

Architectural Realignment in Cislunar Spaceflight: An Engineering and Operational Analysis of NASA's 2027 Artemis III Low-Earth Orbit Demonstration Mission

Abstract and Executive Overview

For nearly a decade following the establishment of Space Policy Directive-1 in 2017, the foundational architecture of the National Aeronautics and Space Administration (NASA) Artemis program rested upon a sequential progression: an uncrewed test flight (Artemis I), a crewed lunar flyby (Artemis II), and an immediate crewed lunar surface landing near the south pole (Artemis III). However, as commercial Human Landing System (HLS) development matured alongside the operational realities of deep-space life support, cryogenic propellant management, and atmospheric reentry physics, aerospace systems engineers recognized that leaping directly from a free-return lunar flyby to a polar surface landing introduced an unacceptable concentration of first-time operational risks.

In February 2026, following a comprehensive agency-wide architecture review, NASA formally restructured its lunar exploration campaign. Confirmed and detailed during a major program briefing on October 23, 2026, by NASA Administrator Jared Isaacman, Associate Administrator Amit Kshatriya, and Artemis Program Manager Jeremy Parsons, the Artemis III mission has been scheduled for summer 2027 (targeted for no earlier than June 2027) as a complex, 14-day crewed demonstration mission in low-Earth orbit (LEO). Rather than descending to the lunar surface, the four-person crew of Artemis III—Commander Randy Bresnik, Pilot Luca Parmitano, and Mission Specialists Frank Rubio and Andre Douglas—will execute a triple-launch orbital test campaign. During this flight, the Orion spacecraft will independently rendezvous and dock with two distinct commercial lander pathfinders: Blue Origin's Blue Moon Mark 2 test vehicle and SpaceX's Starship Version 3 HLS test article.

By shifting the first crewed lunar surface touchdown to Artemis IV in early 2028 (with a second landing targeted for Artemis V in late 2028), the revised Artemis III architecture mirrors the historical precedent of the Apollo 9 mission in March 1969. This analytical study examines the engineering rationale, orbital mechanics, hardware configurations, flight software protocols, and programmatic timelines that define the 2027 Artemis III mission, evaluating how this orbital risk-reduction flight establishes the technical baseline for sustained lunar surface infrastructure.

1. Programmatic Paradigm Shift: The Apollo 9 Precedent and Risk Mitigation

To understand the necessity of the 2027 Artemis III mission profile, one must first examine the systems engineering concept of integrated flight validation. In complex aerospace programs, individual subsystems—such as launch vehicles, crew capsules, environmental control systems, and landing modules—undergo rigorous ground testing in thermal vacuum chambers and hardware-in-the-loop simulators. Yet ground facilities cannot fully replicate the coupled dynamic environments of microgravity, orbital thermal cycling, plasma communication blackouts, and multi-body structural resonance.

Following the uncrewed Artemis I mission in November 2022 and the crewed Artemis II lunar flyby in April 2026, NASA possessed substantial flight data regarding the Space Launch System (SLS) Block 1 vehicle and the Orion crew module operating as an independent spacecraft. However, neither mission required Orion to physically mate with another spacecraft in orbit, transfer electrical power or data across a docking interface, or rely on a secondary vehicle for combined attitude control. Under the pre-2026 architecture, the first time an Orion crew would attempt an active docking maneuver, verify hatch seal integrity, or test integrated guidance software with a commercial lunar lander would have been in a Near-Rectilinear Halo Orbit (NRHO) approximately 400,000 kilometers from Earth. In that deep-space regime, return-to-Earth abort windows require several days of transit, leaving minimal margin for uncharacterized mechanical or software anomalies.

Furthermore, NASA's dual-source procurement strategy for the Human Landing System—awarding prime contracts to both SpaceX (for the Starship HLS) and Blue Origin (for the Blue Moon Mark 2 lander)—created two completely disparate technical architectures. Both systems rely on cryogenic propellants (liquid methane and liquid oxygen for Starship; liquid hydrogen and liquid oxygen for Blue Moon), orbital propellant transfer, and complex autonomous guidance systems. As of late 2026, both providers face compressed timelines to complete their uncrewed lunar landing demonstrations, with SpaceX targeting the fourth quarter of 2027 and Blue Origin targeting the first quarter of 2028. Simultaneously, the Axiom Extravehicular Mobility Unit (AxEMU) lunar surface suits encountered development delays, prompting NASA to adjust specifications toward a lighter, streamlined "sortie" suit configuration for initial polar operations.

