The Geopolitical Implications of Hypersonic Weaponry: The Shift in Geopolitical Influence from Hypersonic Capabilities

(STS Paper)

Hypersonic ReEntry Deployable Glider Experiment (HEDGE)
(Technical Report)

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
Hussain Asaad

October 10, 2022

Lauren Murphy, Kaiya Saunders, and Aidan Case

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

Joshua Earle, Department of Engineering and Society

Christopher Goyne, Department of Mechanical and Aerospace Engineering

Introduction

With a speed of Mach 5 and above, hypersonic weapons raise a number of unique challenges. Hypersonics is a relatively new field that has become an important topic in the defense industry. By using hypersonic technology, missiles or glide bodies can fly trajectories that are vastly different from conventional ballistic missiles. Glide bodies are similar to missiles; however, they can be maneuvered much more effectively using flight control surfaces in a non-ballistic trajectory. Hypersonic weapons can both shorten the time it takes to eliminate a target and ensure that adversaries are unable to detect or hit such weapons using ground-based defense systems. This is possible due to their depressed trajectories that make detecting hypersonic missiles challenging. It's also a result of their increased maneuverability which reduces the likelihood of the missiles being intercepted and destroyed.

Hypersonic missiles provide the capability of using conventional warheads, rather than their nuclear counterparts. These conventional warheads are able to eliminate a target more accurately. This provides an advantage for the nations that possess these hypersonic conventional weapons, as they gain an alternative to using nuclear weapons. Thus, nuclear weapons can remain as deterrence while hypersonic missiles can be used to wipe out selected targets without causing civilian casualties. However, nuclear warheads can be used on these missiles and glide bodies as well. Thus, uncertainty and worry surround this new technology. The nations that gain these advantages begin to have a new influence on the geopolitical scale. China, Russia, and the United States have been heavily investing in developing hypersonic missiles. My research question is as follows: *How will the geopolitical influence of the United States and its adversaries shift once hypersonic capabilities are fully functional by at least one of these nations?*

This paper will start with a discussion of the technical project being performed. The HEDGE mission will be explained in detail starting with its significance and continuing with the objective, methods, and desired outcomes. Next, the STS research topic of the shift in geopolitical influence from hypersonic capabilities will be discussed. This will cover how countries can influence politics and war with these capabilities. Finally, an analysis of four pieces of literature will be given.

Technical Project: Hypersonic ReEntry Deployable Glider Experiment

As hypersonic technology is novel, testing and collecting data on their performance and environmental parameters are key factors to their successful integration into the defense industry. However, since these parameters need to be collected at hypersonic speeds and within a similar flight environment, the difficulty and cost of these tests are substantially high. The University of Virginia's Hypersonic ReEntry Deployable Glider Experiment (HEDGE) uses a CubeSat to immensely reduce the cost of hypersonic flight research. A CubeSat is a miniaturized satellite that typically orbits the Earth and resembles regular satellites but on a much smaller scale. As the satellite reenters the atmosphere, it will naturally reach hypersonic speeds due to the force of gravity. This enables HEDGE to record and relay hypersonic flight data without needing a sophisticated propulsion system. CubeSats have the capability of riding alongside a different mission's payload, eliminating the need to launch the satellite with its own individual rocket. This factor, coupled with eliminating the need for a hypersonic propulsion system, makes HEDGE low in cost.

My functional team is tasked with designing the communication systems. Communication systems are essential for transmitting and collecting the data recorded by HEDGE. These systems must have the ability to operate as intended under various

environmental conditions and at hypersonic speeds. This includes surviving the conditions imposed by launch vehicles as well as functioning in unprotected space and atmospheric reentry environments ("Small Spacecraft," n.d.). Appropriate radios, antennas, bandwidths, and ground station instruments must be carefully selected to fit this unique mission. The CubeSat will measure pressure, temperature, and velocity throughout its short reentry phase before it burns up in the atmosphere. This phase occurs after multiple orbits in which HEDGE must remain in constant contact with ground stations. The data must be relayed to other satellites in orbit through a process known as inter-satellite linking. Ground station satellites will receive the acquired data using local ground stations that receive the transmission from another satellite in range. These factors pose significant challenges that must be resolved to enable a successful mission.

