SPACE AGENDA 2021

TO THE MOON AND BEYOND: CHALLENGES AND OPPORTUNITIES FOR NASA'S ARTEMIS PROGRAM

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In just the next few months, multiple critical decisions will affect human exploration plans of the National Aeronautics and Space Administration (NASA). The FY21 budget cycle will shape significant aspects of the content and pace of NASA space programs and may make already ambitious exploration timelines unachievable. Even an extended continuing resolution, delaying the start of FY21 budget levels, could put current goals out of reach, as would flat funding levels. The continued effects of the novel coronavirus have already delayed progress on NASA programs in general, devastating the broad economy that furnishes the resources for NASA exploration activities. The outcome of the 2020 election may also affect the direction agencies and departments take from January 2021 onward.

The Trump administration has challenged NASA to return humans to the moon by 2024 with the goal of eventually sending astronauts to Mars.[1] To respond to the President's challenge, the NASA Artemis program has been established with the primary goal of landing the first woman and the next man on the surface of the moon before the end of 2024.[2]

The focus of this paper will be on NASA human exploration beyond low Earth orbit (LEO), specifically missions to the moon and beyond. In the following pages, a review of the path back to the moon, from the end of Apollo up until the present time, is provided. Recent exploration initiatives are explained, including the participation of the commercial sector. The importance of the Artemis program in the moon-to-Mars planning is discussed. The Findings section includes assessments of management and technical challenges, and policy points with opportunities highlighted in the closing section.

Introduction

There has recently been a proliferation of new space companies and legacy organizations offering new and innovative launch vehicles, small but capable spacecraft, instruments, and other space-enabled products, services, and capabilities. These new technologies and systems, coupled with NASA's now decade-long demonstrated success in incorporating commercial efforts, point to the commercial sector having a strong potential to impact the path upon which NASA embarks to realize its human space exploration goals. Commercial space companies are foreseen to play a significant role in returning U.S. astronauts to the moon and on to Mars.

The administration has directed that both international and private sector partners be included in pursuing the moon and Mars exploration goals.[3] How the implementation of international and commercial partnerships and collaborations will be accomplished, along with the associated challenges, is still taking shape. Planning program milestones for the lunar return, as well as what we do on the moon after we return, requires that key decisions be made now and in the very near future. Areas of particularly high importance include refining the Artemis integration plans and the concept of operations for lunar surface missions. What we can leverage from lunar exploration, especially in the realm of extended surface operations on another planet, which humans have never done, must be objectively assessed in terms of how the experience and common elements transfer to exploring Mars and beyond.

The elements comprising the Artemis architecture are already under development. The Space Launch System (SLS) and the Orion Multi-Purpose Crew Vehicle (Orion) represent significant agency investments in the overall NASA portfolio of 25 major projects. A major project is defined as one with a lifecycle cost of over $250 million. Major projects comprise by far the majority of the NASA budget.[4] According to the U.S. Government Accountability Office (GAO) report on NASA, published in April 2020, the current portfolio continued to experience significant cost and schedule growth this year, as it has over the last three years, with performance expected to continue degrading. Cost growth for 2020 is approximately 31 percent over baseline and has been increasing steadily since 2017. NASA is doing slightly better this year than last in terms of launch delays, with the average delay being 12 months, rather than 13.

Given NASA's track record of cost and schedule overruns,[5] the GAO findings show that both SLS and Orion have underreported their cost growth. The Artemis I launch date has yet to be firmly established, which likely means additional cost increases and schedule delays as it slips further into the future.

The Path Back to the Moon

Since the final mission of the Apollo program in 1972, the United States has initiated three major programs aimed at returning humans to the moon and beyond. In 1989, on the 20th anniversary of the Apollo 11 landing, George H.W. Bush announced what came to be called the Space Exploration Initiative (SEI).[6] This initiative comprised three major elements, including constructing the Space Station Freedom (announced by President Ronald Reagan in 1984), returning to the moon "to stay," and sending humans to explore Mars. Following the president's announcement, Richard Truly, then the NASA Administrator, directed the agency to embark on a 90-day study[7] to ascertain what such a program would cost and how long it would take to realize. The bottom line was that the estimated cost of the program would be approximately $500 billion spread over 20 to 30 years. The NASA cost estimate caused consternation in both Congress and the White House, both of which were critical of the plan.[8] The SEI ended in 1993 under the Clinton administration. However, the plan to build a space station evolved into what is now the International Space Station (ISS), which includes participation from Russia, Japan, Canada, and the European Space Agency.

The second major U.S. program meant to return humans to the moon was established during the George W. Bush administration. The Constellation Program[9] was a response to the goals set out in the Vision for Space Exploration (VSE),[10] which was announced by President Bush in January 2004, partially in response to the Space Shuttle Columbia disaster as well as to foment enthusiasm for space exploration. It is important to remember that the VSE also set the goals of completing the ISS and retiring the Space Shuttle by 2010, and developing a new Crew Exploration Vehicle, or CEV (now Orion), by 2008.

