Hypersonic ReEntry Deployable Glider Experiment (HEDGE)
(Technical Project)

The Social and Commercial Evolution of Global Positioning System (GPS) Technology
(STS Project)

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By
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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

Satellite technology has developed at a steady rate since the first instance of satellite usage in the 1950's. The Soviet Union launched the first low-Earth orbit satellite, Sputnik 1, on October 4, 1957. After its launch and entry into service, the developers of Sputnik "realized they could track the satellite by the relative strength of its radio signal" (Kumar & Moore, 2002, p. 59). By a similar methodology, scientists further realized that they could use the satellite to determine the location of a receiver on the ground (Aerospace Corporation, 2019, para. 5). They found that by leveraging this technology, a Global Positioning System (GPS) could be created. These technologies were developed with specific military applications in mind, servicing the military's "need to deliver weapons precisely on target and to [expand] navigation systems" (Sturdevant, 2015, p. 332). The first iterations of GPS, the Naval Navigation Satellite System (TRANSIT) and Project 621B, were commissioned by the United States Navy and Air Force respectively in the early 1960's (GPS World, 2010). TRANSIT was developed to provide positioning fixes for submarines (Danchik, 1984, p. 323), and Project 621B had similar intentions regarding positioning missiles and airplanes ("A brief history," 1995). As GPS has evolved over time, its uses have expanded, which in turn have driven technical development.

Using the sociotechnical framework of diffusion of innovation, my STS project will trace, analyze, and seek to understand GPS's development and how its expanded uses have shaped its evolution. Satellite technologies have further developed into the 21st century. The uses of satellites are numerous, providing results and gathering data in advanced applications in various scientific fields.

My technical project focuses on satellite development in another way. In this project, my team will design and develop a small satellite that acts as a hypersonic glider during reentry into the Earth’s atmosphere in order to gather data and show that a small satellite can complete advanced hypersonic flight research. Hypersonic flight occurs when a vehicle’s speed exceeds five times the speed of sound, subjecting the craft to complex aerodynamic and thermal effects. Aircraft such as ballistic missiles and space capsules fly at hypersonic speeds, so research on vehicles at these speeds is important. This research has been historically very expensive; the Pentagon’s 2023 budget request for hypersonic flight research is $4.7 billion (Sayler, 2022). Hypersonic flight research is expensive because of its advanced materials and systems, as well as its relative novelty compared to other aircraft and weapons systems. This novelty causes high prices because the small scale of manufacturing and testing does not allow for cost benefits. Hypersonic weapons have been cited to cost over $100 million per missile (Bugos, 2021). Since the cost of each hypersonic test is prohibitive, our small satellite research is important for making hypersonic flight research more inexpensive and accessible. Using a small satellite offers significant cost savings by decreasing component and operation costs. If my team is successful, our technical project can make a positive impact on the hypersonic flight industry.

Technical Topic

My group’s technical project is the Hypersonic ReEntry Deployable Glider Experiment (HEDGE). The mission utilizes CubeSat technology to achieve hypersonic flight in low-earth orbit (LEO) for a relatively low cost. CubeSats are standardized small satellites that have existing infrastructure in place for launch services. Using CubeSat technology allows for easy integration into a launch and provides set rules and constraints for satellite design. Conforming to these regulations gives our group the most options for reaching orbit. Our CubeSat will reach LEO by riding along on a rocket space mission. Once released into LEO, the HEDGE craft will deploy fins to transform into a hypersonic vehicle and ensure aerodynamic stability throughout the flight, allowing measurement of data including temperature, attitude, and pressure. The craft will complete its flight by burning up in the atmosphere on reentry.

The purpose of this mission is to determine the practicality of CubeSats in sustained hypersonic flight applications for a relatively low cost. The collection and transmission of flight data is held as a secondary objective but holds great importance to the research conducted in the mission. For this project, the team is divided into subsystems: Program Management, Communications, Software & Avionics, Power/Thermal/Environment, ADACS (my group), and Structures and Integration.

ADACS, or Attitude Determination and Control System, is a system of components used to determine, adjust, and maintain the position of a craft in orbit. Determination and manipulation of attitude throughout flight allows for observation, analysis, and control of the mission. Attitude can be controlled passively through components such as spin-stabilizers or fins, or actively using parts such as thrusters or magnetic torquers (NASA, 2021). The ADACS subsystem oversees what attitude control systems best fit our mission's objectives and budget.

