HEDGE: Hypersonic Re-Entry Deployable Glider Experiment

Analysis of the Failure of Nuclear Arms Control After WWII

A Thesis Prospectus
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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.

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Introduction

Hypersonic vehicles, or vehicles that can travel at a speed five times or more the speed of sound, are a growing area of interest for the aerospace industry. While there are commercial applications to these vehicles, the United States, China, and Russia are leading the development of hypersonic missiles for offensive and defensive capabilities (Yoksoulian, 2022, What countries have this technology?). Since these missiles are able to fly below the line-of-flight detection, they are extremely difficult to intercept, and the use of hypersonic missiles can have devastating ramifications.

A significant amount of research and development has been done to study the various applications of hypersonic technology. Hypersonic re-entry vehicles are complex because it is very difficult to fly in a hypersonic regime. At these speeds air temperatures are extreme and most fuels decompose causing the engines to produce drag (Sia, 2022, Regimes). If the engine is producing excessive drag, the flight cannot be sustained. To address issues associated with re-entry hypersonic vehicles, I will propose a concept for a low-cost hypersonic flight experiment known as HEDGE.

Although the goal of this project is to demonstrate low-cost hypersonic flight, it is important to understand the full implications of research such as this and how it can be used for efforts that are not intended for this project. There are various political, social and conceptual factors that can influence the development and use of technology. For example, after the second world war, Robert Oppenheimer, the physicist responsible for developing the atomic bomb, urged for nuclear weapons to be controlled (Leitenberg, 1977, p.131). During the course of several years, human and non-human factors such as political figures, political and social pressure, and war made it difficult to control nuclear weapon development. Within five years of discovering the Soviet Union had tested an atomic bomb, the United States developed and tested a hydrogen bomb; hydrogen bombs have the ability to injure or kill between "100 and 1,000 times more people than an atomic bomb" (Chan, 2017, Why is a hydrogen bomb stronger than an atomic bomb?). Although Oppenheimer is responsible for the atomic bomb, he did not intend for his research to be used for developments like the hydrogen bomb. A lack of understanding the factors that made the nuclear weapon control network unstable can result in the continued exploitation of scientific research for weapon development.

To study hypersonic flight effectively, both the technical and social aspects of the problem must be addressed. Below I outline a technical process for designing a satellite that will alter its shape in space to re-enter as a hypersonic flight vehicle. I also apply Actor-Network Theory to the control of nuclear arms after World War II to analyze how human and non-human actors ultimately influenced the development of nuclear weapons.

Technical Proposal

In 2019, the spacecraft design course at the University of Virginia launched a CubeSat, Libertas, to obtain measurements of the properties of the Earth's atmosphere (Goyne, 2022, slide 45). A CubeSat is a smaller satellite that uses a standard size and form factor (Mabrouk, 2017, What are CubeSats?). To obtain these measurements, the craft was required to stay in orbit for a significant period of time, and as a result, it was designed as a strong metal structure with solar panels to provide continuous power to the hardware on board, as shown in figure 1. The Libertas CubeSat remained in low-earth orbit for 1 year before it re-entered and burned up in the atmosphere. Satellites that do not re-enter contribute to the space junk orbiting Earth; the more objects left in orbit, the higher the probability of collisions between objects (O'Callaghan, n.d.,What risks does space junk pose to space exploration?). The next mission that addresses this issue is HEDGE: Hypersonic Re-Entry Deployable Glider Experiment.

