HEDGE: Hypersonic reEntry Deployable Glider Experiment
(Technical Project)
Evaluating the Impact of the Iron Dome on Palestinian Civilians
(STS Project)

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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

As an aerospace engineer who may one day develop weapons, I am highly interested in the ethical dilemmas which surround military technology. When missile defense systems (any of many various technologies which target and destroy incoming missiles) were first described to me, they seemed the perfect example of a military technology that protected without doing harm, since ideally they would only strike unmanned weapons. However, as I considered them further, I realized that even when functioning perfectly, such defense systems are rife with externalities. I am interested in exploring these through the ethical framework of consequentialism, which "asserts that the morally right action is the one that has the best outcome or that results in the most good," (Shaw, 2014).

The Science, Technology, and Society portion of this thesis will focus on the effects of the Iron Dome, the Israeli Defense Force's advanced air defense system, on Palestinian civilians. A number of organizations have targeted both Israeli military installations and Israeli civilians with rockets and mortar fire over the nearly eighty years of the nation's existence, the most notable being Hamas and its 'Qassam' rockets. The Iron Dome is Israel's response, an incredibly complex technology which includes not only rockets to intercept incoming missiles but also the radars to detect them and the computers to process the necessary information. I have found large volumes of literature discussing the merits of the Iron Dome in regards to the IDF or Israeli civilians, but relatively little considering its effects on Palestinians. My research question is therefore: "What are the direct and indirect impacts of the Iron Dome on the lives of Palestinian civilians?"

The technical portion of this thesis will focus on our development of HEDGE, the Hypersonic reEntry Deployable Glider Experiment. Our goal is to determine if HEDGE, a 3U

CubeSat, can successfully perform hypersonic materials testing during reentry for a cheaper price than standard industry practices (Goyne, 2023). Though the Iron Dome does not at present make use of any hypersonic technology, similar technologies are likely to in the future. If successful, the experimental data from such experiments could be used for the development of offensive and defensive missiles alike. The United States Department of Defense is currently "working in collaboration with industry, government national laboratories, and academia to field hypersonic warfighting capability" out of a desire to match other major powers, namely Russia and China (Navy, 2022). I would like to have a broader idea of the implications of the technology I help develop.

Technical Project

Problem

Over the past 100 years, hundreds of aerospace endeavors and missions have occurred despite the immense financial barrier. Cost reduction has been a key focus of industry, since the cheapest large-scale ventures range from tens to hundreds of millions of USD per launch. To combat the monetary strain, the University of Virginia along with many other entities are engineering small-scale satellite projects (< 1 cubic meter) known as Cubesats. Virginia's Cubesat aims to explore the presently accelerating field of hypersonic travel, which pertains to vehicles reaching upwards of 5 times the speed of sound. The efforts of mechanical, aerospace, software, and electrical engineers are combined with Cubesat technology to produce HEDGE, the Hypersonic ReEntry Deployable Glider Experiment. Expenses are further reduced by constructing the glider using 3 standard unit components with equivalent dimensions (10 cm x 10 cm x 30 cm). The satellite will have deployable fins allowing it to change its geometry after release. This allows for the vehicle to become aerodynamically stable as well as enabling data collection related to mission objectives. Through measuring pressure, temperature, and various additional parameters, gathered information can be utilized to better understand hypersonic flight. Ultimately, the vehicle will conclude its mission by burning up upon atmospheric reentry.

Significance

Attitude determination and control systems (ADACS) use launch specifics and sensor data to approximate vehicle location, orientation, and path. This is executed through utilization of hardware and digital components both on the craft and the ground. In most cases, this is executed through various testing and estimates in software prior to launch, with a combination of physical components and onboard software once for in-orbit calculations. For the purposes of HEDGE, this provides information on the behavior of air molecules under hypersonic conditions, orbital performance, and general atmospheric conditions in low earth orbit (LEO). The passive control systems will allow for remote observation of the spacecraft's behavior and orientation, as well as modeling orbital predictions.

HEDGE originated as an experiment to test the feasibility of hypersonic travel at the reduced scale of Cubesats. Limitations on system requirements, budget, and physical geometry increase the number of obstacles faced. The University of Virginia approaches these challenges by granting students hands-on experience in their areas of interest. The work of this capstone project is divided among subteams specialized to certain technologies required by the mission. Program Management, Communications, Power/Thermal/Environment, Software and Avionics, Structures & Integration, and ADACS teams all contribute to the success of the mission objectives.

Objectives

As a collective, the objective of the HEDGE team is to design and fabricate a low budget hypersonic space vehicle with the mission of entering into 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 working 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 small 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 be in charge of after launch as well. This will mainly entail collection of real time attitude determination using information relayed from pressure sensors on the spacecraft as well as GPS and the onboard computer.

