

Historical Spacesuit Development Strategies in Response to National Objectives

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ABSTRACT

During both the National Aeronautics and Space Administration's (NASA) Apollo and Artemis programs, the race was on to land on the Moon. Both Apollo and Artemis are government programs that are intertwined with national objectives, and spacewalking is a common human spaceflight national goal. From the start of the Gemini program through the modern developments of Artemis, the technical challenges of developing a spacesuit are approached differently depending on the current U.S. national objectives for space. By analyzing the historical spacesuit development strategies used during the space race through modern day, it is observed that the urgency and deadlines associated with national objectives incentivize NASA to obtain commercial partnerships. This offers insight into the future of spacesuit development and program management.

Keywords: Space, Spacesuit, Spacewalk, NASA, EMU, Politics, History, Management, Development, Artemis

Estrategias de desarrollo de trajes espaciales históricas en respuesta a los objetivos nacionales

RESUMEN

Durante los programas Apolo y Artemis de la Administración Nacional de Aeronáutica y del Espacio (NASA), la carrera para aterrizar en la Luna estaba en marcha. Tanto Apolo como Artemis son programas gubernamentales que están entrelazados con objetivos nacionales, y la caminata espacial es un objetivo nacional común de los vuelos espaciales humanos. Desde el comienzo del programa Gemini hasta los desarrollos modernos de Artemis, los desafíos técnicos de desarrollar un traje espacial se abordan de manera diferente según los objetivos nacionales actuales de EE. UU. para el espacio. Al analizar las estrategias históricas de desarrollo de trajes

espaciales utilizadas durante la carrera espacial hasta la actualidad, se observa que la urgencia y los plazos asociados con los objetivos nacionales incentivan a la NASA a obtener asociaciones comerciales. Esto ofrece información sobre el futuro del desarrollo de trajes espaciales y la gestión de programas.

Palabras clave: Espacio, Traje espacial, Paseo espacial, NASA, EMU, Política, Historia, Gestión, Desarrollo, Artemisa

响应国家目标的历史航天服发展战略

摘要

在美国国家航空航天局 (NASA) 的阿波罗计划和阿耳忒弥斯计划期间，登月竞赛一直在进行。阿波罗计划和阿耳忒弥斯计划都是与国家目标交织在一起的政府计划，而太空行走是一项共同的人类航天国家目标。从双子座计划到阿耳忒弥斯计划的现代发展，采用了不同方式应对航天服开发一事的技术挑战，这取决于美国当前的国家太空目标。通过分析太空竞赛到现代期间使用的历史航空服开发策略，可以看出，与国家目标相关的紧迫性和最后期限促使了NASA获取商业合作伙伴关系。这为航天服开发及项目管理的未来提供了见解。

关键词：太空，航天服，太空行走，美国国家航空航天局，舱外移动单元，政治，历史，管理，发展，阿耳忒弥斯计划

Introduction

Spacewalking, more formally referred to as extravehicular activity (EVA), has been a key component of the United States (U.S.) national spaceflight objectives since the start of the Space Race. During the Gemini program, the U.S. raced the Soviet Union to conduct the first EVA.¹ Then during the Apollo program, the race continued to put the first person on the Moon, and subsequently conduct EVA on the Lu-

nar surface.² The national goal of these EVA was to show national superiority on an international stage.³ National prestige and national security were at risk if the U.S. was unable to beat the Soviet Union to achieve selected human spaceflight milestones.

Just one of the many key technological systems that made these national objectives possible is the spacesuit. Without a pressure suit that protected the astronaut from the space environ-

ment while providing a breathable atmosphere, the EVA goals of the era, such as a man walking on the Moon, would have been unachievable. Each time a new EVA goal was established by a political leader, the National Aeronautics and Space Administration (NASA) responded with program changes to ensure spacesuit development timelines were achieved. Strict political deadlines and stiff competition from the Soviet Union required NASA to seek contracts to leverage the core capabilities of commercial industry to develop a safe spacesuit within improbable timelines.

