Hypersonic Reentry Deployable Glider Experiment (HEDGE)

(Technical Paper)

Impact of Reconnaissance Satellites and Hypersonic Weapons on International Disputes

(STS Paper)

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Introduction

Are we in the middle of yet another industrial revolution? With the rapid development on technology in the last decade, the idea of the Fourth Industrial Revolution (Nakaska, 2021) has been gaining an immense amount of popularity. Starting with the discovery of water and steam based mechanized production in late 18th century followed by the use of electricity and mass production in the 19th century to the rise of the computer age in the 1960s (Schwab, 2016), the rate of progression in technology development has been growing exponentially. Now, the world is entering into the next period of this advancement as we encounter the likes of artificial intelligence, autonomous transportation, and even neurotechnology. However, wedged in the middle of all these industries is the world of space research and development.

Within the vast scope of space technology development, satellite communication has had a significant impact revolutionizing the way humans have lived their lives in the last 60 years. From the launch of Sputnik I by the Soviet Union in the year 1957 to establishment of the International Space Station in the late 20th century, these spacecrafts have been utilized for many applications including television, radio, navigation, weather, and defense (Schwab, 2016).

Despite this overarching global adoption of satellites, certain barriers have limited the accessibility to explore this technology, but none more than the massive budgets required to ensure a successful mission. To give some perspective, in the fiscal year 2021, $18 billion dollars of the total budget requested for the Department of Defense was allocated to the space domain (Department of Defense, 2020). Of the total allocation, almost a third of this budget was used for only three projects by the United States Space Force. With this capacity of funds not being attainable to many general researchers or enthusiasts, the interest in low-cost small satellites has grown significantly. Small satellites or SmallSats are a category of satellites consisting of those which weigh less than 180 kilograms and within these classifications, there are several subgroups including femtosatellites weighing as little 1 gram all way to minisatellites weighing anywhere from 100 to 180 kilograms (NASA, 2023). One type of small satellite that has risen in popularity over the past decade is the CubeSat, a small 10 by 10 by 10 cm cube shaped satellite belonging to a group known as nanosatellites which generally weigh 1 to 10 kilograms. To explore this technology, as part of my technical research, my capstone team and I are working on the research and development of a small satellite with hypersonic applications as part of the Hypersonic Reentry Deployable Glider Experiment (HEDGE). The HEDGE project is a proof-of-concept effort to determine if a CubeSat would be able to deploy, orbit, and perform reentry procedures while collecting valuable data within a low Earth orbit (LEO) space environment. Hypersonics refers to a field of aerial vehicles with the capability of travelling at speeds above Mach 5 (1715 m/s). As a non-nuclear, high accuracy technology, hypersonic development has taken over as one of the premier aspects of the defense industry with almost $5 billion being invested into it in the FY2023 budget request by the DOD. While industry applications of this technology generally cost hundreds of millions of dollars, HEDGE aims to be a proof on concept project to show the capability of hypersonic development at a low budget undergraduate level. With an estimated budget ranging from $60K to $100K, this project requires a fraction of the budget of general hypersonic and satellite communication missions, but the military and national security implications of satellite technology have drawn some controversial questions about its social and ethical implications with increased accessibility outside of controlled and highly secure programs.

As was seen during the era of the Cold War, rapid development of up-and-coming technologies sparks competition among powerful nations, each of which intends to build up an arsenal of the most cutting-edge innovations of the time. However, as a result, a subsequent rise of militarized conflicts often seems to follow times of high industrial development and it is no different in the era of space development we are in today.

Ever since its establishment is the early 1960s, espionage or reconnaissance in space has been a development met with various reactions. One point of view comes from a paper publish in the *Journal of Conflict Resolution*, Spying from Space: Reconnaissance Satellites and Interstate Disputes, in which the authors explore the effects of technology innovation and its impact on international disputes, specifically in terms of space innovation. They suggest that spying through use of reconnaissance satellites and raising awareness of their capabilities will decrease the amount of hostile military disputes significantly among nations (Early, Gartzke, 2021).

