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

Dual-Use Dilemmas: Examining the Ethical Responsibilities of Researchers, Government, and Industry in Hypersonic Technology

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Aerospace Engineering

By

Sydney A. Bakir

November 8, 2024

Technical Team Members:
Cole Bixby, Elle Bee Burke, Max Cristinzio, Luke Dropulic, Franklin Escobar, Nathan Kaczka, Jason Morefield, Zachary Morris, Arooj Nasir, Benjamin Petsopoulos, Cade Shaw, Michael Wennemer, and Caleb White

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.

ADVISORS

Prof. Kent A. Wayland, Department of Engineering and Society

Prof. Christopher Goyne, Department of Aerospace Engineering

Introduction: Exploring Ethical and Technical Frontiers in Hypersonic Technology

How can hypersonic technology be responsibly developed to enhance knowledge and benefit society while adhering to ethical standards?

The push to advance hypersonic technology represents a significant milestone in the aerospace field, offering endless possibilities for both military and civilian applications. While these systems have the potential to advance defense strategies, they also offer the same opportunities for scientific innovation and commercial advancements, further displaying the challenges posed by their dual-use nature. However, the high costs and technical demands limit broader access to hypersonic research, restricting its development primarily to well-funded institutions and raising concerns over equitable access to this technology.

The Hypersonic ReEntry Deployable Glider Experiment (HEDGE) addresses these challenges by providing a CubeSAT-based, cost-effective platform for hypersonic experimentation. Developed to advance hypersonic data collection for structural, thermal, and aerodynamic analysis, HEDGE offers a way for academic institutions to engage in affordable hypersonic research. The goal is to bridge the gap between cost barriers and technological advancement, bringing hypersonic capabilities to the small research community.

Given the potential impact of hypersonic systems, ethical considerations are crucial. This dual-use capability demands that developers engage in responsible innovation to prevent the misuse or militarization of these advancements. In parallel with the technical aims of HEDGE, this Prospectus includes a study of ethical responsibilities in hypersonic technology development, examining how key stakeholders view their roles within this dual-use framework. Together, these projects seek to create both a practical tool and an ethical framework for hypersonic research, balancing technological progress with societal accountability and responsible use.

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

How can a CubeSAT-based system provide an affordable platform for hypersonic research, enabling data collection on hypersonic reentry dynamics?

Problem and Significance

Hypersonic technology, with speeds exceeding Mach 5, is transformative for both scientific and defense sectors. However, high costs and technical barriers limit access to hypersonic research for many institutions. The Hypersonic ReEntry Deployable Glider Experiment (HEDGE) addresses this using a CubeSAT framework to offer a scalable, cost-effective platform for collecting data on hypersonic reentry and flight dynamics. Launched from an exo-atmospheric rocket, HEDGE will gather real-time telemetry on structural, thermal, and aerodynamic performance during reentry, filling a critical research gap.

Objectives

The primary goals for HEDGE are to demonstrate a cost-effective hypersonic experiment via rocket launch, validate avionics and telemetry systems, and provide students with hands-on design and test experience. Secondary goals include acquainting students with industry-standard practices, enhancing student-professional networking, and simulating professional teamwork environments.

Methods

Each HEDGE subteam is tasked with specific responsibilities to meet the project's objectives:

1. Program Management: This team ensures the project adheres to the capstone course and RockSat-X mission schedules, using Google Sheets for task management and a Gantt chart for timeline tracking. They also monitor finances, focusing on necessary expenses as sponsorships are secured.
2. Software and Avionics (S&A): The S&A subteam develops software to process and transmit sensor data via the Iridium Satellite Constellation to the UVA ground system. They are replacing a high-powered onboard computer (OBC) with a custom-built alternative to reduce costs. The code is written in C++ and is compatible with a Linux OBC using the open-source F software framework. Testing uses multimeters and microcontrollers to verify system components.
3. Structures and Integration (S&I): S&I is responsible for HEDGE's structural integrity and RockSat-X integration. Using SolidWorks, they have completed the forebody and fin designs and will finalize all assembly drawings by the end of 2024. Deployment methods and launch configurations are also under evaluation.
4. Power, Thermal, and Environment (PTE): The team ensures thermal stability and mechanical durability throughout the mission phases using computational fluid dynamics (CFD) and vibrational testing in Ansys Workbench. They also manage power systems, verifying that the battery provides adequate power and remains within temperature ratings.
5. Communications: This subteam manages sensor data collection, gathering temperature, pressure, and GNSS readings every half-second during reentry. These readings are then

transmitted via Iridium to the ground station. Data analysis will be conducted using MATLAB.

6. Attitude, Stability, and Trajectory (AS&T): AS&T models critical mission metrics such as drag coefficient, Mach number, and trajectory using Ansys Fluent and MATLAB. These predictions are vital for understanding aerodynamic stability and supporting data collection.

