Design of a Hypersonic ReEntry Deployable Glider Experiment (HEDGE)

Analysis of Artemis 1 Cube Satellite Failures

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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

The realm of CubeSats, small and versatile satellites, has promised to revolutionize space exploration and scientific research over the past few decades. With their compact size, affordability, and adaptability, CubeSats have opened doors to new frontiers in space technology and scientific discovery. However, the recent setbacks in the Artemis 1 mission, NASA's ambitious lunar exploration program, have underscored a multifaceted sociotechnical problem that presents both a challenge and an opportunity for the future of CubeSat design. The cornerstone of NASA's Artemis program, which aims to send humans back to the Moon, Artemis 1, experienced a number of unanticipated CubeSat payload failures. These tiny satellites had a number of problems, including communication failures and deployment errors, which made them essential for scientific data collection and lunar reconnaissance. The main objectives of the Artemis program have been hampered by these failures, which have caused significant setbacks in the mission's data collection and communication infrastructure.

The challenges posed by the Artemis 1 CubeSat failures extend beyond developmental mistakes; they delve into a complex sociotechnical arena that encompasses a range of interconnected issues. On one hand, there is the swift evolution of CubeSat technology, facilitating smaller, more affordable, and diverse missions while presenting challenges related to reliability and mission assurance. On the other hand, the collaboration between government agencies, private space companies, and research institutions in CubeSat development adds a layer of complexity, with differences in goals, priorities, and communication protocols. This socio technical issue emphasizes the need for a thorough grasp of CubeSat design and deployment, combining technical know-how, efficient project management, and the alignment of interests among diverse stakeholders. In order to address the sociopolitical nuances that affect the design and operation of CubeSats, in addition to the technical shortcomings, a comprehensive approach is necessary.

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 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 aforementioned 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 (Figure 1).

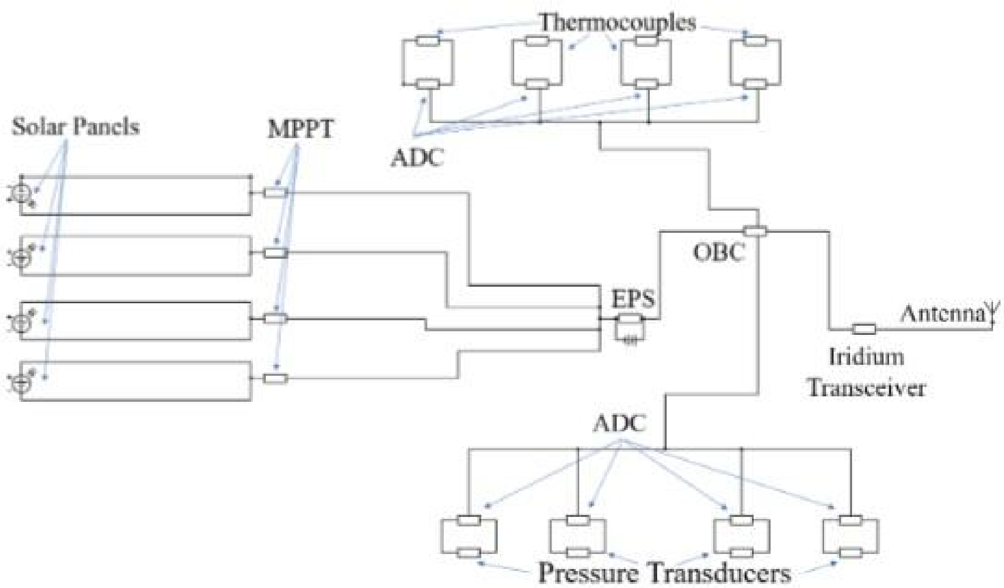

Fig. 1. HEDGE Power subsystem circuit diagram (Source: 2022-2023 *HEDGE* Thesis)

