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

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

Noah Hassett

Spring 2024

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

Advisor

Joshua Earle, Department of Engineering and Society

Introduction

On July 20th, 1969, the first human boots stepped on the surface of the moon, forever immortalizing Neil Armstrong and Buzz Aldrin as pioneers of the last frontier. This triumph, the result of almost a decade of grueling work and sacrifice, captured the imaginations of millions around the globe. The Apollo program, initiated by the National Aeronautics and Space Administration (NASA) in the early 1960s, represented the climax of space exploration during the Space Race era, cementing the United States as the ultimate spacefaring nation. In the coming years after that famous Apollo 11 mission, ten more astronauts would set foot on the lunar surface, performing experiments and documenting their findings. However, NASA would choose to cancel the Apollo program in 1972 due to a lack of funding, and the moon has remained uninhabited since.

Flash forward to the modern day, and the age of space exploration has appeared once again. The Artemis program, aptly named after the twin sister of the Greek goddess Apollo, represents NASA's commitment to return humanity to the lunar surface, and even to prepare for a far-flung crewed mission to Mars within the century. Artemis heralds a renaissance in space exploration, characterized by cutting-age technology, progressive mission goals, and most interestingly, private sector and international cooperation.

In this paper, I investigate the use of cooperation in modern crewed spaceflight, specifically by comparing the Apollo and Artemis programs. By infusing Actor Network Theory, I will analyze the networks involved in both spaceflight programs, shedding light on the decision to implement international and private cooperation for Artemis. Ultimately, I argue that the presence of a decentralized actor network structure in the Artemis program permits the economic and engineering design conditions for a human spaceflight program to succeed in the twenty first century. I begin this paper with background information on the history of the Apollo program, followed by an overview of the objectives and accomplishments of the Artemis program. Next, I introduce the relevant frameworks that will be used for analysis, as well as the utilized methods. Next, I begin the analysis, where I use the framework with the relevant context to investigate why Apollo succeeded to the degree that it did. Shortly after, I apply this analysis to the Artemis program to answer the research question. Finally, I end the investigation with a discussion of the implications of the analysis.

Background: Apollo Program

In 1961, NASA conceived the Apollo program to land an American on the moon. Several factors led to Apollo's creation. In 1957, the Soviet Union successfully launched a small satellite, Sputnik 1, proving that the Russians possessed greater militaristic and technological capabilities than the United States, frightening the public and stoking fears of American nuclear inferiority. One year before his assassination in 1963, President John F. Kennedy issued a powerful speech that called for Apollo to land a man on the moon before the end of the decade, catalyzing and accelerating the effort. Apollo was not the first American space program – it was preceded by the Mercury and Gemini programs which helped to develop American space capabilities throughout the mid-1960s in preparation for a moon mission. Several sacrifices were made to land humans on the lunar surface. Particularly, three astronauts died in the first official Apollo mission, Apollo 1, due to a pre-flight fire on the launchpad in 1967. Despite these setbacks, Apollo 11 successfully landed two astronauts on the lunar surface in 1969 (Mann, 2020).

As was true with most of the government's dealings throughout the Cold War, development and design of spacecraft during the Apollo program occurred under tight government oversight. NASA worked closely with private contractors to design, build, and test several spacecraft components. The program received virtually zero contributions from international countries or partners, likely due to the high risk associated with sending humans to the moon in such an accelerated timeframe (Drucker, 1972). Additionally, the geopolitical landscape of the era certainly shaped the technical decisions of the era. NASA recognized that the United States was engaged in a race to the moon with the Soviet Union. Any international cooperation, even the simplest collaboration, risked interception by adversaries, damaging the United States' bid to ensure the first boots on the lunar surface would be American.