Rather than allowing schedule pressures on deep-space landers and surface suits to stall flight operations—or worse, forcing a premature lunar landing attempt—NASA leadership restructured the sequence in February 2026. By converting Artemis III into an Earth-orbiting integration laboratory in mid-2027, NASA decoupled the initial crewed testing of lander interfaces from the completion of deep-space cryogenic depot infrastructures. Just as Apollo 9 astronaut James McDivitt, David Scott, and Russell Schweickart tested the Grumman Lunar Module in low-Earth orbit before Apollo 10 and 11 ventured to the Moon, the Artemis III crew will validate both commercial landers in an orbital regime where an immediate deorbit burn and atmospheric entry remain less than a few hours away.

Mission Parameter	Pre-2026 Artemis III Baseline	Revised 2027 Artemis III Baseline	Operational & Engineering Impact
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Primary Mission Objective	Crewed lunar south pole landing and surface EVAs	Dual-lander LEO rendezvous, docking, and systems validation	Eliminates deep-space docking first-time risk; validates two HLS designs in one flight
Target Launch Window	Late 2026 / Early 2027 (Delayed)	Summer 2027 (NET June 2027 / Q3 2027)	Aligns with Orion hardware readiness and accelerates crew flight cadence
Operational Regime	Near-Rectilinear Halo Orbit (NRHO) and Lunar Surface	Low-Earth Orbit (426 km to 550 km circularized altitudes)	Reduces abort return time from days to hours; enables ground telemetry coverage
SLS Upper Stage Configuration	Interim Cryogenic Propulsion Stage (ICPS) with RL10 engine	Structural Mass Simulator ("Spacer") without propulsion	Preserves remaining flight-ready ICPS unit for the Artemis IV lunar landing in 2028
Participating Spacecraft	Orion CM/ESM + SpaceX Starship HLS	Orion CM/ESM + Blue Moon Mark 2 Pathfinder + Starship V3 Pathfinder	Provides side-by-side empirical performance data on both commercial lander contractors
Planned Mission Duration	Approximately 30 days	14 days baseline (extendable up to 17 days for launch weather)	Optimizes Orion consumables for intensive orbital maneuvering and suit evaluations

2. Launch Vehicle Architecture and Hardware

Modifications

A critical consequence of moving Artemis III from a translunar trajectory to a low-Earth orbit profile involves the structural and propulsive configuration of the Space Launch System (SLS). In its standard Block 1 configuration—flown on Artemis I and Artemis II—the SLS utilizes a core stage powered by four Aerojet Rocketdyne RS-25 liquid hydrogen/liquid oxygen engines, flanked by two five-segment solid rocket boosters (SRBs). Atop the core stage sits the Launch Vehicle Stage Adapter (LVSA), which encloses the Interim Cryogenic Propulsion Stage (ICPS)—a modified United Launch Alliance Delta Cryogenic Second Stage powered by a single Aerojet Rocketdyne RL10B-2 engine. On lunar missions, the core stage places the upper stack into an initial elliptical orbit, after which the ICPS executes the perigee raise maneuver and the Trans-Lunar Injection (TLI) burn.

However, the manufacturing line for the ICPS has been closed as United Launch Alliance transitions entirely to the Vulcan Centaur launch vehicle, and NASA's exploration upper stage (EUS) for the upgraded SLS Block 1B rocket experienced its own programmatic adjustments. Consequently, preserving the remaining flight-qualified ICPS hardware became paramount to guarantee that Artemis IV could execute its translunar injection in early 2028.

2.1 The Inert Upper Stage "Spacer" and Core Stage Propulsion

Because Artemis III operates entirely within low-Earth orbit, it does not require the high-energy translunar velocity change provided by the ICPS. During the spring 2026 engineering trade studies, NASA evaluated whether to send Artemis III into a High-Earth Orbit (HEO) using an ICPS to closely mimic deep-space thermal environments, or to fly in LEO without an active upper stage. Engineers determined that replacing the ICPS with an inert structural ring—formally designated as a "spacer"—yielded major programmatic advantages.

