Design of a Hybrid Rocket Motor – "Project ATLAS"

Analyzing the Legal Framework Surrounding the Growth of 3D Printing Technology for At-Home Weapons Manufacturing

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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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General Topic:

How has 3D printing democratized manufacturing and production amongst modern society, and what are benefits and dangers of the growth of this technology?

Regardless of the skills and intelligence of an engineer, artists, and/or designer, what generally separates an individual's product from that of a large-scale corporation is the ability to build it. Manufacturability is arguably the most important element of engineering due to it being the only component to tie theory to reality, which is why it carries a high barrier to entry for more complex/advanced designs. Traditionally, subtractive manufacturing was the tried-and-true way to build anything from pens to rockets. This is the practice of cutting away from chunks of material to form the component you desire. This used to be largely the case with metals, but with the rise of plastics, additive manufacturing (3D printing) can take melted materials and build them up into your desired shape.

3D printing technologies have seen such drastic growth, that they are fairly affordable and accessible within the home, making it where everyday people can design and build more than they could imagine. While additive manufacturing was initially only prevalent in the niches of the Aerospace and Medical fields, its advancements have democratized production availability amongst smaller stakeholders. This serves to further its demand amongst the people, incentivizing cheap, at-home products that anyone can learn how to use without needing an engineering background or degree.

Accessibility and affordability are extremely beneficial to societal development and economic growth, but highly capable technology requires informed regulation that balances its growth and safety while preventing the destruction of its market. Regulation is far more manageable when a select few use them, when how can our legal frameworks adapt to account for a mass influx of "manufacturers." Now that people can create almost anything, the dangers of what can be created hidden from the watchful eyes of regulations come to light.

Technical Research Project – Design, Build, and Test Fire a Hybrid Rocket Motor

How can we effectively utilize 3D printing to cheaply attain a high-quality hybrid rocket design that is otherwise inaccessible due to cost and availability barriers?

Rocket propulsion relies on the combustion reaction between a fuel/propellant and an oxygen supply (oxidizer). Traditional rockets are made by mixing liquid fuels with liquid oxidizer or solid fuels and solid oxidizer. The former is expensive and complex due to the plumbing architecture required to regulate two liquids at once. The latter is dangerous because once fired, solid rockets cannot stop until the mixture is used up, risking explosion. Overall, regulatory frameworks are well defined to control the creation, distribution, and usage of these types of engines, which is why the University of Virginia generally prohibits the student-led development of such technologies on grounds.

In order to advance propulsions engineering at UVA, we must adhere to safety standards while lifting the prohibitions surrounding student development. To set such a novel precedent, our team is tasked with designing, building, and test firing a hybrid rocket motor. Hybrid rockets utilize the reaction between a liquid oxidizer and solid fuel (hence the name hybrid) and arguably serve as the best of both worlds (Sutton and Biblarz, 2017). Plumbing for a single fluid reduces complexity and a fuel grain separated by state of matter minimizes explosive risk. Hybrids tend to fail due to over pressurization rather than combustion/explosion, making them significantly safer (Newlands, 2017). The nature of mixing liquid with a solid grain has made hybrid rocketry only useful at small scales. As primary users of this technology, there is an impetus for student rocketry teams and small launch providers such as HyImpulse and Firehawk Aerospace (Perez et al., 2022) to develop means to better characterize the performance of hybrid motors, improve their efficiency, and even investigate methods for constructing them at a large scale. For our team, being able to model and predict the inherently inconsistent combustion processes within a hybrid rocket requires us to develop an optimal design that we can attain invaluable test data from.

While liquid and solid rockets can uniformly combine fuel and oxidizer, the design challenge for hybrids is to inject a supply of liquid oxidizer across the inside of a tube of solid fuel. The injector's ability to evenly coat a solid surface with oxidizer characterizes the quality and efficiency of a hybrid motor. Our group's goal is to predict the nature of the mixing and design an optimal injector. Furthermore, the geometry of the fuel grain receiving the spray can be modified for similar gains.

In order for us to develop complex geometry, additive manufacturing techniques are the most affordable and effective strategy. Our research has defined ABS plastic as the desired solid fuel. ABS is cheap and 3D printable, allowing us to create numerous grains of varying geometries for repeat testing. Our injector delivery system, although more complex, can be manufactured as imagined using ceramic 3D printing. This is a novel application that 3D prints a part out of ceramic-infused resin and feeds it through a kiln, bakes out the resin and produces solid ceramic part. We aim to determine the life cycle of these parts to see if they can realistically be used to rocket engines and be consequently swapped out with ease, removing the constraint of excessive reusability.

The project contains 4 major subsystems/subteams. The Oxidizer team is responsible for the storage and plumbing architecture and injector that delivers our oxidizer, Nitrous Oxide (N_2O), to the combustion chamber. The Fuel Grain subteam is responsible for the design of our solid propellant, made from 3D printed ABS plastic. The Nozzle and Combustion Chamber team designs the assembly that houses the fuel and is responsible for the nozzle geometry that the exhaust jet exits. Lastly, the Ground Testing subteam will construct a test stand and data acquisition (DAQ) system responsible for the safe, static fire of the rocket while obtaining all the necessary data to characterize our assembly.