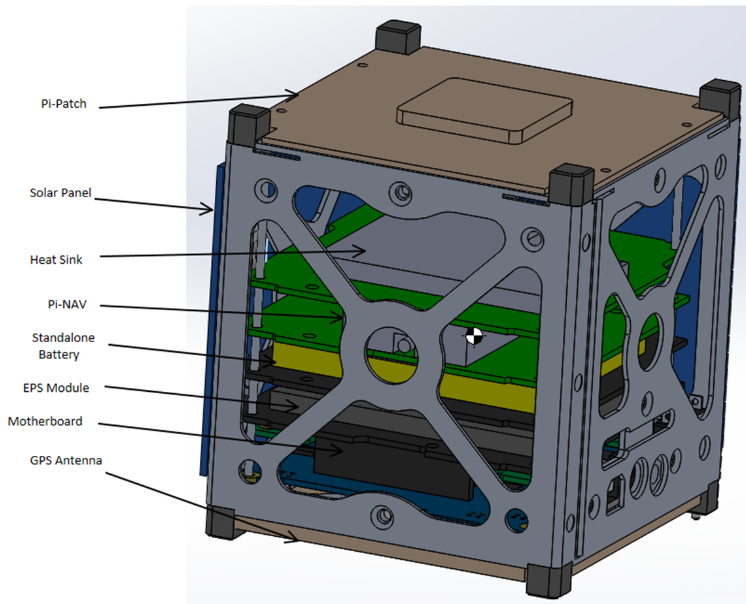

Figure 1: Structure of Libertas CubeSat

The primary goal of this mission is to transmit data about re-entry conditions before burning up in the atmosphere (Angeliotti et al., 2022, p.4). After natural orbit decay, HEDGE will re-enter the atmosphere at hypersonic velocity and send telemetry to the ground. If the vehicle fails to burn up on re-entry, it could land anywhere, possibly hurting civilians. The advantage of this mission is that since the craft is not staying in orbit for a significant period of time and is burning up on re-entry, it will not be contributing to the space junk or the waste on the ground.

A Structures and Integration (S&I) team ensures the construction of the craft is feasible and that the final design will be well integrated with the launch vehicle (Caldwell, 2021a; 2021b). The S&I team for this project will also focus on the structural design of the craft for aerodynamic stability and material selection, addressing the balance between having the craft survive long enough to collect data and burning up in the atmosphere.

Our team developed a series of methods to ensure that the structure meets the design goals. An approach we are taking is to delegate specific members for inter-team communication. Our team must work with the power, thermal, and environment team to select materials that will allow our vehicle to endure re-entry while preserving the viability of the hardware onboard. It is also critical that our team communicates with the Attitude Determination and Control System (ADACS) team to ensure the vehicle is oriented in the proper direction on re-entry, and with the Communications and Avionics team to determine the arrangement of hardware on the vehicle, as shown in figure 2. It is important that all necessary hardware be on the vehicle despite the size restriction for CubeSats (Loff, 2015, paragraph 1). To accomplish this goal, team members will be assigned as designated liaisons to the other subsystem teams.

Another approach that our team has taken on is to use finite element analysis (FEA) software and computational fluid dynamics (CFD) software to verify the structure proposed by the previous year's team, as shown in figure 3. This is critical for reducing risk during spacecraft development (Blandino et al., 2018, Introduction). We will also be using Ansys Granta software to determine which materials are best for our design, taking into consideration cost, strength, temperature resistance, machinability, and commercial availability.

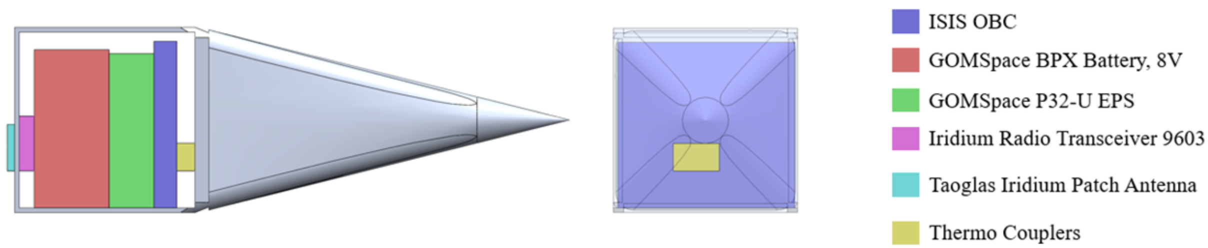

Figure 2: Approximate volume distribution of HEDGE components

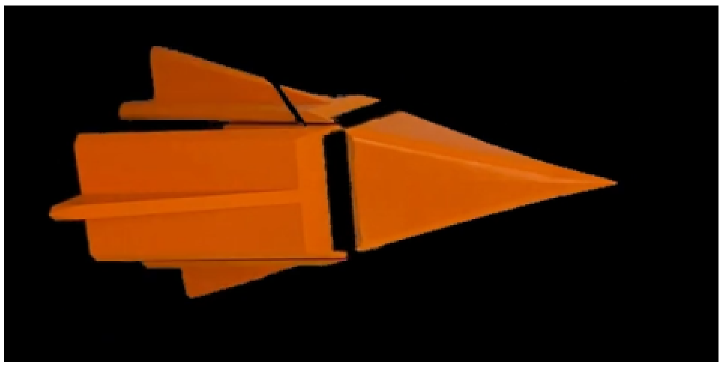

Figure 3: Mockup of HEDGE fins deployed in re-entry configuration

In the design and construction of the HEDGE spacecraft, the group will have access to the UVA Engineering Rapid Prototyping Lab and Mechanical Engineering Machine Shop, which will allow for quick and inexpensive fitment testing and design reviews. We will also have access to UVA Engineering Faculty, including our technical advisor Prof. Chris Goyne, among other subject matter experts (SME) who have experience in mission planning, structural analysis, and materials design.