The spacer matches the exact outer mold line, mass distribution, and structural stiffness of the ICPS and Orion Stage Adapter, ensuring that the aerodynamic loads and bending modes experienced by the SLS stack during ascent through maximum dynamic pressure remain within certified Block 1 parameters. Instead of relying on a second-stage engine for orbital circularization, the SLS Core Stage will inject the Orion spacecraft and the attached spacer into an initial elliptical orbit measuring approximately 16 by 975 nautical miles (roughly 30 by 1,805 kilometers) at an orbital inclination of 33 degrees. Following separation from the core stage and spacer, the Orion spacecraft's European Service Module (ESM)—equipped with an Orbital Maneuvering System Engine (OMS-E) burning hypergolic monomethylhydrazine (MMH) fuel and mixed oxides of nitrogen (MON-3) oxidizer—will perform the necessary orbital adjustments to circularize its trajectory in low-Earth orbit.

Hardware processing for this launch vehicle configuration has progressed steadily at Kennedy Space Center (KSC) throughout 2025 and 2026. The core stage integrates four heritage Space Shuttle Main Engines (RS-25 serial numbers E2048, E2052, E2054, and E2057), each capable of generating 512,000 pounds of vacuum thrust at 109 percent rated power level. The ten solid rocket booster segments arrived at KSC via rail in June 2026 and underwent inspection in the Rotation, Processing and Surge Facility. On October 13, 2026, exploration ground systems teams completed the vertical stacking of both five-segment twin solid rocket boosters atop Mobile Launcher 1 inside High Bay 3 of the Vehicle Assembly Building (VAB). With the core

stage mated between the boosters, NASA scheduled a "short-stack" rollout to Launch Complex 39B for a cryogenic tanking test and Wet Dress Rehearsal (WDR) around the end of 2026. Conducting this fueling rehearsal prior to the arrival of the structural spacer and stage adapters in early 2027 allows launch controllers to verify liquid hydrogen fast-fill protocols and tail service mast umbilical disconnects well ahead of the summer 2027 launch window.

2.2 Orion Spacecraft Enhancements and AVCOAT Heat Shield

Remediation

The Orion Crew Module (CM-004) and European Service Module (ESM-3) manufactured by Lockheed Martin and Airbus Defence and Space incorporate critical hardware upgrades derived from Artemis I and II flight data. Chief among these is the remediation of the Orion thermal protection system (TPS). During the high-energy skip-entry of Artemis I in December 2022, the spacecraft's 5-meter diameter heat shield—composed of 186 individually machined blocks of AVCOAT (an ablative material consisting of novolac resin in a fiberglass honeycomb matrix)—experienced unexpected localized spallation and char loss. Post-flight forensic investigations revealed that gases generated inside the ablating AVCOAT blocks during the thermal soak phase could not vent rapidly enough through the material's low permeability, creating internal pore pressures that fractured chunks of char away from the substructure. While Artemis II utilized an adjusted atmospheric entry trajectory to mitigate thermal loading on its existing heat shield, the Artemis III Orion capsule integrates a modified AVCOAT manufacturing and permeability profile designed to accommodate high-energy lunar return trajectories on future flights. Although Artemis III will reenter Earth's atmosphere from low-Earth orbit—encountering peak entry velocities of approximately 7.8 kilometers per second rather than the 11 kilometers per second typical of lunar return—the two-week orbital soak and entry profile will provide vital flight validation of the upgraded ablative block assembly before crewed lunar return on Artemis IV. Additionally, engineers completed rigorous inspections of the ESM-3 four-wing articulating solar array mechanisms and upgraded the cabin acoustic damping and environmental control software.

3. Crew Selection, Training, and Human Factors

On June 9, 2026, at the Lyndon B. Johnson Space Center in Houston, NASA formally assigned the four prime astronauts and one backup crew member for the Artemis III mission. Because the mission functions as an intensive flight-test campaign involving complex manual and automated proximity operations with two uncrewed prototype landers, crew selection prioritized extensive test pilot credentials, long-duration orbital mechanics experience, and deep systems engineering backgrounds.

Crew Member	Agency	Assigned Role	Prior Spaceflight Experience & Technical Background	Primary Artemis III Responsibilities

Randy "Komrade" Bresnik	NASA	Commander	STS-129 (2009), Soyuz MS-05 / ISS Expedition 52/53 Commander (2017); 148+ days in space; USMC F/A-18 test pilot	Overall mission command; manual piloting during Blue Moon and Starship proximity operations; emergency abort execution
Luca Parmitano	ESA	Pilot	Soyuz TMA-09M / ISS Exp. 36/37 (2013), Soyuz MS-13 / ISS Exp. 60/61 Commander (2019); 366 days in space; Italian Air Force experimental test pilot	First non-U.S. pilot of an Artemis spacecraft; primary docking sensor alignment, orbital rendezvous navigation, and ESM management
Dr. Frank Rubio	NASA	Mission Specialist 1	Soyuz MS-22/MS-23 / ISS Exp. 68/69 (2022–2023); 371 consecutive days in space (U.S. single-flight record); U.S. Army Blackhawk pilot & flight surgeon	Blue Moon cabin ingress; Environmental Control and Life Support System (ECLSS) validation; aerospace medicine and human factors experiments