The program management adaptations to spacesuit development during the Gemini and Apollo programs allowed the U.S. to secure national prestige as the first nation to conduct EVA on the Moon.⁴ The A7L Extravehicular Mobility Unit (EMU) developed during Apollo was adapted to become the EMU that was used during the Space Transport System (STS) program and International Space Station (ISS) program.⁵ The EMU underwent decades of incremental improvement for use in microgravity environments, but NASA did not prioritize the development of a spacesuit that could operate on the Moon or Mars.⁶ Then in 2020, a new political deadline for the U.S. to conduct EVA on the Moon by 2024 as part of the Artemis program shifted NASA's spacesuit development priorities.⁷ Similarly to the program management adaptations during Gemini and Apollo, NASA responded by soliciting commercial proposals to leverage industry.⁸

National objectives have direct effects on the program management

structures, development strategies, and commercialization of EVA spacesuits. During Gemini, Apollo, and Artemis, strict deadlines caused a rapid shift to develop new EVA capabilities. During STS and ISS, progress was incremental with minimal development toward future objectives. This paper analyzes the relationship between U.S. national objectives and EVA spacesuit development structures and priorities within NASA from Gemini to Artemis.

Project Gemini and the Beginning of Crewed Spaceflight

The space race began when the Soviet Union launched a small beach-ball-sized satellite into orbit in 1957.⁹ The small satellite, named *Sputnik*, was the world's first artificial satellite. The Soviet Union beat the United States to space and showed they had a higher payload capacity than U.S. rockets.¹⁰ Inside the outer spherical container of *Sputnik* were two radio transmitters, three batteries, a temperature and pressure sensing system, and a fan-driven ventilation system. The transmitters served as proof that *Sputnik* was in orbit by broadcasting a signal that could be heard by governments and amateur radio operators alike.¹¹

As the signal broadcasted to the world, the White House launched an investigation into the missile capabilities of the Soviet Union and how they compared to American technologies.¹² The results of the study warned of a "critical threat" to national security. It recommended acceleration of missile

development, research and development of defense systems, a fallout shelter program, and programs for public awareness of the “dangers of the nuclear age.”¹³ The United States was technologically behind during the rising nuclear age, a dangerous concept that sparked additional government attention.

The United States, under the leadership of President Dwight D. Eisenhower, understood the dangers of the nuclear threat of the Soviet Union’s missile technology.¹⁴ Eisenhower also understood the symbolic value of space was not to be underestimated, and that *Sputnik* warranted a public reaction.¹⁵ In response, in 1958, NASA was founded partly as a method to separate military and civilian space efforts allowing for a public space program, though military and civilian efforts were undoubtedly closely related.¹⁶ In the coming years, NASA would become instrumental in leading the civilian space efforts, making technological advancements while influencing public perception on world hegemonic power.

After the Soviet Union beat the U.S. into space by launching *Sputnik*, the next high visibility challenge was to put a man in space. Spacecraft could no longer be a hollow cargo bay, but rather they needed to sustain the life of an astronaut. In the event of a pressure loss inside the spacecraft, the astronauts were required to wear a pressure suit to keep them alive, like what other high-altitude pilots wore during the same era.¹⁷ The quick development of a pressure suit for use in space was required to achieve crewed spaceflight

and beat the Soviet Union putting a man in space.

Instead of developing a new pressure suit to use during Project Mercury, NASA decided to purchase and adapt a well-tested aviation pressure suit to use for early spaceflights. The Mark IV Navy pressure suit, developed by the B.F. Goodrich Company, was the perfect candidate. The Mark IV was used operationally in the McDonnell F-4 Phantom II, Douglas F-6 Skyray, Vought F-8 Crusader, and the North American A-5 Vigilante during flight test operations.¹⁸ The suit also set an altitude record in the Phantom II when the pilot flew the jet to 98,560 feet.¹⁹ Little modification was required to adapt the suit for space operations. One of the more notable differences was the aluminum-coated nylon added to the exterior of the suit. While the official reason for the aluminum outer layer was for thermal protection, the spacesuit designers admitted it was more for aesthetics than functionality.²⁰

Despite the quick adaptation of the Mark IV to allow for astronauts to have a spacesuit available to wear during the Mercury launches, spacesuit development was only part of the crewed spaceflight process. In 1961, the Soviet Union beat the U.S. again by launching cosmonaut Yuri Gagarin into orbit.²¹ However, the U.S. was not far behind, and Alan Shepard conducted the first American crewed spaceflight less than a month later.²²