The deliverable for the Fall semester will be a preliminary design review. In the Spring semester, we will present a critical design review and develop a proposal to industry for the funding to build and launch the spacecraft.

STS Proposal

In the years following the second world war, Oppenheimer attempted to control the production of nuclear arms. In 1946, the Baruch plan was implemented with the primary goal to prohibit further development of nuclear weapons (Leitenberg, 1977, p.130). Since the US was the only country to have nuclear arms, the administration was comfortable with this decision. In 1949, the US discovered that the Soviet Union had successfully tested an atomic device (Richelson, 1977, p.222). Fear rose when the US entered the Korean War in 1950 and realized it did not have the capacity to face the Soviet threat (Ojserkis, 2003, p. 89-90). Although Oppenheimer sought to control nuclear weapon development, this goal gradually became harder to accomplish. Atomic research began expanding soon after the Baruch plan was put into effect, and in 1952, the US developed and tested the world's first hydrogen bomb (Galison and Bernstein, 1989, p.328).

The failure of nuclear arms control after World War II is often attributed to the atomic bomb tested by the Soviets and the initial setbacks faced by the United States during the Korean War. While these factors were pivotal in the failure of this project, this fails to account for the mounting political pressure to continue atomic weapon development, the social pressure to prove that the United States has the best military technology, and the eventual withdrawal of the Baruch plan (Galison and Bernstein, 1989, p.273;Leitenberg, 1977, p.131). As an example, when Robert Oppenheimer criticized the Air Force's emphasis on nuclear weapons and urged less dependence on this technology, Thomas Finletter, the Air Force Secretary, and other top Air Force officials became suspicious of Oppenheimer's motives. That same year, Oppenheimer failed to be reappointed to the General Advisory Committee of the Atomic Energy Commission (Galison and Bernstein, 1989, p.326). The Atomic Energy Commission was established to control the military and civilian use of atomic weapons; thus, when Oppenheimer emphasized the use of tactical nuclear weapons, such as short range missiles, over strategic nuclear weapons, such as the atomic bomb, many political figures saw him as a barrier to the development of the hydrogen bomb. If we attribute this failure only to the atomic bomb tested by the Soviets and the setbacks during the Korean war, then we will fail to gain a full understanding of how other conceptual and social actors can influence weapon development, which can allow us to be more susceptible to future weapon control failures, despite the efforts of human actors to curb their development.

I will argue that the failure to control nuclear arms after the second world war can not only be attributed to the atomic bomb tested by the Soviets and the initial setbacks during the Korean War, but it was also a product of the political pressure to continue atomic weapon development, the social pressure to prove that the United States military technology is superior, and the withdrawal of the Baruch plan. The way in which these factors influenced atomic weapon development can be described by Actor-Network Theory. Actor-Network Theory describes the relationship between technology and society through the use of human and non-human actors recruited by a network builder to accomplish a specific goal. The network builder recruits actors to join the network by aligning the interests of the actors to serve those of the network; this is a process known as translation (Cressman, 2009, p.3). I will describe the process by which the nuclear arms control network was unstable to gain an understanding of the human and non-human actors that can amplify weapon development. To support my argument, I will analyze historical accounts from human actors in this network and utilize evidence from press releases, and documents from the Atomic Energy Commission.

Conclusion

The deliverable for the technical problem discussed in this paper will be a preliminary design review, a critical design review and a proposal to the industry for a cubesat that will transform into a hypersonic flight vehicle. The STS research paper will strive to analyze how the instability of the nuclear arms control network led to the development of the hydrogen bomb. I will accomplish this by applying Actor-Network theory to characterize how relevant human and non-human actors influence the development of technology. The combined results of this technical report will propose a design for a hypersonic flight vehicle and highlight the means by which the attempt to control nuclear weapon development failed to address the concerns with exploiting scientific research for weapon development from a socio-technical lens.

Word Count: 1870

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