Dr. Andre Douglas	NASA	Mission Specialist 2	First spaceflight (Selected in 2021 NASA Astronaut Group 23); Ph.D. in Systems Engineering; former Johns Hopkins APL naval and space systems engineer	Spacecraft guidance/software handover protocols; docking dynamics instrumentation; Orion Crew Survival System (OCSS) suit evaluations
Robert "Bob" Hines	NASA	Backup Crew	SpaceX Crew-4 / ISS Expedition 67 (2022); 170 days in space; USAF test pilot	Cross-trained across all four cockpit seats and lander interface procedures to ensure schedule resilience

The inclusion of European Space Agency (ESA) astronaut Luca Parmitano as pilot marks a significant milestone in international spaceflight cooperation, reflecting ESA's critical contribution of the European Service Modules that power and propel the Orion fleet. Throughout the second half of 2026, the quartet completed water survival and egress training off the coast of San Diego with United States Navy recovery personnel, rehearsing cabin depressurization contingencies in the Orion Crew Survival System (OCSS) pressure suits. Furthermore, the crew has worked directly inside high-fidelity engineering mockups at Blue Origin and SpaceX facilities to refine human-machine interface layouts, hatch latch torque tolerances, and emergency undocking protocols.

4. Orbital Mechanics and the 14-Day Concept of Operations (CONOPS)

The operational choreography of Artemis III represents one of the most logistically demanding launch and rendezvous campaigns in the history of human spaceflight. Unlike Apollo 9, where the Command/Service Module and Lunar Module launched together on a single Saturn V

rocket, Artemis III requires three separate heavy-lift launches from the Florida space coast within a six-day window: Blue Origin's New Glenn rocket from Launch Complex 36, NASA's Space Launch System from Launch Complex 39B, and SpaceX's Super Heavy/Starship vehicle from its newly constructed Kennedy Space Center launch pad.

Because Orion was thermally engineered as a deep-space vehicle designed to operate in continuous sunlight during cislunar transit, operating it in low-Earth orbit presents unique thermodynamic challenges. In low-Earth orbit, a spacecraft passes into Earth's shadow (eclipse) for roughly 35 to 40 minutes of every 90-minute orbit, while also absorbing infrared radiation (Earthshine) and reflected sunlight (albedo) from the planet below. To manage these rapid thermal cycles and minimize atmospheric drag on the large lander test articles, mission planners designed a stepped orbital altitude profile ranging from 550 kilometers down to approximately 380 kilometers (300 nautical miles down to 206 nautical miles).

ARTEMIS III MULTI-LAUNCH & ORBITAL RENDEZVOUS ARCHITECTURE (SUMMER 2027)

[Launch 1: Flight Day 1]

New Glenn (LC-36) → Deploys Blue Moon Mk2 Pathfinder into ~440–500 km LEO

(30-90 day loiter capability)

[Launch 2: Flight Day 2]

SLS Block 1 (LC-39B) —→ Injects Orion CM/ESM into 16 x 975 nmi (30 x 1,805 km) Elliptical

Orbit

▼ (ESM OMS-E Burns)

Thermal Stabilization (~550 km / 300 nmi) —> Phasing to 439 km (237 nmi)

[Flight Days 3-5] ▼

DOCKING 1: Orion + Blue Moon Mk2 (Lateral Docking / Orion Active Control)

- 48-hour docked phase: 2 astronauts ingress lander cabin: ECLSS & RCS

checks

Launch 3: Flight Day 6 ▼ (Orion undocks: descends to 381 km / 206 nmi rendezvous

orbit)

Starship V3 (KSC Pad) → Inserts Starship HLS Test Article into 381 km LEO

[Flight Day 8] ▼

DOCKING 2: Orion + Starship V3 (Nose-to-Nose / Starship Active Control)

- 2-hour docked phase: no crew ingress; structural load & thrust-push tests



4.1 Phase 1: Blue Moon Deployment and Orion Ascent (Flight Days 1 to 2)

The mission sequence begins prior to crew liftoff. With the SLS stack already standing at Launch Complex 39B having completed its pre-launch readiness checks, Blue Origin will launch its New Glenn heavy-lift rocket from Cape Canaveral Space Force Station. New Glenn will insert the uncrewed Blue Moon Mark 2 pathfinder lander into a circular low-Earth parking orbit between 439 and 500 kilometers (237 to 273 nautical miles) at a 33-degree inclination. Critically, the Blue Moon test vehicle is engineered with an orbital loiter capability of 30 to 90 days. This extended autonomous lifespan decouples the SLS launch from instantaneous split-second phasing constraints; once Blue Moon is verified healthy on orbit, NASA has at least a full month of daily planar launch windows to launch the crew aboard Orion.

