Hypersonic ReEntry Deployable Glider Experiment

Global Stability & Hypersonics

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
Franklin Escobar

December 3, 2024

Technical Team Members:

Sydney Bakir
Cole Bixby
Elle Bee Burke
Max Cristinzio
Luke Dropulic
Nathan Kaczka
Jason Morefield
Zachary Morris
Arooj Nasir
Benjamin Petsopoulos
Cade Shaw
Michael Wennemer
Caleb White

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.

ADVISORS

Rider Foley, Department of Engineering and Society

Christopher Goyne, Mechanical & Aerospace Engineering

Introduction

Hypersonic systems are at the forefront of aerospace technology. The term “hypersonic” is used to describe an object flying at least 5 times the speed of sound (Schmidt, 2024). Hypersonic systems have been around for over 60 years, first shown by the German V-2 rockets in World War 2 (Van Wie, 2021). Notable contemporary systems that exceed hypersonic speeds are reentry capsules, the Space Shuttle, and SpaceX’s Flacon 9 (Van Wie, 2021). Currently, The United States has placed emphasis into hypersonic offensive strike capabilities (H.R.5515, 2018). Offensive hypersonic weapons are categorized into Hypersonic Glide Vehicles (HGVs) and Hypersonic Cruise Missiles (HCMs). HGVs operate using a traditional rocket to reach orbital/suborbital altitudes and then the glide vehicle deploys and directs itself towards its set location unpowered, using gravity to accelerate it to sufficient speeds (Van Wie, 2021). Figure 1 shows a proposed HGV designed by DARPA. HCMs are powered by air-breathing engines, such as a scramjet engine, which employs a higher degree of maneuverability than an HGV (Sayler, 2024). Figure 2 shows an example of an HCM.

Figure 1. DARPA HGV (Source: Space.com, 2011)

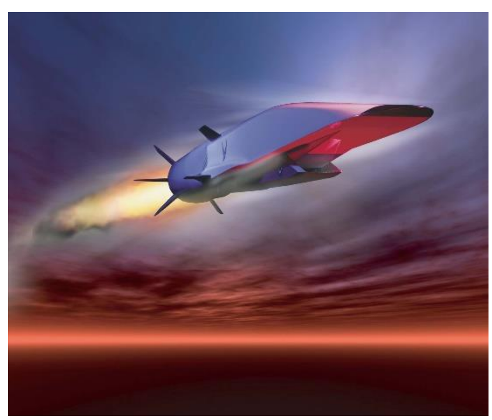

Figure 2. X-51 HCM (Source: Airforce)

Vehicles operating at hypersonic speeds experience severe aerothermodynamic loads (Bertin & Cummings, 2003). For example, the body of a hypersonic vehicle must survive temperatures of up to 2200K, roughly 3500 ºF (Smith, 2021). Therefore, any vehicle intending to go hypersonic speeds must be made of high-strength materials which can withstand those extreme conditions. Additionally, cooling systems such as hydrogen-based active cooling are crucial for achieving optimal performance in an HCM (Tsujikawa, 1996). Due to the technical complexity of hypersonic systems, their deployment becomes exceptionally costly. For instance, the Army's proposed HGV is estimated to cost $41 million per unit (Feickert, 2024).

Such a high cost to launch makes testing such hypersonic systems in real-world applications financially prohibitive. While laboratory testing is a more viable alternative, it doesn't fully replicate the conductions of actual hypersonic speeds. Therefore, an alternative that successfully simulates hypersonic conditions while remaining cost-effective is highly desirable.

This capstone aims to provide a cost-effective, scalable solution for gathering essential data on hypersonic reentry and flight dynamics. Additionally, as nations continuously pour funding into hypersonic research and testing, the second portion of this paper will explore how the development of hypersonic technologies from powers such as the United States impact international stability and power dynamics.

