Hypersonic Re-Entry Deployable Glider Experiment (HEDGE)

A More Nimble Satellite

A Thesis Prospectus
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By
Daniel Fisher

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Technical Team Members:
Danielle Ashbahian, Joseph Abbe, Kevin Nguyen, Samuel Kristy, & Spencer Harris

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.

ADVISORS

Kent Wayland, Department of Engineering and Society

Chris Goyne, Department of Mechanical and Aerospace Engineering

General Research Problem: Accessible Orbital Experiments using Small Satellites

How can we leverage small satellites and commercial space launch vehicles to conduct research in orbit?

At the dawn of the space age, access to orbit was thought of as the exclusive domain of massive national efforts such as the Apollo program in the United States. However, the first signs of independent, small satellite (smallsat) development followed very shortly after Sputnik I with OSCAR (Orbiting Satellite Carrying Amateur Radio) 1 in 1961 – a satellite not much larger than a desktop computer built by amateur radio enthusiasts and launched on a Thor rocket as a rideshare (Sweeting, 2018). OSCAR 1 was also notable for being the first private spacecraft ever sent to orbit. Miniaturization of electronics and developments in microprocessors in the 1980s allowed for the construction of more smallsats, like UoSAT-1 in 1981 by University of Surrey amateur radio operators. However, smallsats were still considered to be ”of interest but little real use” at the time.

The past decade has seen a meteoric rise in the amount of smallsats brought to orbit. In 2021, 94% of 1,849 spacecraft launched were smallsats (Halt & Wieger, 2021). Out of that quantity, 1,273 were a part of the Starlink or OneWeb constellations, reflecting the trend of commercial launch providers displacing nations as the primary actors in sending payloads to orbit. To meet the demand for smallsat launches, companies like RocketLab operate launch vehicles specifically catered to smaller payloads as opposed to sharing a ride on a larger rocket with a different primary payload. The culmination of a wider market for taking payloads to space and relatively inexpensive commercial off-the-shelf components (Lal et al., 2017) has opened the field of conducting research in space to a broader population than was previously possible.

Technical Research Problem: Design of a CubeSat Hypersonic Re-entry Vehicle

What structural considerations will be made for a CubeSat that can endure re-entry long enough to collect and transmit data back to us before burning up?

In 2019, the spacecraft design course at the University of Virginia sent a CubeSat, Libertas, to orbit on a ride-share with an Antares rocket provided by Northrop-Grumman. Contact was successfully made with the satellite until a firmware fault in the radio component of the craft made further communication impossible (Goyne, 2022). Despite this, the mission was considered a partial success and served as the first step to conduct research using CubeSats at UVA. The next mission currently being considered is the HEDGE: Hypersonic Re-Entry Deployable Glider Experiment, which is a concept for low-cost hypersonic flight research using the CubeSat form factor.

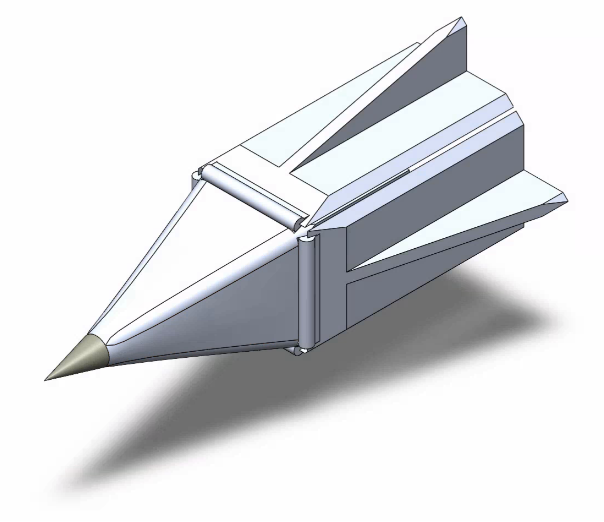

Figure 1: Mockup model of HEDGE in re-entry fin configuration

The primary goal of the mission is to transmit data about re-entry conditions before burning up in the atmosphere (Angelotti et al., 2022). After natural orbit decay, HEDGE will re-enter the atmosphere at hypersonic velocity and send telemetry to the ground. The class of 2023 cohort working on the concept is divided into teams to address different aspects of the mission and craft design. The Structures and Integration team plans the assembly of a spacecraft, ensuring that construction is feasible and that the final design will be able to integrate with the launch vehicle

(Caldwell, 2021). Additional objectives are examining the structural design of the craft for aerodynamic stability and material selection: addressing the balance between having the craft survive long enough to collect meaningful data and being able to burn up in the atmosphere for safety.