On Flight Day 2 (approximately 24 to 48 hours after New Glenn liftoff, assuming nominal weather), the SLS rocket will launch the four Artemis III astronauts from Pad 39B. Roughly eight minutes after liftoff, the core stage engines will cut off, placing Orion and the upper stage spacer into a highly elliptical insertion orbit of 16 by 975 nautical miles (30 by 1,805 kilometers). After separating from the inert spacer, Orion will fire its European Service Module main engine at apogee to raise its perigee out of the dense upper atmosphere, settling initially into a circularized 550-kilometer (300-nautical-mile) altitude. Mission controllers will utilize this intermediate altitude to verify Orion's active thermal control loops, radiator rejection rates, and solar array power generation before descending to the 439-kilometer (237-nautical-mile) co-elliptic rendezvous orbit with Blue Moon.

4.2 Phase 2: Blue Moon Mark 2 Rendezvous and Crew Ingress (Flight Days 3 to 5)

On Flight Day 3, Pilot Luca Parmitano and Commander Randy Bresnik will oversee Orion's terminal approach to the Blue Moon Mark 2 pathfinder. Using optical navigation cameras, laser rangefinders, and relative Global Navigation Satellite System (GNSS) filtering, Orion will execute a lateral docking maneuver—approaching perpendicular to the lander's longitudinal axis to mate with the docking mechanism positioned on the side of the Blue Moon crew cabin. Once hard-mate capture is achieved and structural ring latches are torqued, the two spacecraft will remain docked for approximately 48 hours across Flight Days 4 and 5. During this phase, two astronauts will Equalize tunnel pressures, open the docking hatches, and translate inside the pressurized Blue Moon crew module. Because the Blue Moon pathfinder features a functionally complete pressurized cabin, the crew will execute an exhaustive verification checklist:

- **Environmental Control and Life Support System (ECLSS):** Measuring carbon dioxide scrubbing efficiency, oxygen partial pressure regulation, cabin trace contaminant filtering, and humidity condensate collection under actual two-person metabolic loads.
- **Avionics and Software Handover:** During the Blue Moon docked phase, Orion's flight computers will act as the master controller for the combined two-vehicle stack, commanding Blue Moon's reaction control system (RCS) thrusters, valves, and propellant tanks to execute integrated attitude maneuvers.
- **Thermal and Power Integration:** Evaluating the lander's articulating solar arrays, active pumped-fluid thermal loops, and umbilical power-sharing protocols across the International Docking System Standard (IDSS) interface.
- **Emergency Drills:** Simulating cabin depressurization alarms, toxic atmosphere responses, and rapid crew egress back into Orion.

4.3 Phase 3: Starship Launch and Dynamic Docking (Flight Days 6 to 8)

Following the completion of Blue Moon testing on Flight Day 6, the crew will seal the hatches, undock from the Blue Origin lander, and perform a retrograde phasing burn to lower Orion's orbit to approximately 381 kilometers (206 nautical miles). Concurrently on Flight Day 6, SpaceX will launch an uncrewed Starship Version 3 HLS test article atop a Super Heavy booster from its newly commissioned launch complex at Kennedy Space Center.

On Flight Day 8, Orion will execute a second orbital rendezvous, approaching the Starship test article at the 381-kilometer altitude. Unlike the lateral geometry of the Blue Moon docking, Orion will perform an axial, nose-to-nose docking maneuver with a passive docking adapter mounted directly inside the hinged aerodynamic nose cone of the Starship vehicle.

