NASA's Human Landing System Program: Progress Toward Artemis III and Beyond

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Abstract

As part of its Artemis campaign to once again land astronauts on the Moon and usher in a new generation of science, discovery, and technology development for the benefit of all, NASA's Human Landing System (HLS) program, working with industry providers SpaceX and Blue Origin, made significant progress in the last year toward the Artemis III mission and beyond. In 2021, the HLS program, based out of Marshall Space Flight Center in Huntsville, Ala., awarded a firm, fixed-price (FFP) contract to SpaceX to provide a lunar lander for Artemis III – scheduled to be the first mission to return astronauts to the surface of the Moon since Apollo 17 in 1972. In 2022, NASA awarded SpaceX a contract modification to provide a lunar lander for Artemis IV built to an extended set of requirements. In parallel, the program awarded another FFP contract to Blue Origin and its partners to provide a landing system for Artemis V, giving NASA a dissimilar, redundant capability for human Moon landings. For Artemis VI and beyond, NASA plans to competitively procure landing services. Before the crewed Artemis lunar landing missions can occur, however, there are many milestones the HLS program and its industry providers must accomplish. This paper describes progress made in 2023 and the first three quarters of 2024 and a lookahead to the milestones and testing needed to achieve flight readiness for the Artemis III mission and beyond.

Keywords: NASA, Human Landing System, Artemis

Acronyms/Abbreviations

Air Force Research Lab (AFRL); Authority to Proceed (ATP); Axiom Extravehicular Mobility Unit (AxEMU); Canadian Space Agency (CSA); Certification Baseline Review (CBR); Commercial Crew Program (CCP); Concept of Operations (ConOps); Critical Design Review (CDR); Design, Development, Testing, and Evaluation (DDT&E); Detailed Verification Objectives (DVOs); Environment Control Life Support Systems (ECLSS); Exploration Ground Systems (EGS); Exploration Systems Development Mission Directorate (ESDMD); Extravehicular Activity (EVA); Extravehicular Activity and Human Surface Mobility Program (EHP); Firm, Fixed Price (FFP); Flight Termination System (FTS); Government Task Agreements (GTAs); Human In The Loop (HITL); Human Landing System (HLS); Independent Verification and Validation (IV&V); International Space Station (ISS); Key Decision Point-C (KDP-C); Liquid Oxygen (LOX); Low-Earth Orbit (LEO); Lunar Orbit Checkout Review (LOCR); Methane (CH4); Metric Tons (t); Micrometeoroid Orbital Debris (MMOD); Mission Management Team (MMT); Near-Rectilinear Halo Orbit (NRHO); Preliminary Design Review (PDR); Probabilistic Risk Assessment (PRA); Radio Frequency (RF); Reaction Control System (RCS); Safety & Mission Assurance (S&MA); Science Mission Directorate (SMD); Soft Capture System (SCS); Space Launch System (SLS); Technology Readiness Levels (TRLs); Thrust Vector Control (TVC); Trans-Lunar Injection (TLI).

1. Introduction

One of NASA's strategic goals is to "extend human presence to the Moon and on towards Mars for sustainable long-term exploration, development, and utilization." [1] To achieve this goal, NASA has created the Artemis campaign of lunar missions. Each Artemis mission builds on lessons learned from the previous mission; each mission increases in complexity and risk. The private, commercial space industry has gained decades of spaceflight experience flying cargo and crew to the International Space Station (ISS) in low-Earth orbit (LEO). To leverage this expertise, NASA opted to purchase landing services from commercial companies,

while providing rigorous oversight and insight into engineering processes, but not procuring the landers.

