Hypersonic ReEntry Deployable Glider Experiment (HEDGE)

The Increasing Critical Role of Satellites

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Aerospace Engineering

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October 27, 2022

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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

On July 24, 1996, the first ever recorded collision of space debris and functional space equipment occurred between the French satellite, Cerise, and a piece from the upper stage of the European Rocket, Ariane, which launched a decade earlier. (Gregersen, 2014). Although Cerise continued to function, this served as an omen for future events to come. This event marked the beginning of the Kessler Syndrome, or the accumulation of space debris so dense that low earth orbit (LEO) will eventually be rendered unusable for satellites (Kessler et al., 2010). Subsequent events have led to space agencies enforcing regulations against the accumulation of space debris, as the critical role of satellite technology has become too important to forsake their operational environment.

Communications across the entire world at even the most remote locations can only be possible due to the developments of satellite technology, placing a greater reliance on instant communication. With this influx of demand, then comes the need for the protection of assets in space, creating the U.S. Space Force. These are a few ways that satellites have changed society in recent decades.

Satellite development and regulatory bodies are being affected by the growing debris field as highlighted by the Kessler Syndrome. This is an example of technological momentum; society first determines the trajectory of the development of the technology, and over time as the technology grows and gains momentum, it begins to affect the trajectory of society (Johnson et al., 2021). If we continue to blindly build and test satellites, we fail to account for the lasting impacts it may have on the groups that rely, develop, and regulate them. For my technical project, I will be analyzing the effects of the LEO space environment on a hypersonic glide vehicle (HGV). A CubeSat, or miniature satellite with a volume of 10 cm, will handle the data transmission from space (Canadian Space Agency, 2021). An HGV exits the atmosphere and reenters at a Mach number greater than 5, or 5 times the speed of sound (Zastrow, 2023). My specific task will be mitigating the effects of the LEO environment, which, if not considered, will destroy the satellite. To address the social implications of developing this technology and not accounting for the hazardous environment created over the years, I will use technological momentum to examine the effects of the Kessler Syndrome on satellite development and regulation. Understanding the importance of mitigating debris by accounting for technological momentum through development according to regulation will ensure proper protection for its environment and prevent the acceleration of the Kessler Syndrome.

Technical Project Proposal

CubeSats were developed in 1999 by professors at California Polytechnic State University and Stanford University, enabling students to design and execute satellite missions. They're classified by number of units (1U, 2U, or 3U), and a 1U CubeSat has a volume of 10 cm^3 (Government of Canada, 2022). Size limits its operational ability but allows CubeSats to be integrated into the payload of a larger mission (Woellert, 2011). Our capstone, *Hypersonic ReEntry Deployable Glide Experiment* (HEDGE), aims to demonstrate the viability of CubeSats as an affordable platform for conducting hypersonic glider research, using the Iridium network for communications.

A rocket will launch our 3U CubeSat into low earth orbit (LEO). HEDGE will deploy fins after release, morphing into a hypersonic glide vehicle, and live in LEO until naturally deorbiting (Goyne, 2023). To simulate a real mission planning scenario, the capstone is split into various sub-teams: program management; communications; software and avionics; attitude determination; power, thermal, and environment (PTE); structures and integration. Our group has been assigned to PTE.

The power subsystem has the main objective of supplying electrical power to all other subsystems in the CubeSat, and it must produce more power than what is required by the satellite. The thermal subsystem's objective is to tailor the design of HEDGE to the thermal conditions expected throughout the mission. Considerations include thermal protection in both LEO and reentry, and a complete burnup of the CubeSat after necessary data collection. The environment team's objective is to calculate the mechanical loads experienced by the spacecraft during launch and reentry, as well as to determine the potential space debris or radiation HEDGE will encounter based on the timing and location of its launch.

The power team will combine previous work with information from industry to estimate power generation, collaborating with other sub-teams to determine system requirements and optimal products. The thermal team will run tests and simulations to examine previously selected structures and materials. We will use CFD and FEA software to analyze reentry conditions and thermal loads, ensuring that HEDGE can collect data before burnup. The environment team will conduct research to find values needed for load calculations as well as debris and radiation trajectories.

To determine the power budget, we will use the documented hardware specifications for the components and previous calculations. For thermal analysis, we will use Ansys Fluent and Mechanical to carry out CFD and FEA on an existing CAD model of HEDGE. Prior teams identified Niobium Alloys as the best high temperature material and Teflon as the best ablative material for the hypersonic nose cone, and we will work to predict performance. The environment team will use loads and testing parameters found within the NASA Sounding

Rockets User Handbook and the SpaceX's Falcon User Guide to perform structural tests using the resources. Online databases will be used to track orbital debris and radiation.

The primary task facing the power team is to recalculate the power budget and power flow chart with new EnduroSat components. Components must generate and store more power than the maximum power draw (MPD). The final task is configuring a battery pack that will fit in the nose cone to operate the CubeSat when solar panels aren't producing power. The primary goal of the thermal team is to analyze HEDGE performance under a variety of expected conditions. We will review completed CFD analysis, modify the CAD model and CFD parameters to meet current objectives, and run several iterations of CFD and FEA testing. Part of our work will include predicting the reentry burnup time for the final design to minimize uncertainty. The environment team aims to find the mechanical and vibrational loads during launch and reentry and determine any protections against radiation or space debris.