In a similar vein, the innovation of recon satellite technology has been accompanied by the implementation of hypersonic capabilities in weapons with implications of militarized space disputes and nuclear warfare. For the United States to keep pace will global development, companies such as NASA, Lockheed Martin, Raytheon, and the Defense Advanced Research Project Agency (DARPA) have invested billions into hypersonic weapon development and defense programs (Deloitte, 2020).

As part of my STS research, I would like to investigate the long term and short-term effects of space reconnaissance and hypersonic weapon development on international disputes through historical precedent along with analysis of international relations because of this technology. Through this, my goals are to identify and analyze the limiting factors which have hindered the scope of space development and exploration which, if addressed, could vastly improve international relations among world leading nations to benefit the global prosperity of humankind for years to come.

Technical Discussion

Over the past 100 years, many space missions have occurred despite the immense financial barrier. Cost reduction has been a key focus of industry, with the cheapest large-scale ventures ranging from tens to hundreds of millions of dollars per launch. To combat the monetary strain, the University of Virginia along with many other entities are engineering small-scale satellite projects (less than 1 cubic meter) known as CubeSats. Our CubeSat aims to explore the presently accelerating field of hypersonic travel, which occurs as a vehicle reaches upwards of 5 times the speed of sound. The efforts of various engineering disciplines are coming together to produce HEDGE, the Hypersonic Reentry Deployable Glider Experiment. The work of this capstone project is divided among sub teams specialized in certain technologies required by the mission to ensure success:

1. Program Management
2. Communications
3. Power/Thermal/Environment
4. Software and Avionics
5. Structures and Integration
6. Attitude Determination, Attitude Control Systems (ADACS) and Orbits

As a collective, the objective of HEDGE is to design and fabricate a low budget hypersonic space vehicle with the mission of entering low earth orbit (LEO) and reentry procedures reaching hypersonic Mach numbers greater than 5. In orbit and upon reentry, the onboard systems will conduct pressure and temperature data collection to transmit back to the ground station. As the ADACS and orbits team, our objectives consist of predicting the orbital path of the vehicle, anticipating potential environmental forces disrupting the position and orientation of the vehicle, and collaborating with other teams to ensure stability maintenance based on their respective design choices. Firstly, orbital path determination will be important to predict the rate of orbital decay and overall orbital lifetime which will allow us to know approximately when reentry will begin. Anticipation of environmental forces and stability go hand in hand, as it will allow us to ensure that the CubeSat will leave the launch vehicle in the correct orientation and that the path will not deviate significantly even with minor changes in momentum.

With HEDGE being a passively controlled system, these objectives will be accomplished prior to launch, but there will be a few tasks that our team will oversee after launch as well. This will mainly entail collection of real time attitude determination using information relayed from pressure sensors on the spacecraft. Overall, the objectives of the ADACS and orbits team will be crucial to ensuring mission success, and several resources and strategies will be utilized in the process.

During reentry, attitude will be determined relative to the direction of motion of the craft, i.e., its 'angle of attack.' This will be done through the flush air data sensing (FADS) system, which primarily consists of pressure transducers on either side of the nose of the craft which record the static pressure downstream of the oblique shock generated by the leading edge of the craft. The analog signal from the pressure transducers will be converted into a digital signal and passed to the on-board computer, which will use these values to determine the angle of attack and sideslip angle. The precision of the angle of attack measurement is limited by the precision of the transducers in a manner determined by the flight Mach number, the greater the Mach number, the finer the resolution of our angle of attack. This effect can be seen in Figure 1, below.