The Artemis I mission, an uncrewed, full-up test in deep space of the agency's new super heavy-lift launch vehicle, the Space Launch System (SLS), and the Orion spacecraft for crew, launched on November 22, 2022, with Orion splashing down on December 11, 2022 (see Figure 1). [2] The mission launched from Launch Complex 39B at NASA's Kennedy Space Center and also exercised the agency's upgraded ground processing and launch facilities, as well as launch and mission control procedures and processes newly developed and implemented for lunar missions. [3]

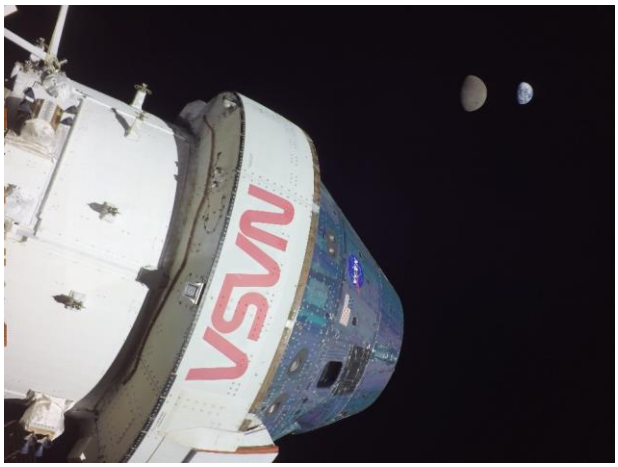

Figure 1. Artemis I tested NASA's Space Launch System (SLS), Orion, and Exploration Ground Systems (EGS) capabilities on the ground and in deep space prior to commencing crewed flights with Artemis II.

Artemis II is scheduled to launch no earlier than September 2025 and will be the first crewed flight beyond LEO since Apollo 17 in 1972. NASA announced the four crew members – Commander Reid Wiseman, Pilot Victor Glover, Mission Specialist Christina Koch, and Mission Specialist Jeremy Hanson – on April 3, 2023 [4]. Koch will be the first woman to fly to deep space and Hanson will be flying for the Canadian Space Agency (CSA). On July 3, 2024, NASA announced Andre Douglas will serve as a backup astronaut for Artemis II [5]. The CSA announced that Jenni Gibbons is the backup astronaut for Jeremy Hanson for Artemis II [6]. The Artemis II mission is scheduled as a 10-day lunar flyby that will feature proximity operations in Earth orbit with the astronauts testing Orion's maneuverability and handling features prior to trans-lunar injection (TLI), outbound transit to the Moon, lunar flyby, return to Earth, and recovery operations by NASA's Exploration Ground Systems (EGS) program and the United States Navy.

2. Role of HLS program in Artemis

Leveraging the commercial provider contract services paradigm used by NASA's Commercial Crew Program (CCP) enables the agency to purchase crew transportation services rather than spacecraft and launch vehicles. The services acquisition strategy takes advantage of advances the private sector has achieved in spaceflight, launch vehicles, human-rated spacecraft, and related technology, to foster a strong high-tech industrial base, rigorous competition, and to nurture a new lunar economic ecosystem. NASA considered it a high priority to bring two providers for lunar landing services online to give the agency dissimilar, redundant human landing capabilities.

Safety remains the key tenet of NASA's human spaceflight enterprise – and the HLS program. To that end, specialists from the Safety & Mission Assurance (S&MA) organization are integrated into both SpaceX and Blue Origin design activities providing expertise, insight, and oversight of:

- Human rating requirements
- Hazard analysis development and risk characterization
- Probabilistic Risk Assessment (PRA) and risk drivers
- Independent Verification and Validation (IV&V) of software

In addition to integrating a safety focus into the various engineering designs and ground testing and processing procedures, the HLS program has also provided technical expertise to its commercial providers to advance Technology Readiness Level(s) (TRLs) and facilitate design, development, testing, and evaluation (DDT&E). Agreements known as Collaboration Tasks allow NASA experts to work directly with SpaceX and Blue Origin. Another avenue for government-commercial cooperation and knowledge-sharing is via Government Task Agreements (GTAs) that enable the commercial providers to access unique government assets and resources, such as test facilities, launch support, or technology [7].