Background: Artemis Program

Since the moon landing of Apollo 17 in 1972, no humans have returned to the lunar surface. However, a combination of factors led NASA to establish the Artemis program in 2017. First, the moon remains an object of key interest to NASA and the scientific community. Re-establishing a human presence on the moon, including building a permanent lunar base, would allow for advanced experiments and studies, building on previous knowledge of the history of the moon and our understanding of sustained human spaceflight. Second, NASA hopes that the technology and protocols used throughout the Artemis missions will serve as a foundation for a future crewed mission to Mars. NASA intends for one such example of this new tech, the Lunar Gateway space station, to orbit the moon and serve as a communications hub, science laboratory, and habitation module for the astronauts (Lagniappe, 2019). Third, NASA intends for the program to land the first woman and first person of color on the moon. It is no secret that throughout the Apollo program, each of the twelve astronauts to step foot on the lunar surface were white men. Artemis provides the opportunity for more diverse crew members that can inspire the next generation of astronauts (McBrayer, 2023).

Finally, and most relevant to this investigation, Artemis provides the opportunity for NASA to collaborate with several private and international aerospace partners (NASA, 2020). The rise of private aerospace entities has led the space industry to make a rapid shift. Companies such as SpaceX, Blue Origin, and Virgin Orbit represent some of the premier private space entities funded by eccentric billionaires. Additionally, NASA has embraced international space organizations such as the European Space Agency, Japanese Aerospace Exploration Agency, German Aerospace Center, and Italian Space Agency, among others (US Department of State, 2022). It is important to note that as of 2024, only one of the three scheduled Artemis missions has occurred. Artemis 1 launched in November of 2022, sending the uncrewed Orion spacecraft on a 25-day journey to the moon and back to test its onboard systems. NASA scheduled Artemis 2, a crewed flyby of the moon, for September 2025. However, it will likely undergo delays. Finally, Artemis 3 will land the crew on the moon no earlier than 2026 (Donaldson, 2024).

Methods and Frameworks

To effectively compare the Apollo and Artemis crewed spaceflight programs, I utilized Actor-Network Theory (ANT) as a sociotechnical framework that I can base my analysis on. ANT will provide insight into the organizational structure between the two programs. Specifically, ANT showcases the shift in the central actor between the Artemis and Apollo programs. The framework can shed light on the decision to alter the operational philosophies of two programs with such similar technical goals, with the network visualizations representing a key method of discerning these choices. I then began my preliminary research.

The declassified nature of the Apollo program allowed me to access documents dating back to the 1960s and 1970s. Particularly, I used the NASA Technical Reports Server (NTRS), an online open-source database that contains thousands of technical documents across the agency's six-decade history. Of the documents available, I found the most value in those pertaining to the organizational structure of the Apollo program, particularly reviews and studies of utilized work hierarchies and supply chains. For Artemis, I found several documents pertaining to the mission goals and motivations behind the program, which I also plan to incorporate into my analysis.

Undoubtedly, the Artemis and Apollo programs each synthesized hundreds of departments, each with their own sub-teams and subtasks, to achieve their end goals. Exhaustively analyzing these programs would be detrimental to the study's focus. Consequently, I chose to use a specific spacecraft component present in both programs as a proxy for analyzing their entirety.

During the Apollo program, the Command Module (CM) served as the main living quarters for the three astronauts as they traveled to and from the moon over the course of roughly eight days. The conical-shaped capsule, approximately the size of a walk-in closet, featured a large cockpit area where the astronauts could monitor and control their spacecraft. The limited size of the CM meant limited storage; the Service Module (SM) attached to the rear of the CM and provided this exact functionality. This cylindrical module stored air, water, power, fuel, and propulsion in the form of a rocket motor for the astronauts. Together, the two spacecraft formed the Command and Service Module (CSM) (Mann, 2020).

Figure 1: The Apollo CSM, composed of the conical Command Module attached to the cylindrical Service Module, with a rocket motor in the rear

Flash forward to the modern Artemis program, and the CSM configuration has remained largely intact, albeit with slight modifications. The Orion capsule serves as the Artemis analog for the Apollo CM, seating four astronauts and allowing them to control the spacecraft from inside the cabin. Similarly to the Apollo SM, the European Service Module (ESM) attaches to the rear of Orion and provides essential storage and navigation ability (NASA, 2021).