The operational parameters of the Starship docked phase differ sharply from the Blue Moon test:

- **Duration and Crew Access:** Orion will remain docked to Starship for approximately two hours (within a broader one-day proximity operations window). Because the Starship Version 3 test article launched on Artemis III is an structural and avionics pathfinder lacking an active, human-rated environmental control and life support cabin, the astronauts will not open the hatch or enter the Starship interior.
- **Control Authority Reversal:** In a deliberate reversal of the Blue Moon protocol, Starship's onboard flight computers will assume primary attitude and translational control of the combined spacecraft stack once docked, while Orion operates in a passive follower mode.
- **Multi-Body Structural Dynamics:** A primary engineering objective of this two-hour connection is characterizing the structural mechanics of an extreme mass-asymmetry docking. With Orion weighing roughly 26 metric tons and the 50-meter-tall Starship Version 3 test article possessing a dry mass exceeding 100 metric tons, firing thrusters on one vehicle induces complex bending moments and shear forces across the docking ring. Mission controllers will command calibrated thruster pulses—described by engineers as measuring "how we are going to push"—to map resonant frequencies, damping rates, and structural load margins required for deep-space NRHO operations.

4.4 Phase 4: Solo Extended Operations and Reentry (Flight Days 9 to

14)

After separating from Starship on Flight Day 8, Orion will spend the remaining six to nine days of the mission operating independently in low-Earth orbit (with consumables allowing the 14-day baseline to stretch to 17 days if launch weather delays the Starship liftoff). During this solo phase, the crew will execute test objectives that could not be accommodated during the 10-day Artemis II flyby. These include prolonged pressurized mobility evaluations in the Orion Crew Survival System suits, optical navigation calibration against stellar and Earth-limb horizons, cabin acoustic mapping, radiation dosimetry, and physiological microgravity studies. On Flight Day 14, Orion will jettison the European Service Module, orient its upgraded AVCOAT heat shield into the velocity vector, execute atmospheric entry, and splash down under three main parachutes in the Pacific Ocean off San Diego.

5. Comparative Engineering of the Commercial Lander Pathfinders

The dual-docking architecture of Artemis III provides an unprecedented opportunity to evaluate two fundamentally divergent philosophies of lunar lander design under identical orbital test conditions. Under NASA's Appendix H (SpaceX) and Appendix P (Blue Origin) NextSTEP-2 Human Landing System contracts, each commercial provider engineered its vehicle around its proprietary heavy-lift launch architecture.

STRUCTURAL & DOCKING GEOMETRY COMPARISON

BLUE MOON MARK 2 PATHFINDER	STARSHIP V3 HLS PATHFINDER
(Height: ~16m Dry Mass: ~16t)	(Height: ~50m+ Dry Mass: ~100t+)

Propellant Tank	Passive	← Orion Docks	
(LH2 / LOX)	Docking	Nose-to-Nose	
	Adapter	(Axial)	
Avionics &			
Radiators	Unpress.		
	Payload		
Crew Cabin	← Orion Docks	Bay	
(Lower Deck)	Laterally		
	(Side-Mate)	Header	
BE-7	Tanks		
Engines			
	Main		
• Control Master: Orion Flight Software	CH4/LOX		

• Crew Ingress: Full Cabin Entry (48 hrs)	Tanks
• Power/Data: Full IDSS Umbilical Transfer	
	Raptor 3
	Engines
• Control Master: Starship Avionics	
• Crew Ingress: None (2-hr Mech Test)	
• Focus: High-Inertia Stack Dynamics	

5.1 Blue Origin: Blue Moon Mark 2 Pathfinder

Blue Origin's lander architecture follows a purpose-built, high-efficiency space-only design. Sizing the vehicle to fit inside the 7-meter-diameter payload fairing of the New Glenn rocket, engineers designed a compact, vertical cylinder standing approximately 16 meters tall. Unlike traditional landers that place the crew cabin at the apex of the vehicle (which requires astronauts to climb down tall ladders or elevators to reach the lunar surface), the Blue Moon Mark 2 positions its pressurized crew module near the bottom of the structure, just above the landing gear and the three BE-7 liquid hydrogen/liquid oxygen engines. The massive liquid hydrogen tank sits at the top of the lander stack.

For the Artemis III LEO demonstration, this upside-down layout requires Orion to execute a lateral docking maneuver. As Orion approaches the side of the lower crew module, its optical sensors must track targets mounted adjacent to the lander's upper propellant tankage and deployed solar arrays. Because the Blue Moon pathfinder does not have to reenter Earth's atmosphere—it is launched inside a protective payload fairing—Blue Origin was able to outfit the Artemis III test article with a fully functional life support cabin, active cryo-coolers, radiator panels, and flight avionics. Furthermore, Blue Origin's hardware readiness for Artemis III is heavily informed by its uncrewed Blue Moon Mark 1 cargo lander flights, which validate the BE-7 engine, precision terrain-relative LIDAR navigation, and liquid hydrogen management prior to the 2027 crewed orbital test.