3. Artemis III HLS

Following the Artemis II crewed lunar flyby mission, Artemis III is scheduled to be the first crewed lunar landing of the Artemis campaign. NASA has contracted with SpaceX (Hawthorne, Calif.) to provide the HLS for Artemis III under the NextSTEP Appendix H: Human Landing System solicitation (see Figure 2). [8] A high-level description of the initial lunar landing mission include:

- Delivery of the HLS to lunar orbit
- A Lunar Orbit Checkout Review (LOCR) in Near-Rectilinear Halo Orbit (NRHO)
- Docking with the Orion spacecraft in NRHO
- Descent to and landing on the lunar surface

- Support of two crew members on the lunar surface for six days (one NRHO orbital period)
- Ascent from the lunar surface
- Rendezvous and docking with Orion in NRHO

The Starship HLS will launch the SpaceX Super Heavy-Starship vehicle from facilities currently under construction in Boca Chica, Texas and at Kennedy Space Center in Florida. Cryogenic refueling in LEO is necessary to enable Starship HLS to head to the Moon with significant payload capability. To accomplish this, SpaceX has three versions of the Starship upper stage in development to facilitate cryogenic propellant transfer operations in LEO:

- Depot
- Tanker
- HLS

Prior to the Artemis III crewed lunar landing mission, SpaceX will demonstrate cryogenic propellant transfer operations in Earth orbit (see Section 6) and an uncrewed lunar landing.

Figure 2. Artist's illustration of the SpaceX Starship Human Landing System (HLS), a variant of the company's commercial launch vehicle, currently in development for Artemis III and IV. (Image credit: SpaceX)

Prior to the Artemis III lunar landing, the HLS program and SpaceX have mapped out numerous milestones, testing, and design reviews to ensure requirements are met as well as to reduce risks. Since being selected as the lander to return humans to the surface of the Moon for the first time since Apollo, SpaceX has completed more than two dozen HLS-specific milestones by designing and testing hardware needed for power generation, communications, guidance and navigation, propulsion, life support, and space environments protection. Artemis III will be a demonstration of this initial two-crew Starship HLS configuration required to safely transport crew to and from the lunar surface. Starship HLS configurations for Artemis IV will have additional capabilities to enable the full range of crewed lunar mission objectives (see Section 7).

4. Early HLS Progress Toward Artemis III, 2021-2023

In the first two years following the award of the Artemis III lunar landing to SpaceX, the company demonstrated significant progress in developing its ambitious HLS system. A series of test flights from the company's Boca Chica, Texas facility provide high-profile, visible progress on the Super Heavy-Starship vehicle. However, the company also achieved significant progress in maturing designs and testing systems of additional components and systems needed for the Starship HLS vehicle at its various facilities.

4.1 Test Flights. Prior to attempting an orbital launch of the integrated Super Heavy-Starship system, SpaceX conducted a series of Raptor engine acceptance tests, cryogenic proof and qualification testing on tank sections, booster and ship engine spin prime testing, booster and ship hot-fire testing, and wet dress rehearsals [9]. Test flights of the Starship upper stage then preceded integrated testing of the fully stacked vehicle with the Super Heavy booster. Each flight test incorporated lessons learned from the previous flight, enabling SpaceX to rapidly mature systems, designs, processes, and launch facilities iteratively. By May 2021, the Starship upper stage achieved a flight apogee of 33,000 ft. (10 km). The company then began testing the integrated Super Heavy-Starship system. SpaceX began its orbital launch campaign with the integrated Starship vehicle launching for the first time on April 20, 2023 (see Figure 3). The vehicle successfully lifted off the pad and achieved an apogee of about 24 miles (39 km) before the Flight Termination System (FTS) activated. [10] A second orbital flight test of the integrated system launched on November 18, 2023. This test marked the first time all 33 Raptor engines ignited and completed full-duration burns. In addition, SpaceX successfully began to employ hot-stage separation to separate the booster and "ship" on this flight. Starship reached an altitude of about 93 miles (150 km) and orbital velocity during this test. [10]

4.2 Early Progress on Other Systems. Early progress on the crew compartment of the Starship HLS included construction of a crew cabin mock-up for human factors testing and evaluation of aspects of the Environment Control Life Support Systems (ECLSS) and thermal control system. In addition, astronaut crews participated in and provided feedback on development of training activities to assess landing trajectories and aspects of vehicle piloting during landing. Material flammability testing has been ongoing with results feeding a trade study evaluating various atmospheres for the cabin.

