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

The Role Undergraduate Aerospace Research in University, Industry and Government
(STS Project)

A Thesis Prospectus
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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 the Thesis-Related Assignments.

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Introduction

In order to meet the graduation requirements for the aerospace engineering degree at the University of Virginia (UVA), I must complete a capstone project. This is not a unique requirement to the major, nor is it only found at UVA. Over the past twenty years, the integration of research into undergraduate programs has been a major focus for universities (Nordheden & Hoeflich, 1999). In aerospace, a popular way to get undergraduate students involved in research is through CubeSats. CubeSats were proposed by two Harvard professors in the late 1990s as a method to help students gain experience in designing and building spacecraft, which is a historically difficult and expensive practice. The program had been adopted by many universities including UVA and the Massachusetts Institute of Technology, and in the beginning few CubeSats were launched every year for educational purposes. That changed in the mid-2010's when commercial companies began to launch the small satellites (Howell, 2021). Since then, the technology has been embraced by both the private and public sectors of aerospace. Government agencies such as NASA and the Department of Defense (DoD) have developed various programs around CubeSats, with missions ranging from atmospheric data collection (Howell, 2021) to hypersonic missile defense systems (Vergun, 2021). The CubeSat is just one case study for how aerospace technologies developed by undergraduate students are being used by all the players in the industry, including the universities where they originated.

Many universities today exist within a "triple helix model" of academic-industry-government relations, with the enhanced role of universities in technological innovation being the major change compared to how universities operated in the past (Etzkowitz et al., 2000). With this greater role, a university can improve the economy on both a regional and national scale, as well as securing a financial advantage for itself and its faculty. The workforce leading this innovation is becoming more and more composed of undergraduate students, often who have little choice in the matter, as it can be a graduation requirement, as seen in my personal case. Government and industry profit greatly from this model for a number of reasons, including cheaper projects, workforce recruitment, and advertisement. In this entrepreneurial system, all parties reap benefits, except the student workforce, who oftentimes are not monetarily compensated for their work, or have clear ownership rights. As the system stands, undergraduate researchers are exploited and do not receive the same gains that would be expected if they were doing the work as an employee. This creates a power imbalance between the students and the participants of the system, and students are taken advantage of and trapped by the current status quo.

The technical project discussed in this paper is set up in a way that directly feeds into the problem as stated. I am required to work on a CubeSat designed to test hypersonic conditions, and the project will most likely be funded by the United States Navy. There is no monetary compensation for my work, and I have no expressed rights to capitalize on it. The STS project seeks to uncover how the triple helix system in aerospace undergraduate research exploits the students involved.

Technical Project

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).

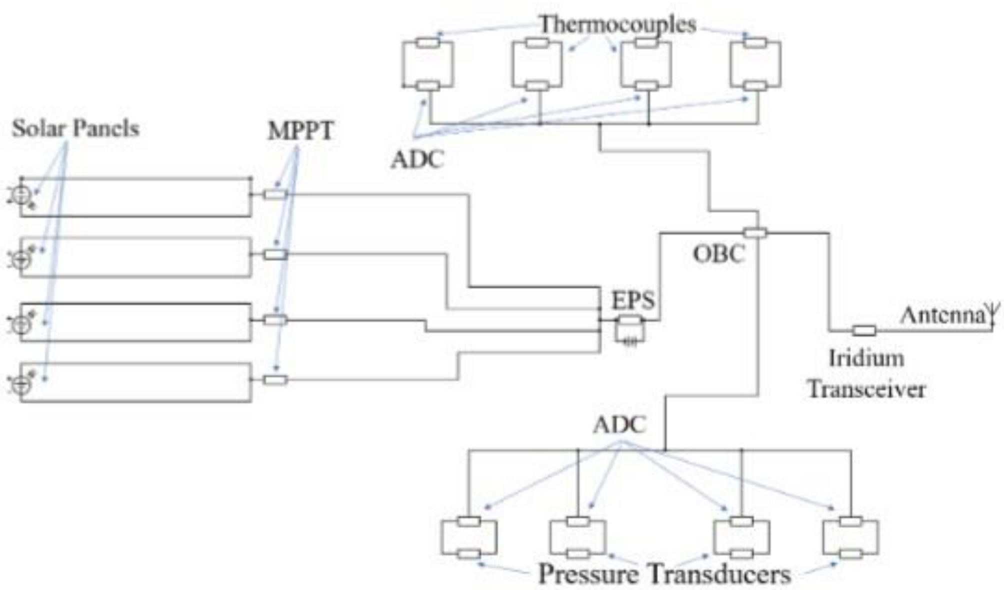

Fig. 1. HEDGE Power subsystem circuit diagram (Source: 2022-2023 *HEDGE* Thesis)