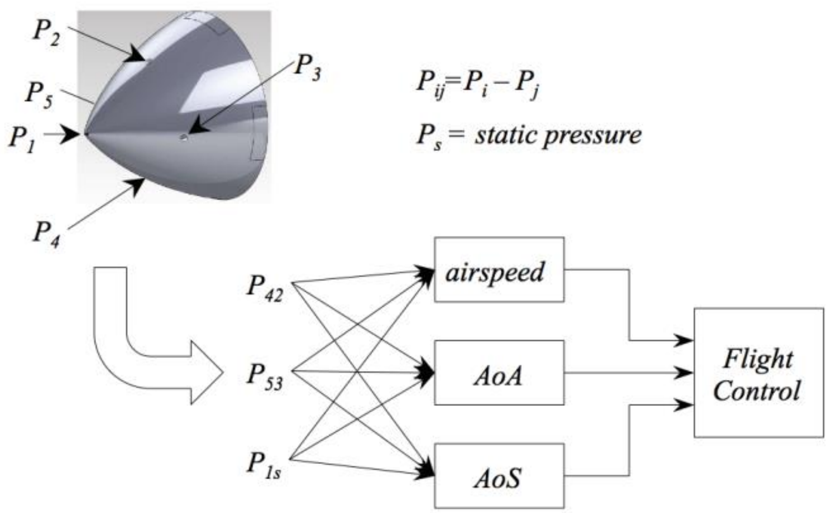
Our first objective is to predict and model the expected orbital path, planning for any potential disruptive forces that would alter the craft's position. Upon launch, our objective expands to performing real-time attitude determination and adjustment and providing consistent ADACS information so that the remaining subsystems can perform their objectives.

My team's approach to ADACS and Orbits is rooted in stability dynamics and pressure sensors. Stability dynamics will ensure that the CubeSat has proper attitude upon reentry. This will require knowledge of the components that will be included in the CubeSat, the way they will be integrated, and how the centers of gravity and pressure will change once the fins are deployed.

My team plans to make use of pressure sensors by implementing a flush air data system (FADS) for attitude determination. FADS is a method of attitude determination commonly used in aircraft that derives important parameters from pressure measurements (Mohan et al., 2018).

Figure 1

Flush Air Data Sensing System Diagram



Note. Depiction of FADS System and Process. From Flush Air Data Sensing for Soaring-Capable UAVs by Langelaan, J. W. & Quindlen, J. F. (p. 7), from *American Institute of Aeronautics and Astronautics*, 2018.

In collaboration with other teams, we will determine whether using a FADS system will be possible. Typically, FADS systems are used at lower altitudes than that of HEDGE at the point of data collection. This is due to the decrease in pressure at higher altitudes, which allows noise disturbances to have a more significant effect on readings (Mohan et al., 2018). When the vehicle is in the lower-atmosphere portion of its reentry, the pressure should be enough to overcome altitude concerns, as the vehicle will be moving at hypersonic speeds and the density of the environment will be increasing during the lower-atmosphere portion of reentry. During the orbital and upper-atmosphere portions of reentry, HEDGE could use a sun sensor for attitude determination. A sun sensor measures the amount of sunlight absorbed on a spacecraft and determines its orientation relative to the sun (Gaebler, 2007). Another option would be to use magnetometers to measure the magnetic field of the Earth and determine the attitude (NASA, 2018). As research is completed, the team will determine the optimal components.

My team's resources include a small operating budget and specialized software. Our allotment of funds could be used to purchase and test attitude determination and control equipment and mechanisms. Prototyping will be essential in validating our systems. Also, spacecraft software will be a useful resource. Access to the Ansys Systems Tool Kit (STK) will be important to orbit determination and prediction. The STK user guide will provide directions for creating and modeling spacecraft (Analytical Graphics Inc., 2022). The advanced capabilities of STK will help us achieve our goals.

The anticipated outcomes of my team are to predict the spacecraft's orbit with STK software, determine what hardware should be used, and to create a design of the subsystem to submit for proposal. Since the launch provider is currently unknown, the orbit determination will make an estimation of the orbit that can be easily changed and used for a specific launch site. The specific hardware that will be used for the ADACS subsystem will depend on the cost of the equipment needed to execute the mission, the space that the spacecraft has for the ADACS system, and the effectiveness of the hardware in the environment in which it will operate. This will culminate with producing a critical design review and a technical paper in the form of a proposal to industry. This research can have an important impact on satellite technology, including possible applications to the Global Positioning System.

STS Topic

The STS portion of this thesis will focus on the development of Global Positioning System (GPS) technology, and how social influences and commercialization shaped its evolution. Interaction with societal factors has greatly shaped the life of GPS, expanding the number of uses of GPS from a small number of specialized military applications to a system that is used by many people around the world for purposes ranging from studying the movements of animals to mobile phone locating operations (Abulude et al., 2015). GPS originally promised great increases in operational efficiency to the military, including enhanced navigational and weapons systems accuracy as well as a passive system emitting no emissions that could be intercepted by opposing forces (McLaughlin, 1997). As a marked separation from an era of many navigation technologies, GPS served as a single common synchronized locating system. The development of an advanced GPS system was revolutionary for the military. Shortly after release into service, the Department of Defense (DoD) started to recognize the usefulness GPS could have to civilians around the world (Sturdevant, 2015).

