Body Development for Multi-Stage Spacecraft Design

Exploring the Shortcomings of Current Federal Regulation on the Environmental Impacts of SpaceX Rocket Launches in the U.S.

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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

As space flight becomes more prominent in our society with the rapid rise of private companies like SpaceX, it becomes more important to consider the environmental effects of repeatedly launching spacecraft. In 2023 alone, SpaceX has launched 61 rockets, with 35 of those using a Falcon 9 rocket (Kurkowski, 2023). Falcon 9 is one of SpaceX's reusable rockets, which reduces the cost per launch since the structure does not have to be rebuilt. These rockets have been frequently used to launch Starlink satellites, which are a SpaceX project with the goal of creating a constellation of thousands of small satellites to provide broadband internet coverage nearly worldwide (Starlink, 2023). With an undertaking of this scale, SpaceX is constantly launching rockets from several launch sites across the United States and the company is looking to increase the number of rocket launches by building additional sites. Under the National Environmental Policy Act (NEPA), before a rocket launch can occur at any launch site in the U.S., SpaceX must submit mission proposals and detailed descriptions of their planned operations so the Federal Aviation Administration (FAA) can issue permits and complete environmental evaluations in the form of Environmental Assessments (EAs) or Environmental Impact Statements (EISs) (Federal Aviation Administration, 2022).

With over 4,500 Starlink satellites in orbit, and potentially up to 42,000 total in the coming years, there is no sign that the frequency of these launches will diminish (Satariano et al., 2023). More launches also entail more launch sites to increase efficiency, but at a cost to the surrounding environment. As seen in Boca Chica, Texas, new launch sites disrupt the local wildlife and failed launches due to inadequate environmental assessment have negative impacts that could potentially become irreversible if nothing is addressed at the federal level, or if

commercial spaceflight companies fail to recognize and work to change these issues within their procedures (Kluger, 2023).

My thesis portfolio aims to address the issues surrounding rocket launches and the environment through a technical project and STS research topic. The technical project will focus on the process of designing, building, and launching a small-scale rocket within a team environment. The STS topic will focus on various SpaceX launch sites across the U.S. and will look at how the U.S. government and SpaceX are displaying technological determinism while managing the Starlink project and show how increased launch activity has impacted the surrounding environment at those locations, and its overall effect on global warming. The goal of this research is to answer: why have SpaceX Starlink missions using Falcon 9 rockets been allowed to function within current regulations while negatively impacting the environment and pollution levels at launch sites across the U.S.? From my research, my goal is to suggest possible courses of action at the federal and administrative level that could be taken to minimize the negative environmental impacts of rocket launches.

Technical Topic: Body Development for Multi-Stage Spacecraft Design

For my technical project, I am working within a team to design and build a multi-stage, small rocket, capable of carrying a payload of three cubesats using a solid propellant with the goal of reaching an apogee of 5,000 feet. This project is modeled from the Intercollegiate Rocket Engineering Competition (IREC) that takes submissions from rocketry teams around the world to launch a payload of 8.8 pounds to either 10,000 or 30,000 feet (Experimental Sounding Rocket Association). Since this is the first year this capstone is available, we are starting with smaller goals to eventually work our way up to the IREC. Working in the body subteam, we are looking

to design the main structure of the rocket that houses the cubesat payload, avionics equipment, parachutes, motors, and fuel. The most important aspects we have to consider are size and material.

The size of the rocket body determines how the components from the other teams and subteams are situated within the rocket. Therefore, we are in constant communication with the other teams to update the body dimensions based on their needs since we have more room to be flexible, while also keeping the surface area and mass as small as possible to reduce drag and fuel requirements.

We chose the body material based on research from other schools that have completed similar projects as part of the IREC. We chose to work with G12 filament wound fiberglass due to previous successes of other schools using this material, its high strength under pressure, low mass, and its lower manufacturing cost. Cost was a very important factor in this decision since our overall budget for this project is around $8,000 and carbon fiber tubes at our desired size are more expensive.