Our team has developed a series of methods to ensure that the structure meets the design goals. An important approach that we are taking is to delegate specific members for inter-team communication. Our team must work with the power, thermal and environment team to select materials that will allow our vehicle to endure re-entry while preserving the viability of the hardware onboard. It is also critical that our team communicates with the Attitude Determination and Control System team to ensure the vehicle is oriented in the proper direction on re-entry; if the craft fails to enter nose-first, the re-entry structure will no longer be optimal for hypersonic flight, and our project would not be a success. Our team will also need to be in contact with the communications and avionics team to determine the arrangement of hardware on the vehicle, as shown in Figure 2:

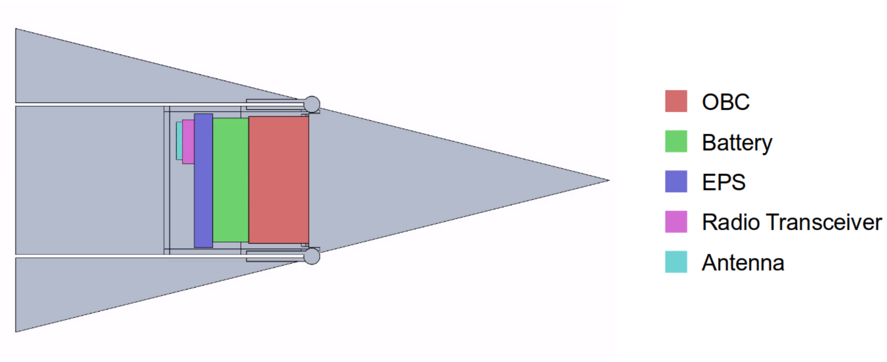

Figure 2: Approximate volume distribution of electronic components

It is important that all necessary hardware be on the vehicle, despite the 10cm x 10cm x 10cm size restriction for CubeSats (Loff, 2015). To accomplish this goal, team members will be assigned to be designated liaisons to the other subsystem teams. Another approach that our team has taken on is to use finite element analysis software and computational fluid dynamics software to verify the structure proposed by the previous year's team, as shown in Figure 2, which is critical for reducing risk during spacecraft development (Blandino et al., 2018). We will also be using Ansys Granta software to determine which materials are best for our design, taking into consideration cost, strength, temperature resistance, machinability, and commercial availability.

In the design and construction of the HEDGE spacecraft, the group will have access to the UVA Engineering Rapid Prototyping Lab and Mechanical Engineering Machine Shop, which will allow for quick and inexpensive fitment testing and design reviews. We will also have access to UVA Engineering Faculty, including our technical advisor Prof. Chris Goyne, among other subject matter experts who have experience in mission planning, structural analysis, and materials design. The deliverable for the Fall semester will be a preliminary design review. This will be followed by a critical design review and a proposal to industry for the funding to build and launch the spacecraft in the spring semester.

STS Research Problem: A More Nimble Satellite

What factors have led to the recent popularity of small satellites?

Small satellites are not novel in concept – they have been a facet of space exploration since the beginning of the space age. However, it's only been in the past decade that they have become a vital component of space research and the growing space economy. In particular, smallsats have become important for academic research and as space-based solutions for global issues. To understand why smallsats have risen to being 94% of the spacecraft sent to orbit in 2021 (Halt & Wieger, 2021), this research will focus on examining missions smallsats have been deployed in and what parties are involved in funding, motivating, and determining who can send their projects to orbit.