Resources

Adequate software and hardware resources are essential for HEDGE. Teams require SolidWorks, MATLAB, Ansys STK, and Ansys Fluent licenses, with high-powered desktops in the UVA Aero/Mec Lounge to meet computational demands. Funding is critical; HEDGE has received $2,800 from the Capstone program and $40,000 from Systems Planning & Analysis (SPA), but additional funds are needed for materials. For instance, an aluminum body requires $62,114, while a plastic alternative would cost $21,517.

Spring Objectives

In the spring, the HEDGE team will focus on manufacturing and system assembly, conducting rigorous testing to verify component deployment, release from the deployer, and integration within RockSat-X. A to-scale 3D-printed model of the allocated deck space will support these efforts.

Future Continuation

HEDGE provides a unique opportunity to advance affordable hypersonic research. By gathering telemetry on structural, thermal, and aerodynamic performance, HEDGE aims to set a standard for accessible hypersonic experimentation. Following a final report in MAE 4800, the system will be delivered to NASA's Wallops Flight Facility for the RockSat-X launch, scheduled for August 2025. Under Professor Goyne, future Aerospace Engineering Capstone students will build on HEDGE's foundations to further develop this innovative program.

Dual-Use Dilemmas: Examining the Ethical Responsibilities of Researchers, Government, and Industry in Hypersonic Technology

How do researchers, government agencies, and private corporations view ethical responsibilities in the development of dual-use technologies like hypersonic systems?

Background/Context

Hypersonic technology, which involves vehicles capable of traveling at speeds exceeding Mach 5, represents a technological frontier with significant potential for both scientific advancement and defense applications. Projects like the Hypersonic ReEntry Deployable Glider Experiment (HEDGE) emphasize this dual-use potential by aiming to provide a low-cost, scalable CubeSAT-based solution for collecting essential hypersonic reentry data. While the HEDGE project focuses on making hypersonic research accessible for academia, its findings could also inform defense applications due to the technology's relevance to national security. The dual-use nature of hypersonic technology brings a multitude of ethical responsibilities, forcing stakeholders to carefully balance innovation with accountability to broader societal concerns, including global security and adherence to ethical standards.

This STS research will investigate how different groups involved in hypersonic technology—researchers, government agencies, and private corporations—view their ethical responsibilities within this dual-use framework. By examining the perspectives of these stakeholders, this project seeks to clarify the ethical standards guiding hypersonic developments, particularly as advancements in this area may influence international relations and potentially escalate arms races.

Literature Review

Dual-Use Technologies: Ethical Challenges and Responsibilities

Dual-use technologies, such as hypersonic systems, inherently blur the line between innovation for societal advancement and potential misuse for militarization. Historical precedents, including nuclear and aerospace advancements, demonstrate the recurring ethical challenges stakeholders face in balancing innovation with accountability to society (Tracy, 2024). The dual-use nature of hypersonic systems necessitates transparency, engagement, and responsible innovation to mitigate risks of misuse or unintended consequences (Stilgoe et al., 2013).

Hypersonic Systems and Their Strategic Implications

The pursuit of hypersonic technologies has escalated global competition among major powers. These systems promise significant military advantages, including the ability to evade missile defenses and conduct precision strikes, yet they exacerbate geopolitical tensions by challenging deterrence frameworks like the MAD doctrine (Wong, 2021). Their speed, maneuverability, and reduced response times heighten the risks of misperception and unintended escalation, particularly during crises (Williams, 2019). For stakeholders, these strategic concerns underscore an ethical command to ensure the responsible development and deployment of hypersonic systems. This includes acknowledging how such advancements may drive arms races or destabilize international security, raising questions about long-term societal consequences (Bugos & Reif, 2021).

Stakeholder Perspectives on Ethical Responsibilities

Researchers, government agencies, and private corporations occupy distinct yet interconnected roles in developing hypersonic technology. The research community bears the ethical responsibility of advancing knowledge while actively engaging with public concerns about dual-use risks. Actor-network theory (ANT) provides a valuable framework for analyzing how these stakeholders interact within the hypersonic socio-technical network (Stilgoe et al., 2013). Similarly, the Responsible Innovation framework emphasizes the need for accountability, transparency, and societal engagement, urging stakeholders to prioritize the long-term implications of their work (Ensminger, 2019). As regulators and funders, government agencies must navigate the balance between promoting innovation and ensuring national security. They are uniquely positioned to establish ethical guidelines and foster international dialogue to mitigate destabilizing risks associated with hypersonic systems (Tracy, 2024). Private corporations, often driven by competitive and profit-oriented motives, face ethical dilemmas in aligning technological innovation with societal well-being. As crucial actors in the arms race for hypersonics, their role in shaping policies, adhering to ethical standards, and supporting arms control initiatives is critical (Bugos & Reif, 2021).