Hypersonic reEntry Deployable Glider Experiment

The Hypersonic ReEntry Deployable Glider Experiment (HEDGE) is a 3U CubeSat that is planned to be launched in the summer of 2025 using NASA's RockSat-X program from Wallops Flight Facility. HEDGE aims to demonstrate the affordability and accessibility of CubeSat technology for hypersonic flight test research. CubeSats are classes of nanosatellites that use a standard size and form factor and start at a size of 1U (10x10x10 cm) but can increase to 1.5,2,3,6, or 12U (NASA, 2024). This standardization drives the low-cost nature of HEDGE as it simplifies the design and manufacturing process. To obtain telemetry, HEDGE will be integrated with the Iridium constellation of satellites. Iridium is a system of satellites in Low-Earth orbit that provide connectivity and communication systems to ground stations (Iridium, 2024).

The sounding rocket is divided into different experiment deck spaces with longerons spanning the exterior deck spaces running through the entire length of the rocket. It can fit 5 full experiments, or 10 half deck experiments (NASA, 2024). Figure 3 shows a conceptual Rocksat-X's experiment deck structure.

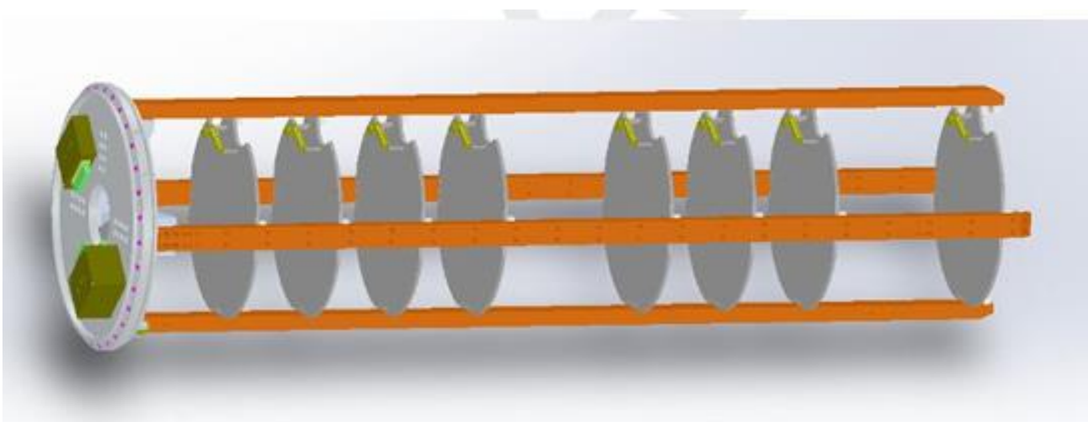

Figure 3. Rocksat-X Experiment Spaces (Source: NASA, 2024)

HEDGE has two configurations; these are its stowed configuration (Figure 4) and its deployed configuration (Figure 5).

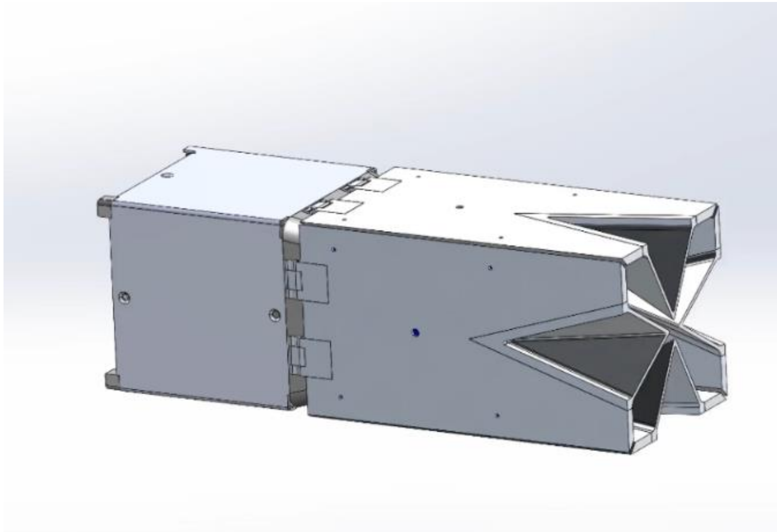

Figure 4. Fins Stowed (Source: HEDGE Team, 2024)

