Thermal, Power and Environment on the Hypersonic Reentry Deployable Glider Experiment (HEDGE)

(Technical Project)

Cost Plus, Regulation and Industry Consolidation in the Defense Sector

(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:

Over the past three decades, the Aerospace & Defense industry has become increasingly consolidated and slow moving. Many Aerospace graduates and students who intern or work for defense contractors find themselves frustrated by the long lead times, bureaucracy and lack of innovation. In 1995, the US government provided funding for the Joint Strike Fighter and a decade later, the F-35 still had yet to fly. Furthermore, a program that was projected to cost $200 billion ballooned to over $400 billion by 2017 (Roblin, 2021). It feels like even as the US pours ever more money into defense technologies the results continue to diminish.

It wasn't always this way. During and following WWII, Lockheed Martin's Skunkworks was famous for pushing the envelope and having lightning-fast development times. The P-80 Shooting Star was built in just 143 days and the U2 spy plane developed in just 9 months (Hudson, 2021). Furthermore, much of the innovation tied to Silicon Valley was associated with defense applications (Wolfe, 2022). Many of our most important civilian technologies came from military research (GPS, microwaves and much more). Unfortunately, today, most of the projects operate on the scale of decades and end up well over budget. Defense contractors struggle to attract and retain top engineering talent. Innovation is increasingly occurring within Fintech or AdTech, consumer facing businesses that are highly profitable, but irrelevant to national security. Part of these difficulties are likely linked to the increased technological complexity of 21st century defense projects, but there is a belief among many investors and engineers in the defense space that the industry needs to change. Ben Rich, the former director of SkunkWorks lamented in his memoir, "In my forty years at Lockheed I worked on twenty-seven different airplanes. Today's young engineer will be lucky to build even one" (Rich, 1996).

There are a few structural reasons that may be partially responsible for how this industry shaped out and are worth investigating. Overregulation, the cost-plus business model and industry consolidation are three likely culprits. As such, this paper will investigate how these factors have influenced the aerospace & defense industry and consider what could change about how business is done in the future. This is particularly pertinent to investigate today with a number of compelling startups attempting to disrupt the space (O'Shaughnessy, 2022).

The technical component of this paper concerns the development of a hypersonic CubeSat (a small satellite, that can be as small as 10x10x10 cm) intended to collect temperature and pressure data in an atmospheric reentry environment. This is useful both for the data itself and as a proof of concept for a relatively cheap method of collecting hypersonic data in the future. Hypersonic speeds refer to those greater than five times the speed of sound (greater than Mach 5). Hypersonic flight is of particular concern for the US government and defense community since current intelligence indicates that both China and Russia are ahead of the US in this area (Ward & McLeary, 2021). The Hypersonic Reentry Deployable Glider Experiment (HEDGE) project will also give hands on experience working on a defense-oriented project to supplement the STS research on the industry referenced above.

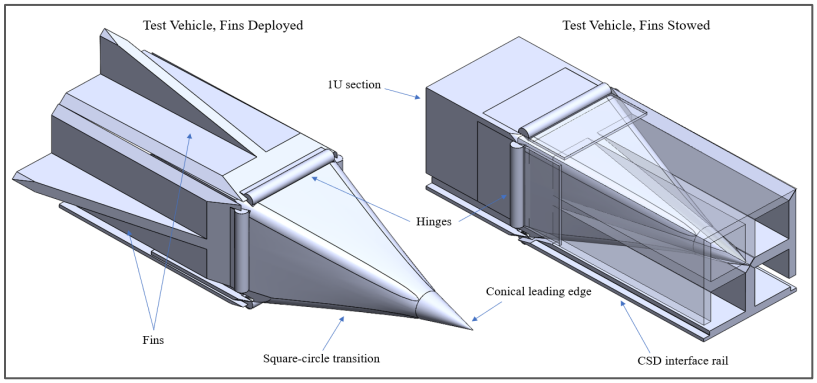
Technical Topic:

HEDGE is an attempt to engage undergraduate students in the field of hypersonics and to display to professionals a significantly cheaper method of carrying out hypersonic research. The current approach to test hypersonic vehicles often requires expensive and complicated high speed wind tunnels (Button, 2022). The HEDGE proposal seeks to undercut the current solution on cost and development time by building a reentry vehicle that can be launched into space on a commercial rocket and reenter the earth's atmosphere, collecting hypersonic data in the process.