A Brief History of Small Satellites

Many early satellites were limited in scope and their sizes reflected this. The first artificial satellite, Sputnik 1, was only 83 kg and had an orbital duration of 22 days (Sweeting, 2018). As the amount of mass able to be taken to orbit increased into the 1970s, national space programs turned away from smallsats in favor of larger, more complex satellites with larger mission scopes. The average mass of satellites was increasing until the mid-1990s; in the United States the number of satellites sent to orbit that were less than 250 kg launched fell precipitously after 1970 (McDowell, 2017). Despite this, smallsats continued to be built and implemented new technologies as they came. Amateur radio operators were largely responsible for landmarks in smallsat development (Sweeting, 2018). OSCAR-designated satellites were notable for being platforms for innovation: e.g. OSCAR 3 (1965) was the first amateur smallsat to carry a radio transponder; OSCAR 5 (1970) was the first to receive control commands remotely (Baker & Jansson, 1994). In 1990, the first smallsat to provide some commercial interest was UoSAT-3, which aimed to facilitate communication between medical institutions in the developing world (Sweeting, 2018). Government interest in smallsats also began to re-emerge in the 1990s: the Air Force Research Laboratory's MightySat program in 1994 was created to use smallsats as a test platform for new technologies (Miller & Davis, 1998). Interest in deploying smallsats as a viable class of spacecraft for conducting commercial, government, and academic research continued well into the turn of the century.

Small Satellites in the 21st Century

The University's research and investment into CubeSats is a reflection of the explosive growth of smallsats in the past decade. However, if smallsats were just amusing and relatively cheap projects for undergraduate capstones, that would not explain the recent boom in governments, corporations, and academic groups alike in deploying them. At a glance, the availability of low-cost and capable electronic components seems to neatly answer the question alone. While a large market of inexpensive off-the-shelf components certainly made smallsats more feasible to construct, especially for smaller groups like academic research groups (Lal et al., 2017), that alone doesn't explain why smallsats are being deployed to tackle global challenges more than ever before, nor does it say anything about the motivations of those investing in these projects.

The 21st century brought the issues of bringing world-wide internet access and modelling the Earth's climate to the forefront of space research, to name just a few. At the turn of the century, only 7% of the world's population was connected to the internet, largely using personal computers to do so. Now, it's estimated that over half of the world's population are internet users (International Telecommunication Union, 2020) and modern life is unimaginable without our connected devices and services. This has generated a huge surge in demand for infrastructure to support internet connectivity (Lal et al., 2017). To address this demand, thousands of smallsats are being brought to orbit largely by private companies to form constellations with the goal to have globally accessible internet connectivity. Constellations of smallsats are also being explored as a way to observe atmospheric conditions. Storms across the planet continue to intensify year by year, and weather models require more data to provide better insight about storm conditions. To address the surging demand for climate data, academic groups have been creating concepts for small weather satellites. An upcoming CubeSat mission by the Massachusetts Institute of Technology called called TROPICS (Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats) hopes to use a CubeSat constellation to observe tropical storms and track volatile regions of the storms like the core (Ranalli, 2018).

These are only some of the issues that smallsats have been deployed to tackle. To explore the reasons for the recent surge in smallsat interest, we can look at how missions are being designed around them. Documents about mission objectives, design choices, and invested parties can be examined across different projects to find common threads between them. Academic groups like our own spacecraft design capstone and the aforementioned MIT group will be the primary focus of this research because documents from academic projects are more readily available than from commercial operators of smallsats. Additionally, sources of funding will be closely examined to understand how different groups influence smallsat projects. Funding is a deciding factor in who gets the opportunity to build a smallsat; this facet of the research will help identify inequities in access to conducting space research.

Conclusion

The University's spacecraft design capstone is a microcosm of the global trend in conducting research and gathering data about the planet in orbit using small satellites like CubeSats. The focus of the STS research is to identify the factors that have driven the growth of smallsats in the past decade. Examining other smallsat projects, particularly those out of other academic groups, will be the primary source of evidence for conducting this research. Each project has a network of stakeholders with their own motivations behind providing support, financial or otherwise. By investigating how other smallsat projects have addressed research or solved a problem with their stakeholders in mind, a greater understanding of how we can leverage these advantages can be applied to HEDGE and future smallsat work at UVA.

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