Undergraduate Thesis Prospectus

Design and Testing of a Student-Built Hybrid Rocket Motor

(technical research project in Aerospace Engineering)

The Apollo Program: Vanity Project or National Voyage of Scientific Discovery?

(sociotechnical research project)

by

Alexander Gorodchanin

November 8, 2024

technical project collaborators:

UVA Project ATLAS team members

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.

Alexander Gorodchanin

Technical Advisors: Chloe Dedic and Daniel Quinn, Department of Mechanical and Aerospace Engineering

STS Advisor: Peter Norton, Department of Engineering and Society

General Research Problem

What is the importance of undertaking engineering projects with no immediate practical purpose?

The pursuit of scientific progress begins with a step into the unknown, where there is no guarantee of success or growth. When the Wright brothers first launched their Flyer in 1903, it was not intended to be the genesis of modern aviation. Orville and Wilbur Wright created the first airplane to prove that controlled flight was possible, and despite its inefficiencies and impracticality, the Flyer laid the foundation for all airplanes to come. In the pursuit of satisfying curiosity and challenging what was thought to be possible, the Wright brothers opened the door for a new form of transportation for humanity, which has since developed in ways they likely could not have predicted. Many engineering projects, both amateur and professional, begin much the same way. Engineers undertake projects to test their skills, or to push the envelope without knowing if it will bring long-lasting benefits. Such projects require time and material, however, and it is difficult to justify speculative efforts when there are more tangible gains to be found elsewhere. Is it right to bank on unintended benefits from a vanity engineering project rather than investing resources into things like social programs?

Design and Testing of a Student-Built Hybrid Rocket Motor

Given limited resources and a tight schedule, how can a team of mechanical engineers develop and experimentally evaluate a hybrid rocket motor?

The goal of the UVA ATLAS capstone project is to create and test-fire a small-scale hybrid rocket motor (which uses liquid oxidizer and solid fuel grain for combustion) and to provide a platform to test different 3D printed designs of oxidizer injectors to experiment with hybrid rocket performance. There are 19 students on the project, advised by Professors Quinn and Dedic under the MAE department.

Hybrid rocket motors are simpler than liquid motors (which use liquid fuel and oxidizer) but have less consistent performance, which makes modeling and predicting combustion difficult. Though these motors are less widespread than their counterparts, they show promise for small-scale applications (such as in student rocketry teams) due to their safety and simplicity, as well as being more environmentally friendly (Rezaei and Soltani, 2014). While not currently an ideal choice for large-scale professional applications, further research and development may make hybrid motors a more promising option for cheap, efficient, and eco-friendly rocketry. The largest obstacle for modern hybrid rockets is maintaining efficiency as the fuel grain burns away, as the thrust is dependent on the oxidizer to fuel (O/F) ratio, which varies across the combustion chamber (Chiaverini and Kuo, 2007). Oxidizer injection at the aft of the chamber has been a recent solution to this problem, but it increases the complexity of the motor (Karabeyoglu, Toson, and Evans, 2014). Instead, there may be some fuel grain and oxidizer injector designs that optimize the O/F ratio for a long burn, leading to efficiency similar to that of a liquid motor. The ATLAS motor will test multiple configurations of custom-designed injectors and fuel grains to determine whether such a route is viable in increasing hybrid rocket performance.

The motor will need to be robust in order to allow for multiple test fires, and the design is constrained heavily by the available parts. If pieces cannot be found in the dimensions needed, they will need to be manufactured, which is difficult and expensive when working with materials that must withstand the temperatures and pressures of combustion. Safety remains the highest priority, as UVA has no standing procedure for testing hybrid motors, so the design will be pitched to an assembled board of professional engineers to determine whether it will be safe to fire. This project will also test the viability of additive manufacturing, as the fuel grain and injectors can both be 3D printed, allowing for cheap testing of intricate designs. If the ATLAS project yields a cost-effective, functioning motor, it may lay the groundwork for the future development of larger motors at UVA, as well as prove the viability of prototyping hybrid motor components, which could extend into professional use.

