The Role of Undergraduate Aerospace Research in University, Industry and Government

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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

When asked to propose my research to my class, I went with this, “Why dinon’t I get paid to make missiles?” Though it elicited laughs plenty of laughs from my peers, it’s a valid question. In my aerospace engineering program at the University of Virginia (UVA), participating in a capstone project is necessary to fulfill the degree requirements in order to graduate. My capstone happens to be a small satellite that intends to test materials in under hypersonic conditions for use in making hypersonic weapons. So, my project comes with pretty big implications, and some pretty big Navy funding. It’s real work, with real data that can be used to change the defense industry in America. Why are my peers and I doing it for free? The simple answer is that UVA never intended to pay us, and we never asked to get paid. We must take the class, we get credit for it, and we get a good experience to put on resumes and talk about in job interviews. With a degree costing more money than ever, rising costs of living across the country, and a job market that’s tight and competitive, paying undergraduate aerospace engineers for their work could make a huge difference in their lives post-graduation. So, this begs the question, what caused the system that we don’t even think about, to be set up like this?

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 (Smith et al., 2011) The program had been adopted by many universities including UVA and the Massachusetts Institute of Technology (MIT), and in the beginning a 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.

In this paper I analyze both the reasonings for installing this system of undergraduate research and the ways in which it was installed that created a practice of not paying students for their work. Using Susan Leigh Star's writings on infrastructures as an STS framework, I explore how the system in embedded within relationships between universities, industry, and government to determine how it developed this way. I argue that industry's call for a skilled workforce in aerospace created an infrastructure that prioritizes industry health over fair distribution of benefits.

Literature Review

In my initial examination of the subject, I found four key shareholders in the issue at hand, universities, industry, the government, and undergraduate students. They have interacted in various ways with each other over the years, creating a web on relationships to explore.

Universities hold a unique position in this issue, as they are often what ties the student to industry and government. Because of this, universities have many motivations for students to be involved in research, and a notable reason is funding. Under pressures to obtain funding from internal and external sources in order to continue performing research, it became common at universities to generate patents to establish a cycle of income for new research (Etzkowitz et al, 2011). As discussed by Etzkowitz et. al. (2011), universities exist in a "triple helix system" of university-government-industry relations. They have over time developed a third mission of economic development in addition to their primary missions of teaching and research. This can be seen in aerospace very clearly as from 2020-2021 federal funding increase 12.3%, from about $1.29 million to $1.45 million (Gibbons, 2022).

Industries participate in the triple helix system so that they can maintain a steady influx of new workers. By supporting student research while they are undergraduates in the form of research grants, summer internships, and loan repayment programs, students are more likely to commit to a full-time position upon graduation (Olivier, 2022). In the long run this will save a company time and money, as there is a large established pool of potential employees, many of which have already been vetted by internships, which cost much less to run than hiring a full-time employee. You can see this clearly in place at the University of Virginia, where our workshop in the Mechanical and Aerospace Engineering building is sponsored by Rolls Royce, who then routinely come to the university to recruit for their internships (University of Virginia, 2021).

The federal government takes an interest in the system for another different reason, and that is the cheap advancement of technology. For aerospace research in particular, the CubeSat program has piqued the interest of the government, after being regarded as simply a method for further undergraduate hands-on experience in the years following the program's inception. CubeSats have already been proposed by federal agencies as solutions to many of our nation's concerns about space defense. Nayak (2016) discusses how the small satellites could be the next step to have a disaggregated defense system that is hard to disrupt, pointing out that they are very easily made considering many aerospace students have done so during their time in undergraduate programs. The Missile Defense Agency has begun using CubeSats to test the technology needed for their Hypersonic and Ballistic Tracking pace sensor (Vergun, 2021). Some of the U.S. defense sector's biggest projects are implementing this technology, which was largely spearheaded by undergraduate students. My own capstone project is using a CubeSat to test different materials under hypersonic conditions. If successful, that information would be shared with the United States Navy, and most likely go on to be used in further research concerning hypersonic weapons. While the federal government could get research on topics like these from a multitude of places, but because the funding going to universities will be strictly based on the physical materials and technology required, not labor costs, it is going to have the lowest price tag when coming from undergraduate programs.