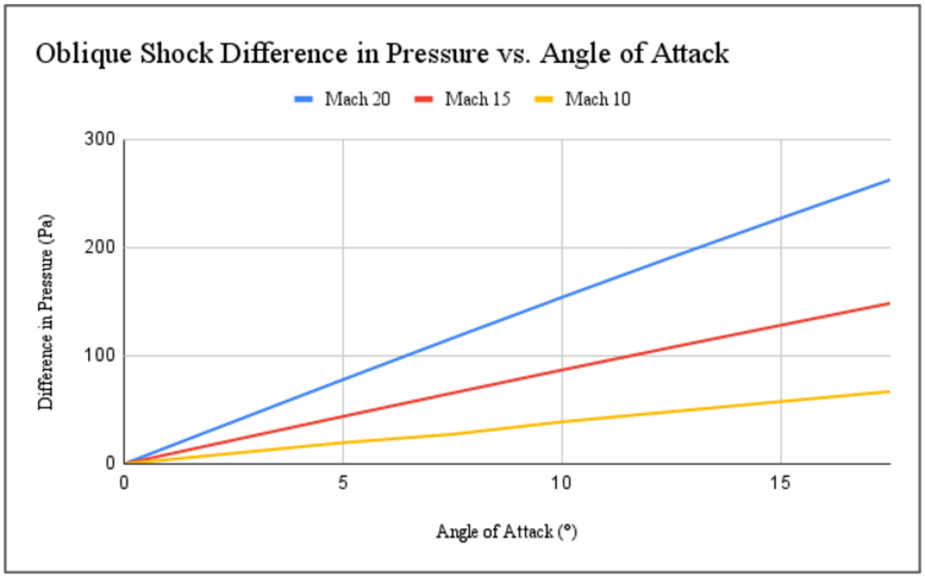

Figure 1: Difference in pressure on opposite sides of the craft as a function of angle of attack and Mach number (Goyne, 2022)

For the purposes of HEDGE, attitude control is limited to passive measures to save on cost. Computational Fluid Dynamics simulations will be run on the craft to determine its center of pressure under a variety of conditions, including a wide range of Mach numbers and air densities and temperatures. Separate models will need to be used for rarefied and dense air. The center of pressure will be compared with the center of mass (determined by the Structures and Integration team) to ensure static stability.

The previous class employed a MATLAB script to predict the rate of decay for HEDGE orbit during reentry. However, now that the project is progressing towards a functioning prototype, greater detail is necessary. For this reason, the Analytical Graphics, Inc. System Tool Kit (STK) along with Computation Fluid Dynamic analysis will therefore be used to study the trajectory of the satellite and drag effects during orbit and reentry.

The goal for HEDGE is to have a completed functioning prototype by the end of the spring semester. Doing so allows the class next year to focus their efforts on the physical construction of the official and final CubeSat product. This goal requires a complete integration of the work of every sub team including ADACS & Orbits.

STS Discussion

The immense capabilities of space-based systems have impacted the lives of humans for several decades and their increased dependence in critical social and economic aspects of daily life has made it imperative that these systems are preserved and constantly innovated. The applications are endless: agriculture, weather monitoring, communication, civilian transportation, autonomous vehicle guidance, electrical power, banking, emergency medical services, navigation, and overall space exploration (Defense Intelligence Agency, 2022). However, the military and civilian applications of space systems have resulted in competition between nations leading them to deny other nations the use of space assets (Defense Intelligence Agency, 2022) through the threat and action of destroying various satellite communication systems, often through the use of hypersonic weapons systems. In addition to this, during times of conflict between countries, intelligence gathering is often conducted using reconnaissance satellites by means of satellite imaging of certain locations to find vulnerabilities in the target. Interference of space assets along with espionage caused by the competitive nature of powerful such as Russia, China, and the United States limits the capacity of space development possible due to the lack of cooperation and integration among the respective space programs of each nation.

The terms “hypersonic weapons” mainly refers to cruise missiles and glide vehicles which can be used for high accuracy targeted attacks from large distances, which can often involve military bases and space assets (Borrie, Porras, 2019). While often thought of to me a more controlled way of attack compared to nuclear weapons, it is undeniable that risk to civilians and bystanders is extremely high. On top of this, nations with relatively substantial economies throughout the world have access to some sort of hypersonic weaponry raising the question about how controlled attacks actually can be and how detrimental the effect of retaliations can be. This was the very question raised in a 2019 study about the implications of hypersonic weapons on international stability and arms control by the United Nations Institute for Disarmament Research (UNIDIR) and the United Nations Office for Disarmament Affairs (UNODA).

> “Hypersonic weapon capabilities, even if primarily intended to strengthen the difference in peacetime, could be highly destabilizing in a crisis (Borrie, Porras, 2019).”

This sentiment was one of the key observations of their study and it really makes one think about how ethical it is to put billions of dollars of funding into hypersonic research.