The goal, aside from creating a successful and operable design, is to test the fidelity of our components while achieving optimal efficiency. Data collection is of the utmost priority to the project and is a reason we are only ground testing the project. Our team is prohibited from firing this engine in anything other than static conditions. Due to the dangers of propulsions engineering, progression into the manufacturing stage of our project is contingent upon approval from an external advisory board of qualified industry professionals. Then and only then, can we progress to building the project.

STS Research Project

How did the rise of Defense Distributed disrupt the legal framework surrounding 3D printed weaponry?

In 1988, the Undetectable Firearms Act made it illegal to manufacture, sell, possess, etc. that could bypass metal detectors (18 USC § 922(p)). Despite this legal framework controlling registration, tracking, and production of firearms in United States, it was unprepared for rise of 3D printed plastic weaponry that can have just enough metal added to be legal. 3D printing has allowed for the democratization of production within society, opening novel routes for misuse and dangerous homemade development.

Defense Distributed, a company founded by Cody Wilson, a former Texas law student, serves to be the most notable example of the creation of dangerous 3D printed weaponry. The first shock to the legal system came with their release of a 3D printable AR-15 standard capacity magazine in January 2013 (Daly). Their most notable creation, the case this STS topic wishes to explore, was the development of the blueprint for the "Liberator". A plastic 3D printed gun which came about thanks to crowdfunding, in May 2013, a fully functional 3D printable pistol shocked the country into realizing that this as a potential problem (Daly).

Upon the release of the Liberator, the Directorate of Defense Trade Controls (DDTC) deemed the release of weapon blueprint a violation of International Traffic in Arms Regulations (ITAR). It was stated that releasing files across the internet requires authorization since it constitutes as an "export" of Defense Articles (Foster). Defense Distributed countered with a lawsuit stating that DDTC was infringing on free speech and their 2nd amendment rights. The legal framework of the constitution addresses the right to "bear arms", but the right to production is a gray area. In 2015, the courts ruled against the Defense Distributed lawsuit. Eventually, they reached an agreement with the DDTC in 2018, alleviating the ITAR restrictions and reallowing internet upload. Multiple lawsuits around the United States soon followed these decisions and they culminated into eventually allowing Defense Distributed to sell and share blueprints to valid US persons, except for posting them on the internet.

When discussing 3D printed weaponry specifically, the case Defense Distributed is the best and only significant case to analyze. I will develop a case study, specifically targeting the social and legal responses and conversations that sprouted because of it. The available literature begins with the congressional reports tracing the legal battle between Defense Distributed and the US government, allowing an understanding of the background context. Another key source is the Undetectable Firearms Act of 1988, which completes the contextual understanding by illustrating the state of the legal framework prior to the disruption caused by Defense Distributed. In order to develop a stronger understanding of the social impacts of technology, I will explore literature that tracks the dissemination of the technology itself throughout the United States. A major component of mutual shaping is the rise of state level initiatives and modifications to their individual legal frameworks across Washington, Oregon, California, Nevada, Colorado, Illinois, New York, Massachusetts, Connecticut, Rhode Island, New Jersey, Maryland, Delaware, and Virginia (Listek, 2023). Since much of the legal battle was ensued by Cody Wilson himself, I will utilize a video interview to develop a more complete understanding of the social and cultural motivations driving Defense Distributed. The modern results of the lawsuits illustrate an active socio-technical shaping as Defense Distributed continues to push products following the lifting of any bans by the 9^{th} Circuit as of 2024 (Iovino, 2024).

I will utilize technological politics to analyze the legal battle between Defense Distributed and the US government. Technological politics follows the theory that technology has political qualities. In addition to their capabilities, they can embody forms of power and authority. 3D printing technology can be incorporated into this theoretical framework when it can be utilized to manufacture weaponry. The political implications of citizens having access to such technologies illustrate the social drivers behind development and restriction. The case of Defense Distributed illustrates how technological disruption can cause a power imbalance in political settings.

The evidence I will require to properly assess my topic will be legislation information surrounding Defense Distributed. I will follow the historic legality defined by the Undetectable

Firearms Act of 1988 and how its shortcomings were addressed throughout the Defense Distributed legal battle. By treating 3D printed artifacts as entities carrying political influence, I can better analyze this case from a more informed point of view. The predominant government entity resisting Defense Distributed, the Directorate of Defense Trade Controls, contextually places 3D printed weaponry in the realm of export control. Technological politics is better applied within this context because it allows for a more politically focused understanding of 3D printing technology. In addition, analyzing the social reshaping done through state-level initiatives will allow me to balance the ethical concerns against the national security concerns regarding Defense Distributed.

Conclusion

The goal of my research is to develop an understanding of how 3D printing technologies will embed themselves into society after having brought about legal disruption. Since their initial growth was found in niche industries like Aerospace Engineering, my technical research will solidify its necessity and importance in the field. The technical research will demonstrate the impactful utilization of additive manufacturing and its positive potential. My STS research, alternatively, will explore the negative extent of the same technology as it diffuses across American society, specifically its political implications and disruption once it has been applied to a diverse field of opportunity. Defense Distributed made the world privy to an unplanned usage of technology, demonstrating how that technology can hold its own authority and serve to shape legal frameworks in response. The problem remains open ended and the continuation of 3D printed weaponry is actively under socio-technical shaping. Together, these projects will allow me to understand the future 3D printing holds amongst our society and how current legal frameworks have adapted federally and at the state-level to constrain it.

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