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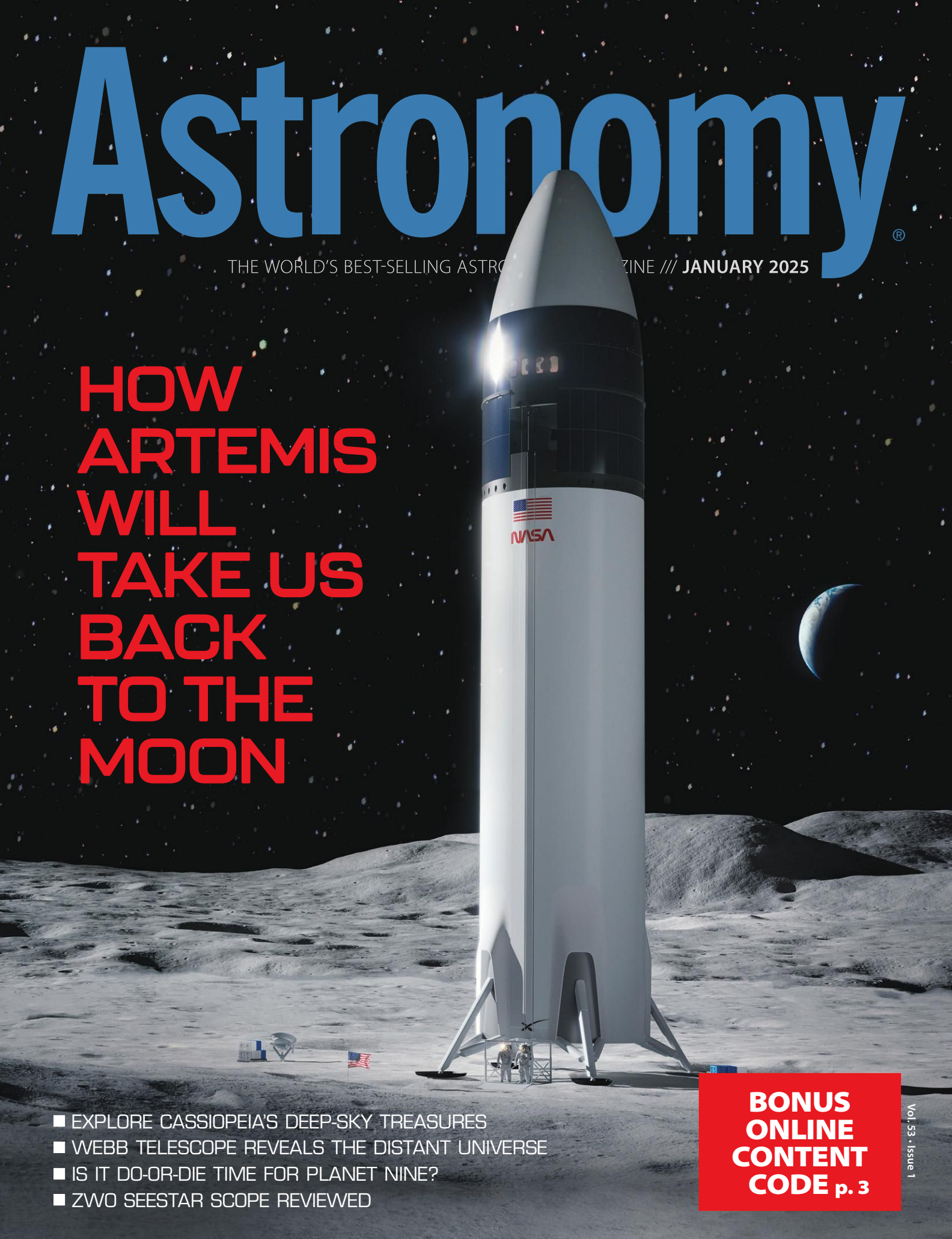

HOW ARTEMIS WILL TAKE US BACK TO THE MOON

- EXPLORE CASSIOPEIA'S DEEP-SKY TREASURES
- WEBB TELESCOPE REVEALS THE DISTANT UNIVERSE
- IS IT DO-OR-DIE TIME FOR PLANET NINE?
- ZWO SEESTAR SCOPE REVIEWED