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

Beginning in the 1990s, the aerospace industry has been relying increasingly heavily on undergraduate research for technological advancements in the field and to bolster workforce recruitment. Though they actively participated in the creation of new technologies, undergraduates have scarce to non-existent ownership rights to their work, and are not paid for it. One example of this can be seen through the CubeSat program, developed specifically to give undergraduates the opportunity to design spacecraft, and now has the potential to be the U.S. government's next big step in space defense. The students who advance this technology have no rights to determine its use or to profit from it. The question I ask is, how does this system exploit undergraduate aerospace engineering students?

As discussed in the introduction to this prospectus, universities are now part of a triple-helix model of academic-government-industry relations. In this entrepreneurial system, academic institutions dedicate more effort into the creation of research and development programs in order to create a revenue stream that will continue that cycle. Most funding for university research comes from either profits generated by patented research or government grants. In recent examples of this, the DoD funded a $2 million Aerospace Education Research and Innovation Center (AERIC) at Tuskegee University that will "support two-year research projects" and "devoted to expanding the future aerospace technical workforce" (Defense Department, 2021). Sponsorship from local industry also allows the university to bring in more funding, as well as laying the groundwork for both prospective student recruitment to the university and potential employee recruitment for the industry. Here at the UVA, many mechanical and aerospace engineering facilities are sponsored by Rolls-Royce, giving the university high-tech labs to promote with a well known name, and giving Rolls-Royce a group of students that they can use to fill internships and job openings (University of Virginia, 2023). The funding and sponsorships are particularly beneficial to universities because only a very small percentage of the grant given needs to be used to pay any wages. Faculty and graduate students are paid for their work, but most times undergraduate researchers are not, and the university can require students to take part in research to graduate (Nordheden & Hoeflich, 1999).

Though I have established that many students do not get paid to research and they do not own their research, many still participate willingly, and choose to go to universities that promote robust undergraduate research programs. A major justification for unpaid undergraduate research is that students are gaining hands-on experience that can be translated onto a resume (Smith et al., 2011). This can theoretically lead to a paying job, but it is not guaranteed. Doing research for a particular entity, such as the DoD or a private company like Rolls-Royce or Lockheed Martin, can lead to internship opportunities with that entity, which can turn into a full-time employment offer post-graduation (Olivier, 2022), but once again, these are just potential earnings that are advertised as real time benefits. The lack of defined intellectual property (IP) rights also hurts a student's ability to earn physical capital off their work. There are currently no explicit laws regarding an undergraduate researcher's IP rights, leaving it up to an individual university to decide them (Warenzak, 2019). Students wishing to conduct research in aerospace do face a unique challenge when compared to other fields, given that the development of spacecraft technology is deeply intertwined with politics and regulations, and they cannot be separated from that, so they must interact with the established system to do research (Winner, 1980).

The federal agencies and private companies within aerospace use this established system with universities and their undergraduate researchers to obtain technological advancements for largely reduced costs and to maintain a recruitment pipeline for the ever-expanding aerospace industry. Going back to our CubeSat example, many predict that the small satellites will be a major step in creating a disaggregated space defense system that is hard to disrupt (Nayak, 2016). Without undergraduate participation in the CubeSat program, it is unlikely that the technology would be advanced enough to be seriously considered for its defense capabilities as it is currently. CubeSats are already being used to test the functionalities of other space defense systems (Vergun, 2021), which is quite impressive, given that ten years ago they were only being utilized by universities. The industry players involved in this system with universities not only get access to physical capital, but to human capital in the form of the university students that get recruited to work for the government or private companies. Some, like Lockheed Martin, have such established connections with universities that recruiting events span a whole day, aptly named "Lockheed Martin Day" (Olivier, 2022).