Each team must integrate their designs into the overall rocket so that we can begin running more comprehensive simulations using OpenRocket software and begin manufacturing. Our project is small-scale compared to a Falcon 9 rocket designed to bring a payload of Starlink satellites into low Earth orbit; however it is still important for us to work through the design process and see how it is applied in the actual spaceflight industry.

STS Topic: Exploring the Shortcomings of Federal Regulation on the Environmental Impacts of SpaceX Rocket Launches in the U.S.

The scientific desire for progress in the space industry has led to a drive for expansion and exploration that is considered more important compared to the long-term effects on our environment. In Merritt Roe Smith's *Technological Determinism in American Culture*, Smith analyzes technological determinism, the belief that "changes in technology exert a greater influence on societies and their processes than any other factor," as a driving force for progress in 19th century America (Smith, 1994, p. 2). For some of the foremost thinkers on progress, like Thomas Jefferson, "progress meant the pursuit of technology and science in the interest of human betterment (intellectual, moral, spiritual) and material prosperity" (Smith, 1994, p. 3). With new advances such as the electric telegraph, locomotive, and steamboat, many Americans saw technological determinism as a positive for society (Smith, 1994, p. 9). However, some argued that as technology continued to advance and industries started to boom, there was a sacrifice of "moral progress for material power" (Smith, 1994, p. 26).

Space exploration is the modern-day version of the U.S. westward expansion. It is the new frontier to be explored and the new technologies that allow us to get there create excitement for the possibilities of what we might find. The National Aeronautics and Space Administration (NASA) was at the forefront of U.S. space exploration, starting in the 1950's. The political pressure to beat the Soviet space program in the Space Race helped drive progress throughout the Cold War (Davis, 2023). However, NASA's primary focus is to "drive advances in science, technology, aeronautics, and space exploration to enhance knowledge, education, innovation, economic vitality, and stewardship of Earth" (Performance.gov). As the private sector has risen and made great strides in technological advancement, companies have shifted towards the pursuit of profit in addition to furthering exploration and asserting political and military dominance. SpaceX, in particular, has been a prominent force in this industry, winning over 60% of

commercial launch contracts. With the market value expected to grow to over $1 trillion by 2030, they have affirmed their position as “a leading player, with a well-established market position in satellite and payload launch services, satellite internet, and space tourism” (Kelly et al., 2023). As the private space industry concentrates its resources on growing this market, the focus shifts from developing technologies for human betterment to developing technologies for profit and reflects a desire for material power from progress.

SpaceX has been launching thousands of satellites with Falcon 9 rockets as part of their Starlink project beginning in 2019. Although this project aims to make a positive impact by providing worldwide internet access, the increase in Falcon 9 launches due to this project has already had a negative impact on global warming and the surrounding environment at various U.S. SpaceX launch sites. Falcon 9 rockets emit around 336,000 kilograms of CO2 per launch to bring an average payload into low Earth orbit (Kilgore, 2023). Rockets also emit gaseous and solid chemicals directly into the atmosphere, unlike other sources of pollution. With reusable rockets, launch chlorine and re-entry nitrogen oxide emissions damage the protective ozone layer. Currently, the ozone loss is small but has the potential to increase as spaceflight and space tourism become more common (Ryan et al., 2022). Additionally, these rockets eject black carbon, or soot, particles directly into the atmosphere, which is a problem because these particles absorb sunlight and transfer the heat into the atmosphere with about one million times the heat-trapping power as CO2. Greenhouse gasses like CO2 tend to stay in the atmosphere for years whereas black carbon tends to stay for about a week, meaning its effects tend to be more regional and can lead to health problems and poor air quality in that area (Schmidt, 2011). Since the Starlink project has yet to provide global coverage and the bandwidth isn’t as quick as desired, thousands more satellites are scheduled for launch in the coming years. The launch emissions

could then exceed millions of kilograms of CO2 and greatly increase the black carbon emissions, which is terrible in reducing the effects of global warming and shows the need for better understanding of the impacts of these launches before they become irreversible (Kilgore, 2023).