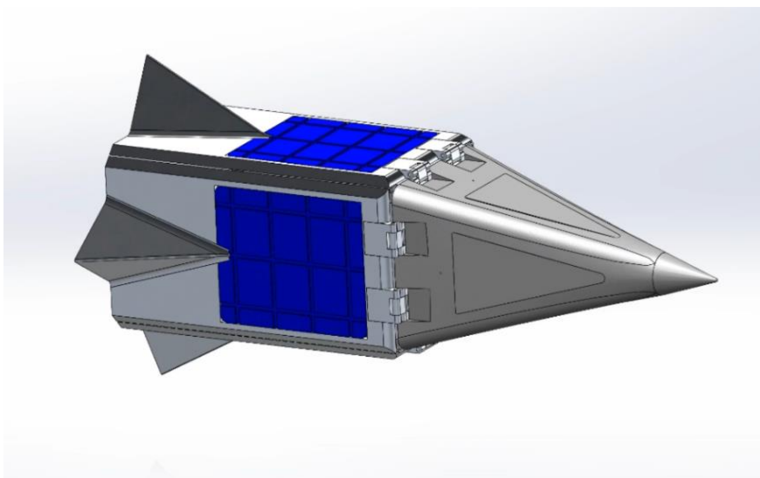

Figure 5. Fins Deployed (Source: HEDGE Team, 2024)

Figure 4 is how HEDGE will be configured when integrated into the experiment deck spaces. HEDGE will occupy 0.5 experiment deck spaces, which has a maximum height of 5.13 inches and a width of 12 inches (NASA, 2024). HEDGE meets these specifications, with a height of 3.96 inches and length of 11.6 inches. Once Rocksat-X reaches an altitude of 70km, a portion of its outer shell will detach, exposing HEDGE and other experiments to the space environment. The rocket will continue ascending until it reaches its final apogee between 150 and 170km

(NASA, 2024). HEDGE plans to deploy shortly before reaching apogee, with aims to use some of its forward momentum to propel it into a glide trajectory rather than falling straight down. Immediately after deployment HEDGE will transition from Figure 4 to Figure 5. The fins will retract to their final position which provides aerodynamic stability. Figure 6. Shows a sectional view of HEDGE in its deployed configuration.

