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**NASA'S Human Landing System: Demonstrating the Capability to Land
Artemis Astronauts on the Moon by 2028**

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Abstract

NASA's Human Landing System (HLS) program, managed out of Marshall Space Flight Center in Huntsville, Ala., is working with United States industry to develop and demonstrate the capability to land crew and large cargo on the Moon in support of the U. S. Administration's goal of landing astronauts on the Moon by 2028. The HLS program is working with SpaceX to develop a variant of its Starship as an HLS and with Blue Origin to develop its Blue Moon MK2 to serve as an HLS for a series of increasingly challenging Artemis missions. The HLS program is making progress toward the first crewed lunar landing of the Artemis program by performing risk reduction and testing activities where needed, such as carrying out the largest ground-based study of plume-surface interaction (PSI) in history. A particularly impactful aspect of the program is making NASA engineers, subject matter experts (SMEs), and facilities available to SpaceX and Blue Origin through collaborations and Government Task Agreements (GTAs). Both companies have taken advantage of collaborations with NASA experts and GTAs at specialized facilities at nearly every NASA center. These public-private partnerships are advancing technology readiness and reducing risks in key areas, such as cryogenic valve development, cryogenic fluid management (CFM), computational fluid dynamics (CFD), wind tunnel testing, vibrational testing of avionics and other electronic equipment, thermal testing and modeling of various materials, and more. Both SpaceX and Blue Origin have made significant progress on lander development for both crew and large cargo during the past year. This paper will review progress the HLS program and its commercial providers have made during the past year and look ahead to significant developments leading up to the first Artemis missions using the human landing systems currently under development.

Keywords: Artemis, Human Landing System (HLS), Starship HLS, Blue Moon MK2 HLS, cryogenic fluid management (CFM), rendezvous, proximity operations, docking, and undocking (RPODU)

Acronyms/Abbreviations

Active Response Gravity Offload System (ARGOS); Black Point-1 (BP-1); Commercial Lunar Payload Services (CLPS); computational fluid dynamics (CFD); concept of operations (ConOps); cryogenic fluid management (CFM); design, development, testing, and evaluation (DDT&E); degree of freedom (DOF); environmental control & life support systems (ECLSS); equivalent engineering personnel (EP); Exploration Ground Systems (EGS); extravehicular activity (EVA); government task agreement (GTA); Human Landing System (HLS); Japan Aerospace Exploration Agency (JAXA); low Earth orbit (LEO);

low Lunar orbit (LLO); Interim Cryogenic Propulsion Stage (ICPS); Lunar Module (LM); main propulsion system (MPS); Mark 1 (MK1); Mark 2 (MK2); metric tons (mT); neutral buoyancy lab (NBL); outer mold line (OML); plume-surface interaction (PSI); Preliminary Design Review (PDR); reaction control system (RCS); rendezvous, proximity operations, docking, and undocking (RPODU); Stereo Cameras for Lunar-Plume Surface Studies (SCALPSS); Space Launch System (SLS); subject matter expert (SME)

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1. Introduction

NASA's Human Landing System (HLS) program, managed out of Marshall Space Flight Center, in Huntsville, Ala., is charged with demonstrating a lunar transportation capability for crew and large cargo for the Artemis missions to the Moon and Mars. The program uses lessons learned from public-private partnership models. The firm fixed-price contracting model incentivizes industry-led development while NASA sets requirements, performs insight and oversight into provider systems and processes, and exercises final control over certification for flight.

Following initial demonstrations of crewed landing capabilities from industry, scheduled for Artemis IV and Artemis V in 2028, NASA plans to competitively procure lunar landing services. NASA's goal is to jump-start a lunar economy and serve as one customer for lunar landing services among many, paving the way for a new era of innovation and technological advances.

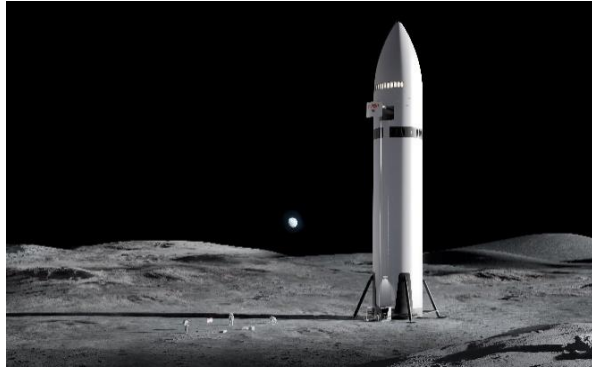


Figure 1. SpaceX's Starship Human Landing System (HLS) is a variant of the second stage of its Starship launch vehicle. (Credit: SpaceX)

