DESIGNING A SOLID PROPELLANT ROCKET

LEANING ON COLLABORATION: THE IMPACT OF NASA'S NEWFOUND PRIVATE AND INTERNATIONAL DEPENDENCE ON MODERN SPACEFLIGHT

A Thesis Prospectus
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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

Fifty years after Neil Armstrong and Buzz Aldrin first set foot on the moon, the government agency that worked tirelessly to get them there has undergone significant changes in its operational philosophy. The end of the Space Race and the rise of private space companies left the National Aeronautics and Space Administration, better known as NASA, with yet another tough problem to crunch on a whiteboard: either keep the red tape in place and remain solely a government operation, or heed the coming shift of spaceflight and embrace the corporations and billionaires funding their own personal space ambitions. My STS deliverable will investigate the decision of NASA to embrace private and international sector collaboration in the development of spacecraft, ultimately addressing the following question: how does NASA's newfound dependence on collaboration contrast with previous mission philosophies, and what are the implications for the future of spacecraft development? This analysis will examine the vast network of actors present in a large space operation, hoping to shed light on the decision of NASA to pursue a collaborative operational approach for Artemis.

My technical project lies on a much smaller scale but will hopefully provide insight into the use of collaboration to execute an aerospace mission. My exploration aims to design a solid rocket capable of delivering a small payload to an altitude of 5000 feet before returning safely to the ground. As the participants in the new capstone project for the aerospace engineering program understand, the project requires excessive collaboration, communication, and coordination between several sources of the University to achieve success, not unlike NASA's endeavors.

My Prospectus will begin with an overview of the technical deliverable, describing the process of designing and building the propulsion system of the rocket, as well as illustrating the collaborative nature of the endeavor. Next, I will discuss the STS topic, beginning with a brief historical anecdote to provide context, and ending with an overview of the research methods that I will conduct for the final product.

Technical

The design of a solid rocket capable of reaching advanced altitudes undoubtedly requires multidisciplinary expertise in aerodynamics, avionics, and materials science. However, the technical deliverable will focus on the propulsion of the rocket, which includes solid motor design, propellant formulation, and heat regulation. The project begins with thorough research into the inner workings of a solid rocket motor. In this context, “solid” refers to the solid state of matter of the propellant that is densely packed into the combustion chamber prior to firing.

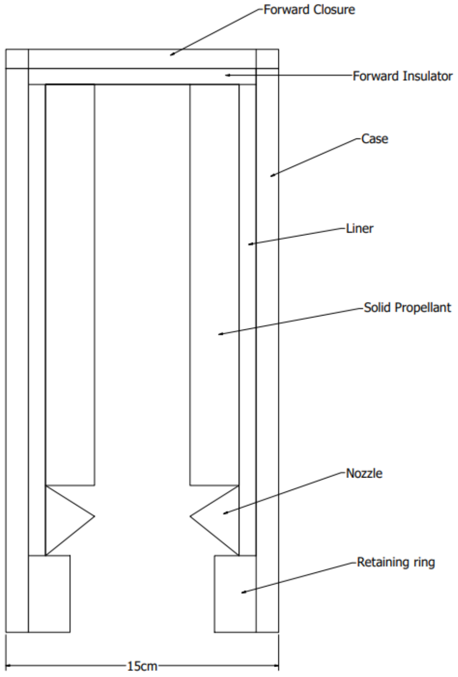

Figure 1: Cross-section of a cylindrical solid rocket motor

The above cross-sectional diagram reveals the complex nature of designing a solid rocket motor. Research conducted by my propulsion subteam revealed several design considerations that required a corresponding decision. Many of these considerations also required information from the aerospace structures subteam. Some examples of this include the diameter of the rocket, the thickness of the casing, and the maximum expected stress on the liner. The rocket diameter, for example, has emerged as an issue that requires significant collaboration to problem-solve. The larger the rocket diameter, the more weight the motor will need to propel, and the more propellant that will be required to fuel the motor (Nakka, 1997). However, increasing the power of the rocket only increases the stress on the parachutes on the outside of the rocket, requiring input from the structures and mechatronics teams. In contrast, decreasing the diameter of the rocket increases the pressure on the outside casing and the supporting fins, requiring input from the structures team. The complexity of the issues at hand, as well as the importance of clear coordination and collaboration between subteams, cannot be overstated.

Possibly the most dangerous branch of the project involves formulating the propellant that will eventually burn to thrust the rocket into the air. Formulating the propellant requires closely following a detailed list of instructions of how to mix several ingredients in a specified manner, many of which can result in serious injury and illness if improperly handled (Nakka, 1997). The novelty of the capstone project reared its ugly head in the research of this process; the lack of access to many of the required chemicals resulted in a search across many sources, both University affiliated and otherwise. The final concoction was chosen because its ingredients could be purchased from the University of Virginia High-Powered Rocketry team.