In order to design a successful HEDGE CubeSat capable of gathering data for researchers and designers, a reliable communication system is necessary. The objectives of the communications team are to investigate and purchase a radio system that can integrate into the CubeSat structure, be compatible with the other subsystems, stay within all budgetary constraints, and successfully transmit hypersonic data. This includes four distinct components that must be decided upon: the transceiver, antenna, relay satellite network, and ground station. Choosing the correct components is a difficult and involved task as hypersonic environments bring many challenges, and extensive research must be done in order to maximize the chances of success. The first primary complication that must be addressed is the formation of a plasma sheath around the CubeSat during atmospheric reentry, which is caused by shock waves heating the surrounding air to the point where the gas ionizes. This plasma cloud interferes with radio

waves and creates blackouts in communication, in which no signal can be received nor transmitted (Rybac, 1970).

A second concern is the possibility of instability of the CubeSat. Directing the antenna is critical to communication systems; if the attitude cannot be held relatively consistent, the direction of transmitted radio waves may be altered to the point where the relay satellites can no longer pick up the signals. Complications from noise, atmospheric attenuations, and Doppler shifts must be considered when choosing the right components, as is the case for all CubeSat missions (Bomani, 2021). Lastly, when researching all the above factors, the following hardware requirements must also be met: aligned frequencies for all components, sufficient data transmission rates, and proper power supply. The overall preliminary goal of the communications team is to research and analyze radio systems that can mitigate and account for all of these factors in an effort to design a dependable communication system that enables the HEDGE CubeSat to properly transmit hypersonic data.

STS Research Topic: Shift in Geopolitical Influence from Hypersonic Capabilities

With the world's most powerful nations investing a significant amount of time, money, and resources towards developing and deploying hypersonic weapons with the intent of pursuing national security, there becomes a paradoxical byproduct: global insecurity. There may be an imbalance in the positive and negative consequences of this new arms race. These consequences are associated with security, arms control, and disarmament.

Hypersonic weapons can be viewed to have varying purposes. Some may say that they are used as a form of strategic deterrence regardless of their deployment while others may suggest that there will be unintended consequences from their inevitable use (Borrie & Porras, n.d.). Nations that possess hypersonic capabilities may be displaying a sense of national military

competence that is viewed to be politically important by many. It can certainly be used as a form of deterrence where warnings can be enough to prevent an adversary from taking a militaristic approach to gain geopolitical power.

There is currently no defense established against hypersonic weapons. Not a single nation has the capabilities to intercept a hypersonic missile regardless of whether the missile or glide body can be detected and even tracked. Although this does not mean it will never be successfully deployed, this capability will not be available during the initial deployment of hypersonic weapons. This means that nations that possess hypersonic capabilities have a significant advantage that cannot be counteracted. This has led certain politicians and defense personnel to discuss limiting or outlawing the so-called “disruptive technology” (Stone, 2020).

The majority of the wars fought by the United States have taken place in the Eastern Hemisphere. Thus, deploying aircraft, personnel, and resources would take months to complete. With hypersonic glide bodies, the U.S. would be able to deliver precision attacks against target areas in an hour or less (Friedman, 2018). The tempo of war can be drastically changed by this capability. The U.S. would be able to quickly and accurately eliminate targets. This may lead to other nations being hesitant to attack the U.S. due to this capability. This is known as deterrence, and the only form of deterrence that is currently used is nuclear deterrence.

The United States is most concerned with Russia and China’s accelerating efforts to fully develop their hypersonic weapons. Russia has shown its new weapon under development called the Kinzhal which is claimed to be able to reach Mach 10 (Friedman, 2018). China unveiled its rocket-boosted hypersonic glide vehicle called the Dongfeng-17. The U.S. is already at the stage of testing a number of hypersonic weapons that are being developed at a rapid pace. As tensions rise and China makes it clear that it is potentially going to invade Taiwan and take control of the

South China Sea, the nation can use hypersonic weapons to destroy U.S. forces in the Pacific Ocean. Thus, hypersonic capabilities can be the sole factor that would enable China to claim Taiwan as part of its country. This is just one example of how a geopolitical shift can occur from the possession of hypersonic weapons. There are countless implications that are yet to be tapped into.

While researching these geopolitical implications of hypersonic capabilities, the relevant social groups include political leaders; U.S., Chinese, and Russian militaries; and civilians. Political and military leaders must be considered as they are ultimately the ones making the decisions on what technologies need to be procured and developed. The STS paper will mainly focus on the world's most powerful countries that are currently the furthest in hypersonic development: the U.S., China, and Russia. Civilians may be facing the consequences of the uncertainties that come with the new era of hypersonic weapons.