2. HLS Updates to Meet Accelerated Artemis Manifest

2.1 Initial HLS Contract Awards

In 2021, NASA awarded the first HLS contract to SpaceX to develop and demonstrate a human landing system based on its Starship vehicle. [1] The Starship HLS is a variant of the second stage of the Starship launch vehicle, the first stage being the Super Heavy booster (see Figure 1). The initial contract directed SpaceX to develop the Starship HLS to meet a set of government requirements, designed to provide an initial level of functionality, including transporting two crew members from the Orion spacecraft in low lunar orbit (LLO) to the Moon's south pole and safely returning them to Orion.

In 2022, the HLS program awarded an additional contract to SpaceX [2] as well as a contract to Blue Origin [3] to develop landers that would meet a more robust set of requirements to enable sustainable lunar

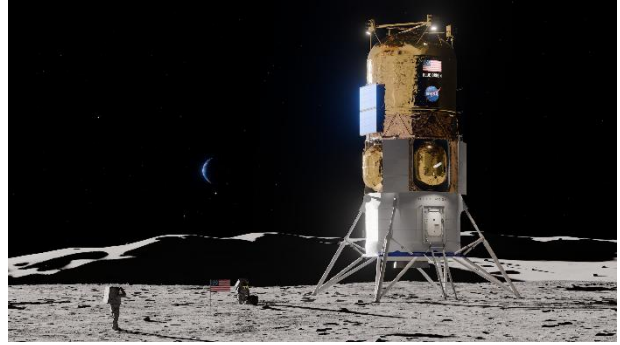


Figure 2. Blue Origin is working to develop its Blue Moon MK2 lunar for the HLS program. (Credit: Blue Origin)

exploration (see Figure 2). In 2023, NASA exercised options in the contracts with SpaceX and Blue Origin, giving the providers authority to proceed on development of robotic, cargo versions of the landers with the capability to deliver 15 metric tons (mT) of payload to the lunar surface. [4]

2.2 HLS Contract Modifications to Support Increased Artemis Mission Cadence

More recently, NASA strengthened its Artemis mission manifest, emphasizing the importance of increased mission cadence to signal demand to aerospace supply chains, provide Artemis teams with opportunities for more frequent training and launch operations, and deliver more exciting missions, assets, science, and technology to the Moon, such as building a Moon Base. [5]

Following the successful Artemis I uncrewed test flight in 2022 and Artemis II crewed test flight in 2026 that verified capabilities of the NASA's super heavy-lift Space Launch System (SLS), the Orion spacecraft for crew, and Exploration Ground Systems (EGS) ground processing and launch facilities at Kennedy Space Center, NASA shifted the Artemis III mission from a crewed lunar landing to a rendezvous, proximity operations, docking, and undocking (RPODU) test in low Earth orbit (LEO). The Artemis III RPODU test in Earth orbit will feature lander test articles from both Blue Origin and SpaceX docking with Orion and performing communications and data exchange tests. In addition, NASA plans for crew to ingress into the Blue Origin MK2 test article for limited testing and evaluation of environmental control and life support systems (ECLSS) inside the MK2 test article's crew cabin.

Similar to the way NASA's Apollo program first tested the Lunar Module (LM) in Earth orbit during the Apollo 9 mission prior to using the new system with crew in cislunar space, the revised Artemis III Earth orbit RPODU mission, scheduled for 2027, will

reduce the risk of first-time use of the landers (see Section 4.1).

NASA's HLS contracts with Blue Origin and SpaceX are undergoing updates to reflect revised mission profiles for the Artemis III demonstration mission in 2027. Both SpaceX and Blue Origin are working toward the new Artemis III RPODU mission under modifications to previous contracts.

NASA also announced the goal of two lunar landings in 2028, with Artemis IV scheduled for early 2028 and Artemis V toward the end of the year. [5] NASA will announce the lander provider for each of those missions at a later date. In order to execute two Artemis crewed lunar landings in 2028, NASA awarded each provider a task order to perform studies and recommend streamlined missions, with reduced requirements and possible architecture updates, that can be accomplished on an expedited schedule to meet the 2028 goal.