The U.S. was still behind the Soviet Union in space technology, a fact that politicians did not overlook. Not

only was Soviet space superiority a detriment to national prestige, but it continued to foster a perceived threat to national security.²³ When John F. Kennedy became president in 1961, he decided to increase NASA's funding and focus on a then-unspecified large national project.²⁴ The details were still in their infancy when Gagarin became the first man in space, and Kennedy turned to his vice president and chairman of the Space Council Lyndon B. Johnson to determine what dramatic space effort best guaranteed U.S. victory over the Soviet Union.²⁵ The results of Johnson's investigation were publicly announced in 1962 during a live speech given by President Kennedy at Rice Stadium in Houston, Texas. The national project Johnson and Kennedy had chosen was a crewed mission to the Moon with a deadline of the end of the decade.²⁶

With only eight years to accomplish landing a man on the Moon, the U.S. would need to regain technological superiority over the Soviet Union. Among the many NASA divisions that needed to rethink their technology processes was the spacesuit development team. For a man to walk on the Moon, pressure suit technology needed to be adapted for EVA by the end of the decade.

During Project Mercury, NASA modified the Mark IV Navy pressure suit for use during space operations.²⁷ With strict development timelines set to achieve Kennedy's goal, NASA elected to again use the B.F. Goodrich Mark IV suit as the base for a new spacesuit design.²⁸ Project Gemini would become

the testing grounds for the technology required for the Apollo program, and prototypes for a Gemini spacesuit led to new contracts with B. F. Goodrich to develop a functional Gemini spacesuit.²⁹

B. F. Goodrich developed several early prototypes, including the G-1G prototype delivered in July 1962.³⁰ The first "G" stood for Gemini, while the second "G" was the company code for B. F. Goodrich.³¹ NASA established company codes because there were additional spacesuit development contractors that were working on creating similar spacesuits.³² To help meet the deadlines required for the Gemini project, NASA used multiple commercial sources to aid in spacesuit development. Arrowhead Products Company and Protection Incorporated were each contracted to create early prototypes, but the B. F. Goodrich's G-1G suit was superior to their designs, which resulted in the loss of their contract early in the program.³³ A third competitor was the David Clark Company with its modified S-951 suit. The updated S-951 was later designated as the G-1C, with the "C" labeling the David Clark Company.³⁴

Each of the two companies, David Clark and B.F. Goodrich, created prototype suits and delivered them to the McDonnell Aircraft Company, the company that was contracted to complete an evaluation of the suits.³⁵ The McDonnell Aircraft Company, the Gemini Program Office, and three test astronauts worked together to select the David Clark Company's G-1C suit as the next Gemini spacesuit.³⁶ With technical feedback from NASA, the G-1C

was later upgraded to the G-3C, which would become the primary intravehicular activity suit for Gemini.³⁷

The Gemini program was primarily designed as a testing ground for Apollo, but there was still national prestige to be earned if the U.S. was able to execute a spacewalk before the Soviet Union. To develop an EVA spacesuit quickly for both the Apollo program concept testing and national prestige, NASA continued the contract with the David Clark Company to adapt the G-3C for EVA.³⁸ The G-4C EVA suit added micrometeorite protection, redundant pressure seals, redundant ventilation inlet and outlet fittings, and new gloves with improved abrasion protection and mobility to the G-3C suit.³⁹ G-4C suit qualification commenced in the fourth quarter of 1964 and completed in the second quarter of 1965.⁴⁰

While the U.S. was developing the G-4C, the Soviet Union was also adapting its intravehicular activity suit, the Berkut, to conduct EVA.⁴¹ On March 18, 1965, the Soviet Union used its modified Berkut spacesuit to conduct the first spacewalk.⁴² By the end of the short first EVA, the cosmonaut had almost experienced heat stroke and was drenched in sweat.⁴³ The suit had technical issues and was barely able to support life. However, it achieved the goal of beating the U.S. to the first spacewalk.

The U.S. conducted its first spacewalk just two and a half months later on June 3, 1965, using the G-4C spacesuit.⁴⁴ Just as the Soviet Union prioritized national prestige and condensed timelines over creating a perfect

spacesuit for EVA, the G-4C spacesuit experienced safety hazards during its implementation. During the first Gemini EVA, the astronaut struggled to close the hatch. The higher workload caused additional body heat production, and the suit's cooling system was unable to keep up. Like the Soviet Union's experience with the Berkut suit, the astronaut overheated in his suit.⁴⁵