SpaceX has also performed development testing and analyses on crew displays, the elevator that will take crew from the airlock deck to the lunar surface and back again, solar array deployment, thermal and micro-meteoroid orbital debris (MMOD) protection tiles, landing legs, docking mechanisms, landing software and sensors, medical systems, and more. [11]

Figure 3. Flight tests of the integrated Super Heavy-Starship system began in 2023 from SpaceX launch facilities in Boca Chica, Texas. (Image credit: SpaceX)

5. Recent HLS Progress (2023-2024) Toward Artemis III

During the last year, the HLS program and SpaceX continued to make progress toward providing the Artemis III HLS. In November 2023, the program passed Key Decision Point-C (KDP-C), signifying agency concurrence to progress to final design and fabrication. In February 2024, the HLS program and SpaceX held a design review for the integrated lander, where SpaceX demonstrated that the lander design meets the requirements levied by NASA within acceptable risk and schedule margins. In addition, the review verified that appropriate design options had been chosen, interfaces identified, and verification methods adequately described. Some other advancements during the past year are described below, but due to space limitations, this list is not comprehensive.

5.1 Raptor Engines. A vacuum Raptor cold-start demonstration test was completed at SpaceX's McGregor, Tex. development facility in August 2023. This test enabled engineers to characterize start operations across a range of parameters, including extreme cold. The test demonstrated the engine's ability to meet the demands of a descent burn from lunar orbit to the lunar surface. Because the HLS will loiter in NRHO during LOCR and until Orion arrives with crew, the Starship vacuum Raptors will be the first engines required to restart in deep space for a descent-landing burn after an extended stay the extreme cold temperatures of deep space. In addition to the successful cold start vacuum Raptor testing, SpaceX continues to upgrade the Raptors, incorporating additively manufactured parts and assemblies.

5.2 Flight Testing. Integrated flight testing of the Super Heavy-Starship system continued in the last year with each flight achieving new objectives. The third flight test lifted off March 14, 2024, from SpaceX's Boca Chica launch facilities, and demonstrated faster ground propellant loading and an electronic thrust vector control (TVC) system. In addition, after a series of ground tests, SpaceX demonstrated internal tank-to-tank cryogenic propellant transfer, as required by its Tipping Point award. [12] The on-orbit demonstration consisted of transferring liquid oxygen (LOX) between the header and main tanks within Starship. This test was an important precursor to an upcoming larger-scale long-duration cryogenic propellant transfer test between Starship-based "target" and "chaser" vehicles (see Section 6.) The fourth flight test of Super Heavy and Starship launched June 6, 2024, and featured a boostback burn of the Super Heavy vehicle, Raptor engine upgrades, landing burns, and controlled sea landings of both Super Heavy and Starship. At the time of writing, SpaceX expects to launch the fifth flight test of Super Heavy and Starship in fall 2024.

5.3 Construction of Additional Launch Facilities. To facilitate rapid reuse, SpaceX has begun construction of a second orbital launch pad at the company's Boca Chica, Texas launch facilities. In addition, early work and environmental reviews are also underway at Kennedy Space Center for launching Starship from Launch Complex 39A.

5.4 Crew Training. SpaceX has achieved significant progress on a training system plan, with the HLS team providing insight, oversight, and review of the plan in 2023 and 2024. Advancements include preliminary definition of Starship training operations and training systems plans, including crew and operator training content; mock-ups and simulation capabilities; training facility loading assessments; and plans to integrate with NASA facilities for joint integrated training.

5.5 Life Support Systems. SpaceX has performed life support system testing applicable to both the initial (Artemis III) and sustaining (Artemis IV) contracts at its facilities in Boca Chica, Tex. The company constructed a mock-up full-scale cabin to test life support and thermal control and evaluate volume for crew systems. The human-in-the-loop (HITL) phase of testing included four people working in the cabin environment to measure system performance against metabolic loading from test participants.

5.6 Elevator testing. SpaceX designs for the Starship HLS include an elevator to take crew from the airlock deck, located near the top of the lander, to the lunar surface and back again. In late 2023, NASA astronauts Nicole Mann and Doug "Wheels" Wheelock helped test a subscale mock-up elevator system, providing feedback to SpaceX and NASA engineers on areas such as elevator controls, gate latches, ramp deployment interfaces for ingress and egress from the elevator basket, available cargo space, and dynamic operations while the basket moved along a vertical rail system (see Figure 4).