NASA is working with Blue Origin and SpaceX to refine requirements, understand systems and vehicle capabilities and manufacturing processes, and evaluate mission designs, to execute crewed lunar landings in the short-term, meeting the goals of U. S. space policy. The program is updating contracts accordingly. [6]

3. HLS Program Role in Advancing Provider Readiness for Artemis

The HLS program partners with SpaceX and Blue Origin to develop the landers, focusing on areas of greatest risk. Providers will not turn over ownership of landers to NASA; the program has instead purchased demonstrations of landing services. The HLS program sets requirements, identifies key risks, manages those risks, works closely with providers to advance technology in key areas, and performs additional risk reduction activities (see Section 3.4). Through engineering collaborations with providers and embedding SMEs in key areas where providers may lack experience or expertise – or even require additional resources during surge periods – NASA's HLS program helps advance industry capabilities and helps ensure mission success. The program also performs verification of provider capabilities and systems and certifies landers for flight readiness.

3.1 Risk Reduction Activities – Insight

To ensure landers in development from industry meet program and mission requirements, as well as agency safety and mission assurance standards, the HLS program exercises insight into key disciplines and systems that represent greatest risk. Engineers and technical experts perform varying levels of insight into providers' designs, development, manufacturing, testing, systems integration, training, procedures, and operations to gain understanding and ensure vehicles

will meet NASA's standards for quality, safety, and performance.

In addition, the HLS program requires its providers to meet:

- NASA Safety Requirements
- NASA Engineering & Construction Standards
- NASA Health & Human Performance Standards
- NASA Medical Standards

To ensure compatibility among interfaces and systems interoperability among NASA-owned assets, such as the Orion spacecraft, and industry designs, such as the landers and extravehicular activity (EVA) spacesuits being provided by Axiom Space, the HLS program set design and construction standards for the providers to adhere to. In cases where providers could show a proprietary standard meets the intent of the NASA standard, NASA approved use of the alternative. This adjudication of standards was completed in 2024 and provides a qualitative baseline that all stakeholders can rely on. As the HLS program is working with providers to increase launch cadence, these agreed-upon design and construction standards ensure the landers will meet NASA's engineering, health, and human performance requirements, facilitating verification and flight certification.



Figure 3. The HLS program manages engineering collaborations and use of specialized government facilities, such as wind tunnels at NASA Ames, to help providers advance technology readiness.

3.2 Engineering Collaborations

Beyond insight, the HLS program manages collaborations between NASA and industry providers to reduce technical risk and accelerate maturation of key systems and technologies. Examples of collaborations include partnerships to advance CFD and CFM, including orbital cryogenic propellant transfer; cryogenic valve development; propulsion; structures and mechanisms; avionics and environmental testing; studying lunar site

characteristics; materials science; and more. Both HLS providers have utilized, and continue to request, engineering collaborations with NASA experts across several NASA centers. The HLS program also supports providers' lander development by providing equivalent engineering personnel (EPs), often embedded directly with the provider, for engineering collaborations and surge support. As a result of the success of collaborations, the HLS program increased the number of collaborations and EPs available to providers in fiscal year 2026. Both providers have more than 100 NASA EPs currently working closely with them.

3.3 GTAs

Through GTAs, the HLS program makes specialized NASA facilities available to providers for testing, potentially reducing provider capital expenditures and reducing testing timelines. For example, SpaceX has used the transonic and supersonic wind tunnel testing facilities at NASA's Ames Research Center to study aerodynamic forces

and moments during atmospheric re-entry of the first stage Super Heavy booster (see Figure 3). Providers have also used the Arc Jet Complex at NASA Ames to study material properties and the flat floor facility at NASA Marshall to test landing algorithms and perform lunar lighting studies. At NASA Johnson, both providers have used lander crew compartment mockups in the Neutral Buoyancy Lab (NBL) to test suited ingress and egress operations, clearances, and other human factors. Blue Origin has used the Active Response Gravity Offload System (ARGOS) test fixture at NASA Johnson to evaluate ladder rung heights in its descent system as well as ease of crew rescue and cargo transfer procedures (see Figure 4).

3.4 Risk Reduction Testing

In areas where there is a gap in industry-wide technology or knowledge, NASA performs risk reduction testing, making results widely available to HLS providers and the larger aerospace community. An area where the HLS program has determined that a new generation of large-scale testing is needed is plume-surface interaction (PSI).