Figure 2: An artist's rendition of the conical Orion capsule attached to the cylindrical European Service Module

The key comparison metric lies in the source of the design of these two sets of vehicles. While the Apollo CSM was developed entirely by American-based companies with direct oversight by NASA, the Artemis ESM is overseen by the European Space Agency, and is a product of Airbus, a European aerospace company (NASA, 2021). Consequently, unique challenges have appeared in its integration with Orion and the general Artemis program. I have centered the ANT framework on this interesting dynamic, hoping to unearth insight into the motivations behind the decision to operate development in this way. A unique advantage of ANT lies in its ability to describe complex relationships in terms of the central and supporting actors. I believe this idea fits nicely with the changes implemented in Artemis after Apollo; NASA now collaborates with the European Space Agency in design, instead of serving in a primary oversight role.

I also managed to briefly speak with an anonymous employee of Lockheed Martin, the American corporation tasked with designing and manufacturing the Orion capsule for the Artemis program. I asked if there existed any challenges associated with integrating the Orion capsule with the ESM, and how those challenges have influenced the state of the program.

Analysis: Why Apollo Worked

The Apollo program stands as a pinnacle of efficiency and collaboration, instrumental in orchestrating mankind's journey to the moon. However, the success of the program's organizational structure may have more to do with the network of actors that supported the project than one might expect. As we unravel the organizational intricacies of the Apollo program, we can gain insight into the actor network that propelled humanity to the lunar surface, eventually applying that to Artemis.

The success of such a high-profile program in such a short period of time has prompted third party investigations of Apollo's organizational structure. One such study, conducted as a joint exploration by NASA and Syracuse University in 1972, investigated Apollo's composition and hierarchy. The report found that the Apollo program was divided into three main groups: headquarters, field centers, and contractors. Headquarters was given complete administrative control and resource control over the total project, including final technical authority. The field centers were specialized NASA facilities across the United States that took on crucial roles in the design, training, and testing of mission protocols and equipment. Some notable field centers of the program include the Johnson Space Center, Kennedy Space Center, Marshall Space Flight Center, Goddard Space Flight Center, and Langley Research Center. The contractors were a set of high-profile American defense companies that NASA awarded contracts to design and manufacture select spacecraft based on provided specifications and guidelines. Some examples of these contractors include North American Aviation, Grumman (today Northrop Grumman), General Electric, and Boeing (Drucker, 1972).

The design and manufacturing of the Apollo Command and Service Module (CSM) represented a monumental effort by all three of these entities. In particular, the Command Module (CM) was designed and manufactured by North American Aviation. Analyzing this complex sociotechnical system using Actor Network Theory (ANT) reveals the underlying network that allowed the Apollo program to succeed in the way that it did. To construct the network, one must first consider all actors involved, both human and non-human, in creating the CSM. Then, we can use arrows to display the flow of influence throughout the project.

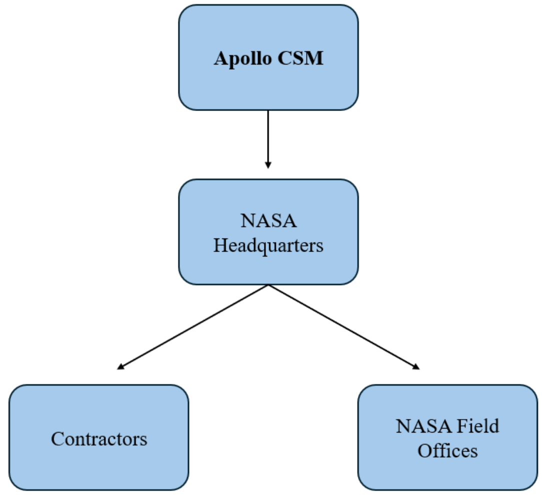

Figure 3: A network diagram of the organizational structure that led to the creation of the Apollo CSM

The diagram includes both the human actors, including the NASA headquarters, field offices, and contractors, as well as the non-human actors, in this case as the Apollo CSM spacecraft. Some key observations stand out. First, the flow of influence is hierarchical, meaning that more powerful actors can influence less powerful actors below them, but not the other way around. Second, the network funnels singly through NASA headquarters, providing a chokepoint for both responsibility and blame at one actor. Consequently, NASA headquarters can make decisions that have an immediate impact on the actors below it, which seems appropriate in a program that made changes rapidly and on-the-fly. The compressed timeframe of Apollo likely influenced its organizational structure, conforming to the pressures around it and producing this unique actor network. I chose to classify the Apollo actor network as centralized.