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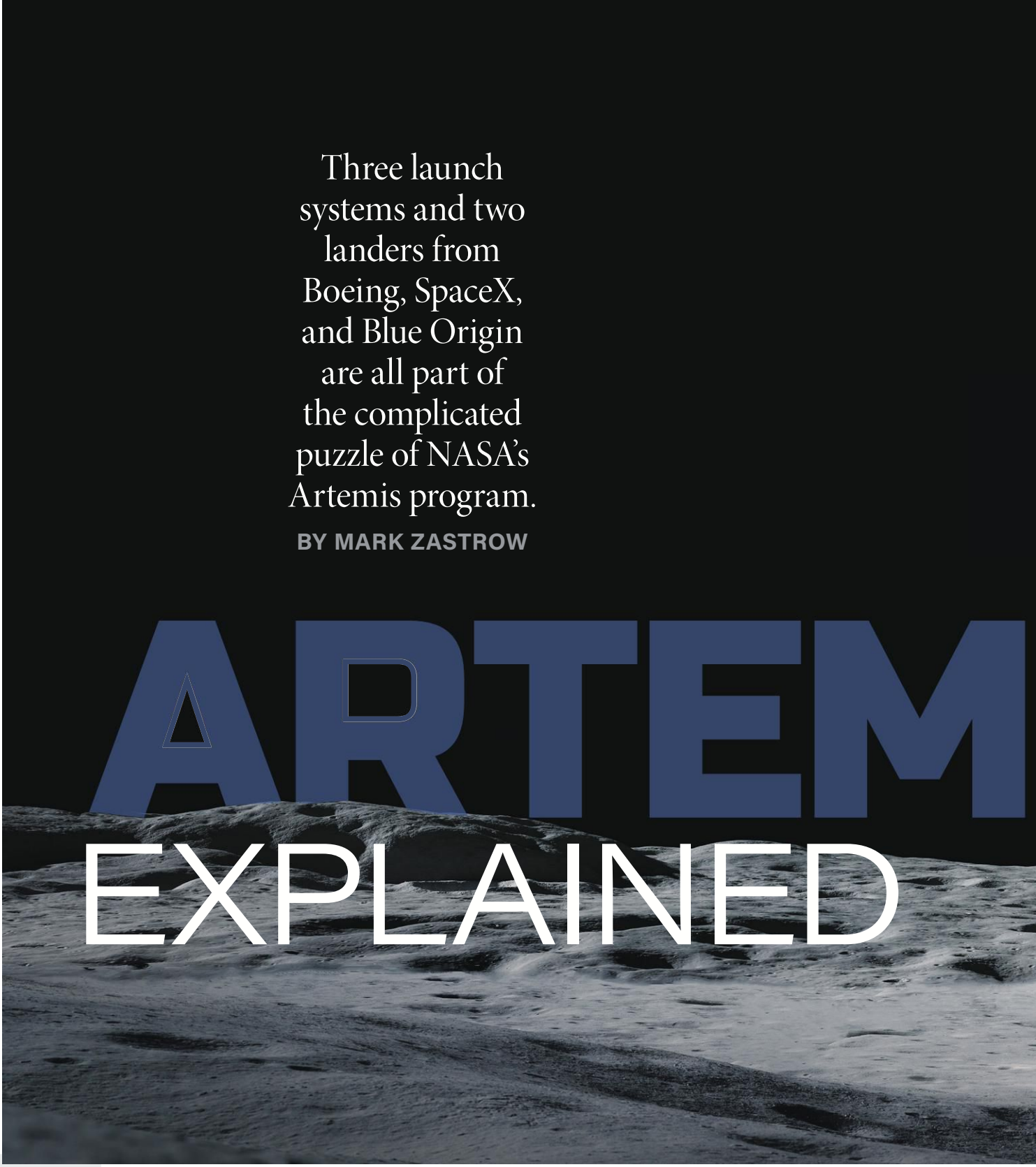
Three launch systems and two landers from Boeing, SpaceX, and Blue Origin are all part of the complicated puzzle of NASA's Artemis program.