The Apollo Program: Vanity Project or National Voyage of Scientific Discovery?

How have social groups in the United States acted to encourage or discourage the Apollo Program?

During the Cold War, U.S.-Soviet tensions drove the development of space programs for both nations. Behind in the race, the United States government, under President Kennedy, chose to commit its efforts towards a manned Moon landing. The resulting Apollo program would go on to cost around $180 billion in today's dollars, with the cost and purpose of the program becoming a source of debate for several groups. President Kennedy represented the government's pioneers, in favor of the program for the symbolic value it had. Others saw political and technological power in the act, namely Lyndon B. Johnson and other anti-Soviet proponents. Budget critics both within and outside of the government criticized Apollo for its

cost, believing that social issues and other programs were more important than a Moon mission. Finally, private contractors were in favor of the program for their own economic benefit and belief that further technology could be developed through the aerospace industry's growth.

Kennedy was initially wary of the cost of the Apollo program, but ultimately committed. To raise public support, he delivered a speech where he proclaimed, "We choose to go to the Moon in this decade, and do the other things, not because they are easy, but because they are hard; because that goal will serve to organize and measure the best of our energies and skills…" (Kennedy, 1962). To Kennedy, the technical challenge of the project ultimately served as its justification, likening the program to the act of climbing Everest. Even with no immediate benefit, proving that the goal could be met would be a success.

Lyndon B. Johnson represented the Cold War-focused sect of the government, and believed that Apollo could "be justified as a solid investment which will give ample returns in security, prestige, knowledge, and material benefits" (Launius, 2024). Johnson favored the Moon landing as a political and technological move, and pushed Kennedy to call out representatives for not supporting the program despite the Soviet threat, and often used anti-communist rhetoric to gain funding. James Webb similarly gained support for the program by appealing to fears of Soviet technological dominance.

To Ralph Abernathy and similar social advocates, the Apollo program was a misallocation of resources. At a rally at Cape Canaveral during the Apollo 11 launch, NASA administrator Thomas Paine met Abernathy, where he said, "the money for the space program … should be spent to feed the hungry, clothe the naked, tend the sick, and house the shelterless…" (Launius, 2014). President Nixon also disliked Apollo's cost, urging that "space expenditures

must take their proper place within a rigorous system of national priorities" during a statement regarding NASA's post-Apollo plans (Nixon, 1970).

Apollo built upon the growing military-industrial complex, and was responsible for the growth of many aerospace companies. To many companies, aiding Apollo was a way to gain money and notoriety. McDonnell Douglas received contracts to create multiple Saturn V third-stage rockets, which, in 1967, brought "McDonnell Douglas' total work on the S4B rocket to $957 million" (Wall Street Journal). In a newspaper, Kodak cameras were said to have taken "the first color close-up stereo photos of the Moon's soil", likely an attempt to further public opinion of the company through appealing to public sentiments about Apollo (New York Amsterdam News, 1969).

Gisler and Sornette aimed to show that the Apollo Program was a "societal bubble", an event of enthusiasm and innovation that did not yield significant return for the cost. The authors hypothesized that Apollo fit the market definition of a bubble, as it was a great risk that led to scientific advances and stimulated the economy, but at a cost that did not match its return. They concluded that over-eager political officials showed favoritism towards the space program, and that their mobilization of the nation snowballed into a rush for the Moon that ultimately could not be financially or technologically justified (Gisler and Sornette, 2008). This research coincides with the topic of this paper, offering an explanation for the nation's willingness to take massive risks via the enthusiasm surrounding space travel at the time, despite the ultimate lack of payoff. Perhaps advances made through more modern spaceflight can still be attributed to interest from the initial Apollo bubble.

Hooks and McQueen attribute America's underdeveloped welfare systems to World War II's economic mobilization, namely in aircraft manufacturing. They believe that the growth of the military-industrial complex allowed a streak of Republican victories, stunting the development of welfare due to an influx of jobs and economic growth. It was also found that the influx of non-white workers in aircraft manufacturing contributed to the urban racial tensions that would become one of America's top issues throughout the century (Hooks and McQueen, 2010). This research shows that there can always be unintended social effects from large economic shifts, calling into question the benefits of Apollo's development of industry.