On the second EVA conducted by the U.S. during Gemini, astronaut Eugene Cernan stated he "had to work continuously against the pressure suit" and that he devoted "fifty percent of his workload just to maintain position."⁴⁶ His workload also recreated the cooling system exceedance from the first EVA, resulting in a fogged visor that resulted in zero visibility.⁴⁷ Astronaut John Young stated with the lack of maneuverability in the suit, "there was no way if anything happened to somebody going outside a Gemini that you could get them back in."⁴⁸ Each of the remaining Gemini EVAs experienced hazards related to the G-4C suit, but the lessons learned were later implemented to improve spacesuit designs for Apollo.⁴⁹

The G-4C spacesuit was commercially sourced and fast-tracked to both attempt to gain national prestige and provide technical data for developing a lunar spacesuit. The Gemini spacewalk successes and failures were timely and educational, but dangerous. The G-4C was an imperfect product sourced for a specific mission, and it did what it was supposed to do, keep a man alive outside of a space capsule in the vacuum of space. The United States may have lost the race to the first man

in space to the Soviet Union. Nevertheless, the U.S. was not far behind. Kennedy's goal for the first man on the Moon was still well underway.

The Apollo Program

Despite the challenges the astronauts faced, after the Gemini spacewalks, EVA was a proven concept.⁵⁰ The next step was to use the lessons learned from Gemini to adapt the G-4C suit for improved safety and lunar implementation. The last Gemini spacewalk took place on November 14, 1966, and time was running out to implement lessons learned to create a lunar EVA spacesuit before the end of the decade.⁵¹

NASA's plan was to continue to modify the G-4C for the early Apollo flights while additional commercial contracts were procured to develop a more robust spacesuit for lunar spacewalks.⁵² Based on the lessons learned from the Gemini spacewalks, the G-4C suit would require mobility improvements, a redesign of the ventilation inlet and outlet fittings, a redesign of the gloves, and wrist and neck bearing disconnects.⁵³ After the Apollo 1 mishap, where three astronauts' lives were lost during a ground test, NASA reevaluated its contracts and then canceled the contract with B. F. Goodrich to modify the G-4C for lunar spacewalks. Instead, NASA established a commercial competition similar to the one used during Gemini to source a new Apollo spacesuit.⁵⁴

When NASA called for a new spacesuit to use on the Moon, the David Clark Company, Hamilton Standard

Division, and the International Latex Corporation each submitted a suit for evaluation by NASA's Manned Spacecraft Center (MSC).⁵⁵ Each spacesuit underwent engineering tests, operational functions evaluations, essential functions tests, and a comfort test.⁵⁶ The result of the tests led to NASA awarding contracts to the Hamilton Standard Division (HSD) and the International Latex Corporation (ILC). NASA tasked ILC to fabricate the Apollo spacesuit consisting of the liquid-cooled undergarment, constant wear garment, pressure garment assembly, and thermo-micrometeoroid protective overgarment.⁵⁷ HSD would design the Portable Life Support System (PLSS), a backpack that contained the environmental systems required to keep the astronauts alive.⁵⁸ The MSC managed the program, integrated the two systems, and was responsible for the qualification of the spacesuit.⁵⁹

The collaborative effort between NASA, HSD, and ILC resulted in a completed spacesuit called the A7L Extravehicular Mobility Unit (EMU). The suit had three major systems, the PLSS, pressure garment assembly (PGA), and the oxygen purge system.⁶⁰ Each component is often discussed as independent systems. For example, the PGA is often called the A7L PGA and was used as a standalone intravehicular activity suit on the first few Apollo missions, while the PLSS is an attachment for the A7L PGA.⁶¹ Considering the Apollo EMU was only used for EVA when the PLSS was installed, the Apollo spacesuit will be referred to as the A7L EMU in this paper to differentiate it from other generations of EMUs.

The A7L EMU was only tested one time in orbit before it was used for lunar EVA. On Apollo 9, the crew members wore the PGA for 52 hours, and then donned the rest of the A7L EMU and depressurized the command module's cabin to test the suits and conduct the only Apollo EVA before the historic Apollo 11 flight.⁶² The cabin was depressurized for 46 minutes with the hatches open, exposing the astronauts to the vacuum of space. Lunar Module pilot Russell Schweickart briefly exited the spacecraft and reported that movement using the handrails attached to the exterior of the spacecraft were more comfortable to use than what he experienced in training.⁶³ This was a notable improvement from Gemini where a reported fifty percent of concentration was spent on maintaining a safe body position.