Once the solid propellant is made, a decision must be made on how exactly to pack it into the rocket. There exist several shapes, or *fuel grain geometries*, that a solid propellant can be packed into. Each fuel grain impacts the way the rocket fires in several different ways, but most notably is how the thrust of the rocket varies with time (Nakka, 1997).

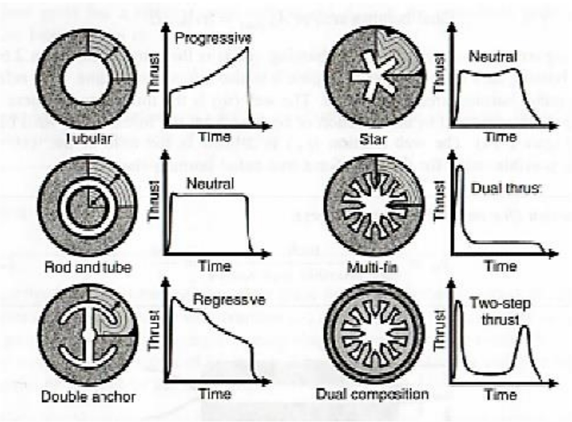

Figure 2: Fuel grain geometries and their associated thrust profiles

Deciding which fuel grain best fits the goals of the rocket once again requires collaboration with the other subteams, specifically the structures subteam. A multi-fin geometry could cause excessive vibrations at the beginning of the launch which could lead to a catastrophic failure in a supporting structure. A dual composition geometry could lead to the melting of the casing if the selected material could not withstand two cycles of high heat in rapid succession (Nakka, 1997). One can find many examples of the importance of collaboration in an aerospace project.

STS Topic

In August 2019, NASA officially unveiled the Artemis program with the goal of "[using] innovative new technologies and systems to explore more of the Moon than ever before. It will collaborate with commercial and international partners to establish sustainable missions by 2028," ("NASA Unveils Artemis," 2018). This influx of commercial and international partnerships can be seen in almost all aspects of the Artemis program. In addition to this program, NASA has advertised its willingness to cooperate with the private sector across several areas of the space and aviation industries (Martin, n.d.). Similarly, Artemis will leverage connections across the international space community, including the European Space Agency, Italian Space Agency, and German Aerospace Center (US Department of State, 2022). However, NASA did not always display this willingness to collaborate with other sectors. During the Apollo program, which successfully landed twelve astronauts on the lunar surface in the late 1960s and early 1970s, NASA operated almost exclusively as the primary designer and manufacturer of Apollo mission concepts and hardware. Analyzing this stark contrast through the lens of Actor-Network Theory, one can decipher truths about how spaceflight has changed and where it is headed.

The contrast between Apollo and Artemis through Actor-Network Theory can be best digested by downscaling the two large programs to a common mission component, such as the service module. For both Apollo and Artemis, the service module attaches to the crew module and provides fuel, power, and water to the crew module until its eventual jettison at the end of the mission ("European Service Module," 2021).

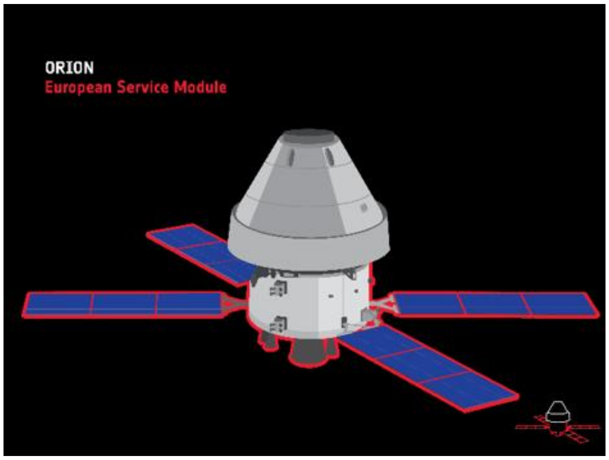

Figure 3: Overview of the European Service Module, a key Artemis mission component

Unlike the service module for the Apollo program, which was designed and built almost entirely by NASA (Drucker, 1972), the Artemis service module was designed by Airbus and exported from the European Space Agency (ESA) as the European Service Module ("European Service Module," 2021). Although still fitting to NASA's mission requirements, the European Service Module represents a divergence in NASA's typical philosophy. Through the lens of Actor-Network Theory, NASA no longer acts as a non-human central actor in the Artemis sphere. Rather, it now acts as a supporting actor to the European Space Agency and Airbus. Not only does this divergence provide clues to the collaborative future of spaceflight, but it also emphasizes a key tenet of Actor-Network Theory: the centralization of non-human actors, such as corporations, challenging the traditional dominating role of a space agency in its own missions (Sismondo, 2010). Ultimately, the Artemis program represents a shift from one centralized actor in the space industry to a distributed network of actors, all working in conjunction for a common goal. This allows Actor-Network Theory to effectively analyze the topic.