The STS framework being used is Technological Momentum. This framework is concerned with how the technology in question aligns with a social or political context for it to be an accepted technological system. Hypersonic technology is new in the sense that it has only just recently gained momentum and interest. Hypersonic weapons have not become mature in their development yet. This means that the latter stages of development such as local application, transfer to other locations, development of supportive infrastructure, and becoming standard, accepted systems that cannot be replaced, must be achieved in order for the technology to get passed the technological momentum.

The methods that will be used include a literature review and policy analysis. Secondary sources that have already analyzed the geopolitical implications of hypersonic weaponry are essential. There also needs to be policy analysis as the regulation and policies surrounding

hypersonic missile deployments are necessary to come to the right conclusion on how political power will vary globally with the possession of these weapons. This has proven to be the case with nuclear weapons and the treaties surrounding them.

Relevant Readings

An important piece of literature I will be using is "The Implications of Hypersonic Weapons for International Stability and Arms Control" by J. Borrie and D. Porras. The paper does an excellent job of describing how hypersonic weapons have created an arms race dynamic, It also covers how hypersonics may lead to uncertainty and unintended escalation and pose challenges for arms control and disarmament. There is also a discussion on strategic imbalances and international instability. This is all essential for my STS discussion as I intend to argue how international stability can be either compromised or strengthened by the use of hypersonic weapons.

The second piece being used is an article titled "Why Is the Use of Hypersonic Missiles in the Russia-Ukraine Conflict Significant?" by L. Yoksoulian. This reading provides a discussion on the first known hypersonic missile being used in combat, which happened to be by Russia during the war in Ukraine. It covers how hypersonic missiles differ from conventional ones, the status of hypersonic technology in various nations, and the implications for missile defense systems. This is an important source to reference when I discuss the current state of hypersonic capabilities. Mentioning the use of the technology by Russia would help make my STS discussion more credible and seem less theoretical.

Another article that is important to consider is "Countering the Hypersonic Missile Threat" by T. Karako and M. Dahlgren. This is a very detailed report that covers how defending against adversarial hypersonic missiles is possible. It provides a thorough high-level view of the

subject as well as a technical analysis of how to make detecting and intercepting hypersonic missiles a reality. This is important for me to consider as the authors make it clear that defending against this novel weaponry is a challenging feat. I need to discuss how complex the field of hypersonics truly is.

The fourth piece of literature is "'National Pride Is at Stake.' Russia, China, United States Race to Build Hypersonic Weapons" by R. Stone. This article goes over the geopolitical differences that exist between the United States, Russia, and China. The authors begin with the history and description of hypersonic weapons. They then provide statistics and an understanding of how these weapons fit from a global perspective. This is of course necessary for my STS paper as it provides insight into the three primary nations I will be including in my discussion.

References

Acqnotes (2021). Preliminary design review. Acquisition Process. https://acqnotes.com/acqnote/acquisitions/preliminary-design-review

Acqnotes (2022). Critical Design Review. Acquisition Process. https://acqnotes.com/acqnote/acquisitions/critical-design-review

Bomani, B. (2021). CubeSat Technology Past and Present: Current State-of-the-Art Survey (Rep.). Cleveland, OH: Glenn Research Center. Retrieved from https://ntrs.nasa.gov/citations/20210000201

Borrie, J., & Porras, D. (n.d.). The Implications Of Hypersonic Weapons For International Stability And Arms Control. UNIDIR. Retrieved from https://unidir.org/sites/default/files/2019-10/Hypersonic%20Weapons%20Tabletop%20Exercise%20Report.pdf

Hypersonic Weapons: A Challenge and Opportunity for Strategic Arms Control. UNIDIR. (2019). Retrieved from https://unidir.org/publication/hypersonic-weapons-challenge-and-opportunity-strategic-arms-control

Karako, T., & Dahlgren, M. (2022, January). Center for Strategic & International Studies. Center for Strategic and International Studies |. Retrieved from https://www.csis.org/

Rybac, J. (1970). Causes, effects and diagnostic measurements of the reentry plasma sheath (Rep.). Bedford, MA: Air Force Systems Command. Retrieved from https://apps.dtic.mil/sti/citations/AD0718428

Small Spacecraft Communication Systems. Small Business Innovation Research. (n.d.). Retrieved from https://sbir.nasa.gov

Stone, R. (2020, January 8). 'National Pride Is at Stake.' Russia, China, United States Race to Build Hypersonic Weapons. Science. Retrieved from https://www.science.org/content/article/national-pride-stake-russia-china-united-states-race-build-hypersonic-weapons

Yoksoulian, L. (2022, March 22). Why is the use of hypersonic missiles in the Russia-Ukraine conflict significant? Illinois. Retrieved from https://news.illinois.edu/view/6367/1254629557