5.2 SpaceX: Starship Version 3 HLS Test Article

In contrast, SpaceX's Starship HLS is an adaptation of a monolithic, fully reusable second-stage launch vehicle integrated with its propellant tankage and aerodynamic structure. Constructed from cold-worked 304L stainless steel with a 9-meter outer diameter and a height exceeding 50 meters, Starship Version 3 represents an order-of-magnitude increase in volumetric capacity and structural inertia compared to the Apollo Lunar Module or Orion.

As detailed during NASA's October 23, 2026 technical briefing, SpaceX achieved a major developmental milestone in late September 2026 with Integrated Flight Test 14 (Flight 14), which marked the first successful orbital flight of the upgraded Starship Version 3 architecture. Engineers subsequently resolved earlier Raptor engine boostback and landing relight anomalies through permanent hardware revisions scheduled for Flight 15 in late 2026, while simultaneously nearing completion of the Kennedy Space Center Starship launch pad and Giga Bay integration facility. In early 2027, prior to Artemis III, SpaceX plans to execute a critical ship-to-ship cryogenic propellant transfer demonstration in low-Earth orbit, launching two

Starships in rapid succession—one from Starbase in Boca Chica, Texas, and one from Kennedy Space Center—to validate orbital refueling.

For the Artemis III mission itself, SpaceX is providing a specialized Starship Version 3 test article launched directly from Florida. The primary hardware modification distinguishing this vehicle from standard orbital Starships is the installation of a passive low-impact docking system inside the forward nose cone, shielded during atmospheric ascent by a hinged aerodynamic cover. By November 2026, the passive docking mechanism design and aero-cover had been finalized ahead of mechanical fit-checks at NASA's Marshall Space Flight Center. During the two-hour docked phase on Flight Day 8, communication routing will also utilize SpaceX's high-throughput Starlink satellite laser-interlink network alongside NASA's Near Space Network, allowing engineers to verify multi-gigabit telemetry streaming during automated attitude handovers.

Technical Attribute	Blue Origin Blue Moon Mark 2 Pathfinder	SpaceX Starship Version 3 HLS Test Article
Launch Vehicle & Site	Blue Origin New Glenn (Cape Canaveral LC-36)	SpaceX Super Heavy Booster (Kennedy Space Center Pad)
Propulsion & Propellants	3x BE-7 engines; Liquid Hydrogen / Liquid Oxygen (LH2/LOX)	6x Raptor 3 engines; Liquid Methane / Liquid Oxygen (CH4/LOX)
Orbital Loiter Duration	30 to 90 days (Enables flexible SLS launch window)	Short-duration LEO insertion (Launched on Flight Day 6 while Orion is in orbit)
Target Rendezvous Altitude	~439 km to 500 km (237 to 273 nautical miles)	~381 km (206 nautical miles)
Docking Geometry	Lateral (Side-mounted docking port on lower crew cabin)	Axial (Nose-to-nose docking inside hinged forward nose cone)
Integrated Stack Control	Orion flight computers command the combined stack	Starship flight computers command the combined stack
Docked Duration & Crew Ingress	~48 hours docked; 2 astronauts enter	~2 hours docked; no crew ingress (unpressurized/no

	pressurized cabin	ECLSS)
Primary Engineering Test Goals	ECLSS life support validation, hatch seal checks, dual-vehicle RCS control, power/data umbilical transfer, emergency egress drills	High-mass-asymmetry structural load testing, thruster push calibration, passive nose-cone docking mechanics, Starlink telemetry integration

6. Contact Dynamics, Flight Software, and Guidance Protocols

A central scientific and engineering justification for conducting Artemis III in low-Earth orbit lies in the physics of spacecraft contact dynamics and automated flight software handovers. Both Orion and the commercial landers utilize variations of the International Docking System Standard (IDSS)—an androgynous, low-impact electromagnetic capture mechanism originally developed for the International Space Station.

In an IDSS docking event, the active docking mechanism (mounted on Orion) extends a soft-capture ring actuated by six electromechanical linear actuators (stewart platform configuration). As Orion makes physical contact with the passive docking ring on Blue Moon or Starship at closing velocities of just a few centimeters per second, load cells measure the contact force vector. A closed-loop control system immediately drives the six actuators to align the rings, damp out relative angular momentum, and engage electromagnetic capture latches before retracting the ring to engage 12 structural hook assemblies.