With the success of Apollo 9's single EVA, NASA was ready to send the A7L EMU to the Moon. On July 20, 1969, Neil Armstrong and Buzz Aldrin became the first two people to walk on the lunar surface. The first EMU related challenge the astronauts experienced during the first lunar spacewalk was the size of the PLSS. During development, the hatch on the lunar lander was redesigned and made smaller, while the PLSS was not reduced in size to accommodate the change.⁶⁴ This caused some difficulty exiting the lunar lander, and higher than typical heart rates for the astronauts was observed during entry and exit of the lunar lander. Another issue encountered was the mobility of the A7L EMU. The astronauts described that to avoid falling in the reduced

gravity with the stiff suit they needed to plan "six or seven" steps ahead.⁶⁵

Besides the higher metabolic rates and low mobility, no significant incidents were reported during Apollo 11.⁶⁶ The quick development and testing of the A7L EMU spacesuit allowed NASA to accomplish Kennedy's goal of putting a man on the Moon by the end of the decade. It was the outside contracts, multiple competitive options, and accelerated flight certification that fast-tracked the development of the A7L, making EVA operations on Apollo 11 possible.

The Gemini and Apollo Spacesuit Design Process

By analyzing the steps NASA took to develop the G-4C and A7L EMU spacesuit, the successful design chain model used during the 1960s can be determined. The Apollo and Gemini design process described in this paper was derived from Chu's model for design chain management and was adapted to include the commercial competition and outsourcing approach NASA used to accelerate spacesuit production to achieve the U.S. national goals.⁶⁷

Once Kennedy set his political goals and objectives for Apollo, NASA began planning the EVA spacesuit project and gathering lessons learned from previous space and pressure suits. This information was shared with commercial industry partners, and competitions were established among commercial companies. Each company was

responsible for its concepts and detailed design, which often originated from an earlier pressure suit or spacesuit the company previously designed. NASA management would then select the products that best fit the mission and offer contracts to one or more companies to produce the spacesuit. The suit would undergo additional testing and design feedback until it was time for launch.

The competitions NASA created to quickly obtain a complete EVA spacesuit was a form of design chain outsourcing. Outsourcing has advantages and disadvantages that NASA had

to weigh the pros and cons of before deciding to use commercial companies to develop future spacesuits. Some advantages of outsourcing include the allowance for NASA to specialize in other areas besides spacesuit design, leveraging the core activities of other companies and organizations, lower costs, continuity and risk management, access to skilled resources, and faster and overall better-rated products and services.⁶⁸ Typical disadvantages of outsourcing are loss of managerial control, loss of internal innovative capabilities, the economic cost of transactions, social costs, and the threat to trade secrets and confidentiality of the project.⁶⁹

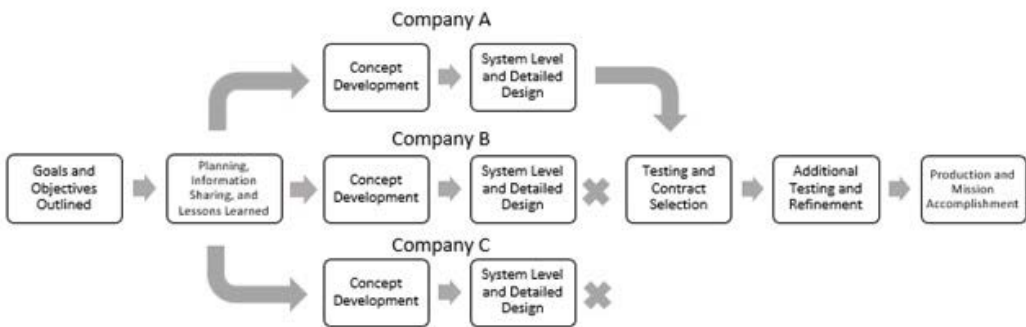


Figure 1: Apollo and Gemini Design Process. Adapted from Chu, et al., the Gemini and Apollo spacesuit design process was nearly linear, allowing for quick adaptation from one generation of a spacesuit to the next without the need for a complete redesign or time-consuming research. With no time available to solve every minor issue before certifying a suit for flight, the focus was on safe mission accomplishment, not a perfect product.