Toward Ethical Oversight in Hypersonic Development

The rapid development of hypersonic systems demands a collective approach to ethical oversight. The risks inherent in dual-use technologies can be mitigated by fostering transparent, interdisciplinary dialogue among stakeholders. Addressing questions of accountability and societal impact is paramount to ensuring that advancements in hypersonics benefit society while minimizing harm. Responsible innovation frameworks offer valuable tools to navigate these challenges, urging researchers, governments, and industry leaders to align their objectives with broader ethical priorities (Terry & Cone, 2020; Wong, 2021).

Theoretical Framework

This research draws on Actor-Network Theory (ANT) and the Responsible Innovation (RI) framework to analyze ethical responsibilities within the hypersonic technology network. Using ANT allows us to consider how researchers, government agencies, and private corporations operate as interconnected actors within the hypersonic socio-technical network. For example, HEDGE's development brings together academic researchers, industry partners, and government agencies, each contributing their own priorities and shaping the direction of the project in different ways.

The Responsible Innovation framework adds depth to this analysis by focusing on accountability, transparency, and engagement in technology development. It stresses the need to align technological advancements with societal well-being and encourages stakeholders to consider the long-term consequences of their work. This approach is particularly relevant to HEDGE, which aims to make hypersonic research more accessible in an ethical and socially responsible way, setting a potential example for future developments in the field.

Methods: Evidence/Data Collection and Analysis

This study will employ a comparative case study approach, analyzing policy documents, ethical guidelines, and public statements from academic, governmental, and corporate stakeholders involved in hypersonic technology. For HEDGE, we will examine institutional and departmental documents outlining ethical guidelines for student-led research in aerospace and funding and sponsorship agreements that might influence project priorities.

Additionally, relevant case studies from other dual-use technologies, such as AI or nuclear research, will be used to draw parallels and understand recurring ethical challenges. Speaking directly to stakeholders could also offer valuable insights into how researchers, corporations, and government officials view their ethical responsibilities and the potential impacts of furthering hypersonic technology.

Conclusion

This Prospectus outlines two interconnected research efforts: the Hypersonic ReEntry Deployable Glider Experiment (HEDGE) technical development and an STS analysis of ethical responsibilities in dual-use hypersonic technology. Through the technical project, the HEDGE team seeks to demonstrate a cost-effective approach to hypersonic research using a CubeSAT platform, advancing accessibility to crucial hypersonic data for academic and research purposes. This project provides hands-on engineering experience while contributing to the aerospace field's understanding of hypersonic reentry and flight dynamics.

In parallel, the STS research explores the ethical responsibilities of stakeholders—researchers, government agencies, and corporations—involved in developing dual-use technologies like hypersonic systems. The STS study seeks to create a framework for understanding the complicated ethical issues tied to hypersonic advancements by exploring how each group perceives its role in upholding ethical standards. These insights are crucial because hypersonic technology could have a major impact on global security dynamics and might fuel an arms race if ethical concerns are not properly addressed.

Together, these projects are complementary efforts to address how hypersonic technology can be responsibly developed to advance knowledge and societal welfare without compromising ethical standards. The thesis contributes to a more balanced and ethically aware approach to hypersonic research by producing new technical expertise and offering moral guidance. The combined findings will support the technical feasibility and scalability of hypersonic research and underscore the importance of aligning such research with broader societal needs and ethical principles.

References

Bugos, S., & Reif, K. (2021). Understanding Hypersonic Weapons: Managing the Allure and the Risks. Arms Control Association Report.

Leyva, I. A. (2017). The relentless pursuit of hypersonic flight: How much new science will it take to design a vehicle that can routinely fly at many times the speed of sound? *Physics Today, 70*(11), 30–36. https://doi.org/10.1063/PT.3.3762

Noland, J., & Phillips, R. (2010). Stakeholder engagement, discourse ethics, and strategic management. *International Journal of Management Reviews, 12*(1), 39–49. https://doi.org/10.1111/j.1468-2370.2009.00279.x

Terry, N. B., & Cone, P. P. (2020). Hypersonic technology: An evolution in nuclear weapons? *Strategic Studies Quarterly, 14*(2), 74–92.

Tracy, C. L. (2024). Weapons design, engineering ethics, and the duty to inform: A case study on U.S. hypersonic missile development. *IEEE Technology and Society Magazine.* https://doi.org/10.1109/MTS.2024.3434518

Williams, H. (2019). Asymmetric arms control and strategic stability: Scenarios for limiting hypersonic glide vehicles. *Journal of Strategic Studies, 42*(6), 789–813. https://doi.org/10.1080/01402390.2019.1627521

Wong, W. K. O. (2021). First strike hypersonic weapons: The end of the “MAD” doctrine and peace for our time? *Pacific Focus, 36*(3), 343–379. https://doi.org/10.1111/pafo.12199