A multidisciplinary team from several NASA centers has designed a large ground-based vacuum test to better understand PSI and update models – a key area where new data and modeling is needed to better reflect the scale and operations of the Artemis HLS vehicles in development. The complex test series is currently underway inside the 18 m- (60 foot)-spherical vacuum chamber at NASA Langley Research Center. This facility provides a unique combination of a large volume to minimize ambient pressure rise during PSI testing, an ability to integrate non-combusting and hot-fire scaled propulsion systems, and permission to test with large quantities of lunar regolith simulant. [7]

The team conducts testing with two types of propulsion systems, a non-combusting, heated ethane plume, designed by NASA's Stennis Space Center and built by Purdue University, to replicate hydrogen-oxygen engine exhaust without the complexities of a hot-fire system; and a gaseous oxygen/solid fuel hybrid rocket motor developed by Utah State University and NASA Marshall. The team is targeting a minimum of 30 test runs for each propulsion system, impinging plumes into a 0.3 m (1 foot)-deep bin of Black Point-1 (BP-1) geotechnical lunar regolith simulant to capture plume structure, cratering and erosion, and ejecta data. Figure 5 shows imagery from current HLS PSI risk reduction testing.



Figure 4. Blue Origin conducted testing using the Active Response Gravity Offload System (ARGOS) test fixture at NASA Johnson to evaluate ladder functionality during suited crew operations.

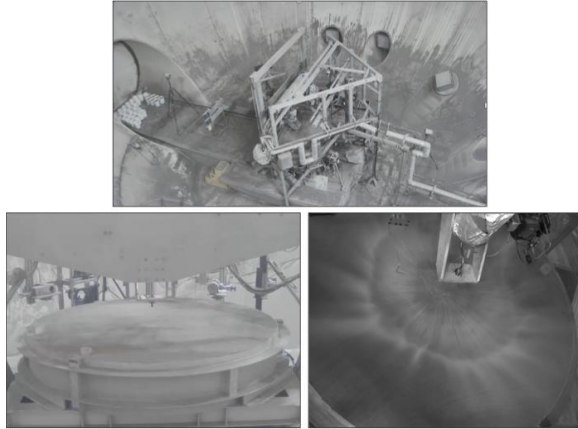


Figure 5. Imagery from inside the 18-m (60-foot) vacuum sphere at NASA Langley showing the test integration, prepared bed of lunar regolith simulant, and ethane plume impingement during a test run of current plume-surface interaction (PSI) testing.

Several instruments, including a version of the specialized camera system that imaged PSI when Firefly Aerospace's Blue Ghost lunar lander for NASA's CLPS program landed on the Moon in 2025 (see Figure 6), are capturing data and imagery from the tests. Instruments are measuring crater formation, angle and height of the ejecta sheet, spatial distribution of solid ejecta, and the speed of the regolith particles as they are ejected. Because the landers in development for Artemis are much larger, heavier, and more powerful than the Apollo LM, understanding the physics of exhaust from rocket nozzles interacting with lunar regolith is pivotal to helping NASA update and improve PSI predictive models.

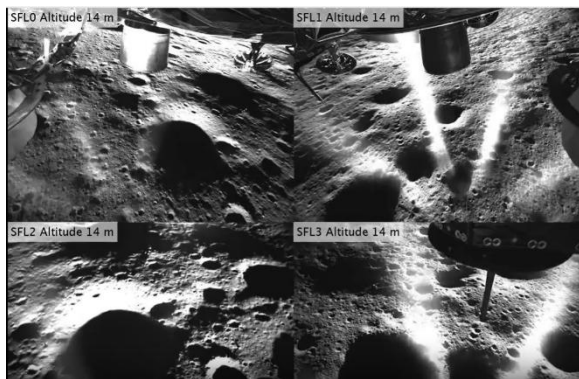


Figure 6. The Stereo Cameras for Lunar-Plume Surface Studies (SCALPSS) NASA payload captured video of PSI during the CLPS Blue Ghost mission; SCALPSS is also manifested as a payload on the Blue Origin uncrewed lunar landing demonstration to help characterize PSI.

4. HLS Utilization for Artemis Missions

4.1 Artemis III

The Artemis III RPODU mission is designed to be able to be executed in the near-term using simplified lander vehicles that include key systems that can be tested in LEO to reduce risk before future crewed landings; full-functionality landers are not needed. Scheduled for 2027, Artemis III will test communication and data exchange between both commercial landers and the Orion spacecraft and the ability of the HLS test articles to maintain alignment with Orion's approach trajectory.

