Propellant Formulation for an M-Class Rocket Engine

The Impact of Propellant Manufacturing on its Surrounding Community

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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 history of rocketry started over a thousand years ago in China with the discovery of gunpowder and its subsequent use in fireworks. Since then, rockets have advanced to where it is difficult to understand how 'simple' gunpowder started it all. Despite the makeover, however, the underlying process is the same: point away (suggested) and light an explosive charge to provide thrust. The explosive charge, otherwise known as the propellant, has undergone many redesigns as time has passed; gone are the days of gunpowder, most modern solid rocket boosters (SRBs) use composite modified double base (CMDB) propellants in its stead (Beckstead, 1982).

Despite a transition away from SRBs to liquid fueled rocket boosters having occurred in the space sector, modern militaries continue to use solid fuel for missiles and intercontinental ballistic missiles (ICBMs) for its rapid response time and ease of storage (Nuclear Threat Initiative, 2023). The United States is no different, continuing to utilize CMDB propellants in its ICBMs and air defense systems (Global Security, 2018; Center for Strategic and International Studies, 2023). Composite modified double base propellants are the culmination of knowledge that the world has acquired since beginning to blow things up. Despite the long name, the formula is simple enough: an oxidizer, a fuel, a binder, and then whatever additives you want mixed in (Anderson, 2004). Modern SRBs use aluminum powder as fuel, a trifecta of ingredients for oxidation- nitroglycerin, nitrocellulose (remember this one for later), ammonium perchlorate- and a resin as the binder.

The manufacturing process behind military grade propellant is dangerous; an obvious statement – after all, it has been developed to explode. However, in addition to the physical danger posed to those who work in the manufacturing plants, the surrounding community and environment are exposed to toxic and carcinogenic chemicals which are released before, during, and after the propellant is manufactured. Often, this dangerous work performed for national security is completed in small towns and communities which are left to bear the overwhelmingly negative consequences of the manufacturing process. The air, water, and group surrounding a manufacturing plant will always suffer, it is a forgone conclusion (Cairns & Dickson, 1973; Phipps, 1997). However, one would hope that the importance of military grade propellant manufacturing would provide precedent for safe manufacturing practices in and around the plants. The strategic importance alone should provide enough push for safety, as if the United States is expected to continue to provide military aid to the rest of the world, having your manufacturing facility explode would not be very helpful. Unfortunately, this hope is unfounded. The disposal and manufacturing of propellant has enormous negative consequences on the surrounding environment and community- an issue which must be addressed if the process is going to continue.

My thesis portfolio aims to address the issues surrounding propellant manufacturing through a technical and STS topic. The technical topic will focus on the manufacturing process of rocket fuel: the ingredient research, the mixing and casting, and the testing processes required to get from idea to reality in launching a rocket. The STS topic will focus on the effect that the large-scale manufacturing processes, which take place to provide the military with propellant, have on the surrounding communities and environments they take place within.

Technical Topic: Propellant Formulation for an M-Class Rocket Engine

A phrase often used to describe the ease of a task is “it is not rocket science.” The love of rocket science is how this capstone project came to be. The project explores the challenging task of designing, manufacturing, and testing a student researched and developed M-class solid propulsion system in an attempt to launch a rocket carrying a payload to 5000 feet above ground level. This project represents a significant leap in rocketry capabilities at the institution. In the university's history, never before have students worked together to create a sub-orbital rocket from the ground up. Every step along the way is crafted by the students, all we have been given is a height target. Beyond offering invaluable hands-on experience for undergraduate students, this project has the potential to fill crucial gaps in students' knowledge, laying the groundwork for future advancements and enhancing the university's standing in the field of aerospace engineering.

Due to the sheer size of the project, it has been broken into three groups: propulsion, aero-structures, and mechatronics / controls. These groups are further divided into subgroups focused on a specific part of the creation process of a rocket. To produce a mixture capable of propelling our rocket to 5000 feet, an ammonium perchlorate composite propellant (APCP) formula was chosen following thorough research. Taken and slightly altered from MIT's "Cherry Limeade" formulation, the solid propellant will power the M-class designated motor being developed by the team. Solid rocket motors are separated into several classes using the Latin alphabet as a guide; with each letter representing a doubling of total output thrust, or impulse (National Aeronautics and Space Administration, 2021; National Association of Rocketry, 2012). In order to reach the desired designation, the engine must have a total impulse between 5120 and 10240 Ns.

To formulate a propellant capable of producing the required thrust, 25-micron aluminum powder and both 200- and 90-micron ammonium perchlorate will be carefully combined with a resin binder (HTPB). Trial mixtures will be created to test the manufacturing process and samples to perform strand tests on (to determine burn rate of the fuel). The final deliverable will be carefully cast and shaped to maintain correct grain geometry before being inserted into the rocket engine. Barring any external interference, the propellant will gradually burn and propel the rocket to 5000 feet (or more!), delivering the glider payload to its target destination.