The goals of the Constellation Program were essentially the same as those set out in the SEI; however, the first goal became completing the International Space Station by 2010. The program also aimed to send humans back to the moon no later than 2020, with the ultimate goal of sending a crewed vehicle to Mars. The NASA Authorization Act of 2005 was based on the results of the Exploration Systems Architecture Study,[11] led by then NASA Administrator Michael Griffin. The act reshaped the goals laid out in the VSE with Constellation initiated in 2005. The launch vehicles were named Ares, the crew vehicle was called Orion (which continues today), and Altair would be the vehicle taking astronauts to the surface of the moon. The Constellation Program was cancelled after the 2009 Augustine Committee concluded that the program was behind schedule and could not be completed without a significant injection of additional funding. President Obama made the decision to cancel the program, which was terminated in October 2010, when he signed the NASA Authorization Act of 2010.[12]

In 2011, the super-heavy lift Space Launch System (SLS), which replaced the Constellation Ares V, was initiated. SLS was to replace the Space Shuttle as the NASA flagship vehicle, carrying both crew and cargo. The path for planned SLS evolution is shown in Figure 1. It represents the largest development of a space launch system undertaken by NASA since the beginning of the Space Shuttle program nearly 50 years ago. Congress mandated that SLS is to follow the design of Ares V and make use of Space Shuttle heritage components, which significantly constrained its design, but also provided continuity for work at various NASA centers and contractors. Development of the Orion crew vehicle continued, and Constellation morphed into the Exploration Systems Development (ESD) program that was working towards again landing humans on the moon by the late 2020s.[13]

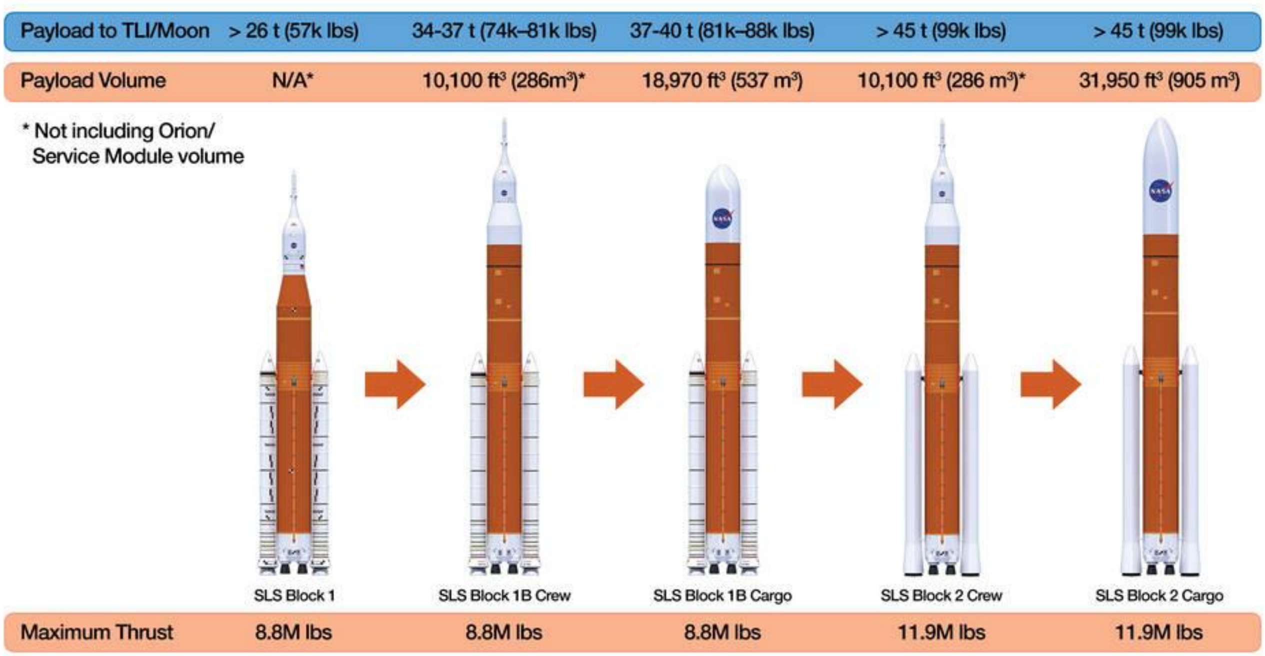

Figure 1: Planned evolutionary path for SLS Block 1 through Block 2 Cargo. *The first copy of Block 1 is in test with a new expected launch date no sooner than November 2021. (Courtesy of NASA)*

Recent Exploration Initiatives

The Trump administration has been relatively active in the domain of space policy. The National Space Council (NSpC), established by the George H. W. Bush administration in 1989 as a modified version of the earlier National Aeronautics and Space Council (1958–1973), was re-established by the Trump administration by Executive Order in 2017.[14] Chaired by the Vice President, the NSpC functions primarily as a policy development body. Civil, commercial, national security, and international space policy matters are all handled by the NSpC, the members of which are cabinet-level officials supported by a small staff and the Users' Advisory Group, which comprises non-government experts. The NASA Administrator also sits on the Council. Working with the NSpC, the administration issued four Space Policy Directives in its first three years and a National Space Strategy in March 2018.