Each vehicle will be inserted into orbit in a single launch and certain technology development activities, such as large-scale on-orbit CFM, will not be needed. On the ground, Artemis III will also exercise the capabilities of NASA and commercial providers to choreograph and execute a multi-provider, multi-location launch campaign within a short timeframe, followed by in-space operations. Providers will deliver test versions of spacecraft for Artemis III, and all launches are scheduled to occur from NASA Kennedy.

4.1.1 Blue Origin MK2 test article for Artemis III.

The test article for Artemis III from Blue Origin will be based on its Blue Moon MK2 crew lander, with some systems commonality with the company's smaller robotic Mark 1 (MK1) lunar lander that will deliver several payloads to the lunar surface under NASA's Commercial Lunar Payload Services (CLPS) initiative to help build NASA's Moon base (see Figure 7). Since the MK2 test article for Artemis III will not include a main propulsion system (MPS), the CLPS missions using the MK1 vehicle will provide NASA engineers with data on and experience with the Blue Origin-developed BE-7 liquid hydrogen/liquid oxygen engines that will be utilized in the later HLS uncrewed and crewed lunar missions (see Section 4.2.2).

For Artemis III, the Blue Origin MK2 test article will include a crew module incorporating avionics and partial Environmental Control and Life Support System (ECLSS). The test article will have a reaction control system (RCS) for attitude control but will not include an MPS. The Artemis III mission using the MK2 test article will allow NASA and Blue Origin to reduce many operational risks, such as avionics and software integration and crew cabin ECLSS performance, prior to Blue's first lunar landing attempt.

4.1.2 SpaceX Starship test article for Artemis III.

SpaceX is currently manufacturing and performing test flights with version 3 of its commercial Starship launch vehicle (see Section 5.1). For Artemis III, SpaceX will outfit a standard Starship version 3 with a docking assembly attached to the nose cone of Starship. The Starship HLS will not include ECLSS,

and crew will not egress into Starship HLS during Artemis III.

4.1.3 Artemis III Concept of Operations (ConOps).
The Blue Origin test article will launch first as part of the Artemis III multi-launch campaign. Blue's two-stage heavy-lift New Glenn launcher will insert the lander test article into orbit. After suffering a mishap with a vehicle on the pad at Launch Complex 36 at Kennedy Space Center in May 2026, Blue is actively

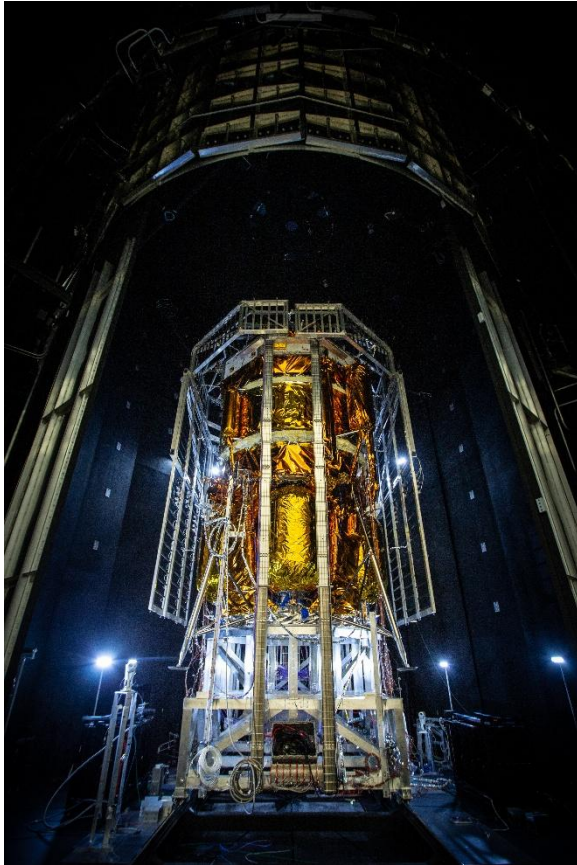


Figure 7. Blue Origin's Blue Moon MK1 lander, shown here in thermal vacuum testing at NASA Johnson, will deliver payloads for buildup of NASA's Moon Base and will share several common systems with the MK2 lunar lander for the HLS program. (Credit: Blue Origin)

rebuilding launch facilities at Kennedy and working to return New Glenn to flight before the end of 2026.