In order to avoid unnecessary damage to inhabitants on the ground, the vehicle would be designed to send data to a ground station during flight and burn up upon reentry. There are a number of benefits to this solution beyond the massive cost reduction (current hypersonic experiments cost millions, HEDGE is projected to cost less than $100,000). This solution also engages undergraduate students in a field that is likely to grow and be important to the US government and defense industry. Finally, the high-speed wind tunnels used in hypersonic research often see wait times north of 2 years to use (Tegler, 2020). This is an added benefit of the CubeSat approach: it skips wind tunnel usage altogether.

Figure 1

Hedge Vehicle Concept

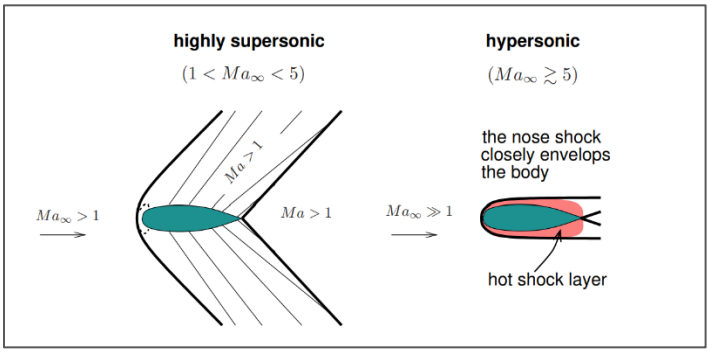


Looking specifically at the thermal, power and environment team on HEDGE, the problem being solved is one of enablement. It is our job to ensure that all subsystems on the HEDGE platform are receiving their power needs, that the spacecraft remains intact, and that HEDGE remains within temperature ranges where systems can function. If HEDGE burns up too quickly upon reentry or if onboard instruments are exposed to conditions outside of acceptable temperature limits it will not be possible to collect meaningful data. On the other hand, if HEDGE does not burn up at all, UVA and professionals involved in the program could be liable for any damage caused by the spacecraft hitting the earth. It is the job of the thermal team to find

the happy medium between these two scenarios. This is especially important given that at hypersonic speeds, the shockwave around a spacecraft will envelop the body and create a hot shock layer that has the potential to damage the fuselage (shown below in Figure 2). This means we must consider thermal effects across the entire spacecraft and not just focus on leading surfaces. Success in this task, coupled with success of the other functional teams, will display HEDGE as a proof of concept for a hypersonic CubeSat and allow for the collection of temperature and pressure data in a hypersonic environment.

Figure 2

Flow pattern around a slender body with increasing Mach number (Urzay, 2020)



STS Topic:

The development of new technology is inherently a societal issue as well as a technological one. It is clear throughout history that government incentives can shape where resources are allocated and how new technologies are developed. Engineers do not exist is a vacuum and are influenced in a profound way by politicians and the public. This is especially important in the defense industry where the primary customer for most products is the US government. Furthermore, regulation in the defense space is rather unique relative to other areas in the economy (Weidenbaum, 1992). There are 2 key unique aspects beyond the broader

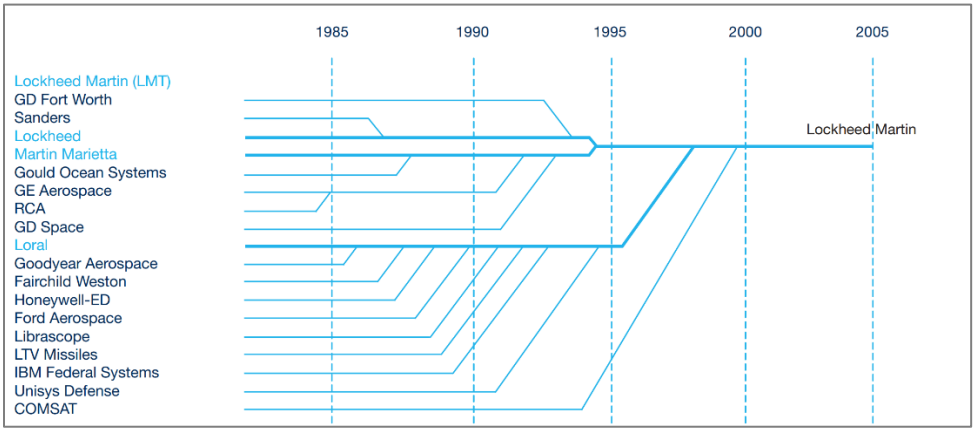
"overregulation" (mentioned in the introduction) worth explaining in the context of the defense industry.