Compared to relatively new field of hypersonic technology, satellite reconnaissance has been around since the era of the Cold War. During this time, information about the enemies was very lacking and countries often tended to send spies to other countries to gather intelligence and put them one step ahead of the opponent. However, this did not last for too long as the lack of proper resources and training led to the spies being captured rather quickly (Foust, 2010). This led to the development of satellite reconnaissance which has proved to be rather beneficial in terms of preventing declarations of war due to the transparency due the photographic capabilities allowing opposing countries to learn about the various technologies available in the arsenals of their adversaries. This deterred nations from performing certain offensive or retaliatory strikes because this technology can detect threats well before they arrive and form a plan of action to address them (Muszyński-Sulima, 2023) . However, the mistrust between the nations is still highly apparent and this is limiting the capability of cooperation between nations.

As part of my STS research, I plan on further looking into the timeline of the hypersonic weaponry and reconnaissance satellites technologies to look at the state of international relations before and after their establishment. This will shine light on what was going well and what was not, and I will specifically focus on the effects on global development. From this, my goal is to determine how approaches to these technologies can change in order to allow for better global prosperity.

Conclusion

Hypersonic and satellite technologies are extraordinarily complex systems that offer valuable capabilities to users in the scope of space travel and exploration. However, development of these technologies often requires high budgets around hundreds of millions of dollars, so this type of research is not very accessible. For this reason, my technical research, the Hypersonic Reentry Deployable Glider Experiment (HEDGE), will function as a proof-of-concept project to demonstrate the capability of students to develop a function small satellite that is able to enter low earth orbit and perform hypersonic reentry procedures. While it is done on a relatively small scale, this project does draw some military implications in terms hypersonic weaponry and satellite data collections, drawing some questions about the ethics. As such, my STS research will focus on exploring the effects of hypersonic and reconnaissance satellite technologies on international relations to determine certain factors which have limited the potential of global development in terms of space exploration.

References

Borrie, J., Porras, D. (2019). *The Implication of Hypersonic Weapons for International Stability and Arms Control*. Report on a UNIDIR-UNODA Turn-Based Exercise. https://unidir.org/files/2019-10/Hypersonic%20Weapons%20Tabletop%20Exercise%20Report.pdf

Defense Intelligence Agency. (2022). *Challenges to Security in Space: Space Reliance in an Era of Competition and Expansion*. https://www.dia.mil/Portals/110/Documents/News/Military_Power_Publications/Challenges_Security_Space_2022.pdf

Deloitte. (2020). *Breaking New Barriers: The Rise of Hypersonics*. Aerospace and Defense Consulting Team. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/energy-resources/us-breaking-new-barriers.pdf

Department of Defense. (2020, February 10). *DOD releases fiscal year 2021 budget proposal*. U.S. Department of Defense. https://www.defense.gov/News/Releases/Release/article/2079489/dod-releases-fiscal-year-2021-budget-proposal/

Early, B. R., & Gartzke, E. (2021). Spying from space: Reconnaissance satellites and Interstate Disputes. *Journal of Conflict Resolution*, *65*(9), 1551–1575. https://doi.org/10.1177/0022002721995894

Foust, J. (2010) *Emerging Opportunities for Low Cost Small Satellites in Civil and Commercial Space.* 24th Annual AIAA/USU Conference on Small Satellites. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1211&context=smallsat

Goyne, C. (2023). Hypersonic ReEntry Deployable Glider Experiment Critical Design Nguyen_Kevin_Technical_Report.pdf

Muszyński-Sulima, W. (2023). Cold War in space: Reconnaissance satellites and US-soviet security competition. *European Journal of American Studies*, *18*(2). https://doi.org/10.4000/ejas.20427

Nakaska, A. (2021). The Fourth Industrial Revolution and why we should care about it. https://www.ncda.org/aws/NCDA/pt/sd/news_article/384029/_PARENT/CC_layout_details/false

NASA. (2023). *What are SmallSats and CubeSats?* https://www.nasa.gov/what-are-smallsats-and-cubesats/

Schwab, K. (2016). *The Fourth Industrial Revolution: What It Means and how to respond*. World Economic Forum. https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/