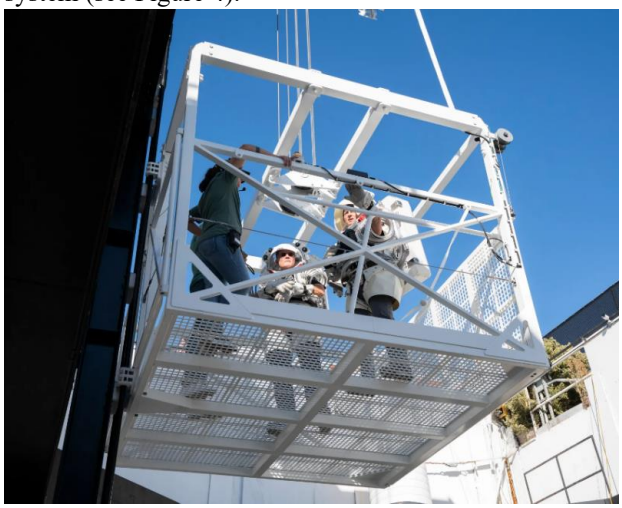

Figure 4. In 2023, NASA astronauts Nicole Mann and Doug Wheelock tested a subscale mock-up of the elevator that will take crew from the airlock deck to the lunar surface in the Starship HLS during Artemis III and Artemis IV. (Image credit: SpaceX)

5.7 AxEVA Suit Integration. In 2024, the NASA HLS and Extravehicular Activity and Human Surface Mobility (EHP) programs, Astronaut Office, and Artemis commercial providers SpaceX and Axiom Space, performed the first full-scale HITL integrated testing for Artemis III. NASA astronaut Wheelock and Axiom Space astronaut Peggy Whitson donned pressurized AxEVA suits and worked in a full-scale mock-up of the Starship HLS airlock, hatch, and elevator basket with gate and ramp mechanism and performed several flight-like tasks (see Figure 5). The astronauts evaluated placement and functionality of mobility aids, such as handrails and straps hanging from the ceiling in the airlock to assist with donning and doffing the suits. In addition, the crew practiced traversing the airlock deck, and egress and ingress of the hatch, giving engineers data on physical clearance, suit mobility, and more. Placement of control panels and ease of use of physical controls with spacesuit gloves was also tested. Completion of the HITL full-scale integrated AxEVA-Starship HLS airlock testing marked an important milestone achieved on the path to the first Artemis Moon landing.

Figure 5. In 2024, the NASA HLS and EHP programs and Astronaut Office and commercial Artemis providers SpaceX and Axiom Space held the first integrated test for Artemis III. (Image credit: SpaceX)

6. Lookahead for Artemis III HLS Development

In the near term, NASA's HLS program and SpaceX expect to meet several significant milestones on the path to initial human landing capability. Flight testing from SpaceX Boca Chica facilities is expected to continue, with SpaceX adding numerous upgrades to Starship and its Raptor engines. The HLS program and SpaceX will also be working toward Critical Design Review (CDR), which will signify the program is ready to proceed with system assembly, integration, testing, and launch. Following the Tipping Point cryogenic propellant transfer test (see Section 5.2), SpaceX is scheduled to perform a larger-scale, long-duration cryogenic propellant transfer test between two Starships in LEO. That test will involve launching two Starship vehicles that will dock in Earth orbit. The first vehicle to launch will serve as the "target" with the second vehicle, a "chaser," docking to it, then transferring cryogenic propellant into the target vehicle (see Figure 6). The long-duration cryogenic propellant transfer test is expected to generate valuable data to help reduce the risk associated with orbital cryogenic propellant transfer.