On the ground at the Boca Chica, Texas launch site, the U.S. Fish and Wildlife Service found that the activity at this site has caused a decline of endangered piping plovers surrounding the facility and has potentially harmed other wildlife, such as sea turtles and shorebirds, in the area. With additional launch sites being proposed in Georgia and Michigan, local officials and activist groups are worried based on the environmental effects already seen at existing launch sites and do not think the economic benefits are worth the risk. The proposed site in Camden County, Georgia has the potential to spread debris and wildfires over the Cumberland Island National Seashore, disrupting the habitats of endangered sea turtles and birds. Additionally, in Michigan, failed launches from a proposed spaceport near Lake Superior could contaminate the drinking water for local communities and lead to more harmful industrialization in that area (Brown, 2023).

These doomsday-sounding scenarios are not unfounded. In May, 2020, SpaceX launched one of their Starship rockets from the launch site in Boca Chica, Texas, which then exploded four minutes after liftoff (Kluger, 2023). Although Elon Musk considered the launch a success, Tweeting, “Congrats @SpaceX team on an exciting test launch of Starship!” environmentalists would argue otherwise (Musk, 2023). This explosion caused widespread damage to the surrounding area, with debris found within 385 acres of the launch site. In this case, the FAA’s EA, which is a concise document that reviews the purpose of a proposal, any alternative actions, and brief environmental impacts, resulted in a Finding of No Significant Impact (FONSI), meaning they did not complete an EIS, which is a more comprehensive extension of an EA that

looks more closely at alternative actions and the cumulative environmental impacts that this proposal may have (Citizens for a Healthy Community). Therefore, the FAA did not take steps to mitigate the potential risks to the surrounding environment (Kluger, 2023). This launch acts as an example of the negative effects that improper environmental consideration entails and shows the need for increased regulation and federal intervention in approving rocket launches moving forward as space activity increases. Similarly to the Starship rocket launch, the Starlink satellites themselves are categorically-excluded from environmental review under the Federal Communications Commission (FCC), meaning neither an EIS nor EA needs to be approved. Therefore, there has been no regulation on the materials or fuel sources of these satellites, leading to unknown, and potentially harmful, environmental impacts (Ryan, 2020).

Research Question and Methods

This paper will seek to answer the research question: why have SpaceX Starlink missions using Falcon 9 rockets been allowed to function within current regulations while negatively impacting the environment and pollution levels at launch sites across the U.S.? This topic is important because space flight is a rapidly growing industry, and it is necessary to know the impacts of continuously launching rockets on the environment before reaching a point where the effects are irreversible. To answer this question, I will analyze the existing policies relating to spacecraft launches and the environment, and conduct several case study analyses on specific launch sites in the U.S.

Policy analysis refers to tracing the development, passage, and implementation of a specific policy or set of policies. I will gather sources relating to EAs, EISs, and other federal regulations on spacecraft launches. I will also investigate incident reports from the failed launch

in Boca Chica, Texas to analyze the impacts and shortcomings of these policies. I will look for these sources from the FAA, other relevant, federal agencies, and SpaceX and further limit the scope to U.S. launches.

Case study analysis refers to an in-depth examination of a single situation. I will gather sources that have insights into environmental impacts and numerical data from specific launch sites, such as Boca Chica, Texas, and Cape Canaveral, Florida, to analyze how operations are conducted, what procedures are followed, and the subsequent effect on the environment. I will gather these sources from scholarly websites, journals, and SpaceX and NASA reports to fully capture the performance of each launch site.

Conclusion

Increased SpaceX launches to complete the Starlink constellation have negatively impacted the environment. This paper aims to address the environmental issues of rocket launches by completing a technical project and STS research. The technical topic will result in the development of a small rocket and a better comprehension of the engineering design process to prepare aerospace engineering students to enter the professional field. The STS research project focuses on the impacts of rocket launches on global warming and the local environment at various launch sites across the U.S.. The goal of this research is to better understand these effects and present possible courses of action to reduce harmful atmospheric emissions from rocket launches and protect the environment surrounding the launch sites. SpaceX and other private aerospace companies can use this research to improve their procedures before, during, and after launches to better understand and reduce their negative impacts on the environment. The FAA and other federal agencies can also use this research to recognize the need for more

comprehensive policy as spaceflight becomes more common. Both of these projects work to show the design process and impacts of rocket launches and can improve the environmental effects of the space industry moving forward.

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