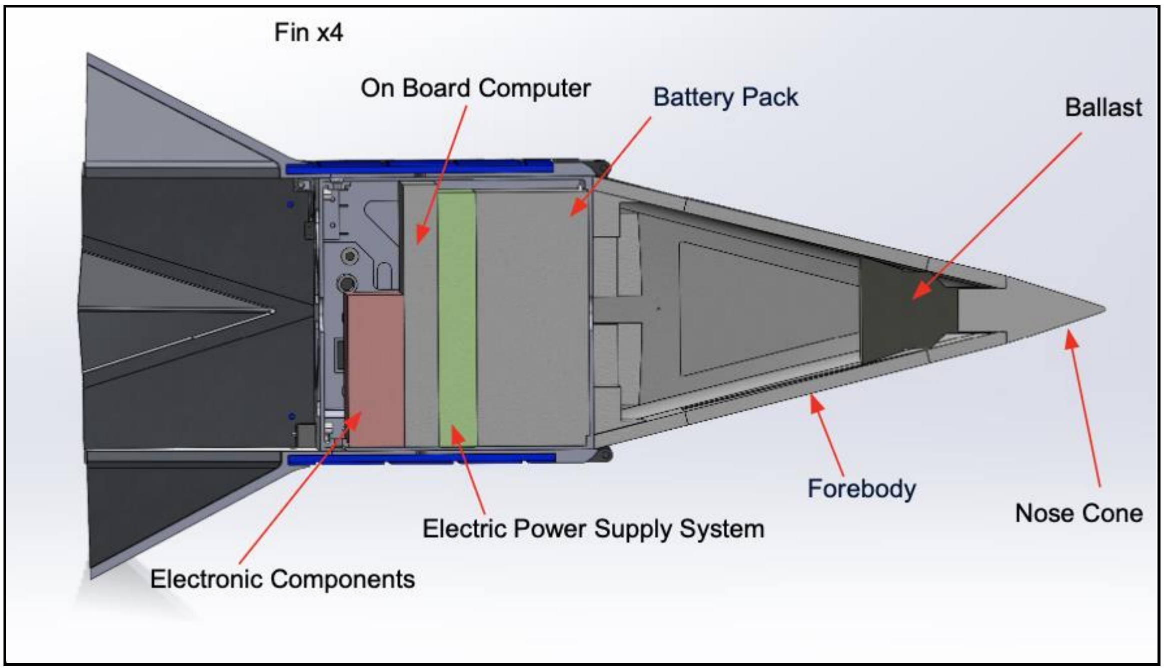

Figure 6. Side Section View of HEDGE (Source: HEDGE Team, 2024)

HEDGE is split into three major components shown by Figure 6. The right-most side of HEDGE is the forebody which houses the ballast and is optimized to reduce drag upon re-entry. Following that is the central body where all the electrical components for testing are located which are housed in a 1U chassis. After that are a set of four fins that are deployed following separation from the RockSat-X.

Current efforts are focused in securely attaching HEDGE to the experiment deck, as it must be able to withstand 25g's in all directions, along with 50g impulses (NASA, 2024).

Additionally, the mechanisms for fin deployment and HEDGE's separation from RockSat-X have not yet been finalized.

Global Powers & Hypersonics

A country is considered a global power when it exerts significant cultural or political influence over other nations, often bolstered by its military or economic strength (Zreik, 2024). Such examples that fit these criteria in the contemporary world are the United States, China, and Russia. Nobel Laureate and British Philosopher Bertrand Russel argued that power is "insatiable" and that it is "the strongest motive in the lives of important men" (Russell, 1950). This concept can be extended to nations as well, suggesting that a global power is driven by its desire to maintain its influence.

For a country to maintain their influence, they must remain technologically relevant (Meierding & Sigman, 2021). However, when adversarial nations compete for influence, this leads to technological races. These technological races could arguably be beneficial like the Space Race which brought technologies we use everyday such as GPS (Smithsonian, 2023). However, technological races can also threaten global stability, like the nuclear arms race. Such example of destabilizing effects is shown by the Cuban missile crises which marked the closest point the world entered nuclear war (Britannica, 2024). Therefore, technological races centered on weapon capabilities tend to threaten international stability. With the emergence of offensive hypersonic systems, we may be heading down this path.

During his farewell speech, President Eisenhower delivered a warning against the establishment of the military industrial complex, a term he coined (National Archives, 2021). The military industrial complex refers to the increasingly powerful relationship that the government has with defense contractors. During his speech Eisenhower expressed concern that this relationship would increasingly influence national policies and priorities. Eisenhower's concerns appear to have become reality, as defense contractors spent $70 million in lobbying in 2023 (Schumer, 2023).

Increased military research, such as the funding of offensive hypersonic weapon capabilities create multiple social implications. Firstly, this divides the nation into "pro-war", or "anti-war" groups, as the anti-war people do not want their tax money to go into these kinds of endeavors. Additionally, it's important to note that the United States is not the only one funding research into offensive hypersonic weapons. In fact, Russia already deployed a hypersonic missile in the Ukrainian battlefield called the "Kinzhal", and China is estimated to have conducted 20 times as many tests regarding hypersonic as the United States (David, 2023) (Sayler, 2024). As hypersonics continue to advance this leads to a sense of insecurity among the public, as American citizens recognize the United States vulnerabilities to these advanced weapons.

American sociologist Susan Leigh Star explores how infrastructure is interconnected with social practices and communities. Infrastructure is a critical aspect that shapes and is shaped by everyday life (Star, 1999). It can be read as a simple material artifact, a record of activities, and a truthful representation of the world. This shows a broader definition of infrastructure, as it is not confined to materialistic things. In essence, infrastructure is not just a technical system, but one that also involves people, practices, and relationships. Star defines infrastructure as showing one of the following: embeddedness, transparency, reach/scope, learned as a part of membership, links with conventions of practice, embodiment of standards, build on an installed base, visible upon breakdown, and fixed in modular increments.