NASA had success during Gemini with outsourcing the spacesuit design process and had a lot to gain from using the same method during Apollo. The possible advantages outweighed the possible disadvantages, especially with the requirement for speed and the ability to leverage the core activities of

other companies. For example, ILC's patented materials that were used in the A7L EMU allowed for a lighter and more mobile suit as opposed to what NASA could have internally designed.⁷⁰

Disadvantages can be mitigated by partnering with the right service provider.⁷¹ By opening a competition

among commercial organizations and having several spacesuit and company options to choose from, NASA was able to choose whom they wanted to work with. This process allowed NASA management to optimize the advantages of outsourcing while mitigating the disadvantages.⁷² This ultimately led to close collaboration with B. F. Goodrich, ILC, and HSD.

If NASA had elected not to outsource spacesuit design and manufacturing, it would have needed to quickly develop the core capability of spacesuit development within NASA's internal structure. This would require the hiring of relevant industry experts, which would likely be hired out of companies such as B. F. Goodrich and ILC. NASA would have likely cannibalized the industry to ensure it had the internal capabilities required to develop an operational EVA spacesuit before the end of the decade per Kennedy's goal.

The linear approach with clearly laid out goals and timelines with multiple companies submitting their designs to NASA allowed the U.S. to quickly develop a spacesuit that allowed Kennedy's goal of a man walking on the Moon to be achieved on time, providing America with the prestige Kennedy wanted.⁷³ One side effect was neither the Gemini nor the Apollo suits were hazard-free nor perfectly designed.⁷⁴ However, in order to build a lunar EVA suit by the end of the 1960s, extensive testing before operational use was not an option.

The Space Transport System (STS) and the International Space Station (ISS)

Following the completion of the Apollo Program, crewed missions to the moon were no longer a national priority to President Richard Nixon. When Nixon discussed the future of the space program, he said:

“We must think of [space activities] as part of a continuing process... and not as a series of separate leaps, each requiring a massive concentration of energy. Space expenditures must take their proper place within a rigorous system of national priorities. ... What we do in space from here on in must become a normal and regular part of our national life and must, therefore, be planned in conjunction with all of the other undertakings which are important to us.”⁷⁵

There were no more quick deadlines, international races, or national prestige to be earned. The new focus for NASA would be sustained space operations. In the coming years, NASA would develop the Space Transport System (STS), also known as the Space Shuttle, and later begin designing and building the International Space Station (ISS).

During the development of the Space Shuttle, engineers realized that instead of making every system on the shuttle redundant, some parts could be repaired using EVA as the primary tool.⁷⁶ Using EVA to conduct shuttle repairs not only reduced the overall weight of the shuttle by eliminating many of the redundant parts, but de-

veloping an EVA capability provided NASA with a new ability for satellite repair as well.⁷⁷ Once again, NASA set out to develop a new spacesuit.

This new spacesuit had different requirements than what NASA needed during the Apollo era. With no plans to return to the Moon, the new spacesuit only needed to be able to operate in zero gravity, meaning weight and lower body mobility were not a primary

concern. More of a concern was finger dexterity and glove abrasion resistance considering astronauts using the suit would be using their hands to maneuver, similar to how astronauts maneuvered during Gemini and Apollo 9. The International Latex Corporation had already specialized in the Apollo suit development, and they were the best company to develop the new spacesuit using the Apollo EMU as the base.⁷⁸

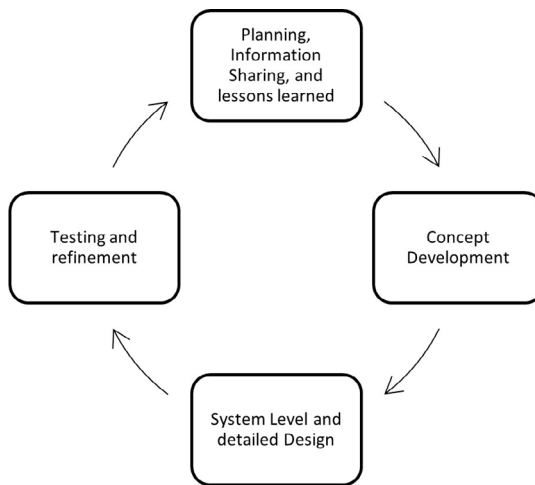


Figure 2: STS and ISS EMU Circular Development. During the STS and ISS era, there were no defined goals that necessitated the linear design and product-oriented EVA spacesuit development observed during Gemini and Apollo. Due to NASA maintaining a contract with ILC and developing the EMU before strict timelines when the ISS was announced, NASA already had a certified spacesuit that would be available for astronauts to use in microgravity conditions. This allowed NASA to continue to adapt and improve upon the EMU program with a circular design model creating additional lessons learned and EMU improvement over time.