Nominally, the MK2 test article will remain in Earth orbit about two weeks, with Blue Origin testing systems and performing checkouts to its spacecraft before NASA launches four crew in Orion on an SLS Block 1 vehicle from Launch Complex 39B at Kennedy. SLS will launch with a spacer in place of the Interim Cryogenic Propulsion Stage (ICPS) upper stage; ICPS performance is not needed to place Orion



Figure 8. Artist's concept of Orion approaching the Blue Origin MK2 test article during the Artemis III mission. (Credit: Blue Origin)

into the desired orbit. The spacer is currently being manufactured at NASA Marshall's Advanced Weld Facility.

Once both vehicles are in orbit and flight controllers have determined the sequence of docking events can begin, Orion will serve as the "chaser" vehicle while the MK2 test article will be the docking "target." As the passive vehicle, the MK2 HLS test article will be required to maintain orientation for Orion's approach and docking. The HLS program and Blue Origin are also planning for off-nominal events; timelines can accommodate more than one docking attempt if necessary.

While Orion is docked with the Blue Origin test article, Orion's software and RCS will control attitude of the stack keeping Orion in a tail-to-sun orientation (see Figure 8).

After a successful docking between the spacecraft, crew members will open the hatch on the MK2 test article and egress from Orion into the prototype MK2 lander. This objective will encompass pressurization of the test article vestibule, and pressurization and atmospheric controls of the MK2 cabin to the determined atmospheric set point with Orion. Crew will perform assessments of the MK2 test article's interior, translation paths, cabin habitability, usable volume, mobility aids, reach and view/access, stowage access and logistics transfer, lighting adequacy, and possibly more, depending on systems maturity.

Following rendezvous and docking operations with the MK2 test article, the Artemis III crew in Orion will undock from the MK2 test article. The MK2 test article will remain in Earth orbit, with Blue Origin ground controllers continuing to test systems to advance readiness for future missions.

The third launch in the Artemis III campaign will be from SpaceX facilities currently under construction at NASA Kennedy. SpaceX will launch a Starship

version 3 variant with a docking assembly attached to Starship's nose cone to support a second docking event with Orion (see Figure 9). This demonstration will focus on software integration in addition to RPODU. Orion will again function as "chaser" with Starship HLS as the "target." The key software integration test during this phase of the Artemis III mission will ensure Starship adequately controls the integrated stack. Following undocking operations between Orion and the Starship HLS test article, Orion and crew will return to Earth.



Figure 9. Artist's concept of Orion docked with the Starship HLS test article during the Artemis III mission. (Credit: SpaceX)

In addition to testing critical functions such as attitude control and positioning, docking dynamics, ECLSS performance where available, Artemis III also will allow NASA and its partners to execute multi-launch logistics and operations – in addition to training leading up to those operations.

4.2 Uncrewed Lunar Landing Demonstrations

Building on the knowledge gained during Artemis III and to further reduce risk prior to crewed lunar landings, SpaceX and Blue Origin will demonstrate autonomous precision lunar landings of their landers, return of telemetry to Earth, and ignition of MPS in the lunar environment.

4.2.1 SpaceX HLS propellant transfer demonstration prior to uncrewed lunar landing demonstration. For the uncrewed and crewed lunar landings that the SpaceX Starship HLS will perform, the company will utilize three variants of its Starship vehicle – depot, tanker, and Starship HLS – and orbital CFM (see Figure 10). In preparation, SpaceX is currently working toward a long-duration orbital test of Starship that will conclude with a large-scale on-orbit cryogenic propellant transfer between Starships to demonstrate this technology. For missions utilizing CFM, the depot variant will launch first and await a series of tankers in LEO. The tankers dock with the depot and transfer cryogenic methane and oxygen to corresponding tanks in the depot. Engineers expect results from the propellant transfer test, which will

measure thermal properties and boiloff rates, among other objectives, to inform the eventual number of tanker launches required for the uncrewed and crewed lunar landings that use the Starship HLS.

4.2.2 Blue Origin HLS uncrewed lunar landing demonstration. Blue Origin will also perform an autonomous precision lunar landing prior to landing crew on the Moon. For its uncrewed lunar landing demonstration, Blue Origin will use an MK2 lander and launch system closely representative of the HLS that will be used for its crewed landing mission. As mentioned in Section 2.2, both providers submitted plans to streamline mission objectives, architectures, manufacturing processes, and technology development to meet goals of national space policy and deliver systems that will land crew on the Moon in 2028.