While this mechanism is well understood on the International Space Station—where the 420-metric-ton station acts as a quasi-infinite inertial mass compared to a visiting capsule—docking two free-flying vehicles with active reaction control systems introduces complex control-structure interaction hazards:

1. **Slosh Coupling and Center-of-Mass Shifts:** Both the Blue Moon Mark 2 and Starship Version 3 vehicles contain large volumes of liquid cryogenics. When Orion docks and thrusters fire to maintain attitude against gravity-gradient torques in LEO, the resulting angular accelerations excite fluid slosh waves inside the lander propellant tanks. If the frequency of the slosh wave couples with the firing cadence of the attitude control thrusters or the structural bending frequency of the docking ring, resonant oscillations can rapidly build up, threatening to shear the docking latches.
2. **Lateral Moment Arms (Blue Moon):** Because Orion docks to the side of the Blue Moon lander rather than along its central axis, the combined center of mass of the mated stack is offset from the centerline of both vehicles. When Orion's flight software commands translational or rotational burns during Flight Days 4 and 5, it must continuously recalculate the cross-products of inertia, blending firings from Orion's European Service

Module auxiliary thrusters and Blue Moon's RCS jets to prevent unintended yawing or rolling torques.

3. **High-Inertia Thruster Plume Impingement (Starship):** During the Flight Day 8 nose-to-nose docking with Starship, the massive cylindrical hull of Starship extends 50 meters forward of Orion. When Starship's flight computers assume active control of the stack, firing Starship's cold-gas or methalox RCS thrusters generates substantial bending moments across the narrow 0.8-meter tunnel neck of the IDSS adapter. By instrumenting the docking adapter with strain gauges and triad accelerometers during the two-hour docked window, engineers will empirically validate the finite-element structural models required to certify Starship for NRHO dockings on Artemis IV.

7. Strategic Horizon: From Artemis III to the 2028 Lunar Surface Campaign

The execution of Artemis III in summer 2027 does not exist in isolation; it serves as the operational linchpin for NASA's accelerated lunar surface architecture unveiled in late 2026. By validating both Blue Origin and SpaceX docking interfaces, software command handovers, and environmental control systems in low-Earth orbit, NASA places itself in a position to certify whichever commercial lander completes its uncrewed lunar landing demonstration first for the historic Artemis IV crewed landing in early 2028.

Under the multi-phase roadmap detailed by NASA leadership in October 2026, the agency has moved away from single, isolated flags-and-footprints sorties—and bypassed the previously planned Lunar Gateway orbital station requirement for early missions—in favor of high-cadence surface infrastructure development:

- **Uncrewed Lunar Demonstrations (Late 2027 – Early 2028):** Directly following the Artemis III LEO flight, SpaceX (targeting Q4 2027) and Blue Origin (targeting Q1 2028) are scheduled to execute full-scale, uncrewed end-to-end lunar landing demonstrations of their human-rated landers, verifying orbital propellant depot refueling and polar touchdown precision.
- **Artemis IV (Early 2028):** Utilizing the preserved Interim Cryogenic Propulsion Stage (saved by the use of the inert spacer on Artemis III), SLS will launch four astronauts into cislunar space to rendezvous with the certified HLS lander, executing the first crewed lunar surface landing since Apollo 17 in December 1972.
- **Artemis V (Late 2028):** Targeted for the end of the same calendar year, Artemis V is planned to execute a second crewed lunar landing utilizing the second commercial provider's lander, initiating the deployment of permanent surface habitat and excavation assets.
- **Long-Term Lunar Base Expansion (2029 – 2032+):** NASA's expanded architecture outlines a multi-stage campaign featuring 27 planned cargo and crew landings between 2029 and 2032 (Phase 2), followed by 28 additional landings post-2032 (Phase 3) to establish a semi-permanent human presence on the Moon—a program encompassing up to 73 total commercial and institutional surface deliveries.

Viewed through the lens of aerospace systems engineering, the restructuring of Artemis III into

a 2027 low-Earth orbit demonstration represents a vital maturation of the American space program. By resisting the temptation to rush unproven multi-vehicle interfaces into deep space, and instead orchestrating a rigorous, triple-launch orbital flight test with both SpaceX and Blue Origin hardware, NASA has systematically retired the highest operational risks of cislunar spaceflight—laying a resilient empirical foundation for humanity's return to the lunar surface in 2028.