We see that all four shareholders in this system benefit in some way from this system, but the main crux of the issue is that students don't benefit monetarily, while universities, industry, and government all do. This largely stems from the fact that the undergraduate students will almost never own their research. Most researchers, including graduate students and professors, are required by their universities to transfer ownership of their work to the school for any patents that may stem from the research (Warenzak, 2019). So, if a student completes research and makes a great discovery, they can add it to their resume, say they worked on it, bring it to all the conferences, but they can never sell it or spin it around someway for a profit. In the late 1990's and early 2000's, when it was becoming more commonplace to undergraduate students to participate in research, they were given the same ownership rights as graduate students and professors, meaning the university had the patents rights. From the beginning, this work was often unpaid, and a student would receive academic credit towards their degree program or “experience” in lieu of any monetary compensation (Nordheden & Hoeflich, 1999). This is the system that is still in place today.

My analysis of the system of undergraduate aerospace research draws on infrastructures, which allows me to view the system as an infrastructure and explore the relations that stem from that. The main ideas of the STS theory of Infrastructures is that infrastructures are invisible and always part of the background. They are not seen or highlighted on a regular basis. Star (2016) describes them as “both relational and ecological – it means different things to different groups and it is part of the balance of action, tools, and the built environment, inseparable from them.” (p. 377). While there are many properties of infrastructure, there are four that I find most applicable to the issue, are:

- Embeddedness – “Infrastructure is sunk into and inside of other structures, social arrangements, and technologies.” (Star, 2016, p. 381)
- Learned as part of membership – “The taken-for-grantedness of artifacts and organizational arrangements is a sine qua non of membership in a community of practice…New Participants acquire a naturalized familiarity with its objects, as they become members.” (Star, 2016, p. 381)
- Links with convention of practice – “Infrastructure both shapes and is shaped by the conventions of a community of practice.” (Star, 2016, p. 381)
- Is fixed in modular increments, not all at once or globally – “Change takes time and negotiation, and adjustment with other aspects of the systems in involved.” (Star, 2016, p. 382)

Using these concepts, I will analyze how the practice of undergraduate aerospace research as it stands now is embedded within the university-government-industry processes and how it is continually accepted and enforced by those who are involved.

Methods

To collect research to answer my question, I went through a process of pinpointing the start of the issue and following various avenues to expand upon it. From my personal experience, I knew that CubeSat programs were common in aerospace undergraduate curriculum across the country, so I collected firsthand reports on the implementation of CubeSats at various universities. From these I learned that the program was developed to meet a need in the industry, so I gathered sources that detailed why the aerospace industry had an insufficient labor force, mostly in the form of journals or conference presentations on engineering education and aerospace engineering. I had also been introduced to a commission on the future of the aerospace industry by a peer, which lead me to look at the National Aeronautics and Space Administration Authorization Act that allowed for funding for aerospace research to occur. In each of my sources, I examined the ways in which they interacted with preexisting infrastructure and the potential ways in which they shaped the current system.

Analysis

Using infrastructures as an analytical framework, the system of undergraduate aerospace research can be viewed as an embedded infrastructure that became visible when broken and subsequently modified over time to establish a new infrastructure that unwittingly prioritizes the needs of universities, industry, and government, over the students which partake in it.

About a decade ago, it became clear that the job requirements set forth by the aerospace industry were not being met by recent graduates of undergraduate aerospace engineering programs. Employers felt that students were not leaving their university with the proper hands-on skills that were in demand, including the "non-technical skills" of proper communication, and the "employability skills" such as problem-solving and decision-making (Dubikovsky et al., 2010). The standard model of aerospace undergraduate education didn't match what employers needed, which wasn't ideal for either party. The universities exist to prepare students for the workforce and specialized industries like aerospace depend on these new graduates for labor. The part of infrastructures being highlighted here in links with conventions of practice. Industries had always expected that universities would teach their students the necessary skills and when that didn't happen, the system broke down. This disconnect between universities and industries was concerning for students as well: "While the number of graduates in STEM fields have continuously increased over the last decade, graduates in increasing numbers are reporting that they are unable to gain employment in the fields closely related to their highest degree," (Zender et al., 2014, p. 1). The aerospace industry was effectively at a plateau in the hiring process. Companies didn't want to hire new graduates, new graduates couldn't get jobs in the field, and fewer students enrolled in aerospace programs because there were fewer job prospects. Zender et al. (2014) explained this further, "This trend is having a significant impact on companies like Boeing where the average age is 48, a workforce trait found across the aerospace industry." (p. 1) Because the established infrastructure had broken, a new one had to be built atop the old, with many of the same practices in place.

To solve this pressing issue of a lack of skills taught at universities, there was an increased call for the integration of research and labs into undergraduate aerospace curriculum.