ILC designers added features to make the Apollo suit more flexible and laser scanners precisely fitted the gloves to the astronauts.⁷⁹ The new spacesuit for the shuttle era, also called the EMU, was designed to be quickly turned around for multiple spacewalks and was sized to fit multiple astronauts so that a

single suit could be used by multiple people.⁸⁰ This meant a single suit could be used by multiple people and could be reused with proper maintenance for extended durations.⁸¹

The new EMU was first flown in 1983 on STS-6.⁸² Astronauts Don-

ald Peterson and Story Musgrave conducted a four hour and ten-minute spacewalk with no significant complications, but there were a few small issues during the EVA preparation and execution. First, the EMU was designed to be self-donning, but it was determined during STS-6 that another crew member was required to help don the suit. The treadmill inside STS also got in the way of donning the suit. During the EVA, Musgrave reported his fingers were cold. With just a few gripes and an overwhelmingly successful EVA, NASA Associate Administrator for Space Flight James Abrahamson commented on STS-6 saying the mission “was flown exactly as planned, including a marvelous EVA.”⁸³

On January 25, 1984, President Ronald Reagan directed NASA to build a space station by the end of the decade.⁸⁴ The EMU suit had already been developed and tested during previous STS missions, so there was no need for agile development, competitions, or contracting that NASA experienced to develop the Apollo spacesuit to meet Kennedy’s deadline. Nevertheless, further testing was required, and the next wave of spacewalks focused on operational procedural development and spacesuit testing to determine the feasibility of using astronauts as the primary tool for building a space station.⁸⁵ EVA tactics, techniques, procedures, and technology were established and developed throughout the STS program, and the new EMU suit proved as an excellent tool for on-orbit construction.⁸⁶ From 1981 through 1996, STS accomplished 33 EVAs to aid in the construc-

tion of the ISS. From 1997 to 2010, there were 126 EVA devoted primarily to ISS assembly.⁸⁷

The development of the EMU that was used during the STS program and for the construction of the ISS was an incremental process. Due to the early sequential development of the EMU during the Apollo program, the design process was not heavily influenced by national goals and objectives. By the time the construction of the space station was announced by President Reagan, the suit required to conduct that construction was already designed and tested. For the remainder of the STS and ISS programs, the EMU development maintained a circular program-oriented model as opposed to the nearly linear design model the Apollo and Gemini projects experienced.

Going Back to the Moon

Returning to the Moon is not a new concept. In 2004, President George W. Bush gave a public address stating he wanted to return to the Moon by the year 2014. Although the 2014 goal was not achieved due to changing political priorities, it would not be unreasonable to expect a lunar spacesuit would have been developed after Bush’s initiative.⁸⁸ However, NASA did not have an EVA spacesuit ready for flight qualification.⁸⁹

In 2019, researchers at the Johnson Space Center predicted that the next generation of spacesuit would not be ready for testing on the ISS until the 2023 to 2025 time frame.⁹⁰ With ILC managing the EMU (EMU referring

to the current suit used on the ISS), NASA decided to internally design the next generation of a spacesuit for lunar use.⁹¹ The suit NASA pushed to test is the Exploration Extravehicular Mobility Unit (xEMU). NASA had produced an xEMU demo that uses the EMU lower torso assembly while the advanced upper torso was redesigned based on lessons learned from the EMU.⁹² The xEMU hard upper torso had several new components that still needed testing and certification, such as a redesigned helmet and visor assembly, liquid cooling and ventilation garment, integrated communications system, and an environmental protection garment.⁹³

NASA's internal advanced EVA team was designing the xEMU for preliminary ISS and lunar missions.⁹⁴ Although NASA had a viable prototype that was used to conduct research, the xEMU project progression appeared to be academically focused rather than prioritizing a flight certified operational suit. The xEMU design process closely replicated the STS and ISS EMU circular development model shown in figure 2. This model worked well for STS and ISS programs due to the progression of the EMU from the earlier Apollo EMU and with no pressing political deadlines.

On February 19, 2020, former Vice-President Mike Pence delivered an address stating NASA, by order of President Donald Trump, was to return to the Moon by 2024 by any means necessary.⁹⁵ In order to complete lunar extravehicular activity (EVA), the xEMU or a derivative suit must be available for lunar use by 2024. The development

timeline and development model of the xEMU did not support the success of Trump's 2024 goal but is not the first-time political influence has led to a requirement for accelerated technological development.⁹⁶ NASA responded by adapting their circular development model to a linear development model to turned to commercial industry to help expedite development.