Overall, the objectives of the ADACS and orbits team will be crucial ensuring mission success, and several resources and strategies will be utilized in the process.

Approach & Methodology

During reentry, attitude will be determined relative to the craft's direction of motion, 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. Our team will need to dedicate some time to ensuring that these pressure taps and the transducers inside them are well-positioned to collect these data. This will involve CFD analysis of the flow properties inside the taps and consultation of the literature on the pressure transducers themselves.

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.

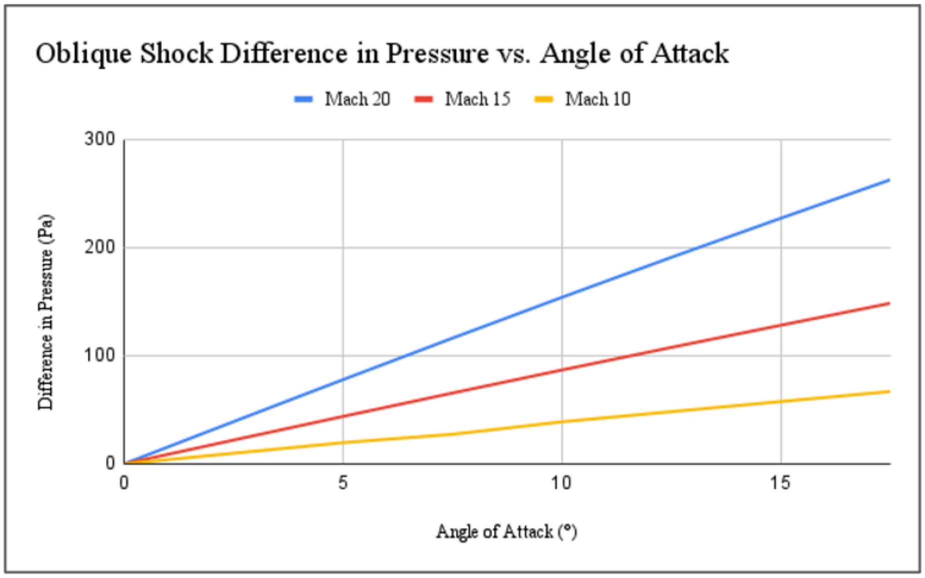

Figure 1: Difference in pressure on opposite sides of the craft as a function of angle of attack and mach number (HEDGE Conceptual Design Review, 2022)

For the purposes of HEDGE, attitude control is limited to passive measures in order to save on cost. Computational Fluid Dynamics simulations will be run on the design of 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 year's class employed a MATLAB script to predict the rate of decay of HEDGE's orbit during reentry. However, now that the project is progressing towards a functioning prototype, greater detail is necessary. Analytical Graphics, Inc.'s System Tool Kit (STK) will therefore be used to study HEDGE's trajectory during orbit and reentry. ADACS aims to model the craft's orbit and reentry as a function of Mach number and time. Results from the CFD analyses will allow STK to better model the effects of drag on the craft. This will yield an estimate as to the Cubesat's orbital lifetime, which should be roughly a week as directed by mission objectives. Given sufficient time, we are looking into the possibility of performing a dynamic stability analysis.

Outlook

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 in the physical construction of the official and final CubeSat product. This goal requires a complete integration of the work of every subteam including the ADACS & Orbits team. The m

The goal for the team is to build upon the work of previous classes while also ensuring that subsystem level requirements for the ADACS & Orbits team will be fulfilled when it comes time for the official HEDGE mission. The stability of HEDGE inside and outside the atmosphere is a key factor in the success of the mission and it is the main focus of the ADACS & Orbits team. Therefore, the ADACS & Orbits team will be looking to complete four main objectives this year. We will run simulations of the orbit of HEDGE using CFD and STK. There are three pieces of information we will be looking to find using these simulations. The simulations will provide vital information on orbital timeframe, vehicle stability inside and outside the atmosphere, and predicted trajectory for re-entry. The final objective of the team is to implement the FADS system into the prototype successfully come spring time. As previously mentioned, this will give stability data of the active HEDGE mission.

STS Project

For my STS project, I intend to do a deep dive into the Iron Dome. This will entail some research into the technology itself (which is fascinating to me, as an engineer), but I will primarily be focused on externalities, i.e. its effects on civilians, primarily palestinian civilians. This will be a challenge, as most of the existing literature (at least in regards to the Iron Dome in particular) seems focused on Israeli civilians, but it does have the upside that my work will hopefully be relatively novel.

My primary social group will be Palestinian civilians. I will secondarily be concerned with the Israeli Defense Force, and especially its leaders, as their actions influence Palestinian lives. The lives of Israeli civilians are obviously also important, but the wealth of existing literature in that regard (at least in regards to the Iron Dome) makes me feel comfortable sidelining that aspect of the issue. I expect to build my work in the framework of Actor-Network Theory, as I consider the interactions between Palestinian civilians and the IDF as mediated through the Iron Dome. As such, Sisomondo's *An Introduction to Science and Technology Studies* and Latour's *Aramis or The Love of Technology* will be key sources.