One redeeming feature of Apollo's accomplishment of ending the space race lies in its declassified nature. Due to de-escalation of Cold War tensions, much of Apollo leadership is now known, allowing me to focus the network diagram analysis on a select few individuals and their philosophies, rather than large groups. The Administrator of NASA serves as the highest level of internal leadership of the modern agency. However, during the Apollo program, the Flight Director oversaw all NASA activities missions. Gene Kranz served in this role in the pivotal years of the program. Over the years, Kranz has reiterated his stance that America must come first, but also that international cooperation in space "is incredibly important." Kranz has also criticized the International Space Station for its lack of transparency to Americans, maintaining that 'nobody in America really understands what is going on there [and] why we are doing this. We have done a very poor job of selling this program," (Kranz, 1999). Clearly, Kranz believes in the potential for international space programs. However, he recognizes the risks and challenges associated with executing successful internationally involved space programs, likely influenced by his extensive role in the success of the Apollo program. Additionally, Kranz stressed the importance of personal accountability in crewed spaceflight missions, something he believed could be best achieved when all engineers worked under the same roof. The Artemis project stands in sharp contrast to this philosophy, spreading the program between several agencies and countries.

As for contractors, their motives lie almost entirely in financial opportunity. Limited information exists for how NASA granted contracts, whether that be through competition, bidding war, or direct selection. However, all companies given contracts for Apollo vehicle design were based in the United States (Drucker, 1972). The reason for this characteristic likely lies in the previously mentioned nature of the Apollo program: an accelerated and compressed timeframe, and a highly secretive project marred in geopolitical tension.

Analysis: How Artemis Compares

The Artemis program has emerged as a token of humanity's renewed quest to return to the moon. Yet, the triumphs of Artemis owe much to the intricate web of collaboration and expertise woven into its fabric. As we delve into the organizational structure of the Artemis program, we can uncover a network of actors whose collective efforts may end with humans once again walking across the lunar surface. By examining the actors involved in Artemis, from NASA to private aerospace companies and international partners, we illuminate the relationships that underpin humanity's aspirations to establish a sustainable presence on the Moon. Through the lens of ANT, we can once again analyze these relationships to shed light on why the organizational structure of NASA's crewed spaceflight programs has shifted.

Once again, we must consider both the human and non-human actors before constructing the network. Artemis provides a new wrinkle to the familiar Apollo network. While the Orion capsule is designed and manufactured by Lockheed Martin, the European Service Module (ESM) is designed by Airbus, a European aerospace company, and overseen by the European Space Agency. This introduces unique complexity to the Artemis network, rarely encountered by NASA before. Once again, we can use arrows to signify the flow of influence.

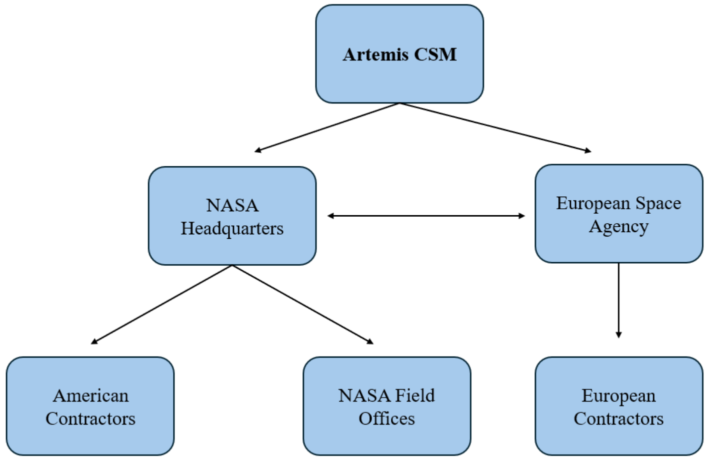

Figure 4: A network diagram of the organizational structure that led to the creation of the Artemis CSM

This network diagram includes both the human actors, including the NASA headquarters, field offices, contractors, and the ESA, as well as the non-human actors, represented by the Artemis CSM. Some key deviations exist from the Apollo network diagram. First, the network is no longer entirely hierarchical, as NASA and the ESA must cooperate to integrate Orion and the European Service Module, as represented by the double-sided arrow. In this way, responsibility for the success of the program splits between two distinct entities. Another key observation lies in the independence of the European contractors from NASA. Ultimately, the ESA oversees Airbus's development of the European Service Module, with NASA relinquishing some control over the program. In this way, I characterized the Artemis network as decentralized.

