Attitude Determination and Control & Obrits, University of Virginia – HEDGE Cubesat
(Technical Project)

Private Influence Over Public Security: Privatization, Regulation, and National Security in the Aerospace Industry

(STS Project)

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By
Justin Carroll
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Technical Team Members:

Samuel Falls
Isaac Farias
Rishab Gopisetti

On my honor as a university student, I have neither given nor received any unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

ADVISORS

Dr. MC Florelle, Department of Engineering and Society

Prof. Chris Goyne, Department of Mechanical and Aerospace Engineering

Introduction

Rockets, satellites, and spacecraft mark the pinnacle of aerospace engineering feats. The advancement of this technology has ushered the digital era with innovations such as satellite television, GPS, weather tracking, cell phone service, and critical knowledge of how our universe functions. Ukrainian Digital Minister Mykhailo Fedorov recently referred to Elon Musk's *Starlink* satellite program as "...indeed the blood of our entire communication infrastructure now" as Ukraine relies on critical services during wartime (Satariano, 2023). Marvels of human engineering are no easy tasks, and understandably require substantial financial support to fund all necessary aspects of large scale engineering projects. 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, with large-scale ventures ranging from tens to hundreds of millions of USD per launch. Currently, the cheapest ride to space for any entity is SpaceX's Falcon 9 rocket, costing a mere 62 million USD per launch (Jones, 2018), still far less than NASA's space shuttles, which cost an average of $1.6 billion per flight (Chow, 2022). Naturally, many nations have been excluded from the space race since its genesis. Countries often elect not to take on the undertaking and ensuing budget necessary for entry in an already competitive market, strengthening the industries reliance on its handful of major players.

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 occurs as a vehicle reaches 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 Cubesat components with equivalent dimensions (10 cm x 10 cm x 30 cm). Through measuring pressure, temperature, and various additional parameters, gathered information can be utilized to better understand hypersonic flight capabilities. Ultimately, the vehicle will conclude its mission by burning up upon atmospheric reentry.

The incentives of those in the aerospace industry are affected by cost of entry, forced to innovate new technology or methods to become faster, cheaper, more effective, and more capable. In the past, these actors were mostly government entities. Politics surrounding the space industry since the cold war resulted in nations spending billions of dollars creating long standing agencies with numerous international responsibilities and influences. Until 20 years ago, this is how Russia, China, the United States, and others facilitated their programs.

The shift occurred in the early 2000s, as NASA's percentage of federal budget reached its lowest (Rodgers, 2010) and they looked to subsidize private sector development, paving the way for corporations to win contracts and begin conducting government operations faster and more efficiently than ever before. These companies are for-profit with internal motives, and don't face many of the restrictions a governing body might. This allows private companies to grow and innovate on their own accord, all while being responsible for life-altering domestic and foreign services. Exploring how the broader system features provide convenient means for establishing authority (Winner, 2017), my research challenges the quiet nature in which these young companies came into key roles in our country's technological framework. How has the aerospace industry's reliance on the private sector impacted the safety and directions of advanced technologies? The STS topic will focus on the aerospace industry's economic shift placing current technology in political contexts, and the implications it may have on the welfare of our most valuable institutions.

STS Topic

Since the Cold War, nations around the world have rushed to join the space race as satellite technologies have shaped the digital world in which we live. Power dynamics have characterized the space industry since its birth, and industry many see as the mere product of larger politics. From moon landings to international surveillance crafts, the power has always been in the hands of the most technologically advanced. Until the early 2000s, these were the hands of government entities, long standing systems with global responsibilities, considerations, and accountability. Recent history, however, has proven private corporations such as SpaceX, Blue Origin, and Virgin Galactic as more capable alternatives to well-known and trusted agencies like NASA. Few of these corporations have more peculiar financial backings, something news channels often refer to as the “billionaire space race”, a phenomenon observed as the product of the cost of entry.

The United States has trailblazed its path to a significant role in space exploration and technology, yet the federal budget for NASA reached an all time low in 2006 (Roders, 2010). To remedy this, NASA now outsources the manufacturing and facilitation of most major missions, spending 73.5% of its budget on contracts in 2023 (NASA, 2023). There is an apparent placing of an ever increasing workload on private corporations to support and maintain global systems and infrastructure. This can be seen as over 10,000 private space companies (SpaceTech, 2021) have emerged into the global market valued at nearly 300 billion USD in 2020 (Riley, 2021). This shift towards reliance on the private sector has resulted in mission contracts being awarded to the large corporations financially capable of high caliber engineering, who then further outsourcing for specialized tasks. The expansiveness of the industry today makes it difficult to regulate, leaving current methods to misrepresent how worthy of protection our vital technologies are. With only a handful of actors able to produce meaningful work in the field, the values of the safety and trust provided by long standing government agencies has been substituted for the efficiency and innovation of younger companies. These qualities, though desirable in any engineering regard, do not deem such organizations as fit to maintain the precious assets which yield the daily lifestyles enjoyed globally. As put by the Bulletin of Atomic Scientists,

> "There is a huge shift in the type of dominant actor in space and this may result in instability, caused by ripple effects disrupting the existing governance structure… As a result, the fundamental nature of space is changing, and with that change comes disruption as to how the domain has been governed to date. If international governance does not evolve along with the domain, then we run the risk of seeing inadvertent escalations or even conflict between countries as a result" (Samson, 2022).