In order to provide locating access to civilians but provide protection to the US military, GPS was first released to the public with a feature known as Selective Availability, which gave the military more precise signals than commercial users. By 1990, civilian and commercial users had over ten times as many GPS receivers as their military counterparts, and they pushed for even more access to the technology (Sturdevant, 2015). Users found ways to augment the system and navigate around Selective Availability for applications that were not previously imagined. The social and commercial push for increased GPS access and expanded uses resulted in a myriad of technological features and a continuous goal to lower the cost of GPS technology. The eventual removal of Selective Availability in 2000 allowed even more growth of GPS technology and applications (Aerospace Corporation, 2019). Social and commercial factors have become critical drivers for the further development of the technical system.

This project will explore how GPS development occurred between the research, military, and commercial entities, and trace how GPS gained uses over time as it developed. It will track how this technology has expanded from a narrow focus to covering a wide realm of applications across society. To do this, the wealth of new uses will be analyzed alongside a timeline of how GPS technology has developed. Economic analyses and benefits from an extensive research study by the Research Triangle Institute will be used to evaluate benefits in different sectors (O'Connor et al., 2019).

To evaluate and understand this evolution, the theory of diffusion of innovation is critical. This theory establishes a framework for understanding how technological systems are accepted over time and drive social and technical change (Katz et al., 1963). By using this framework, the diffusion of GPS technology from select military use to wide societal use can be traced and understood. In Katz, Levin, and Hamilton's foundational work on this framework (1963), diffusion is characterized by "(1) acceptance, (2) over time, (3) of some specific item-an idea or practice, (4) by individuals, groups or other adopting units, linked (5) to specific channels of communication, (6) to a social structure, and (7) to a given system of values, or culture" (p. 240). By analyzing these seven key components of diffusion, the diffusion of GPS technology can be better understood. This piece also offers examples of diffusion research that could reveal interesting parallels to GPS development. Another foundational scholar of diffusion research is E. M. Rogers. His work, *Diffusion of Innovations* (1983), describes key stages of the innovation development process and provides a model for studying consequences of innovations. Using this research will be helpful in analyzing how GPS has developed and what consequences the development has caused. There are also many factors that contribute to the diffusion of advanced technologies. Factors such as innovativeness, awareness, competition, and resistance to change can affect how technologies are spread and accepted (Askarany, 2009). By analyzing the factors associated with GPS's diffusion, its expansion of use cases can be traced.

Research Question and Methods

The research question of this project will be: how has GPS technology expanded from a focused military application to having numerous uses across society? This question is important for understanding how societal and commercial factors shape the technologies that people use. Answering this question will enhance understanding of technology diffusion and development as well as technology and user relationships by closely studying a specific technology system: GPS. The understanding and learnings drawn from this close research will be able to be applied to other space technologies and possibly other artifacts that have been originally intended for military use but have expanded to serve all civilians. By tracking the diffusion, acceptance, and innovation of GPS technology, lessons can be learned about social and technical relationships.

I will analyze this topic by reviewing and synthesizing previous research done on the topic of GPS and societal influences. This will be done by completing a literature review of a breadth of sources relating to the topic, as well as on the sociotechnical frameworks that have been discussed. To encapsulate the full scope of GPS development, a few different types of sources will be analyzed and integrated. First, military resources describing the initial development of GPS technology will be important in seeing the initial purposes for GPS without a backward-looking eye on history. Additionally, broad overarching histories from various sources will be used to see the technical and social developments of GPS technology. These histories will include sources from longstanding GPS companies that give unique perspectives relating to their involvement with GPS. Independent research papers will also be used to gather economic, social, and other data to assess the diffusion, development, and impact of the technology. Using these resources, my project will be able to thoroughly assess my research question.

Conclusion

Since the 1950's, satellite technologies have been used for many distinct and creative purposes. The Global Positioning System (GPS) was one of the first major satellite developments and has evolved to have a large impact on society today. This satellite technology has progressed throughout its lifetime from having very specific military uses to being implemented by civilians around the world in numerous ways. By tracing GPS's development through the framework of diffusion of innovation, knowledge and understanding of sociotechnical relationships will be found. My research will show the importance and impact of society and commercialization on GPS technology. Along with my technical research project, the innovation and expansion of satellite uses will be tracked and better understood. This research will shed important light on the far-reaching impact sociotechnical advancement can have, specifically in the Aerospace Engineering field.

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