resources have been made available for HEDGE and our subteam. The CubeSat lab is available for us to ask questions and make progress on our established goals. The computers in the Mechanical and Aerospace Engineering building are equipped with valuable software for our purposes. The two main software we plan to use are SolidWorks and ANSYS. SolidWorks is a CAD software that will be a massive asset for us as we work to better the structural design and organize the interior components to optimize the space and balance of the CubeSat. ANSYS is a beneficial software that will allow us to perform finite element analysis and simulate the reentry conditions that the CubeSat will experience. These simulations will help us estimate the current state of our structural design in terms of its strength and temperature distribution. A member of our team has a connection to an individual with a machine shop. This could be a valuable resource once we have the Inconel prototype. Inconel is a 3D-printed metal that HEDGE will be made out of (Xometry, 2023). The technical advisor for the HEDGE project, Professor Christopher Goyne, has been working to obtain funding from the US Navy. Various materials manufacturers have also agreed to send CAD models of their products to ensure they fit inside HEDGE.

Objectives for Spring Semester

The goal of this project in the upcoming spring semester is to finalize and 3D print the HEDGE CubeSat design to create a functional model following the Technical Interchange Meeting (TIM) that will occur during the fall semester. This model should perform all of the functions that the final CubeSat design can, including deploying the fins, collecting reentry data, transmitting and receiving signals using Iridium satellites, and testing materials under hypersonic conditions. This technical project's mission will rely on certain events occurring successfully, such as the deployment of the CubeSat and hypersonic glider as a unit, the stability of the glider during flight, and data being properly relayed during reentry. By creating and demonstrating the feasibility of CubeSats for hypersonic glider flight tests, this technical project will open new doors for low-cost hypersonic research with conditions that are not achievable from the ground. Another goal is to garner greater appreciation and attention for aerospace and hypersonics research for other undergraduate students.

Type of Technical Paper

The final paper will comprehensively describe the design creation sent to coordinators Professor Goyne and the University of Virginia, detailing our creation of a hypersonic glider vehicle experiment using a CubeSat for submission to the Navy for funding. The class will be finalized by a System Integration Review (SIR) that will review each team's work throughout the semester.

STS Statement

Hypersonic weapons were first developed because of fears that then-current missile defense systems would prevent countries from having a nuclear second strike. Countries like Russia and China have developed hypersonic glide bodies that can carry a nuclear payload to ensure a second strike if needed (Artikel, 2020). However, the United States has announced that its hypersonic glide bodies will not carry a nuclear payload. The United States first conceived using hypersonic weapons as a means to have a long-range, high-precision conventional missile to respond to terrorism. The only missiles that had the requirements necessary were nuclear-tipped missiles. Thus, development began to create a new missile that would avoid the usage of nukes. The current hypersonic weapons are considered boost-glide weapons. This is because they are boosted to a designated altitude, dropped back to Earth while using gravity to speed up the vehicle, and glide at low altitudes for the rest of the flight.

As hypersonic weapons become more common in warfare, there are fears that current air defense systems will be unable to counter the threat from these hypersonic missiles (Iroegbu, 2022). The fast speeds, maneuverability, low flight paths, and unpredictable trajectories make these hypersonic weapons challenging to counter. However, they have been stopped before. In the Ukrainian war, the Patriot system has been documented downing the Kinzhal. The Patriot system was invented in the 1970s and has been upgraded many times (Tucker, 2023). This shows that the United States has a crude hypersonic defense. Furthermore, it proved that current defense systems can be upgraded to stop first-generation hypersonic weapons.

However, a dedicated defense system is necessary as more breakthroughs happen in the hypersonic field and with the introduction of missiles from different countries. The North American Aerospace Defense Command (NORAD) is currently working to upgrade Aegis SBT (sea-based terminal) to counter the growing hypersonic threat. Aegis is the Navy's most modern surface missile defense system (DOT&E, 2020). The Space Force and the Missile Defense Agency are also developing hypersonic ballistic tracking from space (Vergun, 2023).

The primary mission of HEDGE is to prove that CubeSats are capable of hypersonic experiments. CubeSats have generally been used in simple LEO missions and have never been used in hypersonic experiments. If HEDGE is successful, it opens up the gateway for other universities to do their research. HEDGE has direct implications for these hypersonic missiles since their trajectories are similar. Both are flown to a specific altitude and released as glide bodies. Thus, any data gained from HEDGE will be primarily used to develop new hypersonic missiles.

Conclusion

With times changing rapidly, the need for new technology and advancements grows. Hypersonic weaponry has finished its development stage and is now being used and tested by many countries. Along with it, hypersonics also brought fear, as many believed these weapons would be near unstoppable. However, recent events brought light to the weakness of these first-generation weapons. Despite that, the need for a dedicated defense system grows with more research being conducted and improvements made to these weapons.

HEDGE was created to show that universities could partake in hypersonic research. Students who worked on HEDGE or other hypersonic CubeSat experiments gain much-needed experience to perform future innovative research that will improve hypersonic capabilities. HEDGE will also collect flight data to be analyzed and sent to the Navy's Strategic Systems Program. With Russia and China already having hypersonic weaponry, the United States needs more support and interest in hypersonics from the next generation of students to ensure its standing in the world military stays secure.

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