The Next Moon-Mars Program is Officially Endorsed and Accelerated. On December 11, 2017, the Trump administration issued a Presidential Memorandum, referred to as Space Policy Directive-1 (SPD-1), with the subject line "Reinvigorating America's Human Space Exploration Program." SPD-1 amended Presidential Policy Directive-4 of June 28, 2010 (National Space Policy) by replacing the paragraph beginning "Set far-reaching exploration milestones" with the words:

> Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations.

The seeds were thus planted for the next exploration missions to the moon and on to Mars. The SPD-1 document endorsed the ESD program with the goal of sending humans to the moon by 2028. The first mission, which would be an uncrewed swing around the moon comprised of the Orion, the European Service Module (ESM), and the SLS, was known as Exploration Mission-1 (EM-1). That mission would be followed by EM-2, a crewed mission that would again make a pass around the Moon and return to Earth. EM-3 would be humans on the Moon. It should be noted that the ESD budget was capped at $3 billion per year.

About 15 months later, on March 26, 2019, Vice President Pence surprised almost all concerned when he announced to the crowd at the NASA Marshall Space Flight Center, during the fifth meeting of the NSpC, that the U.S. would land "the first woman and the next man" on the surface of the moon by 2024. He further stated that getting there by 2028 "is not good enough" and that "we can do better than that." The lunar exploration program was summarily kicked into high gear. In May 2019, the name Artemis, twin sister of Apollo, was chosen for the program.

Artemis

The Artemis program is marching forward to fulfill the goals set out in SPD-1 on an accelerated schedule, returning humans to the moon and eventually to Mars. Specifically, the program is to land humans on the moon by 2024, create a sustainable human presence by 2028, and proceed towards the ultimate goal of exploring Mars in the 2030s. Artemis leverages the elements that were under development during ESD, including the SLS, Orion, and the Exploration Ground Systems (EGS).[15] The missions planned under ESD were renamed Artemis I, Artemis II, and Artemis III. The Artemis system architecture now comprises the Orion crew vehicle (Figure 2), the SLS, Gateway, the Exploration Ground Systems, the Human Landing System (Figure 3), and advanced Artemis Generation spacesuits.[16] Implicit in the architecture is the ESM, which will be integrated with Orion for all three of the Artemis missions on the books. The program will leverage the Commercial Lunar Payload Services (CLPS) program in which commercially provided lunar landers transport various types of payloads to the lunar surface as well as potentially placing them in lunar orbit. CLPS plans to eventually deliver an unpressurized lunar rover to the lunar surface, as well.

Figure 2: Orion crew vehicle with solar panels attached. *(Courtesy of NASA)*

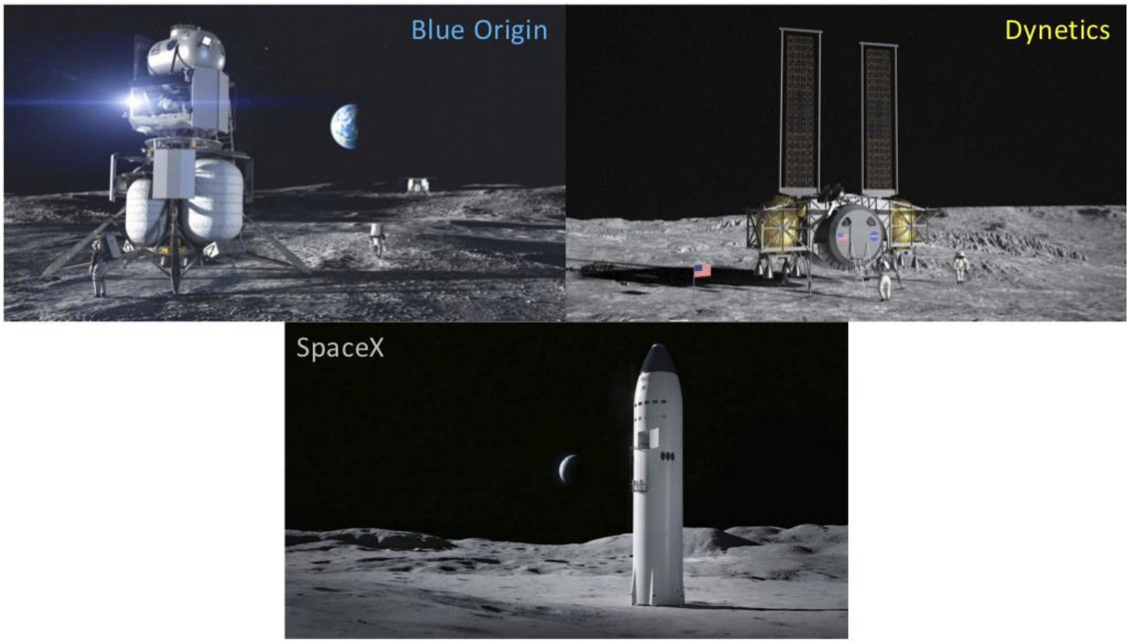

Figure 3: The three selected concepts for the Human Landing System. *(Courtesy of NASA)*

Both Orion and SLS have been in development since well before SPD-1 was issued as they are derivatives from the Constellation Program. Gateway (Figure 4), a lunar orbiting outpost formerly known as the Deep Space Gateway and then renamed the Lunar Orbiting Platform-Gateway in 2018, has been under study in one form or another since NASA made public a plan for a cislunar station in 2012 called the Deep Space Habitat. The development of these elements has not been without challenges.