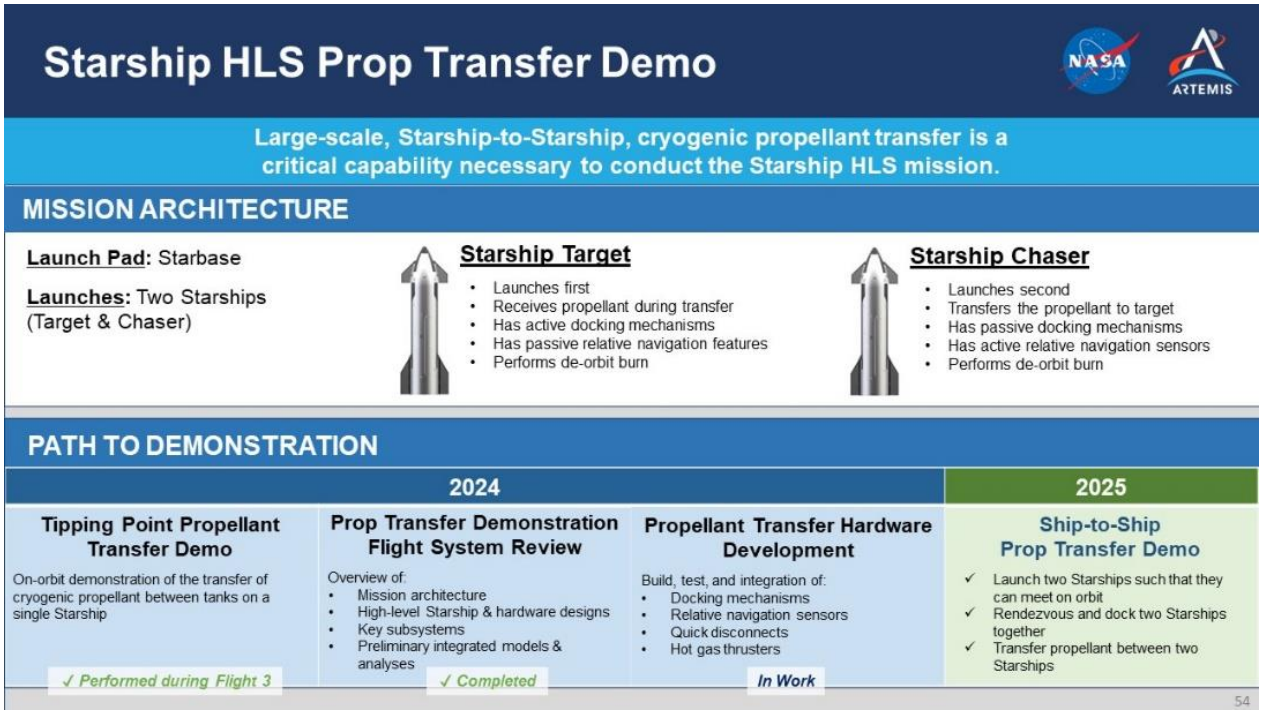

Figure 6. Overview of upcoming long-duration HLS cryogenic propellant transfer demonstration from SpaceX.

7. HLS Progress Toward Artemis IV

Recognizing the need to balance attainable mission schedules that include elements of the deep space architecture from numerous commercial providers with ever-increasing mission capabilities, the agency decided that human landing missions after Artemis III will require a more capable lander. In 2022, the agency awarded SpaceX a contract modification to provide an HLS that meets a more robust set of requirements for a second human lunar landing, scheduled for Artemis IV. [13] The Artemis IV mission and subsequent missions will require HLS to support landing a crew of up to four and have the capability to land and operate for extended durations at the lunar south pole as well the ability to land at non-polar sites. The HLS will also require additional performance capabilities to enable increased up-mass and down-mass, and extended EVA duration and frequency. All missions after Artemis III will require the HLS to dock with Gateway.

7.1 Docking System. In order to support docking with Gateway, SpaceX performed qualification testing on its Starship docking system, which is based on the flight-proven Dragon 2 docking system. The Starship docking system can also be configured to dock with Orion. The testing included more than 200 docking scenarios, with various approach angles and speeds. Full-scale dynamic testing demonstrated "soft capture" capabilities while in the active docking role with the soft capture system (SCS) of the active docking system is extended toward the passive system.

8. HLS Progress Toward Artemis V

In spring 2023, NASA awarded Blue Origin (Kent, Wash.) and its partners – Lockheed Martin (Bethesda, Md)., Draper (Cambridge, Mass.), Astrobotic (Pittsburgh, Penn.), Honeybee Robotics (Brooklyn, N. Y.) – a contract to develop an HLS for sustaining missions, with the more robust requirement set for Artemis IV.