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

The Artemis 1 CubeSat mission, initially intended to deploy 10 CubeSats into orbit for various research purposes, ultimately faced significant challenges which led to its failure. Some analysts attribute the project's failure to a stuck valve in one CubeSat's propulsion system, a hydrogen leak during fueling, and partial battery drainage after the CubeSats had been secured to the rocket (Aubert, 2023). While acknowledging the importance of these actors, this view overlooks the role played by government agencies, private company funding, and environmental conditions that led to the project's failure. If we attribute the project's failure solely to the hardware failures, we have an incomplete narrative. It does not account for the range of factors that were integral to the project's downfall. Drawing on Actor-Network Theory (ANT), I argue that the failure of the Artemis 1 CubeSat project was not solely the result of hardware failures. Instead, these actors in conjunction with human actors contributed substantially to the network's failure. The examination of the roles and interconnections among these actors is essential for a comprehensive understanding of the network dynamics that substantially contributed to the project's downfall. ANT studies the activity of network builders who construct heterogeneous networks to solve a problem or accomplish a goal (Laugelli, 2023). In the context of the Artemis 1 CubeSat failure, ANT allows us to examine the project as a network of interconnected actors, both human and non-human. To support my argument, I will analyze evidence from *Small-Satellite Mission Failure Rates* and *Multiple Artemis 1 CubeSats Missions End in Failure* which provides information about the interactions and relationships among the various actors involved in the Artemis 1 CubeSat project.

Within the framework of CubeSat development, this idea acknowledges that success is intricately linked to social, political, economic, and regulatory factors rather than being only a result of engineering and scientific proficiency. A key role in the development of CubeSats is played by universities and research facilities. They act as centers of knowledge, offering the scholarly and scientific know-how required for CubeSat design and construction. They also help with knowledge transfer by introducing students to space technology through educational activities. Government agencies like the European Space Agency (ESA) and NASA are essential to the development of CubeSats. They offer launch possibilities, finance, and regulatory monitoring. Moreover, they frequently determine the strategic course for space exploration, which may have an impact on the goals of CubeSat missions. The involvement of private companies in CubeSat initiatives has grown. These businesses might provide funding, technological know-how, and launch assistance. They might upend established space exploration paradigms and bring fresh ideas to the field.

Non-human players that contribute to the network are the CubeSats' technological systems and components. These consist of power supplies, sensors, propulsion systems, and communication apparatus. Because it presents difficulties like radiation, microgravity, and extremely high temperatures, the space environment itself is a non-human actor. For missions to be successful, these environmental conditions need to be taken into consideration in CubeSat designs. The infrastructure supporting data storage and processing, as well as the networks that transfer data from CubeSats to Earth stations, are non-human entities that are essential to the accomplishment of CubeSat missions.

A strong case study to highlight the importance of social issues in CubeSat development is the recent Artemis 1 program setbacks. There were several obstacles in the way of the Artemis

1 program, which sought to launch a constellation of CubeSats for lunar exploration and scientific study. Key players in the Artemis 1 CubeSat program, including governmental organizations, commercial enterprises, and academic institutions, failed to work together effectively. The sharing of knowledge, assets, and vital information was hampered by this lack of coordination, which led to mission failures. Government agencies placed financial restrictions on the Artemis 1 CubeSat program. Mission failures resulted from inadequate financing, which affected component selection, system redundancy, and quality control.

The setbacks experienced by the Artemis 1 CubeSat program highlight the crucial role that social factors play in CubeSat development. The success of the program was determined by a combination of technical factors, budgetary constraints, collaboration, regulation, and educational goals. My analysis will draw from various sources, including articles that detail the causes of Artemis 1 CubeSat failures to emphasize the necessity of balancing the network's demands while recognizing the interdependence of both human and non-human actors. In developing CubeSats, it also highlights how crucial strong networks, efficient governance, and resource allocation are.

Conclusion

Ultimately, CubeSat development is a complex field that encompasses more than just engineering skill and innovative technology. It's a field in which non-human actors like satellite parts, launch vehicles, legal frameworks, and the space environment work closely with human actors such as educational institutions, governmental organizations, and commercial enterprises. By using the Actor-Network Theory, the complex network supporting CubeSat projects becomes visible. The recent CubeSat failures of Artemis 1 serve as a sobering reminder of the significant influence that social factors can have on the outcomes of CubeSat projects. The failures were caused by a combination of factors, including insufficient cooperation, regulatory obstacles, and financial limitations rather than just technical issues. These lessons highlight how important it is to strike a balance between the technical requirements and the network's complexities, placing a strong emphasis on resource allocation, strong governance, and interdisciplinary cooperation in the development of CubeSats. Insights from Artemis 1 can help us identify areas for improvement in CubeSat development and implement them into HEDGE. Understanding and navigating these social factors will be critical to ensuring CubeSat effectiveness and success in a changing and dynamic space as they continue to shape the future of space exploration.

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