Witko examined how public opinion of defense spending was influenced by Soviet actions and the rhetoric used by political elites. He concluded that the public was not reacting to Soviet aggression, but to American politicians making belligerent statements, stating that "the public appears reliant on U.S. political leaders to make sense of complicated, international political events" (Witko, 2003). Witko deems this unsettling, as politicians with an interest in defense spending could manipulate public opinion for their own benefit. As such, the Cold War sect of Apollo supporters should be examined more closely, as they may have been deliberately upselling the conflict as a means to secure funding for the project, either for personal gain or out of genuine fear of the enemy.

In studying the connection between aerospace contractors and the U.S. government during Apollo, Turcat (2008) examines the economic causes and effects of Apollo's contracting. He investigates which states saw the greatest benefits from the program and how politics drove the choice of using private contractors. He finds that Apollo was a means for the government to invest in the growth of R&D throughout the nation, and that the civilian aerospace sector is one of Apollo's most successful "spin-offs". The increase in money in the aerospace industry and a

growth of scientific majors (with universities citing Apollo as a large reason for engineering interest) coalesced into a post-Apollo boom of private aerospace companies, which would go on to make money through military/space contracts alongside their civilian work. This can be argued as a positive economic output of Apollo, disconnected from the program's dismal immediate gains.

References

Chiaverini, M. J. and Kuo, K. K. (2007, May 1). Fundamentals of Hybrid Rocket Combustion and Propulsion. American Institute of Aeronautics and Astronautics, Inc.

Gisler, M. & Sornette, D. (2008, November). Exuberant innovations: the Apollo program. (Web of Science).

Hooks, G. & McQueen, B. (2010, April). American exceptionalism revisited: The military-industrial complex, racial tension, and the underdeveloped welfare state. *American Sociological Review, 75(2),* 185-204 (Web of Science).

Jones, H. W. (2018). NASA's Understanding of Risk in Apollo and Shuttle. In *2018 AIAA SPACE and Astronautics Forum and Exposition* , 5235. https://ntrs.nasa.gov/api/citations/20190002249/downloads/20190002249.pdf

Karabeyoğlu, A., Toson, E., & Evans, B. (2014, July 28-30). 'O/F shift' in hybrid rockets. In *50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference 2014*, 5237-5255. Curran Associates (Google Scholar).

Kennedy, J. F. (1962, September 12). We choose to go to the Moon. *Speech delivered at Rice University, Houston, Texas on*, *12* (Google Scholar).

Kodak Film Used During Apollo 12. (1969, Dec 20). New York Amsterdam News (1962-), 39. (ProQuest Historical Newspapers: Black Newspapers).

Launius, R. D. (2014, June 6). *The Apollo 11 Mission and the Challenge of Solving the Plight of the Poor. Roger Launius's Blog. https://launiusr.wordpress.com/2014/06/06/the-apollo-11-mission-and-the-challenge-of-solving-the-plight-of-the-poor/*

Launius, R. D. (2024, September). *Constructing Apollo: The American South and the Moon Landings.* In *NASA and the American South,* 13-35. University Press of Florida.

McDonnell douglas gets added apollo contracts. (1967, Oct 05). Wall Street Journal (1923-), 10 (ProQuest Historical Newspapers).

Nixon, R. M. (1970, March 7). *Statement About the Future of the United States Space Program.* The American Presidency Project. https://www.presidency.ucsb.edu/documents/statement-about-the-future-the-united-states-space-program

Rezaei, H., & Soltani, M. R. (2014, November). An analytical and experimental study of a hybrid rocket motor. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, *228*(13), 2475-2486 (Web of Science).

Turcat, N. (2008). The link between aerospace industry and NASA during the Apollo years. Acta Astronautica, 62(1), 66-70. (Web of Science).

Witko, C. (2003, July). Cold war belligerence and US public opinion toward defense spending. *American Politics Research, 31(4),* 379-403 (Web of Science).