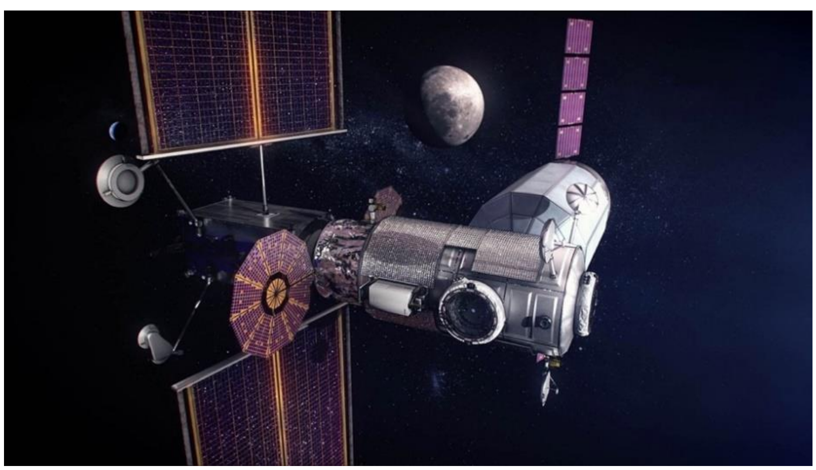

Figure 4: Concept artwork of the initial Gateway configuration comprising the Power and Propulsion Element (PPE), Habitat and Logistics Outpost (HALO), and a notional HLS. *(Courtesy of NASA)*

Artemis System Architecture Elements. Referring to the collection of elements that will comprise the Artemis missions as an architecture is an overstatement because a formal Artemis systems engineering and integration (SE&I) plan is missing.[17] The SLS and Orion implementation efforts have been underway for quite some time, as has the ground systems development. These elements, which are systems in themselves, have been on independent development tracks with their own SE&I at the piece-part hardware element level. The elements are being brought together in a bottoms-up fashion loosely tied together with 18 requirements at the NASA Headquarters (HQ) Human Exploration and Operations

Mission Directorate (HEOMD) level, which were selected based on synchronization points where hardware elements come together. There is essentially no SE&I plan associated with integration of all of these elements into one functioning system of systems.

Table 1 provides short descriptions of the NASA-developed Artemis architecture elements along with the development status of each based on the GAO 2020 report and reports on the SLS and Orion recently published by the NASA Office of Inspector General.[18,19] The information in the table provides a recent snapshot of the Artemis elements status.

The Artemis Accords. The Artemis Accords,[20] issued in May 2020, are intended to establish a means for safe and cooperative development of space resources. Because international partnerships will play a key role in achieving a sustainable and robust presence on the moon while preparing to conduct a historic human mission to Mars, such an agreement is necessary. There will be numerous international and private sector players conducting missions and operations in cislunar space; therefore it is critical to establish a common set of principles to govern the civil exploration and use of outer space. Space agencies joining NASA in the Artemis program will do so by executing bilateral Artemis Accords agreements, which will describe a shared vision for principles, grounded in the Outer Space Treaty of 1967, to create a safe and transparent environment which facilitates exploration, science, and commercial activities.

The Artemis Accords are similar to the Intergovernmental Agreements (IGA) that were executed between the U.S. and the international partners on the ISS.[21] NASA desires that all of the ISS partners participate, including Canada, Japan, Russia, and the countries in the European Space Agency (ESA). The Artemis Accords have been developed in consultation with the U.S. Department of State to cover operations *on the lunar surface*. The administration argues that the 10 principles in the accords are grounded in the 1967 Outer Space Treaty and that they cover the following:

- Peaceful purposes
- Transparency
- Interoperability
- Emergency assistance
- Registration of space objects (applies to Earth orbit as well as at the moon)
- Release of scientific data (in a timely manner, for free)
- Protecting heritage
- Space resources (extraction and utilization allowed)
- Deconfliction of activities (operate with due regard, establish safety zones)
- Orbital debris and spacecraft disposal

The accords are meant to cover activities on the surface of the moon, so the international partners involved with Gateway are not expected to abide by them. Russia is already pushing back on the U.S. position that companies should have rights to space resources. In fact, NASA had hopes for Russia to provide an airlock for Gateway, but the country has declared that it will not be participating in the Artemis moon program. "For the United States, this right now is a big political project. With the lunar project, we are observing our American partners retreat from principles of cooperation and mutual support," said Dmitry Rogozin, head of Roscomos (the Russian space organization), in an interview translated by CNBC.[22] Rogozin further stated that Russia and China intend to lead the development of a lunar science base. China is apparently reviewing preliminary studies for a crewed lunar landing mission in the 2030s with the possibility of the construction of an outpost near the lunar south pole with international cooperation.[23]