Hypersonics and their development are intertwined in various infrastructure properties mentioned by Star. Firstly, hypersonics show off a high degree of embeddedness. Hypersonics are interdependent in other pieces of infrastructure such as satellite networks, offensive strike capabilities, and even global supply chains. This shows their deep roots in the military industrial complex and their embedded structure underscores how they are a product and a driver of countries desire towards global dominance. Next is “transparency”, or rather lack thereof. As their offensive capabilities are still under development, countries are constantly undergoing testing. In an ideal world, everyone would share their data. Unfortunately, this is not the case which leads to individual countries guarding their results with extreme secrecy. This fosters a global sentiment of mistrust among those undergoing research which can lead to broader instability. Lastly, the scope of hypersonics has greatly expanded in the recent decades. More specifically, new HCMs show the broadening in strategic utility. From what were once ballistic missiles with predictable trajectories, they now evolved into weapons with highly unpredictable flight paths. As the scope of hypersonic technologies expands, it increasingly leads to tensions and conflicts, as nations inevitably encroach upon each other’s strategic regions and objectives

Research Question and Methods

This leads to my research question, how does the development of hypersonic technologies from global powers impact international stability and power dynamics? This is an important question to address because hypersonic technologies are disruptive to missile defense systems, raising significant security concerns that can influence international relations. No nation wants to be left vulnerable, making it crucial to understand how these advancements may reshape global stability.

To answer this question, I plan on analyzing the key actors in this field which are the United States, Russia, and China (Sayler, 2024). I plan on examining the historical, current, and projected future developments of hypersonic capabilities between these nations. By looking at the rate of development and speed of progress, this will help me assess whether we are already in an arms race, on the brink of one, or far from it. Additionally, I plan on looking back roughly the last 10 years and obtaining public opinion data of each country using the service provided by Gallup Analytics. Analyzing how the public views a particular nation offers valuable insights into the broader national sentiment and its general attitude towards that country. I plan to conduct a trend analysis of the defense budgets of the three countries as changes in budget allocations can indicate how much emphasis is being placed on these systems. While I would ideally focus on obtaining figures specific to hypersonic technologies, it is unlikely that Russia or China publicly discloses such data. Available documentation on hypersonic weapon exercises would provide valuable understandings on their strategic implications (Borrie & Porras, 2019). I also hope to investigate how much more destruction a hypersonic weapon would bring when compared to a traditional one. This can be done by analyzing the impact of an HCM's speed on its destructive potential, assuming the same amount of explosive is used.

Deterrence plays a significant role in maintaining international stability. I plan on investigating if the introduction of hypersonic weapons increases the likeliness of a country to adopt "first-strike" capabilities due to the time advantage that hypersonics offer (Borrie & Porras, 2019). Obtaining Putin or Xi-Jinping's public speeches would be valuable too. This would enable me to explore whether they highlight their hypersonic capabilities to project power or use them to fuel fearmongering, shaping public sentiment against the West. Lastly, I plan on using the Global Peace Index from various years provided by the Institute for Economics & Peace. Negative shifts in GPIs show instability, tensions, and overall leads to a greater likelihood that the country will get into conflict.

Conclusion

The current issue with hypersonics lies in its high testing costs, which causes massive financial burdens for institutions. Solutions would lead to more widespread development and deployment of these technologies, but also have the potential to escalate military competition, possibly triggering arms races or destabilizing relations. The expected result of this research paper is that, like the nuclear arms race, the development of hypersonics have worsened global relations between adversarial nations and sparking a new arms race.

Citations

Air Force. (n.d.). *X-51A Waverider*. Air Force. Retrieved November 7, 2024, from https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104467/x-51a-waverider/

Bertin, J. J., & Cummings, R. M. (2003). Fifty years of hypersonics: Where we've been, where we're going. Progress in Aerospace Sciences, 39(6–7), 511–536. https://doi.org/10.1016/S0376-0421(03)00079-4

Bertrand Russell. (1950, December 11). *Nobel Lecture*. https://www.nobelprize.org/prizes/literature/1950/russell/lecture/

Borrie, J., & Porras, D. (2019). *The Implications of Hypersonic Weapons for International Stability and Arms Control*.

