Thesis Project Portfolio

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

(Technical Report)

Redefining the Hypersonic Frontier: CubeSats, Democratization, and Dual-Use Risk

(STS Research Paper)

An Undergraduate Thesis

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Table of Contents

Sociotechnical Synthesis

My technical capstone project, the Hypersonic ReEntry Deployable Glider Experiment (HEDGE), and my STS research paper exploring governance challenges in CubeSat-based hypersonic research are deeply interconnected. The HEDGE project serves as a physical example of the trend examined in my STS research: the increasing use of accessible, lower-cost platforms like CubeSats for research in complex engineering and strategically relevant fields such as hypersonics. The HEDGE project focused on designing, fabricating, and testing a platform for educational hypersonic research. Alongside the hands-on engineering, I used my STS research to explore broader governance concerns in the hypersonics field. This was especially relevant to me, as I'll be working on infrared hypersonic missile targeting systems with the U.S. Naval Research Laboratory after graduation. I wanted to better understand how we govern emerging technologies, especially those with serious dual-use implications.

The HEDGE capstone project's main goal was to address the significant cost and technical barriers that traditionally limit access to hypersonic flight research, particularly for university-based undergraduate programs. Standard hypersonic testing requires extensive infrastructure and funding, which restricts it to major government agencies and aerospace corporations. HEDGE proposed a more accessible alternative by utilizing the CubeSat standard, a 10 by 10 by 10, 20, or 30 cm platform for small, cost-effective, modular satellites, to develop a deployable glider launched by a suborbital sounding rocket (RockSat-X). The primary objectives included demonstrating the viability of this approach for low-cost hypersonic flight experimentation, validating the performance of the integrated avionics, sensor systems (for temperature, pressure, GNSS position), and satellite communication telemetry (Iridium network) to reduce risk for future UVA HEDGE teams and to give undergraduates like me real, hands-on experience in designing, building, and testing aerospace systems for hypersonic flight. A few of the key engineering tasks involved designing the glider's structure and deployment mechanism, integrating commercial-off-the-shelf (COTS) and custom components, developing the necessary software for data acquisition and transmission, and performing analyses of the anticipated aerodynamic, thermal, and structural loads during reentry, all while checking in with the rigorous constraints and safety requirements of the RockSat-X program and even other bodies like the FAA and FCC.

Alongside the hands-on engineering, I used my STS research to explore the broader governance concerns associated with the rise of CubeSat-based hypersonic reentry research, shown by projects like HEDGE, university initiatives such as HyCUBE, and commercial efforts like Varda Space Industries. The paper explores the argument that the very qualities that make Cube-Sats attractive like affordability, standardization, and rapid development cycles also challenge the existing frameworks for international space law, national export controls, and responsible engineering ethics. Hypersonic technology has in itself dual-use capabilities, which are applicable to both civilian high-speed transport and potentially destabilizing military systems. Using a literature review and the Social Construction of Technology (SCOT) framework, the research analyzed how different social groups (universities, student teams, funding agencies, startups) interpret and utilize CubeSat technology in the hypersonic field. This analysis highlighted potential breaking points with governance structures originally designed for a different era of state-led technological development. Specifically, it considered the vagueness within the Outer Space Treaty regarding non-state actors and "peaceful purposes," the complexities of using export control regulations (like the U.S. EAR) to research conducted in open university settings, intangible knowledge transfer, and the absence of specifically hypersonic tailored ethical guidelines for navigating dual-use research dilemmas, especially when military funding intersects with academic spaces that rely on openness and collaboration.

Working on both HEDGE and my STS research gave me a perspective I wouldn't have had if I'd only done one. The hands-on technical challenges of HEDGE like component selection, power management, data handling within telemetry constraints, meeting launch vehicle requirements, physically showed me the "democratization" theme central to my STS paper. It grounded concepts like accessibility and low-cost innovation in the realities of engineering practice. Building even a small hypersonic test platform helped me see how technical skills actually develop, not just in theory, but through late nights, testing setbacks, and unexpected fixes. At the same time, investigating the sociotechnical dimensions through my STS research helped me better reflect on the HEDGE project itself, beyond just the technical measures of success which I would have usually focused on. It encouraged me to think about the potential dual applications of the data collected, the implications of specific technology choices (like global satellite communications), the background context of the program affiliations and sponsors, and the ethical responsibilities outlined in our technical report concerning responsible research conduct. The STS research showed me how even an educational project like HEDGE is part of, and contributes to, a larger sociotechnical system with significant security and governance issues. By simultaneously working on both my Capstone and research paper, I gained a deeper understanding of engineering practice, showing how technical decisions affect complex social, political, and ethical considerations, giving me a better appreciation for responsible innovation as a UVA engineer.