On September 29, 2021, NASA released a Request for Proposal (RFP) allowing companies to propose and compete for a contract to develop NASA's next spacesuit.⁹⁷ Just as NASA leveraged commercial industry to expedite spacesuit development during Gemini and Apollo, NASA's RFP created open competition for spacesuit contracts, a historically proven program management technique that was implemented to ensure the EVA suit development timelines can meet Trump's rapidly approaching 2024 deadline. However, the subsequently elected President Joe Biden had yet to release any clarifying statements about the new administration's human spaceflight goals.

Two months after the RFP began accepting proposals, during a press conference the NASA Administrator stated, "the first human landing under Artemis is likely no earlier than 2025."⁹⁸ This press conference was followed by the publication of the White House's space priorities framework, where the 2024 lunar landing deadline was officially removed from the government's goals.⁹⁹ Despite the deadline delay and lack of deadline specification of the new administration, the goal of a lunar land-

ing and the necessary EVA suit development to accomplish that goal persisted. The result of the RFP was announced on June 1, 2022, where Collins Aerospace and Axiom Space were awarded a combined three and one-half billion dollars to develop and implement the next generation of EVA systems.¹⁰⁰

Conclusion

National objectives in human spaceflight are historically tied to building national prestige through being the first to accomplish an exploratory achievement. As can be said with many components of a space program, without a spacesuit delivered on time and within the desired safety specifications, national objectives of putting humans in space would not have been possible. After Kennedy's speech to go to the Moon, NASA responded by increasing commercial

partnerships and enacting a linear design chain to expedite spacesuit development. Although NASA used commercial partners to meet strict national goals, during ISS and STS where political narratives echoed sustainment rather than innovation, new spacesuit development became internal to NASA with a circular and incremental management plan rather than expeditiously certifying the next generation of spacesuit. After Pence's speech setting a short deadline to return to the Moon, NASA responded with a request for proposals from commercial industry to re-enact similar program structures as identified during Apollo. This collaboration between NASA and commercial partners paired with a shift in program focus to achieve a national goal has been a key contributing factor to NASA's success in creating program structures that allow astronauts to conduct EVA.



*Figure 3: “Apollo 11 Commander Neil Armstrong prepares to put on his helmet with the assistance of a spacesuit technician during suiting operations in the Manned Spacecraft Operations Building (MSOB) prior to the astronauts’ departure to Launch Pad 39A. The three astronauts, Edwin E. Aldrin Jr., Neil A Armstrong and Michael Collins, will then board the Saturn V launch vehicle, scheduled for a 9:32 a.m. EDT liftoff, for the first manned lunar landing mission. [NASA. *Apollo 11 Commander Neil Armstrong prepares.* Photograph. June 04, 2023. [https://images.nasa.gov/details/ksc-69pc-377.](https://images.nasa.gov/details/ksc-69pc-377)]”*



Figure 4: “Kristine Davis, a spacesuit engineer at NASA’s Johnson Space Center, wearing a ground prototype of NASA’s new Exploration Extravehicular Mobility Unit (xEMU), is seen during a demonstration of the suit, Tuesday, Oct. 15, 2019 at NASA Headquarters in Washington. The xEMU suit improves on the suits previous worn on the Moon during the Apollo era and those currently in use for spacewalks outside the International Space Station and will be worn by first woman and next man as they explore the Moon as part of the agency’s Artemis program. [Kowsky, Joel. *Kristine Davis, a spacesuit engineer at NASA’s Johnson Space Center*. Photograph. June 04, 2023. <https://images.nasa.gov/details/NHQ201910150008>]”



Figure 5: “NASA astronaut Drew Feustel is pictured tethered to the International Space Station just outside of the Quest airlock during a spacewalk he conducted with fellow NASA astronaut Ricky Arnold (out of frame) on June 14, 2018. During the six-hour, 49-minute spacewalk the duo installed high-definition cameras to provide enhanced views of commercial crew spacecraft, including the SpaceX Crew Dragon and the Boeing Starliner, as they approach and dock with the orbital laboratory. [NASA. *NASA astronaut Drew Feustel*. Photograph. June 04, 2023. <https://images.nasa.gov/details/iss056e011980>]”

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