[14] Blue Origin and its partners are developing the Blue Moon MK2 lander for the Artemis V lunar landing (see Figure 7).

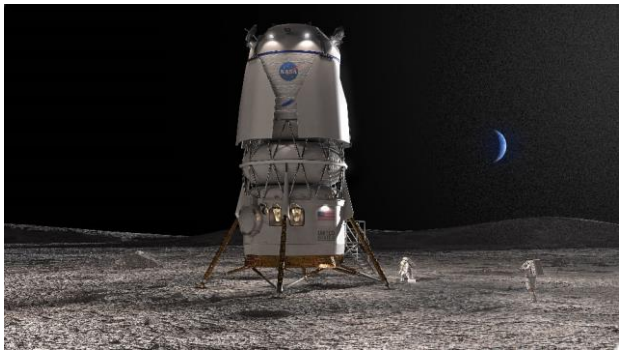

Figure 7. The Blue Moon lander is being developed by Blue Origin and its partners for the Artemis V mission. (Image credit: Blue Origin)

8.1 Standards and design reviews. Several early milestones completed by the HLS program and Blue Origin were focused on design and construction standards, requirements, interface definitions, integration, and design reviews. An early effort required with commercial companies, known as "standards adjudication," was completed in December 2023. NASA's HLS program and the provider agreed to a set of standards that included some NASA standards and some provider standards that meet the intent of the NASA standards. In November 2023, the HLS program and Blue Origin also completed a Certification Baseline Review (CBR). For CBR, NASA reviewed many contract deliverables that provided early verification of compliance to requirements. Some of the CBR deliverables provided by the Blue Origin team and reviewed by the HLS program and independent reviewers included: specifications, verification objectives, and the Concept of Operations (ConOps). Following successful completion of the standards adjudication process and CBR, the HLS program and Blue Origin held a Preliminary Design Review (PDR) in February 2024 that covered design and analysis of the integrated lander architecture.

8.2 Lunar Crew Module Mock-up. Blue Origin delivered a low-fidelity mock-up of the Blue Moon crew module in 2023 at its facility in Kent, Wash. The lander replica includes simulated crew systems and flight deck to provide a representation of the area focused on EVA excursion activities. The lunar crew module mock-up will serve as a testbed for subsystem development, HITL evaluations, integrated analysis, and configuration testing. In addition to the crew module representation, Blue Origin also built a low-fidelity lander training simulator in 2023. This virtual reality-based simulator, located at NASA's Johnson Space Center, supports assessments of crew module design and lunar landing operations feasibility.

8.3 Engine development. Blue Origin is developing its BE-4 engines to propel the New Glenn launch vehicle. BE-4 engines are tested and qualified at the company's Van Horn, Tex. facility and manufactured at the company's Huntsville, Ala. rocket engine factory. Blue Origin is developing its BE-7 engine to propel the Blue Moon lander. A development engine recently initiated vacuum chamber testing at the Air Force Research Lab (AFRL) at NASA's Armstrong Flight Research Center (see Figure 8).

8.4 Launch Complex Progress. Preparations to the New Glenn launch pad at Kennedy Space Center's Launch Complex 36 are in progress prior to first flight. Blue Origin recently completed testing the New Glenn launch vehicle's six hydraulically actuated landing legs on its first stage, that will secure the reusable first stage during landing on a barge platform.

Figure 8. The Blue Origin BE-7 in-space engine, in development for the Blue Moon lander for Artemis V. (Image credit: Blue Origin)

9. Designs for Large Human-Class Cargo Delivery Services Initiated

In late 2023, the HLS Program exercised contract modifications to enable SpaceX and Blue Origin to begin work on large-scale cargo landers to deliver 12-15 t payloads to the lunar surface. Cargo delivery services ensure NASA can deploy multidisciplinary science and technology tools, instruments, and payloads to the lunar surface. Design of these human-class cargo delivery landers leverages designs of the companies' HLS landers with an expected 80% common functionality overlap, but includes modified payload interfaces, elements for offloading cargo and deployment mechanisms. The current contracts include delivery from Earth and is not dependent on the timing of any Artemis missions. The large cargo landers are required to be able to operate autonomously and a payload delivery using a cargo lander could occur between crewed Artemis missions.