Table 1: Summary of the Artemis Architecture Elements					
Heritage	**Status**	**Original FD Estimate**	**Current FD Estimate**	**ABC or Initial Estimate**	**Cost Through FY2020**
SPACE LAUNCH SYSTEM (Marshall Flight Center)					
Ares V from the Constellation program, Space Shuttle	◆ Contracts awarded to Boeing, Northrop Grumman, and Aerojet-Rocketdyne in 2011-2012. ◆ Boeing Core Stage is in testing at the NASA Stennis Space Center. ◆ Northrop Grumman completed the Shuttle-derived solid rocket motor boosters for Artemis I; now working on motors for Artemis II. ◆ Aerojet-Rocketdyne upgraded and tested the 16 RS-25 Space Shuttle engines in inventory. ◆ The Interim Cryogenic Propulsion Stage (ICPS) derived from the Delta IV cryogenic second stage delivered to KSC. ◆ A complete SLS Block 1 unit has not yet been integrated.	Artemis I November 2018	Artemis I November 2021	$9.7B	$18.6B

Table 1: Summary of the Artemis Architecture Elements					
Heritage	Status	Original FD Estimate	Current FD Estimate	ABC or Initial Estimate	Cost Through FY2020
ORION (Johnson Space Center)					
Constellation Crew Exploration Vehicle (conceptualized in 2005)	• Original contract with Lockheed-Martin initiated in 2006 for $3.8B • Three successful test flights: Pad Abort-1 in May 2010 at White Sands tested Launch Abort System; Exploration Flight Test-1 December 2014 (launched on a Delta IV, two Earth orbits); and Ascent-Abort (AA-2) in July 2019 tested the launch abort system and other Orion subsystems. • Artemis I unit in testing; work proceeding on Artemis II unit	Original construction goal was 2008	Artemis I vehicle is in test, Launch November 2021	$6.2B (2012)	$13.7B ($18.7B since 2006)
EXPLORATION GROUND SYSTEMS (Kennedy Space Center)					
Saturn V, Shuttle, ESD	• Infrastructure to support different kinds of spacecraft and rockets that are in development, including the Artemis launches and commercial • Upgrading Launch Pad 39B, the crawler-transporters, the Vehicle Assembly Building (VAB), the Launch Control Center's Young-Crippen Firing Room 1, mobile launcher (ML), and other facilities • EGS ready to support Artemis I launch as soon as November 2020	Schedule follows Artemis I launch date	Schedule follows Artemis I launch date	$2.8B	$3.3B

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Heritage	**Status**	**Original FD Estimate**	**Current FD Estimate**	**ABC or Initial Estimate**	**Cost Through FY2020**
HUMAN LANDING SYSTEM (Marshall Space Flight Center)					
New Designs	• July 2019 MSFC named lead center for developing Lunar Landers (HLS) • Using Broad Agency Announcement for procurement for design and development by U.S. companies • Three companies selected April 2020 (Blue Origin, Dynetics, and SpaceX), three different concepts, total value of the three contracts is $967M to initiate the work[24]	2024	Schedule follows Artemis III	Project just initiated	~$18B through 2024 based on 2021 PBR
GATEWAY (Johnson Space Center)					
2012 Deep Space Habitat; 2017 Deep Space Gateway; 2018 Lunar Orbiting Platform-Gateway (Gateway)	• PPE - Contract awarded to Maxar Technologies May 2019.[25] PPE under direction of Glenn Research Center. $375M, but already increasing.[26] • First U.S. commercial provider for Gateway Logistics Services - contract awarded to SpaceX in March 2020.[27] • HALO contract awarded to Northrop Grumman June 2020. $187M.[28] • Planned International Cooperation with Canada (robotic arm), Japan (habitat and research capacity), and the European Space Agency (refueling and communications hardware).	PPE and HALO launched together November 2023 on commercial launch vehicle	TBD	Project just initiated	~$2.3B through 2024 based on 2021 PBR

Table 1: Summary of the Artemis Architecture Elements

Heritage	Status	Original FD Estimate	Current FD Estimate	ABC or Initial Estimate	Cost Through FY2020
ARTEMIS GENERATION SPACE SUITS (Johnson Space Center)					
Extra-vehicular Mobility Unit (EMU) – Shuttle and ISS; Exploration EMU (xEMU) – ISS 	• Exploration Extra-Vehicular Activity (xEVA) comprises the Artemis Generation Suits, vehicle interfaces, and tools. • Suit based on xEMU which has been in development to replace LEO suits, which are 40 years old. • NASA is doing an “in-house” build at JSC – Jacobs is the contractor building the suits as Government Furnished Equipment. • After the first 10, an RFP will be issued for competitive procurement • xEMU originally funded from ISS budget – now funded from Gateway.	November 2023	TBD	Unknown	Development cost estimated to be between $300M and $500M

Notes:

a. FD is flight date.
b. ABC is the Agency Baseline Commitment or the original estimated budget.
c. Cost through FY2020 is what has been committed in real-year dollars.
d. The lead NASA centers are indicated parenthetically.

Moon to Mars

One of the defining characteristics of the Artemis program is the push to use experience gained on the surface of the moon to inform the technologies, operations concepts, and policies that will be needed to explore Mars beginning as early as the 2030s. This is important to ensure successful Mars missions, as there are limitations to existing analogs or other opportunities from which relevant experience can be gained.