BY MARK ZASTROW

ARTEMIS EXPLAINED



SIXTY-FIVE YEARS AGO, the USSR shocked the world by sending the first robotic emissary from Earth to the Moon. The September 1959 impact of Luna 2 on northeastern Mare Imbrium was a stunning achievement, reaching the Moon less than two years after the launch of Sputnik 1 ushered in the Space Age. The event helped ignite the technological firestorm now known as the Space Race between the U.S. and the USSR.

The Starship HLS stands like a giant 1950s science-fiction spaceship in this artist's concept, spanning 30 feet (9 m) wide and reaching 160 feet (50 m) above the Moon's surface. NASA

The U.S. responded to the lunar challenge with a flurry of robotic and human explorers. Less than 10 years after Luna 2 reached the Moon, Neil Armstrong took his "one small step for mankind" on the Sea of Tranquility.

But just as Apollo reached its stride and the scientific exploration of the Moon began in earnest, politics ended the greatest technological effort in the history of humankind and the Moon faded from our dreams.

Now, in the first decades of the 21st century, the Artemis program to return to the Moon has taken root. The U.S. and international partners have formulated plans and hardware that will return humans to the Moon within the next several years.

The current, publicly available Artemis timelines remain very

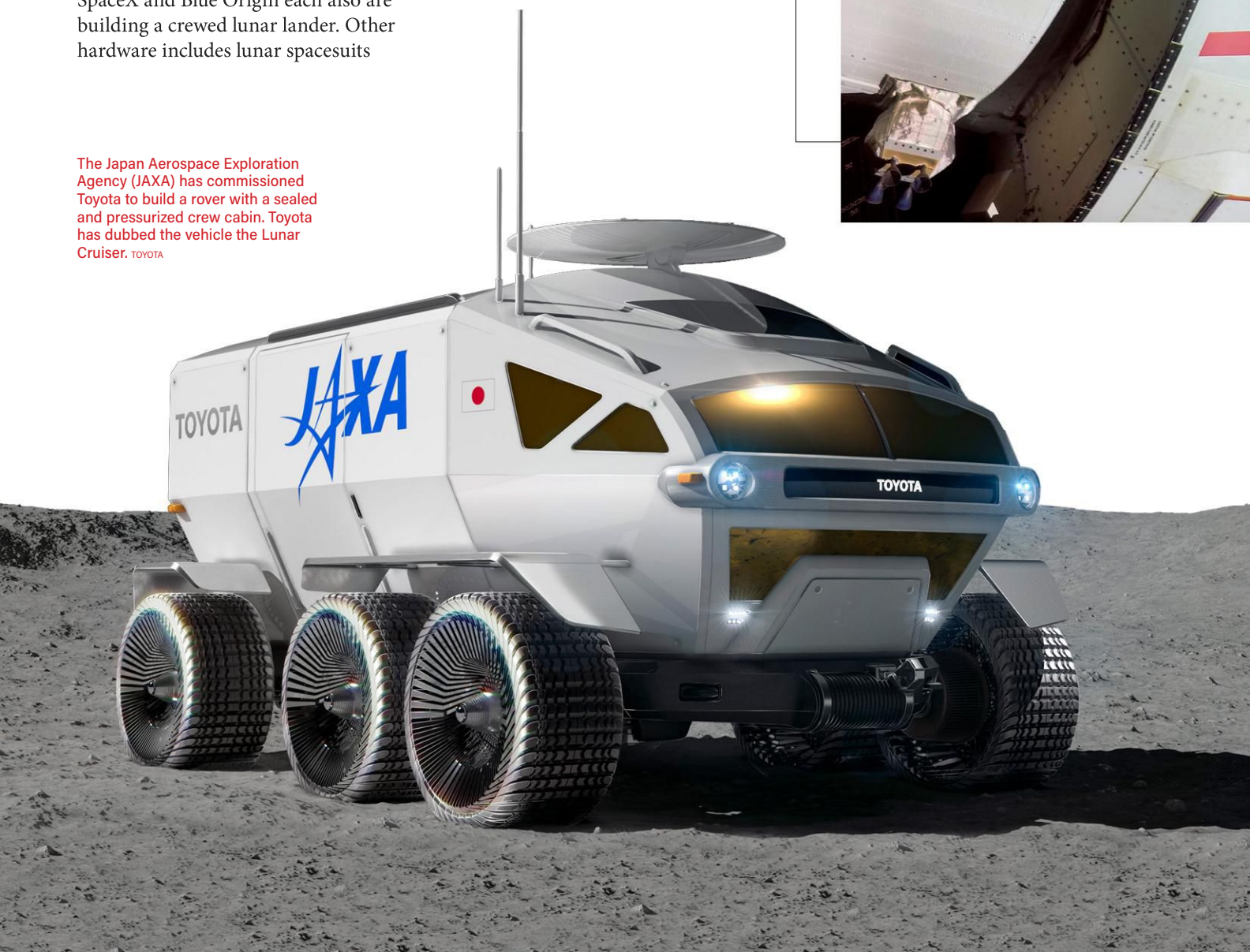
optimistic, but they must be tempered with the program's extraordinary complexity and ambition. Perhaps unsurprisingly, Artemis is facing repeated development delays, although none of the technological obstacles appear to be showstoppers.