My research question is: "What are the direct and indirect impacts of the Iron Dome on the lives of Palestinian civilians?" I believe this is an important question because it is (or should be) a major component of ethical evaluations of the technology, but it is often overlooked. The Iron Dome could save Israeli lives and still be harmful overall if it does enough damage to Palestinians.

My principal method will be a historical and philosophical literature review. *Experiences of Urban Militarism: Spatial Stigma, Ruins, and Everyday Life* (Pasquetti, 2019) will serve as a fantastic model for studying the effect of Israeli military technology and practices on Palestinian civilians, though it does not discuss the Iron Dome in particular.

Richemond-Barak & Feinberg (2016) argue that positions consistent with international law should support autonomous defense systems such as the Iron Dome because they reduce civilian casualties. The primary flaw in this argument, as I see it, is that it does not consider the effect on civilians in other nations. There is always the risk of a malfunction directly causing civilian deaths, but I am also interested in indirect effects. How does the existence of the Iron Dome affect the policies of the Israeli Defense Force and Hamas? Does the sense of security it provides allow the IDF to feel confident in exercising greater brutality without repercussions, or does it reduce the perceived necessity of more violent methods of self defense?

It is worth mentioning that a number of scholars have questioned the effectiveness of the Iron Dome even in serving its intended purpose. Machold's inflammatory 2021 article makes bold claims that its interception rate "might even be as low as zero." In the face of my other sources, I would not seriously consider this claim, but Machold provides a list of other scholars who have similarly questioned the Iron Dome's effectiveness, and I intend to make use of that list. Johannsen (2011) takes a more nuanced position, emphasizing that Qassam rockets (the most frequent ballistic missile employed by Hamas against Israel) are not accurate enough to reliably strike military targets. Instead, they serve as psychological weapons against the Israeli populace by forcing civilians to take shelter and creating an atmosphere of fear. Johannsen argues that this effect cannot be disrupted by any defense system with less than 100% effectiveness (which is, of course, impossible), because civilians will still have to shelter in place and fear for their lives.

In an ideal world, ethnography would also be a valuable method for my research. However, I do not anticipate having many opportunities to interview Palestinian civilians. I certainly won't be able to travel for the sake of my STS project. I do intend, however, to look into any possible internet-based ethnography techniques. I would need to do some reading to determine what ethical review boards would govern that research.

I have several directions in which to explore, which I hope will eventually converge. I intend to read *Aramis* over winter break to improve my understanding of ANT. I need to continue my search for literature from Palestinian perspectives. And I need to look into ethnography methods and how I might conduct surveys or interviews online.

Key Texts

Latour, B. (1996). Aramis or The Love of Technology (C. Porter, Trans.). Harvard University Press. (Original work published 1993)

- ‘Scientifictional’ portrayal of the history and ‘death’ of Aramis, a personal transit technology which was in development in late 20th-century Paris for years before eventually being scrapped
- Serves as a demonstration of the us of Actor-Network theory as a framework

Pasquetti, S. (2019, May 24). Experiences of Urban Militarism: Spatial Stigma, Ruins, and Everyday Life. International Journal of Urban and Regional Research, 43(5), 848-869. https://doi.org/10.1111/1468-2427.12797

- A study of the militarization of Lydda-Lod, an Israeli mixed-town (meaning it has substantial Israeli and Palestinian populations), and how surveillance has impacted how Palestinians think and feel about where they live
- Useful to my project because it provides an example of analyzing the effects of militarization and technology, specifically in regards to the IDF and Palestinian civilians

Richemond-Barak, D., & Feinberg, A. (2016). The irony of the iron dome: intelligent defense systems, law, and security. Harvard National Security Journal, 7(2), 469-525. https://heinonline.org/HOL/Page?handle=hein.journals/harvardnsj7&id=469&collection=journals&index=

- Discusses the Iron Dome from the perspective of international humanitarian law
- Argues that systems like it should be encouraged because they preserve civilian lives, which is the point of international humanitarian law
- Demonstrates how to argue about the ethics of a military technology

Yeini, S. (2022). Iron dome and jus ad bellum proportionality. Harvard National Security Journal, 13(1), 121-157. https://heinonline.org/HOL/Page?collection=journals&handle=hein.journals/harvardnsj13&id=127&men_tab=srchresults

- Argues that the Iron Dome alters our perceptions of proportionality by reducing Israeli casualties
- Argues that “quantitative proportionality” is not a part of any international law, and that the IDF’s actions may be justified if they are in proportion to the actions taken by Hamas, even if the casualties are unbalanced
- Useful to me as an example of legal literature examining international law

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