The NASA Human Research Program (HRP) is prioritizing research to address the top five hazards to crew during spaceflight.[29] These include:

1. **Space radiation**, which increases cancer risk.
2. **Isolation and confinement**, which can cause sleep loss, cardiac desynchronization with work overload leading to performance degradation.
3. **Distance from Earth**, which means that detailed forward planning and exploration systems self-sufficiency are of paramount importance.
4. **Reduced gravity environment**, which will range from zero-g en route to 0.38 g on the surface of Mars, the effects of which are not well understood for longer surface stays.
5. **Hostile and closed environments**, which is a result of the environment inside the spacecraft and surface modules, including things like temperature, humidity, atmospheric composition and pressure, noise, lighting, and space available.

NASA and other space agencies have undertaken robotic missions to Mars to better understand the Martian environment. In fact, three missions just launched in July 2020 including the Perseverance rover mission from the U.S., which includes the Ingenuity helicopter; the Hope orbiter developed by the United Arab Emirates and launched by Japan; and the Chinese Tianwen-1, comprising an orbiter, lander, and rover. Altogether a total of 55 attempted robotic missions have been sent to Mars by eight nations, 28 of which were successful. From those successful missions, much has been learned about the planet. However, there is still much more to learn before humans set foot on the Martian surface.

NASA is now working on the development of six key technologies[30] required to send humans to Mars. More powerful propulsion systems are required to take humans there and back again more quickly, thereby reducing radiation, isolation, and physiological risks from low gravity, among others. Propulsion options may include nuclear electric and nuclear thermal propulsion systems. Another key technology is a deployable entry, descent, and landing system, which has an inflatable heat shield that will provide the protection required upon entering the Mars atmosphere but will not take up as much mass and volume on the space vehicle as would a rigid heat shield. The next generation spacesuit, the xEMU, is being developed for exploring both the moon and Mars. The spacesuit is basically a custom mini-spacecraft for one person that provides all the life support systems needed to sustain and protect the astronaut. A Martian pressurized rover, which will serve as both a habitat and a means of transportation, is also being investigated. Nuclear surface power systems are also under study and development to provide efficient and reliable power systems for lunar and Martian surface operations. Finally, laser communications systems are being developed to manage the large amounts of real-time information and data, including high-definition images and video feeds that are anticipated.

A New Era for Deep Space Exploration and Development. On July 23, 2020, the White House and National Space Council released a document titled *A New Era for Deep Space Exploration and Development*[31] that lays out a new vision, an ambitious and sustainable strategy, and a definition of the role of government for U.S. space exploration. The document includes a plan to take the U.S. from working in LEO to exploring the moon and Mars as well as addressing the potential for deep space science studies. Emphasis is placed on involving commercial and private sector companies, research laboratories, universities, and international partners.

This clearly represents a movement towards a whole-of-government approach to space exploration and utilization that incorporates the timely insertion of private enterprise. For example, the commercialization and privatization of LEO activities, if successful, would free up funds for government agencies to forward the country's exploration initiatives and allow for extending government-supported space activities into cislunar space and to the moon. In due course, commercialization and privatization of human activities on the moon would then allow shifting government resources and support to living and working on the surface of Mars.

Findings

These findings are based on the information gleaned from the references cited coupled with input from NASA and Artemis experts, most of whom are former NASA officials, program managers, or scientists. The findings are divided by general subject area into programmatic and management challenges, technical challenges, and policy points.

Programmatic and Management Challenges. Based on past and current GAO and NASA IG assessments it is clear that more management attention could be directed to large programs. No doubt exacerbating the present situation in human exploration is the fact that HEOMD at NASA HQ has undergone a change in leadership three times in a little over a year. With each change of leadership comes a reorganization and reassignment of senior leaders, which takes time to resolve.

According to several experts interviewed, the Artemis program seems to be missing a strong and informed management structure that includes high-level planning functions (such as site selection boards, operations practices, flight techniques, training, the mission build sequence, control boards, system integration, and other key functions) as well as the science advisory structure. NASA management might well revisit what was required to successfully execute the Apollo missions. It is sobering to realize that the average age of the civil servants in Mission Control when Apollo 11 splashed down was 26, while Flight Director Gene Kranz had not yet reached the age of 36. The average age of NASA civil servants when Space Shuttle Atlantis launched in May 2009 was 47. Now, many experienced NASA personnel with significant "corporate knowledge" and honed management skills are retired or near retirement. Furthermore, the emphasis at NASA over the last four decades has been on operations (e.g., Space Shuttle and ISS) with the vast majority of NASA personnel being operations specialists who are more familiar with sustainment activities rather than the development of new systems. These factors lead to another management challenge regarding the transition from an operations and sustainment mode to a mission design, build, fly, and execute mode. The task that lies ahead is daunting in its complexities and would benefit from taking onboard the lessons learned during Apollo to optimally leverage state-of-the-art technology for successfully revisiting the moon and going beyond.