Britannica. (2024, October 15). *Cuban Missile Crisis*. https://www.britannica.com/event/Cuban-missile-crisis

David, R. (2023, May 6). Ukraine downs Russian hypersonic missile with US Patriot. *AP News*. https://apnews.com/article/russia-ukraine-war-patriot-kinzhal 6b59af8e60853b4d6d16dd8d607768be

Feickert, A. (2024). The US Army's Long-Range Hypersonic Weapon (LRHW): Dark Eagle. *Congressional Research Service*.

HEDGE Team. (2024, October 17). *MAE 4790 HEDGE Conceptual Design Review*. https://docs.google.com/presentation/u/2/d/1cDR7MVQdMVX7k3T_JOCXdvTWvuCPBDS62ZP4Bk-od6w/edit?usp=drive_web&ouid=117166420333996594043&usp=embed_facebook

H.R.5515 - 115th Congress (2017-2018): John S. McCain National Defense Authorization Act for Fiscal Year 2019. (2018, August 13). https://www.congress.gov/bill/115th-congress/house-bill/5515/text/statute

Iridium (2024). https://www.iridium.com/network/

Latour, B. (1992) 'Where are the missing masses? The sociology of a few mundane artifacts', in Bijker, W. E. and Law, J. (eds) Shaping Technology/Building Society: Studies in Sociotechnical Change, Cambridge, MA, MIT Press, pp. 225-58.

Meierding, E., & Sigman, R. (2021). Understanding the Mechanisms of International Influence in an Era of Great Power Competition. *Journal of Global Security Studies*, *6*(4). https://doi.org/10.1093/jogss/ogab011

NASA. (2024). “RockSat-X”. https://www.nasa.gov/wallops/stem/rocksatx/

National Archives. (2021, September 29). *President Dwight D. Eisenhower’s Farewell Address (1961)*. https://www.archives.gov/milestone-documents/president-dwight-d-eisenhowers-farewell-address

Sayler, K. (2024). *Hypersonic Weapons: Background and Issues for Congress* (No. R45811). Congressional Research Service.

Schmidt, A. (2024). Hypersonic Capabilities: A Journey from Almighty Threat to Intelligible Risk. *Military Review*, *104*, 85–94.

Schumer, M. (2023, October 20). Defense contractors spent $70 million lobbying ahead of annual defense budget bill. *OpenSecrets News*. https://www.opensecrets.org/news/2023/10/defense-contractors-spent-70-million-lobbying-ahead-of-annual-defense-budget-bill-ndaa/

Smith, C. R. (2021). Aerodynamic heating in hypersonic flows. *Physics Today*, *74*(11), 66–67. https://doi.org/10.1063/PT.3.4888

Smithsonian. (2023, August 23). What Was the Space Race? https://airandspace.si.edu/stories/editorial/what-was-space-race

Space.com. (2011, August 11). *Gallery: DARPA's Falcon Hypersonic Glider's Mach 20 Launch Test*. Space.Com. https://www.space.com/12604-darpa-hypersonic-glider-falcon-htv2-photos.html

Tsujikawa, Y. (1996). Effects of hydrogen active cooling on scramjet engine performance. *International Journal of Hydrogen Energy*, *21*(4), 299–304. https://doi.org/10.1016/0360-3199(95)00077-1

Van Wie, D. M. (2021). Hypersonics: Past, Present, and Potential Future. *Johns Hopkins APL Technical Digest*, *35*(4).

Zreik, M. (2023). Navigating the Dragon: China's Ascent as a Global Power Through Public Diplomacy. In S. Kavoğlu & E. Köksoy (Eds.), *Advances in Public Policy and Administration* (pp. 50–74). IGI Global. https://doi.org/10.4018/978-1-6684-9161-4.ch003