10. Conclusion

Artemis is ushering in a new era of deep space exploration, drawing on the experience of launching, technology development, habitation, and performing science in LEO aboard the ISS. The HLS program is playing a key role by drawing on the experience of contracting for crew transportation service from commercial providers and transferring that paradigm to a new generation of lunar missions. Once astronauts have egressed from the HLS, significant science and technology data will be collected through a series of walking, rover, and robotic traverses on the lunar surface that will help humankind to learn how to operate sustainably on the Moon and prepare for the exploration of Mars. Science activities during surface EVAs and traverses using a rover will be varied, and may include geophysical measurements, environmental monitoring, image and data acquisition, crew observations, sample collection, and characterization of regolith geotechnical properties. With NASA leading the Artemis missions and aligning with other countries of the world to enable peaceful science and discovery of the Moon through the Artemis Accords, a golden era of human exploration and discovery in space dawns.

11. References

[1] NASA Strategic Plan 2022, 28 March 2022, pg. 20 https://www.nasa.gov/wp-content/uploads/2023/09/fy-22-strategic-plan-1.pdf?emrc=ff1a1e, (accessed 24.09.04)

[2] Artemis I https://www.nasa.gov/mission/artemis-i/, (accessed 24.09.04)

[3] D. Sempsrott, Artemis I Simulations Ramp Up for the Countdown, https://www.nasa.gov/centers-and-facilities/kennedy/artemis-i-simulations-ramp-up-for-the-countdown/, 14 July 2021, (accessed 24.09.04)

[4] C. O'Shea, NASA Names Astronauts to Next Moon Mission, First Crew Under Artemis, 3 April 2023, https://www.nasa.gov/news-release/nasa-names-astronauts-to-next-moon-mission-first-crew-under-artemis/, (accessed 24.09.04)

[5] T. Doyle, NASA Announces its Artemis II Backup Crew Member for Moon Mission, 3 July 2024, https://www.nasa.gov/news-release/nasa-announces-its-artemis-ii-backup-crew-member-for-moon-mission/, (accessed 24.09.04)

[6] The Artemis II Mission, https://www.asc-csa.gc.ca/eng/missions/artemis-ii/mission.asp, (accessed 24.09.04)

[7] L. Watson-Morgan et al., Propulsion and Human Landing Systems: Marshall Space Flight Center's Expertise, doi: 10.1109/AERO58975.2024.105213032024, IEEE Aerospace Conference, Big Sky, MT, USA, 2024, 2-9 March.

[8] E. Mahoney, NextSTEP Appendix H: Human Landing System, 5 April 2019, https://www.nasa.gov/nextstep/humanlander2, (accessed 24.09.04)

[9] SpaceX web site, https://www.spacex.com/vehicles/starship/, (accessed 24.07.16)

[10] SpaceX web site, https://www.spacex.com/launches/starship-150m-hop/, (accessed 24.07.16)

[11] L. Watson-Morgan, et. al. NASA's Human Landing System: A Sustaining Presence on the Moon, IAC-23, B3,1,10, x787972, 74th Baku, Azerbaijan, International Astronautical Congress (IAC), 2-6 October 2023

[12] L. Hall, NASA Tipping Point Selections, 15 October 2020 https://www.nasa.gov/technology/2020-nasa-tipping-point-selections/, (accessed 24.09.04)

[13] L. Means, 15 November 2022, NASA Awards SpaceX Second Contract Option for Artemis Moon Landing, https://www.nasa.gov/humans-in-space/nasa-awards-spacex-second-contract-option-for-artemis-moon-landing/(accessed 24.09.04)

[14] C. O'Shea, 19 May 2023, NASA Selects Blue Origin as Second Artemis Lunar Lander Provider, https://www.nasa.gov/news-release/nasa-selects-blue-origin-as-second-artemis-lunar-lander-provider/, (accessed 24.09.04