4.2.3 HLS uncrewed lunar landing requirements. For the uncrewed lunar landing demonstrations, both providers will be required to demonstrate autonomous landing accuracy within 100 m of a target landing site. Following landing, the vehicles are required to transmit telemetry back to Earth for a minimum of two hours. Finally, providers must demonstrate ignition of main engine propulsion in the lunar environment by relighting an engine. Disposal plans following the uncrewed lunar landing demonstrations are still in development.

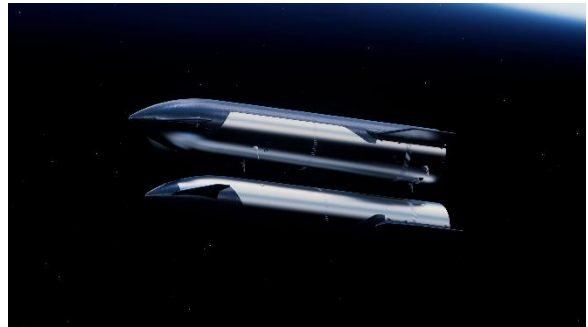


Figure 10. Artist's concept of SpaceX large-scale on-orbit cryogenic propellant transfer demonstration between two Starships. (Credit: SpaceX)

4.3 Crewed lunar landing demonstrations

Following Artemis III and the uncrewed lunar landing demonstrations, each provider is working toward executing a crewed lunar landing in 2028. Providers will be assigned to an Artemis mission at a later date, but the agency is working toward executing the Artemis IV crewed lunar landing in early 2028 and a second crewed landing, Artemis V, in late 2028. NASA is working with providers to evaluate possible changes to orbits and mission architecture, based on provider recommendations from their task order

studies (see Section 2.2) with the goal of establishing an initial cadence of lunar missions.

All mission designs in the trade space involve the landers docking with Orion, with two crew remaining in Orion while two crew descend to the lunar surface near the Moon's south pole in the HLS. Length of surface stays and number of EVAs are currently in the trade space. Following the surface stay phase of the missions, the two crew will ascend from the lunar surface in HLS, dock with Orion, and ingress into the crew spacecraft for the journey back to Earth.

5. HLS Provider Vehicles and Progress Toward Mission Readiness

As discussed in Section 3, NASA actively partners with the commercial HLS providers to advance technology and systems readiness, reduce risk through testing and collaborations, ensure safety and mission assurance and ultimately drive the intended outcome: a brisk cadence of crewed lunar landings and construction of a Moon Base.

5.1 SpaceX Starship HLS

Starship version 3, expected to be the baseline vehicle for HLS missions, launches on a version 3 Super Heavy first stage. SpaceX currently has launch facilities at Starbase, Tex. and two additional pads under construction at Kennedy and at Space Launch Complex 37 at nearby Cape Canaveral Space Force Station.

Super Heavy uses 33 Raptor version 3 liquid methane/liquid oxygen full-flow combustion staged engines. The Starship second stage uses six Raptor version 3 engines: three vacuum and three sea-level. For version 3 of Super Heavy, changes to the outer mold line (OML) of the vehicle include reducing the number of grid fins from four to three and integrating a hot-staging separation system. In addition, the aft section of the booster includes an integrated thermal protection system instead of individual engine shrouds. Inside, the Starship version 3 MPS has been redesigned with a goal of increased redundancy and reliability.

The large-volume crew compartment that will be part of the Starship HLS, with a pressurized habitable volume of more than 600 m³, is located at the top of the vehicle and is designed with two airlocks [8]. A simple pulley system will lower two crew members to the surface in an elevator basket. SpaceX is fabricating a flight-like crew cabin at its Starbase location for testing and training. The full-scale crew compartment, called "Cabin One," will include flight-like avionics and power systems, crew operations mechanisms, ECLSS, crew communication systems, a dedicated thermal control system, and more. Cabin One's high-fidelity systems will help SpaceX and NASA test and



Figure 11. Flight 13 of Starship, July 24, 2026, was the second flight of the Starship version 3 vehicle and demonstrated in-space reignition of a Raptor engine.
(Credit: SpaceX)

mature systems and will serve as the platform for human-in-the-loop training.

