**Hypersonic ReEntry Deployable Glider Experiment (HEDGE): A CubeSAT Approach to Low-Cost Hypersonic Research**

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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

The development of hypersonic flight technology has opened new frontiers in both scientific research and military applications. This research addresses a central question: How can CubeSat-based systems be used to gather critical hypersonic flight data affordably while managing the ethical implications of this technology's dual-use potential in both civilian and military domains? Hypersonic speeds, defined as velocities exceeding Mach 5, impose extreme aerodynamic and thermal stresses on objects traversing the Earth's atmosphere. Understanding how materials perform under these conditions is critical to advancing hypersonic capabilities, yet traditional methods of gathering such data are often extremely expensive and technically complex.

The Hypersonic ReEntry Deployable Glider Experiment (HEDGE) seeks to address these barriers by utilizing a 3U CubeSat platform to collect essential hypersonic flight data in Extreme Low Earth Orbit (ELEO). Equipped with thermocouples, pressure transducers, and deployable fins, this CubeSat-based system is designed to autonomously record and transmit data on temperature, pressure, and velocity during reentry. By leveraging CubeSat technology, HEDGE offers a cost-effective solution for gathering high-quality data in extreme flight environments, contributing valuable insights into the design of future hypersonic systems.

Beyond its technical purpose, HEDGE raises essential ethical and socio technical questions about the dual-use nature of hypersonic technology. Hypersonic research can advance scientific knowledge and enable potential applications such as faster global transportation, yet it also has substantial military implications. As more nations invest in hypersonic weapons technology, like intercontinental ballistic missiles, the potential for escalated global tensions grows. This dual-use nature of hypersonic technology requires a balanced approach, considering not only technological advances but also the ethical responsibilities that come with developing systems that could disrupt global security.

This research explores both the technical and sociotechnical dimensions of HEDGE's development. Technically, it examines how CubeSat-based systems can provide an affordable and accessible means to gather critical hypersonic flight data. From a sociotechnical perspective, it addresses the ethical considerations surrounding hypersonic technology's potential for both scientific progress and militarization. Together, these perspectives provide a comprehensive framework for understanding the role of CubeSat technology in hypersonic research, balancing technological advancement with societal responsibility.

**Technical Topic Proposal**

The Hypersonic ReEntry Deployable Glider Experiment (HEDGE) represents an innovative application of CubeSat technology for hypersonic research, aiming to address traditional barriers of high cost and complexity in studying hypersonic flight dynamics. Hypersonic speeds, those exceeding Mach 5, create extreme thermal and aerodynamic forces on vehicles, making data collection challenging but essential for understanding material and structural performance in these conditions. HEDGE tackles this by providing a scalable, low-cost alternative designed to collect critical reentry data in Extreme Low Earth Orbit (ELEO). Launched on an exo-atmospheric sounding rocket through NASA's RockSat-X program from Wallops Flight Facility, HEDGE autonomously gathers telemetry on temperature, pressure, and position during reentry.

HEDGE's mission is to demonstrate the viability of CubeSat-based technology for hypersonic research. Its primary objectives are to prove that CubeSats can withstand hypersonic reentry, validate avionics, telemetry, and data acquisition systems under extreme conditions, and provide hands-on experience in aerospace design for undergraduate students. Secondary goals include student exposure to industry-standard engineering practices and professional networking opportunities, preparing students for careers in aerospace.

The CubeSat's design meets both functional and operational requirements from RockSat-X and the demands of hypersonic reentry. HEDGE must endure launch accelerations up to 25 g and withstand reentry temperatures of 260°C (500°F), along with the vacuum and vibrational stresses of ELEO. After reaching an apogee of approximately 170 km, the CubeSat deployer will release HEDGE, initiating a sequence of autonomous operations. Upon deployment, the CubeSat's fins will extend and lock into place, stabilizing HEDGE during its descent.

The RockSat-X launch propels HEDGE to its peak altitude, where it begins its descent, autonomously collecting data on temperature, pressure, altitude, and position. This information is transmitted to UVA's ground station via the Iridium satellite constellation, maintaining a reliable communication link with a target signal strength of at least 15 dB and a transmission rate of one data packet per second.

Each subsystem supports HEDGE's success. The Software and Avionics (S&A) subteam programs the onboard computer (OBC) for real-time telemetry, integrating sensor data from thermocouples and pressure transducers. The Structures and Integration (S&I) subteam manages HEDGE's structural configuration, designing the fin deployment mechanism and integrating the CubeSat with the RockSat-X deployer. The Power, Thermal, and Environment (PTE) team ensures thermal and structural resilience, using Ansys Workbench to simulate and confirm the CubeSat's endurance under high temperatures and vibrations. This team also manages HEDGE's power systems, ensuring sufficient energy for the OBC, sensors, and transceiver throughout the mission.

The Communications subteam handles data transmission, with the Iridium 9603 transceiver relaying data packets to ground stations. The Attitude, Stability, and Trajectory (AS&T) subteam uses MATLAB and Ansys Fluent to model HEDGE's reentry trajectory, ensuring controlled descent for optimal data collection.