One NASA expert interviewed argued that the program to return Americans to the moon has been underfunded by at least $1 billion per year since the early days of ESD. In addition, the NASA budget is not stable year to year and the mission portfolio changes from administration to administration. Artemis is the third attempt to return Americans to the moon since Apollo. Regarding funding and affordability, it is unlikely that NASA can execute Artemis while continuing to fund the ISS and LEO operations at approximately $4.5 billion per year. [32,33]

Another challenge is associated with the competition amongst the NASA Centers. The main NASA-developed Artemis elements are being loosely coordinated by NASA HQ and managed out of three different centers: Marshall, Johnson, and Kennedy. The other seven centers are providing various levels of support, some managing the development of major element subsystems. (See Table 1.) This could be problematic in light of the fact that there is no overall integration plan for Artemis at the HQ/HEOMD level.

Many costs associated with Artemis are hidden, intentionally or not, as a result of the changes from Constellation to ESD to Artemis. One interesting case, as related by an individual close to the program, is that of the xEMU. Because the EMUs onboard the ISS are approaching 40 years old and experiencing all the pains associated with aging, with maintenance becoming extremely challenging, development of the xEMU began and was funded under various lines in the ISS budget. When it recently became obvious that a space suit for lunar surface operations will be needed well before 2024, the xEMU development oversight and funding was moved from ISS to Gateway to be part of the Artemis program. It has now morphed into the xEVA, which also requires the development of Gateway and HLS vehicle interfaces (donning and doffing racks, for example) and tools that the astronauts will use on the moon. With the costs of the xEMU and xEVA intertwined between two different programs spread under different funding lines and spanning more than 10 years so far, determining the actual cost will be challenging.

According to two interviewees, NASA might well consider rethinking the acquisition strategy for planned Mars missions. An honest assessment of whether the SLS is the right rocket for the mission should be undertaken. The SLS production tempo is not designed to support the two to three Block 2 launches per year needed to provide the six to eight launches required for **one** Mars mission. Block 2 is not yet under development and the need for Block 1B is already in question.

Technical Challenges. The ESD program began already constrained by Congress to use Ares V as the basis for the SLS, but without the more powerful upper stage. The Ares V was constrained to use shuttle heritage hardware. This has resulted in limitations on SLS capability. SLS development has also been fraught with numerous technical and manufacturing issues leading to schedule degradation and budget overruns.

A former NASA program manager indicated that the technical problems are further exacerbated because an Artemis systems integration plan has not been developed. In fact, said former program manager stated that the three main elements under the purview of three different NASA centers (SLS, Orion, and EGS) are expected to "self-integrate." That is, the three different management teams are to cooperate to ensure a successful integration without the benefit of an overall SE&I plan. This situation will lead directly to technical challenges if the three systems are brought together without any overarching integration plan. What happens if the interfaces are incorrect or other conflicting requirements emerge? Obviously, that would mean additional schedule pressure and increased cost.

Other technical concerns resulting from program management challenges include the lack of a concept of operations (CONOPS) for Artemis III lunar surface EVAs. According to an expert familiar with the Artemis program, the CONOPS and logistics for the 2024 mission are still unknown. Specifically, the space suits do not fit in the Orion spacecraft with the crew onboard, so there needs to be a plan for how to get them to the moon. Do they come in the HLS? Will there be a separate logistics module quickly developed to support Artemis III? It is known that the Orion will need to dock with the HLS. If the suits are not carried up in the HLS, then somehow, the astronauts will need to get the suits onboard. Given that three concepts for the HLS are being considered and nothing has yet been built, it seems that now HLS is pacing the run-up to the 2024 boots on the moon target date. There are a significant number of technical hurdles to jump to make that date. From a technical point of view, first landing in the 2028 timeframe is much more realistic, according to several experts interviewed for this paper.

Policy Points. How space exploration initiatives evolve hinges on policy decisions and implementation. The National Space Council is setting the broader U.S. space policy with this administration paying significantly more attention to space and space exploration than any in the recent past. However, perhaps the space policy decisionmakers need to take a step back with respect to space exploration and exploitation and ask a few basic questions. *Why go? What are we trying to do? What is the economic motivation for exploring the Moon and Mars? How do we achieve sustainability? How can we maximize the productivity of our time on the Moon? How can we maximize the productivity of our time on the moon? Why the accelerated timeline?* Fast does not equal sustainable. Establishing artificial deadlines forces decisions to be made. They may not be the right decisions at the end of the day if sustainability is a critical objective.

One lunar exploration expert emphasized that sustainability is a strong function of being able to harvest the needed resources for a self-sustaining lunar base. There are mountains of legal and policy challenges that need to be surmounted, and the Artemis Accords are a first step. Working through these challenges will no doubt take as much or more time than that required for the technology to develop.

From a policy perspective, there are questions regarding how to smoothly transition from LEO to exploration as well as how to incorporate lessons learned from the bumpy transitions that occurred between Apollo and the Space Shuttle Program, and then between Shuttle and the Commercial Crew Program (CCP). Specifically, in the transition from Apollo to Shuttle, significant numbers of jobs were lost with a not inconsequential economic impact. Then, when the Shuttle program ended in 2011, Kennedy Space Center was downsized and more jobs were lost, profoundly affecting the economy of the Florida's Space Coast. After Shuttle, there was a transition to the Commercial Crew Program, but that brought only modest, delayed relief to the Space Coast workforce because the program was four years behind schedule.