SpaceX began flight testing Starship version 3 May 22, 2026, from Starbase. Starship test flight 13, the second test flight of version 3 system, launched July 24, 2026, and featured reignition of a single Raptor engine in space, an important demonstration of a core capability for future missions (see Figure 11).

5.2 Blue Origin Blue Moon MK2

Blue Origin is working to accelerate development of its MK2 lander to meet an increased launch cadence of Artemis missions. MK2 will be manufactured at Blue's Lunar Plant 1 near Kennedy Space Center. Blue Origin completed a docking test at NASA Johnson, successfully completing soft capture system testing at NASA Johnson's six-degree-of-freedom (DOF) dynamic test facility, meeting International Docking System Standard requirements (see Figure 12). In addition, Blue installed a full-scale Blue Moon MK2 crew cabin prototype at NASA Johnson (see Figure 13). The prototype will be gradually outfitted

to become flight-like and will be used for training, human-in-the-loop testing, and design feedback.



Figure 12. In preparation for Artemis III, Blue Origin successfully completed soft capture testing of its Blue Docking System at the Six-Degree-Of-Freedom (6-DOF) Dynamic Test facility at NASA Johnson. (Credit: Blue Origin)

5.3 Robotic landers for large mass/volume payloads

The HLS program exercised a contract option in 2023 enabling both HLS providers to begin development on robotic versions of the human landing systems. Capable of operating with a human in the loop or autonomously, the cargo landers will be able to deliver 15 mT of payload to the lunar surface. Cargo landers share significant systems commonality with the crew landers, with the addition of payload interfaces and deployment mechanisms for offloading cargo to the lunar surface. The landers for large cargo are not expected to be available before Artemis VII.

In November 2024, NASA announced its intention to award SpaceX delivery of a pressurized rover being developed by the Japan Aerospace Exploration Agency (JAXA) using the Starship HLS cargo lander



Figure 13. Blue Origin installed a prototype crew cabin of its Blue Moon MK2 HLS at NASA Johnson, which will be gradually outfitted for flight training and other evaluation tasks.

no earlier than fiscal year 2032. NASA also intends to award Blue Origin a contract to deliver a lunar surface habitat using its Blue Moon MK2 cargo HLS. [9] SpaceX and Blue Origin have each completed a Certification Baseline Review for their cargo landers and are working toward Preliminary Design Review (PDR). See Figure 14 and Figure 15 for concepts of the cargo landers.



Figure 14. Artist's concept of the Starship HLS autonomous cargo lander, capable of delivering 15 mT of payload to the lunar South Pole to support NASA's goals for sustainable exploration. (Credit: SpaceX)



Figure 15. Artist's concept of the Blue Origin Blue Moon MK2 HLS lander for large cargo, such as an initial surface habitat. (Credit: Blue Origin)

6. Conclusion

After the successful Artemis I and Artemis II test flights of several of NASA's new assets for deep space exploration, including EGS ground processing and launch facilities at NASA Kennedy, the super heavy-lift SLS launch vehicle, and the Orion spacecraft for crewed deep space transportation, the HLS program is working with its commercial providers to bring human landing systems online for the next Artemis missions. Both SpaceX, providing a variant of Starship as a lunar lander, and Blue Origin, supplying a Blue Moon MK2 lunar lander, are working toward the Artemis III RPODU mission in LEO in 2027 using test versions of the landing systems. Artemis III offers NASA and

providers an opportunity to test systems' functionality and integration prior to operating the systems with Orion in deep space.

Other significant milestones prior to the planned Artemis IV and Artemis V crewed lunar landings include a large-scale on-orbit propellant transfer between Starships that SpaceX is scheduled to perform near-term. In addition, each provider will perform an uncrewed lunar landing to demonstrate such objectives as precision autonomous landing, transmission of telemetry back to Earth, and main propulsion system combustion in the lunar environment, prior to the Artemis IV and Artemis V crewed lunar landings. The Artemis IV and Artemis V lunar landing missions are currently being rebaselined to meet goals of launching in 2028.

Ultimately, the HLS program intends to purchase landing services from industry on a competitive basis following initial crewed lunar landing demonstrations. The program has forged strong partnerships with SpaceX and Blue Origin and engages in significant reduction activities, including insight into development and integration of systems and engineering collaborations to further technology readiness and transfer knowledge. As with the Apollo program, NASA is embarking on increasingly complex missions to land astronauts on the Moon. Unique to Artemis, NASA will this time build out the infrastructure to conduct sustainable science and exploration missions on the Moon.

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