The individual motives of key actors in the Artemis program are less involved in the overall program than with Apollo. Mission overviews of Artemis stress collaboration, transparency, and progressiveness as critical goals, rather than speed and secrecy. However, with these goals of collaboration come unintended consequences that strain the ability of engineers to communicate ideas. In interviewing an anonymous Lockheed Martin employee about the difficulties of working on a program with international partners, they provided valuable insight. First and foremost, they expressed the unique difficulty of coordinating several engineering teams across long distances and sometimes even a language barrier. Ultimately, the use of international cooperation for Artemis has introduced unique challenges absent from the Apollo program. The interviewee also stressed how these challenges have produced slim results thus far. Five years and $100 billion since the program's introduction, Artemis has yet to launch a human into space. Additionally, the lack of reusability of the Space Launch System, the rocket designed to carry the Orion capsule to orbit, has ballooned the cost of the program further and sparked comparisons to the reusable Falcon 9 rocket and Dragon capsule developed by SpaceX.

Discussion

The networks of actors present in each of the two crewed spaceflight programs provide clues as to the purpose of their organizational structures. Particularly, NASA's dependence on international partners in Artemis represented a significant shift from the framework that allowed Apollo to succeed in the way that it did. Ultimately, the networks informed me of two key differences between the two programs that likely motivated their organizational structures: timeframe and oversight.

The centralized nature of the Apollo actor network can be attributed to its accelerated timeframe of completion, leading to an environment that needed to be able to adjust rapidly. The existence of a 'bottleneck' in the network, represented by the NASA headquarters actor, permitted this breakneck environment. This also conformed to the highly secure nature of government programs during the Cold War. The goal of beating the Soviet Union to the moon meant keeping a tight grip on technology and information, especially in a period of espionage and looming nuclear danger. In this respect, tight oversight by NASA provided the security needed for such an important program.

NASA established Artemis in an entirely different political world. While space still serves as a key strategic battlefield, the threat of nuclear war no longer looms over our heads, especially with the dissolution of the Soviet Union three decades prior. With no Space Race, Artemis exists purely as an engineering and scientific objective, in stark contrast to the political atmosphere that Apollo resided in. The decentralized nature of the Artemis network reflects this; international cooperation provides for the sharing of technology and services that simply was not permissible in the sixties and seventies. Additionally, without an overarching time constraint (although Congress still expects the program to make steady progress), NASA deemed immediate oversight unnecessary to the success of the program. While this does enable valuable technology and labor sharing, it is not without challenges. The lack of immediate oversight can lead to difficulties integrating Orion and the European Service Module, such as confusion over requirements, mistakes across measurement systems, or even mistranslations across language barriers.

Ultimately, the actor networks of each of the two programs reveal that their organizational structures depend on the political environment surrounding each program. With Apollo, a tense atmosphere led to a more centralized program built on immediate oversight and rapid decision-making. With Artemis, a more relaxed atmosphere has led to a more decentralized program built on international cooperation and sharing of technology. For the foreseeable future, I expect the crewed space industry to follow that of Artemis. However, if the United States were to enter a period of tense space relations with an adversary, I expect the organizational structure to revert to that of the program that first landed humans on the moon.

Bibliography

Donaldson, A. (2024). *NASA Shares Early Progress Towards Early Artemis Moon Missions with Crew*. NASA Headquarters.

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*.

Kranz, G. (1999, April 28). *NASA Johnson Space Center Oral History Project* [Interview].

Mann, A. (2020). *The Apollo Program: How NASA sent astronauts to the moon*. Space.com.

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*.

NASA's Lunar Exploration Program Overview. (2020). National Aeronautics and Space Administration.

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

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