HEDGE relies on industry standard tools, including MATLAB, Ansys Fluent, and SolidWorks, with high-performance computers in UVA's Aerospace Lounge supporting the project. With $42,800 in funding from UVA Capstone and Systems Planning & Analysis (SPA), the team is seeking additional funds to complete HEDGE's aluminum body and testing, as the design prioritizes minimal plastic use to ensure structural integrity.

Upon completion, HEDGE will provide a viable, low-cost model for hypersonic reentry experiments, contributing critical data on CubeSat performance under extreme conditions. The mission's findings will be documented in a Critical Design Review (CDR) presented to NASA's RockSat-X program, establishing HEDGE as a scalable, accessible framework for future hypersonic research.

**STS Project Proposal:**

As hypersonic technology advances, it opens new possibilities for civilian applications but also raises ethical concerns, particularly due to its potential use in military contexts. This socio-technical investigation centers around a critical question: How can CubeSat-based hypersonic data collection systems, like HEDGE, be developed responsibly, given their capacity to serve both scientific and military goals? This question invites a closer look at how data collected from hypersonic research might progress aerospace innovation while potentially contributing to global security risks if repurposed for military objectives.

Hypersonic technologies, as Kunertova (2021) argues, don't necessarily deliver significant strategic advantages, but instead risk igniting an arms race. Kunertova suggests that hypersonic weapons add pressure on nations to invest heavily in new technologies just to keep up, much like during the Cold War. CubeSat-based experiments like HEDGE, which collect data essential for hypersonic research, directly lead to advancements in aerospace which could inadvertently fuel military pursuits.

One major concern is the lack of arms control frameworks for hypersonic technology, which make it difficult to ensure responsible development. Hursh (2020) points out that, unlike nuclear arms, hypersonic technology lacks international regulation, allowing it to proliferate unchecked. For HEDGE, this raises a key challenge: How can we protect CubeSat research intended for scientific progress from being misused when current regulations don't effectively limit its potential military applications?

The ethical complexities surrounding hypersonic technology deepen when we consider the potential integration with AI and machine learning. Lindborg (2020) compares hypersonic weapons to nuclear arms, suggesting that society may be unprepared for the unintended consequences of these technologies. Autonomous hypersonic systems, for example, could make accidental conflict more likely, as their capabilities might be perceived as both offensive and defensively evasive. If CubeSat data were used to enhance autonomous hypersonic systems, it could heighten global fears and even provoke conflict due to perceived threats.

In addition to military applications, hypersonic technology has promising civilian uses, like faster global transportation and satellite deployment. NewSpace Economy (2024) highlights that hypersonic advancements could revolutionize commercial travel and space exploration. However, these projects risk misinterpretation by other nations, potentially sparking international tensions. This combination of civilian and military goals reflects broader socio-political pressures on technological development. Jones (2024) explains that countries often pursue hypersonic technology not just for practical defense needs but also to assert technological superiority, creating an arms race fueled by both security and prestige. This perspective suggests that projects like HEDGE are influenced by these external pressures, where even scientific advancements are seen through a competitive lens, regardless of the researchers' original intentions.

This research will explore policy and ethical frameworks to guide responsible CubeSat development for hypersonic research. By examining arms control efforts, such as nuclear non-proliferation treaties, the study will assess whether these models could apply to hypersonic technology. Insights from Lindborg (2020) on hypersonic ethics and Hursh's (2020) call for cooperative policy frameworks will provide foundational perspectives. Additionally, sources like NewSpace Economy (2024) and Jones (2024) will help contextualize the dual-use challenges and socio-political pressures on hypersonic advancements. As Roberts (2023) argues, dual-use technologies must be developed with strong ethical commitments to prevent their misuse. By identifying policy and ethical recommendations, this study aims to contribute a framework for managing CubeSat-based hypersonic systems like HEDGE. It will work to ensure that hypersonic data collection supports civilian research while safeguarding against unintended military applications, creating a responsible path forward for hypersonic technology.

## Conclusion

The Hypersonic ReEntry Deployable Glider Experiment (HEDGE) represents a breakthrough in affordable hypersonic research. The technical deliverable of HEDGE, a CubeSat-based hypersonic re-entry vehicle, demonstrates the feasibility of collecting essential hypersonic data at a fraction of the traditional cost. By autonomously gathering and transmitting data on temperature, pressure, and velocity during reentry, HEDGE contributes valuable insights to the design of future hypersonic systems, addressing both performance and material durability under extreme conditions.

Beyond the technical achievements, the sociotechnical research associated with HEDGE examines the ethical and regulatory implications of hypersonic technology's dual-use potential. By exploring frameworks inspired by arms control treaties and emphasizing ethical guidelines, this work proposes approaches for responsible hypersonic data collection that protect against misuse. Together, these deliverables offer a pathway for balancing scientific advancement with global security considerations, setting a new standard for responsible innovation in hypersonic research. This dual approach ultimately supports both the technical progress and ethical stewardship required for the sustainable development of aerospace technology.

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