Research Question & Methods

The question my research aims to investigate is as follows: What influence has the aerospace industry's dependence on the private sector exerted on the safety protocols and developmental trajectories of advanced technologies?

I hope to analyze the patterns observed by questioning the manufacturing, R&D, and use of space systems and the politics associated with such devices. As Langdon Winner writes, "To see the matter solely in terms of cost-cutting, efficiency, or the modernization of equipment is to miss a decisive element in the story" (Winner, 2017). I seek to outline how socioeconomic influences fostered variations and selection (Pinch & Bjiker, 1987) that created vulnerabilities in the infrastructure behind applied science. Anticipated findings should highlight frequently overlooked concerns and may prove beneficial in evolving governance.

I will develop my answer through performing an intensive literature review, applying theoretical frameworks, case studies and data analytics. Researched literature will include existing work on the roles of the private sector, studies related to aerospace safety protocols and security measures, and examining research on the implication of private engagement on the development and direction of advanced technologies. Additionally, I will explore the politics within the technology itself, "ways in which specific features of the design or system provide a convenient means of establishing authority in a given setting" (Winner, 2017). Case studies involving prominent aerospace companies and significant events will be selected, noting the degree of private involvement and inherited risks. Statistics and analytics will be used to discern trends in a rigorous assessment of the relationship between private sector participation, system security, and scientific advancements.

Technical Topic

HEDGE originated as an experiment to test the feasibility of hypersonic travel at the reduced scale of Cubesats. Limitations from system requirements, budget, and physical geometry make small-sat 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.

Attitude determination and control systems (ADACS) use launch specifics and sensor data to approximate vehicle location, orientation, and path. 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.

As a collective, the objective of HEDGE 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.

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. 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.

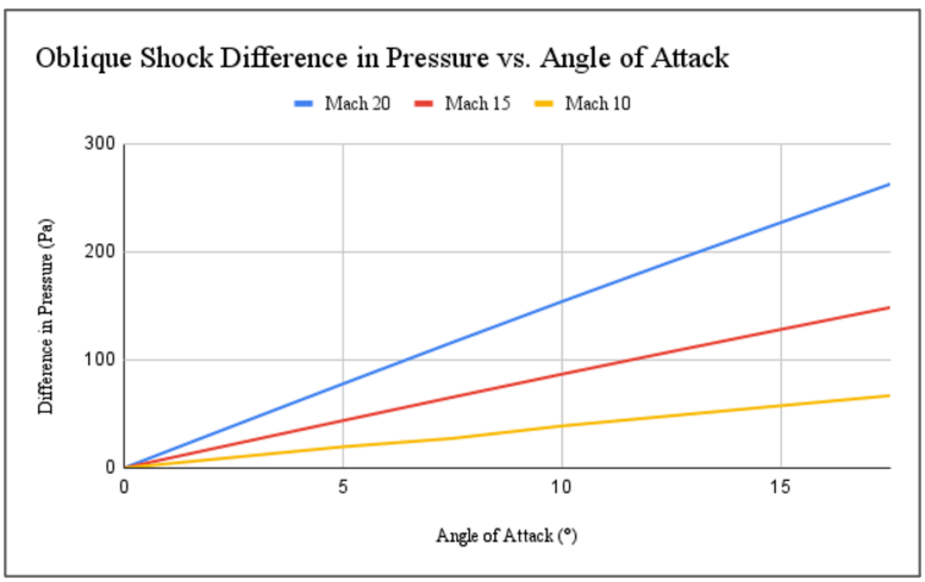

Figure 1: Difference in pressure on opposite sides of the craft as a function of angle of attack and mach number (HEDGE Conceptual Design Review, 2022)

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.

Analytical Graphics, Inc.'s System Tool Kit (STK) will be used to study HEDGE's trajectory during orbit and reentry. ADACS aims to model the craft's orbit as a function of Mach number and time which will be executed in STK. Results from the CFD analyses will allow the software 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.

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. The goal for the subteam is to build upon the work of previous classes while also ensuring that subsystem level requirements for the ADACS & Orbits team will be fulfilled, and to fully implement all components into the final prototype. The ADACS & Orbits team will be looking to achieve four main goals this year. A simulation of the orbit of HEDGE using CFD and STK will provide vital mission information to estimate orbital timeframe (1), ensure vehicle stability inside and outside the atmosphere (2), and predict trajectory for re-entry (3). To ensure that stable flight occurs throughout the mission, the ADACS & Orbit team must implement FADS into the prototype (4) successfully come spring semester.

Conclusion

Aerospace technology maintains a vast range of tools and services that have become essential to life as we know it. The socioeconomic significance held by the space race embodies this, with actors naturally quick to reduce costs in order to get ahead. This paper aims to analyze the implications stemming from an economic shift within industry through a technical and STS topic. The STS topic focuses on utilizing the social construction of artifacts to highlight how recent economic changes have shaped technological developments, as well as applying technological political theory to comprehensively understand the significance and power inherent to them. Through this, I address the ways in which the nature of the field has transformed leaving behind susceptibility and instability. The technical project explores another means of cost reduction, testing the feasibility of smallsat alternatives. The results of a successful operation may hold value in improving Cubesat technology, expanding university space participation, and increasing small satellite use and capability.

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