The fall semester of MAE 4690 will conclude with a Technical Interchange Meeting (TIM), where sub-teams will merge work into one Critical Design Review (CDR) and present completed research and future design plans.

STS Project Proposal

In 1978, NASA scientist Donald J. Kessler predicted that by the early 2000's, small debris would exponentially increase the number of debris even without adding more sources of debris (Kessler et al., 2010). The collision between the Cerise satellite and the upper stage of the Ariane marked the beginnings of the Kessler Syndrome. Based on Kessler's prediction and statistical models, this will continue exponentially until LEO is rendered unusable for satellites. Revisiting Kessler's research shows that the debris field has grown faster than originally projected (Kessler et al., 2010). Now, there are about 56,450 tracked objects in orbit with half of them being tracked by the US Space Surveillance Network, and only 4,000 of those objects are operational satellites (*About Space Debris*, n.d.). The sizes of these objects vary from 5-10 cm, and although these sizes may seem small, objects within this size range travelling between 5-10 km/s have enough kinetic energy to obliterate satellites (Office of the Inspector General, 2021).

As a response to the Kessler Syndrome, space agencies have started to implement policies to prevent the Kessler Syndrome from reaching its full effect. Companies, such as SpaceX, have changed their practices to ensure proper satellite end-of-life disposal. SpaceX has engineered their Star Link satellites to orient themselves in such a way so that the satellite reenters the atmosphere and burns up within 4 weeks of their shut down (SpaceX, 2022). The Inter-Agency Space Debris Coordination Committee (IADC) was founded to exchange information about space debris as well as identify ways to mitigate its accumulation across international space agencies (IADC, 2019). In 2001, based on NASA's guidelines, the United States Government Orbital Debris Mitigation Standard Practices (ODMSP) was established to mitigate the creation of new orbital debris, and their policies are enforced by government bodies such as the U.S. Department of Transportation, U.S. Department of Commerce, and the FCC which then influence space and launch vehicle development in the commercial sector (Office of the Inspector General, 2021).

In the past century, the Space Age launched an age of unprecedented technological developments in rocketry and satellites. Satellites were originally created as experimental technology in the 1950s as a display of power and to map the surface of the earth (*History of Satellites – timeline, 2013*). Once different countries achieved independent launch capability, the satellite soon evolved to perform many different functions. For example, NASA launched the TIROS-1 satellite to monitor Earth's weather patterns (*History of Satellites – timeline, 2013)*.

This program accelerated to see use in research and military applications. People use the meteorological data from these satellites to know what the weather is like every day. Power dynamics in the military have been shifted to protect assets in space. The U.S. Space Force was created with the vision to "Provide freedom of operation for the United States in, from, and to Space," and now has 14,000 active-duty military personnel (United States Space Force, n.d.). Satellites have become more than just an experimental technology, and their advancements have grown to be a necessity in the modern world. To meet these demands, the LEO environment has become congested. Failure to address the debris problem has led to the increasing importance to address the Kessler Syndrome, and in turn, has affected future satellite design and government regulation.

Currently, the satellite is used as a cornerstone in modern life for communications and as a technology that has brought upon further development. Although it appears that the satellite has always functioned as a vessel for innovation and on-demand communication, it was initially designed to map the surface of the earth and to display technological superiority between countries. The growth of this technology beyond its original purposes has led to its demand and reliance on the groups that need it and develop it. Failing to recognize the rapid growth of satellite technology will lead to us not realizing the influence it has placed on space agencies, governments, and satellite manufacturers from the congestion of low earth orbit as demonstrated by the Kessler Syndrome. Although the satellite was designed initially as a display of power, it has evolved to become an important part of everyday communications and has forced governments and manufacturers to account for the congestion in the LEO environment. The Kessler Syndrome is an effect of technological momentum; multiple stakeholders have diversified and expanded the system to the point that it has influenced the groups that design and regulate it (Johnson et al., 2021). To support my analysis, I will utilize official documents from NASA and other agencies addressing the Kessler Syndrome, Donald Kessler's analysis on the continuing growth of debris fields, and finally, I will use the U.S. Space Force's military doctrine as well as recruiting reports to show the shift of power dynamics in the U.S. military due to the increasing importance of protecting space assets.

Conclusion

For my technical project, I will be accounting for the effects of the space environment at Low Earth Orbit on an HGV to support a greater mission. the previous Power, Thermal, and Environment sub team did not account for the harsh space environment impacting the mission. For the STS project, I will be drawing on the framework of technological momentum to analyze how the evolution of this technology has led to growing concerns of the Kessler Syndrome and forced companies and government bodies to act. I hope to see how space regulations affect the design and launch process of the glide body as the mission nears its execution. I also hope to see what considerations must be taken to ensure that it doesn't contribute to the growing field of debris. Launching and communicating with a hypersonic glide body while designing it to withstand a harsher space environment that did not exist before shows that Technological Momentum was not accounted for in the original intent of the satellite.

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