Another consideration during these transitions is to ensure that what is left behind remains sustainable as things move forward. Looking even farther ahead, policies need to be in place to ensure a graceful transition from sustainable moon to exploring Mars followed by sustainable Mars. NASA has seemed to struggle with transitions, according to several of the experts interviewed.

It is clear that moving to a full-up Artemis effort will likely mean not being able to support operations in LEO at the current level. Even though NASA managed to maintain the Shuttle program while developing the ISS (which depended on the Shuttle for its construction), it is not clear that without additional budget allocations both sustaining the ISS and developing Artemis at the desired pace is possible. Funding for the ISS, Commercial Resupply Services (CRS), CCP, spaceflight support, and commercial development now totals close to $4.5 billion per year.

There are two main activities to be executed on the moon: a) surface operations for sustainability and habitation that map directly to Mars exploration, and b) exploration of the lunar surface followed by development of a self-sustaining base of operations. This will take more funding than is currently committed. According to one expert, if the ISS support cost can be dropped to about $1 billion per year, then lunar exploration becomes more feasible in the immediate timeframe. A policy change coupled with clear direction to NASA to commercialize and significantly reduce the cost of LEO operations, including the ISS, are needed for current exploration plans to succeed.

The Artemis Accords are garnering praise as being a good vehicle for clarifying the interpretation of international legal principles, according to one of the experts interviewed. There are also those who are not pleased and think that turning commercial enterprise loose to exploit resources off planet is problematic. Even though currently limited to supporting the European Service Module and contributing to Gateway, there is still a fair amount of international interest in participating in Artemis, particularly from Canada, Japan, and ESA. Interest is also being expressed by the United Arab Emirates, Australia, and South Korea. As already mentioned, Russia has opted out and plans to work with China.

Building on the recently released New Era document that promotes a whole-of-government approach to space exploration, NASA and the USSF signed a memorandum of understanding on September 21, 2020.[34] The first paragraph in the background section of the document reads:

> NASA and relevant precursor organizations of the USSF share a long history of mutually beneficial cooperation that contributes to the Parties' respective civil and defense roles. Such cooperation was built on synergies in certain operational capabilities and in research and development activities in science and technology. With the historic establishment of the USSF as a new branch of the Armed Forces in December 2019 and with NASA's Artemis Program under way to land the first woman and next man on

> the Moon by 2024, NASA and USSF hereby reaffirm and continue their rich legacy of collaboration in space launch, in-space operations, and space research activities, all of which contribute to the Parties' separate and distinct civil and defense endeavors.

Eleven cooperative areas are specified, including space domain awareness, near-Earth object detection, cislunar operations, search and rescue, launch support, safety standards and best practices, fundamental scientific research, interoperable space communications, and workforce sharing. This marks an important policy step in the collaborative exploration and exploitation of cislunar space. Indeed, there are commonalities among space exploration, development, and security that provide strong incentives for coordination and collaboration.

Opportunities

In spite of the management, technical, and policy challenges facing America's return to the moon and moving forward to Mars exploration, there are many opportunities ripe for exploitation. The Artemis program is different from previous programs in that it is pulling on the commercial sector to develop some of the key program elements. There are, in fact, already opportunities for the commercial sector, including CLPS, launch services, HLS, and Gateway modules. The use of commercial launch providers is foreseen in all of the architectures for operations in cislunar space and lunar surface exploration and operations.

Significant attention is now on in-situ resource utilization (ISRU) for sustaining lunar bases and refueling launch vehicles. The harvesting of water ice, heavy metals, and helium-3 are activities that would be ripe for commercial development if there is a market for those resources on the moon. Studies on ISRU and resource harvesting have been ongoing for decades. Already, companies focused on off-planet resource harvesting have come and gone. The Artemis Accords were developed to provide a framework in which these sorts of operations can be executed commercially. It seems that the government and commercial sector are in synch. Now it is time to work out if there is any "there" there.

Another *potential* market is building and launching spacecraft from the moon for exploration beyond cislunar space. *If* the resources to do this are present and *if* they can be processed in-situ, then launching spacecraft becomes much easier. There is no atmosphere, so no fairing is required. The lunar gravity well is much weaker than that of the Earth, therefore much lower thrust would be required, resulting in reduced vibrations and a less harsh launch environment. That is, *if* a way to produce spacecraft on the moon at a sufficiently attractive price point can be found. Assuming, of course, that sustainable operations and functional ISRU are possible.

Perhaps the biggest question of all is whether or not there can be a lunar-based economy. For private enterprise in space to succeed, there needs to be a value proposition and business plans to identify the needs to be filled. Just what is the next "killer app" for NASA and the commercial space enterprise? Hopefully the answers will be revealed in the coming decades as cislunar exploration marches onward.

NASA leadership, at least at a high level, is thinking of something more than just boots on the moon. They are laying out a vision that ties together Gateway with a cislunar transportation infrastructure enabling a sustained lunar presence and serving as a launching pad for Mars. Forward thinking is crucial to the success of Artemis. The leadership of NASA is enthusiastically and optimistically looking to the future.

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