The analysis of this topic leads to several questions regarding the ethicality of collaboration in large space missions such as Artemis. In a broad sense, the goals of the Artemis program beckon a discussion into what precedents will be set for future missions, as well as what kind of future Artemis wants to create (McBrayer, 2023). For instance, tribal nations raised objections when NASA purposefully crashed their Lunar Prospector spacecraft into the moon in 1999, with the native peoples showing concern for the spiritual sanctity of the moon (Pirtle, 2023). Among several others, these ethical issues intensify with the inclusion of international and private partners, who may or may not agree with moral qualms posed by both NASA and American stakeholders. In a more technical sense, the use of collaboration in a large space program presents several challenges in shared accountability. Unlike the Apollo program, NASA no longer makes the final engineering decisions for space vehicles. For instance, the European Service Module must undergo several crucial safety checks throughout its development, all of which are carried out by ESA-affiliated engineers and technicians before being fitted into the NASA mission. This presents a significant challenge in the NASA team's responsibility for endorsing the safety of the vehicle due to not having oversight and approval roles in the design process (Kennedy, 2018). Ultimately, my STS topic will leverage these ethical considerations in an encompassing analysis of the new program.

Several research sources can serve as the foundation of this analysis, including primary sources from the 1970s that describe NASA's motivation behind keeping Apollo vehicle manufacturing largely in-house. Specifically, NASA's Technical Reports Server provides records of documents from all eras of space missions, including those from Apollo. The server contains many key primary documents that examine the effectiveness of NASA's operational strategies during the Apollo program, allowing for an effective comparison to Artemis.

Key Texts

1. Artemis, Ethics and Society: Synthesis from a Workshop

   This document, published in September 2023, serves as an overview of the ethical and societal dilemmas that surround the Artemis program. The included study questioned several individuals about issues such as cultural reflection, international cooperation, and technical accountability. This source describes meaningful background information about several issues that can arise in the case of international cooperation and outlines ethical challenges that a new international space program would need to maneuver, a key consideration of my STS topic about the implications of international cooperation in spaceflight.

2. NASA Unveils Artemis

   This magazine, published by NASA in August 2019, features a full-page article about the announcement of the Artemis program to the public. The article highlights NASA's goals for the program, which include testing new technology, landing the first woman on the moon, and collaborating with private and international partners. NASA's verbiage in the announcement of this program is key to my STS topic; the goals they emphasize pertain to how NASA wishes for their program to be digested by the public, providing insight into the operational philosophy of the program.

3. Project Management in the Apollo Program: An Interdisciplinary Study

   This document is a joint study conducted by NASA and Syracuse University to investigate the project management strategies that helped and hindered the Apollo program. The study focuses on several aspects of project management, including the broad organizational structure of the program, the use of in-house labor, and NASA's relationship with contractors. The report provides several conclusions, mostly centered on how the in-house development of Apollo vehicles expedited the design and manufacturing process, allowing the program to operate at the pace that it did. For my STS topic, I plan to use this analysis to contrast Apollo with the collaboration-heavy Artemis program, which has encountered several obstacles associated with exported design work.

4. Public-Private Partnerships: NASA as Your Business Partner

   This presentation provides an overview of NASA's willingness and commitment to partner with private space entities to achieve success in the space industry. The presentation argues that the government should play a crucial role in expediting private space operations. NASA argues that partnerships can offer access to world-class facilities, spur innovation, and ultimately develop a competitive US commercial space sector. NASA's advertisement of their partnerships provides crucial context to their decision to use private sector contracting in Artemis missions, a key tenet of my STS topic.

Bibliography

Drucker, E., Pooler, W., Wilemon, D., & Wood, B. (1972). *PROJECT MANAGEMENT IN THE APOLLO PROGRAM: AN INTERDISCIPLINARY STUDY*. NASA, Syracuse University.

European Service Module. (2021). NASA.

John C. Stennis Space Center. (2019). NASA unveils Artemis. *Lagniappe*, *15*(7), 1–14.

Kennedy, J. J. (2018). *Balancing Public & Private Partnerships for Future Human Spaceflight*.

Martin, G. (n.d.). *Public-Private Partnerships: NASA as Your Business Partner*.

McBrayer, K. (2023, October 23). *Artemis and Ethics Workshop Lessons Learned*.

Nakka, R. (1997). *Richard Nakka's Experimental Rocketry Web Site*.

Office of the Spokesperson. (2022). *International Cooperation in NASA's Artemis I Program*. US Department of State.

Pirtle, Z., McBrayer, K., & Beauchemin, A. (2023). *Artemis, Ethics, and Society: Synthesis from a Workshop*. NASA Office of Technology, Policy, and Strategy.

Sismondo, S. (2010). *An Introduction to Science and Technology Studies* (Second Edition). Wiley-Blackwell.