The first is the cost-plus business model. This means that the government prices contracts based on how much it costs to build the product plus an additional amount. Unlike most other industries, this fails to incentivize businesses to cut costs and as a result it is becoming increasingly common for defense projects to end up significantly over budget. Transdigm is a company that supplies many parts to contractors and has repeatedly been brought to court for price gouging but receives little more than a slap on the wrist (Committee on Oversight and Reform, 2022). Contractors are willing to pay the exorbitant price tag because these costs can be passed onto the government. Startups like Anduril and SpaceX are making a name for themselves today in running a non-cost-plus defense business, but it remains to be seen if they will be able to compete with the established players (Anonymous Tegus Client, 2022).

The second is the high degree of consolidation. The vast majority of contracts are awarded to the 5 defense "primes," namely: Lockheed Martin, Northrop Grumman, Boeing, General Dynamics and Raytheon (Macais, 2019). Numerous studies by academics have indicated that as industries become more concentrated among a few major players, prices increase, productivity growth slows and consumer surplus decreases (Schechter, 2019). Incumbents are able to "rest on their laurels" in a way that is not seen in more competitive markets. Figure 3 shows how 18 businesses currently operate under the same banner (Lockheed Martin). The other defense primes were all formed through a similar path.

Figure 3

Acquisitions that created Lockheed Martin 1985 – 2005 (Hooke, n.d.)



Investigating and remedying the faults within the structure of the defense industry is arguably more important than developing any specific technology because it could result in a lasting improvement in innovation. As mentioned previously, the US has fallen behind China and Russia in hypersonics. In order to catch up, not only is technological development necessary, but the incentives need to be put in place so novel technologies built at a reasonable price are rewarded handsomely.

The STS framework that will be used throughout this paper is Actor Network Theory (ANT), a framework typically associated with Michel Callon, Bruno Latour and John Law (Callon, 1999; Latour, 1992; Law, 1992). This is relevant to this topic because not only are humans and existing technology at play, but also the structure of our government and society. ANT analyzes how the interaction between human and non-human actors plays a role into the development of technology. In the defense industry, the humans working in various roles in the DOD and at all levels in private contractors are actors worth investigating. Additionally, the interaction between numerous non-human actors such as existing defense technology, foreign technology, government structure and the legal framework of the industry are particularly interesting to look at.

Research Question and Methods:

The research question being posed by this paper is the following: how has the cost-plus business model, industry consolidation and government regulation influenced the development of Aerospace technologies? This question is important to understand because incentives work (Michalopolous, 2005). If the US wants to fix the many issues coming to light in the defense space, the government needs to be very explicit and thoughtful about what incentives are being created when it regulates the industry and awards contracts.

This question can be analyzed using data from a number of different sources. First off, there are a number of academic papers (often in the field of history and economics) that do deep dives on the history of defense in America (Burns, 1969). In addition to looking at the current structure, new startups attempting to disrupt the defense industry will be researched as examples of what can be done differently. For this, as well as for understanding the current state of the industry, interviews with company executives and government officials as well as books and podcasts can be utilized. Transcripts of many such interviews exist because there is a lot of investor (mainly venture capital) interest at the moment in defense.

In regards to the technical portion, temperature and pressure data will be collected during the flight and sent back to a ground station. However, since the launch will not take place until 2024, in the near-term, data collection is concerned with designing the HEDGE platform. For the thermal team, data on ideal materials will come from tools like the Granta Edu Pack materials science software and looking at industry standards. Additionally, testing and data collection may be done using a kiln or NASA Langley facilities. The end goal of this research is to determine the optimal heat shield material and cooling subsystems that will be onboard HEDGE.

Conclusion:

For better or for worse, developing new defense technologies is crucial for the national security of the US and its allies. Russia's unprovoked invasion of Ukraine is evidence of what can occur when an enemy nation state believes they have a military advantage (Pfifer, 2020). The development of HEDGE will showcase a low-cost method of collecting hypersonic data, an area the United States is currently lacking. Furthermore, it will build the foundation for undergraduate students to participate in hypersonics research in the future. The STS portion of this paper will review the current state of business in the defense industry and suggest how the US Department of Defense can better organize itself to empower low-cost research and development. This may take the form of suggesting changes to existing regulations, revisions to the current contract award process or adjustments to how the DOD allocates funds more broadly.

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