Conclusion

The result of the technical project described will be new data on how materials will perform under hypersonic conditions, but more than that, it will result in a hands-on experience on constructing a spacecraft that begins the process of integrating aerospace engineering students into the industry. The role of the aerospace industry in establishing and defending the United States' role as a global leader in the last century can not be denied (Commission on the Future of the United States Aerospace Industry, 2002), but the current system in place between universities, government, and private companies, could be exploiting the undergraduate students involved. The members of the triple helix system will benefit from my technical research, but I hope that students and faculty involved in this type of technical research can learn from the findings of this STS project and make changes to the system in order to bring more power to undergraduate researchers.

References

Canadian Space Agency. (2022, May 6). *CubeSats in a Nutshell.* Government of Canada. www.asc-csa.gc.ca/eng/satellites/cubesat/what-is-acubesat.asp

Commission on the Future of the United States Aerospace Industry. (2002, Nov. 18). *Final Report of the Commission on the Future of the United States Aerospace Industry.* https://history.nasa.gov/AeroCommissionFinalReport.pdf

Defense Department Launches $2 Million Aerospace Research and Education Center of Excellence at Tuskegee University. (2021, February 22). *U.S. Department of Defense.* Retrieved October 26, 2023, from https://www.defense,gov/News/Releases/Release/Article/2511291/defense-department-launches-2-million-aerospace-research-and-education-center-o/.

Goyne, C. (2023, Aug, 23). *Class1 [PowerPoint slides].* Aerospace Engineering, University of Virginia.

Etzkowitz, H., Webester, A., Gebhardt, C., & Terra, B. R. (2000). The future of the university and the University of the Future: Evolution of Ivory Tower to entrepreneurial paradigm.

Howell, E. (2018, June 19). *Cubesats: Tiny Payloads, huge benefits for space research.* Space.com. https://www.space.com/34324-cubesats.html

Nayak, M. (2016, January 18). *CubeSat Proximity Operations: The natural evolution of defensive space control into a deterrence initiative*. The Space Review. https://www.thespacereview.com/article/2902/1

Nordheden, K. & Hoeflich, M. H..(1999). Undergraduate research and intellectual property rights. Educations, IEEE Transactions on, 42, 233 – 236. 10.1109/13/804526.

Olivier, I. (2002, August). *Inside Lockheed Martin's sweeping recruitment on college campuses.* In These Times. https://inthesetimes.com/article/lockeheed-martin-recruting-military-industrial-complex-student-debt

Smith, M. W., Miller, D. W., & Seager, S. (2011). Enhancing undergraduate education in Aerospace engineering and planetary sciences at MIT through the development of a CubeSat mission. *SPIE Proceedings,* (8146). https://doi.org/10.1117/12.896130

2021-2022 Spacecraft Design Team. (2022, April 27). *HEDGE Conceptual Design Review [PowerPoint Slides]*. University of Virginia.

2022-2023 Power, Thermal, and Environment Team. (2022, Fall). *Power, Thermal, and Environment Technical Thesis Prospectus.* University of Virginia.

2022-2023 Spacecraft Design Team. (2023, April 12). *HEDGE Thesis.* University of Virginia,

University of Virginia. (2021, October 26). *Rolls-Royce Undergraduate Student Opportunities.* University of Virginia School of Engineering and Applied Science. https://engineering.virginia.edu/research/centers-institutes/rolls-royce-technology-center/rolls-royce-undergraduate-student

Vergun, D. (2021, July 12). *Nanosatellites could play pivotal role in defense against enemy missiles.* U.S. Department of Defense. https://www.defense,gov/New/News-Stories/Article/Article/2685840/nanosatellites-could-play-pivotal-role-in-defense-against-enemy-missiles

Warenzak, M. (2019, March 8). *Universities and intellectual property law.* SGR Law. https://www.sgrlaw,com/ttl-articles/universities-intellectual-property-law

Winner, L. (1980). Do artifacts have politics? *Daedulus, 109*(1), 121-136. http://www.jstor.org/stable/20024652

Woellert, Kirk, et al. (2011, Feb. 15). CubeSats: Cost effective science and technology platforms for emerging and developing nations. *Advances in Space Research 47*(4), 663-684. www.sciencedirect.com/science/article/abs/pii/S0273117710006836