The main case against inclusion of research in undergraduate programs is cost and work: "In recent years, there has been a shift toward involving undergraduate students in mentored research activities, The benefits and rewards … have been recognized, however there are many challenges to implementing a successful research program at the undergraduate level" (Friend & Beneat, 2013, p. 3). The authors go on to discuss that it's very expensive to set these programs up and run them, especially for smaller universities. It's also hard to change a set curriculum to now include a research course, taking up space that might have previously been reserved for other classes. The need for more research in aerospace programs was clear, but it left some universities scrambling to figure out how to implement it. A trait of infrastructures is that they are fixed in modular increments, not all at once. It took many years for universities across the country to create new research programs, and there was no one way to do it. The path that many chose was a required capstone project: "To successfully counter this skills gap, companies are increasingly reaching out to academia to actively participate and shape the education of students, particularly by supporting capstone projects." (Zender et al., 2014, p. 1). Capstone projects are popular choices because they can more easily be tacked on to the end of a curriculum, and can lead directly to employment post-graduation, through the company or government entity that was supporting the project. Of course, every university will have its capstone program set up in a different way, but many possess the same hallmarks. At UVA, it's based on the concept of design-build-fly. Students work together to design a spacecraft, rocket, airplane, etc., then manufacture it, and then launch or fly it when completed. These courses are generally required for graduation and only course credit and the experience are received upon completion, though many classes will have been part of a project that could have been given to government or industry employees to work on. By requiring students to complete a capstone project, universities are bridging the gap between their curriculum and what industry requires, so graduates are more likely to get a job in their field upon graduation, but do not receive any monetary compensation for the extra work.

Universities discovered that research could be used as a method of student, engagement, recruitment, and retention to aerospace undergraduate programs. Promoting having research as part of undergraduate curriculum became a tool for universities to increase the number of students in aerospace programs, which has been dwindling due to the lack of job prospects upon graduation: “As an added benefit, universities are finding that such projects tend to attract better-prepared students and keep current students interest in technology, which makes it less likely that they will change majors to a different area they find more engaging.” (Dubikovsky et al., 2010, p. 1). Many students are attracted to universities that have robust undergraduate research programs because of the promise of acquired skills, experience, and connections to industry and government that will make finding a job easier. It also turns out that doing hands-on activities in the classroom is engaging and even the prospect of doing these activities causes students to stay in programs. Looking at a case at Purdue University, which has one of the most established aerospace engineering programs in the world, “Under [Dean of Engineering, A.A. Potter’s] leadership the School grew in students numbers and in research expenditures, so that by 1985, the sponsored research budget had reach $1,500,000 per year.” (Grant & Gustafson, 2003). More and more students began to want to participate in research for the benefits, and the system was becoming so ingrained that few stop to examine why every other player was making money, except them. This can be examined as part of infrastructures through learned as a part of membership. When you begin to apply to colleges, you accept the system as it stands.

When the United States aerospace industry was on a clear decline, the federal government prioritized industry health above all else, and used undergraduate students as a means to restore industry standing. For decades the U.S. had been considered the world leader in the aerospace industry, but starting in the late 80's, the decline of interest in the industry and having skilled enough workers to fill positions was evident. The federal government felt it was critical to bolster the industry so as not to lose its place as the industry leaders. A federal commission was put together to examine the industry in the early 2000's and presented its findings to the president. It found that the industry had been suffering and had the potential to fall behind other countries: "We stand dangerously close to squandering the advantage bequeathed to us prior generations of aerospace leaders. We must reverse this trend and march steadily towards rebuilding the industry." (Commission, 2022, p. 6) Having universities produce capable aerospace engineers was embedded into the level of security and power that the United States had over other counties. If the undergraduate aerospace infrastructure broke, it could very well lead to the breakage of the nation's position as the dominant world power since aerospace is so closely tied to defense operations. One way of achieving this goal was through the form of research grants, and many programs were established with the sole purpose of providing funding for aerospace research at universities. An example of this is the National Space Grant College and Fellowship Program, established when Congress passed a piece of legislation in 1988. "In 1987 a joint congressional study panel met to address a number of issues facing the aerospace industry and the nation, among them, a looming shortage of workers prepared for a high tech workforce and decline in scholastic achievement…" (Virginia Space Grant, 2024). The government starting handing out lots of grants to universities for aerospace research, which was then used to set up the systems we have discussed previously. The universities have enough money to create the necessary curriculum, industry gets its skilled workers to get the job done, and the United States continues to be a world leader for aerospace. All the while, students are pushed through as system that supposedly benefits them and no one looks to closely to see how the skewed the distribution of benefits are, especially when it comes to monetary benefits.