STS Topic: Impacts of Manufacturing Plants on the Communities They Inhabit

Radford is a small town in southwestern Virginia, home to about 17,000 people in 2023(US Census Bureau, 2020). Despite its small population, Radford is home to one of the most strategically important manufacturing plants in the United States: the Radford Army Ammunition Plant. The location of the only manufacturing facility in the whole United States capable of producing military-grade nitrocellulose, the United States military has a lot invested in the plant (Grymes, 2023). Established in 1941, the plant has produced different propellants over the years: black powder, TNT, nitroglycerine, etc. Despite its importance to the military industrial complex, the plant has suffered many issues over the years, with a multitude of deadly explosions and substantial amounts of toxic emissions being released into the nearby areas. Environmental degradation caused by the plant has been profound, with air quality around the plant being among the top 1000 toxic hot spots across the country and biodiversity in the surrounding waterways suffering from the release of harmful pollutants (ProPublica, 2021; Cairns & Dickson, 1973). The biggest culprit of this pollution has been the burning of waste materials produced from the production process. The manufacturing plant is Virginia's largest polluter, releasing nitrogen into the nearby waterways, heavy metals such as lead, mercury, and cadmium from burning of waste into the air, and other air pollutants from the manufacturing process (Phipps, 1997; Mastrangelo, 2018; Grymes, 2023).

Between the years of 1970 and 1985, nine major explosions occurred at the Radford plant, resulting in seven deaths, over 100 injuries, and millions in damage (Mintz, 1985).

Since then, there have been many more explosions and fires that have occurred at the plant, and to date there have been at least 40 deaths which have occurred since the facility's inception, (Otey, 2023). Besides the danger to those working in and around the plant from explosions and fires, the plant has regularly exceeded emission levels authorized by the state and has only recently reduced lead emissions to a point which the Virginia Department of Environmental Quality reported they were below ambient air standards (Mastrangelo, 2017; Virginia Department of Environmental Quality, n.d.). Following a new air quality permit being issued in 2021, the plant's allowance for open air burning of waste products was reduced by 51% (News Messenger, 2020). To meet the new requirements, construction began in 2022 on a new incinerator to process the waste products and in 2023, another new incinerator, scheduled to come online in 2026, broke ground (Wall, 2021; Gangloff, 2023). Despite these recent changes, community members continue to speak out about the release of harmful byproducts into the local atmosphere signaling a disconnect in allowable pollution between the operators and the community (Paulin, 2022; Harris, 2018).

To understand how each of the players have been involved, I plan to utilize the Social Construct of Technology (SCOT) developed by Trevor Pinch and Wiebe Bijker. "Advocates of SCOT argue that technology does not determine human action, but that rather, human action shapes technology" (Klett, 2018). Through the utilization of this framework, I will dive into the relevant social groups to the issue, interpretive flexibility of the issue, and the closure provided for the issue. By compiling the relevant social groups, it will be easier to see the impact that the plant has on every group, rather than only detailing a single group. Interpretive flexibility is the idea that a technology can have different meanings and/or interpretations based on the social group being analyzed and utilizing this concept will allow for multiple points of view to be understood. Closure, the point of agreement of the social groups, is the final goal of the SCOT methodology, and when reached, means the perceived problem is solved. Discovering the answers to these three concepts will let one look at the whole picture and see if the facilities in Radford benefit the surrounding community.

Research Question and Methods

This paper will seek to answer the question: what are the impacts of propellant manufacturing at the Radford Army Ammunition Plant on the surrounding communities and environment? This research question is important because propellant manufacturing (for both military and non-military uses) is a sector that will continue to exist for as long as there is conflict, and with the growing importance of environmental and community-wide impacts of different industries, analyzing the impacts that a (likely) permanent industry has will allow for the improvement and restructuring of facilities to better align with the push for environmentalism and positive community impact. The research methods utilized to answer this question will be case study analysis and policy analysis.

Case study analysis is a “research approach that is used to generate an in-depth, multi-faceted understanding of a complex issue in its real-life context” (Crowe et al., 2011). Utilizing it will allow a deeper insight into the environmental and communal impacts that propellant manufacturing causes. Sources will be gathered from scholarly websites and journals, local newspapers, and communication with locals to determine scientific and anecdotal beliefs about the plant and its impact on the area.

Policy analysis refers to tracing the development, passage, and implementation of a specific policy or set of policies. Information regarding the laws and requirements of pollution causing manufacturing will be investigated. The EPA's website and other government documents will be utilized to determine the rules set by the federal government.

Conclusion

Propellant manufacturing will continue to be a constant in our world for years to come, and so understanding the effects that it has on the world around it is incredibly important. My technical and STS topic hope to address the issues surrounding propellant manufacturing, on a small and large scale. The technical topic will focus on researching, manufacturing, and testing of propellant for use in powering a small rocket engine and will provide better insight into the real-world process to launch a rocket. The STS topic focuses on the impacts that propellant manufacturing has on its surrounding community to understand how to reduce the harmful effects it causes on the environment and people surrounding the plant. The hope is that propellant manufacturing facilities will utilize this research to improve their process of manufacturing, storing, testing, and disposing of their propellant to reduce the negative effects that it has on the environment and people surrounding the facility.

-1999 Words-

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