A common critique of my argument would be that students do benefit from the triple helix system, gaining knowledge of practical application, building confidence, and developing workplace skills such as communication and interpersonal skills. (Dubikovsky et al., 2024). I argue that the system of undergraduate research was not developed to intentionally exploit students, but that it was still created to meet the needs of industry, government, and universities, and any benefits to students is a coincidence of overlapping benefits of the students and the other shareholders. The students are simply the vessel of information and skills, their happiness, well-being, and success never truly factored into the creation of the system.

Conclusion

When it was becoming clear that the American aerospace industry was on a steep decline a joint team of universities, industry players, and the federal government took steps to ensure it recovered and expanded. At the crux of the issue was that recent graduates had not been properly prepared for the workforce by the curriculum at universities, and the solution to this was increasing attention and spending on undergraduate aerospace research. Over the years, this led to the development of the current system where research is required for credit to graduate from an aerospace program, and students are not paid for the important work that they complete.

For years students have been told they are receiving benefits through these programs, but the main purpose of these programs are not to provide benefits, but rather to maintain participation in the triple helix system. Universities promote perks such as “strengthening your resume”, “making industry connections”, and “learning job-applicable skills” to their undergraduate students taking research-based curriculum. These phrases all imply that there will be monetary benefits for these students down the line, as they will theoretically be able to secure better, higher-paying jobs in their industry, but none of that is guaranteed. Universities, companies, and the government may have different motivations for being part of the system, but they all profit from it. While the future of the United States aerospace industry is now more secure and universities, companies, and the government are working hand in hand to continue attracting more undergraduates to aerospace, the urgency that created the system that is exploitative to students can be revised to redistribute some of the monetary benefits to student researchers.

References

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

Dubikovsky, S., Grandt, A. F., Goodrich, T. A., & Sterkenburg, R. (2024). International Conference on Engineering Education ICEE-2010. In *iNEER*. Gliwice. Retrieved March 1, 2024, from https://www.ineer.org/Events/ICEE2010/papers/W16C/Paper_1008_1210.pdf.

Etzkowitz, H., Webster, A., Gebhardt, C., & Terra, B. R. C. (2000). The future of the university and the university of the future: evolution of ivory tower to entrepreneurial paradigm. *Research Policy*, *29*(2), 313–330. https://doi.org/https://doi.org/10.1016/S0048-7333(99)00069-4

Friend, R. D., & Beneat, J. N. (2013, June). *Development of Aerospace Engineering-Focused Undergraduate Research at a Small University: Accomplishments and Lessons Learned Paper presented at 2013 ASEE Annual Conference & Exposition, Atlanta, Georgia. 10.18260/1-2—19440*

Gibbons, M. T. (2022, December 15). *Universities Report Largest Growth in Federally Funded R&D Expenditures since FY 2011*. NSF. https://ncses.nsf.gov/pubs/nsf23303

Grandt, A., & Gustafson, W. (2012*). 41st Aerospace Sciences Meeting and Exhibit. In Aerospace Research Council.* Reno. Retrieved March 1, 2024, from https://arc.aiaa.org/doi/abs/10.2514/6.2003-234.

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. *IEEE Transactions on Education.* 42. 233 - 236. 10.1109/13.804526.

Olivier, I. (2022, August). Inside Lockheed Martin's sweeping recruitment on college campuses. *In These Times.* https://inthesetimes.com/article/lockheed-martin-recruiting-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

Star, S. L. (2016). The ethnography of Infrastructure. *Boundary Objects and Beyond*, 473–488. https://doi.org/10.7551/mitpress/10113.003.0030

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/News/News-

Stories/Article/Article/2685840/nanosatellites-could-play-pivotal-role-in-defense-against-enemy-missiles/

Virginia Space Grant Consortium. (2024, February 2). *History*. https://vsgc.odu.edu/about-us/

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

Zender, F., Wright, M., Richey, M., Gorrell, S., McPherson, K., & Madni, A. M. (2024). The International Conference on E-Learning in the Workplace 2014. In *ICELW*. New York. Retrieved March 1, 2024, from https://cmapspublic3.ihmc.us/rid=1NWPXTBPG-34964K-17GG/+++++201403014%20ICELW%20-%20Connecting%20Industry%20and%20Academia%20E-Learning%20v6.pdf.