The real question is: When will new footprints appear on the Moon?

The Artemis plan

In contrast to the Apollo program's singular push to the Moon, with modules for an entire mission all stacked atop a single Saturn V rocket, the Artemis program will use multiple vehicles developed by both NASA and private industries. These include NASA's Space Launch System (SLS) with a Boeing-built core stage, the SpaceX Super Heavy launcher, and Blue Origin's New Glenn rocket. SpaceX and Blue Origin each also are building a crewed lunar lander. Other hardware includes lunar spacesuits and autonomous rovers to carry astronauts and cargo near the Moon's south pole.

The uncrewed Artemis 1 mission has already flown, in 2022. The Artemis 2 mission in 2025 will use the SLS rocket to send a crew of four on a looping flight around the Moon aboard an Orion spacecraft. The first Artemis lunar landing comes with Artemis 3; that and future landing missions will employ a complex scheme of multiple rocket launches and combinations of three different crewed spacecraft. The development of two independent lunar landing systems is intended to foster competition and also serve as an insurance policy if technical issues delay the development of one of the vehicles.



The Japan Aerospace Exploration Agency (JAXA) has commissioned Toyota to build a rover with a sealed and pressurized crew cabin. Toyota has dubbed the vehicle the Lunar Cruiser. TOYOTA

ARTEMIS 1

AFTER A DELAY OF SIX YEARS, the uncrewed Artemis 1 mission launched Nov. 16, 2022, and validated the Space Launch System rocket and Orion spacecraft systems. The 25-day test flight included six days in lunar orbit and approached within 80 miles (130 kilometers) of the lunar surface. After splashdown and recovery off the coast of Baja California, Mexico, it was discovered that the Orion spacecraft's heat shield suffered higher than expected erosion during atmospheric reentry. This, along with a testing failure of the Orion environmental system, has delayed the flight of the crewed Artemis 2 mission while these issues are analyzed and corrected.

The Moon and Earth loom in the background of this image taken from an uncrewed Orion capsule on the Artemis 1 mission. NASA

SUITING UP FOR THE MOON

ONE OF THE MANY DRIVING FACTORS determining when Artemis will alight on the Moon is the spacesuits to be used by the astronauts. Apollo astronauts worked for up to three days on the Moon using spacesuits developed in the late 1960s. Long-term comfort and wear from the extremely abrasive lunar dust quickly became issues. Artemis will initially spend six days on the Moon, eventually extending to 30-day excursions, and the factors that surfaced during Apollo must be addressed for future explorations.

NASA's new lunar suits are being developed by startup company Axiom Space, headed by seasoned ex-NASA managers. Fashion giant Prada is lending expertise with stitching skills and working with exotic materials. The design of the new suit, known as the Axiom Extravehicular Mobility Unit, or AxEMU for short, is particularly challenging. Unlike the Apollo suits that operated only in daylight and were designed to keep the astronauts cool, the Axiom suits must operate for up to two hours inside permanently shadowed craters near the south pole. Here temperatures can dip to less than 30 kelvins (minus 405 degrees Fahrenheit [minus 243 degrees Celsius]). The engineering challenges encountered by Axiom can be solved, but they have slowed progress in developing the next generation of lunar spacesuits. *—R.R.*

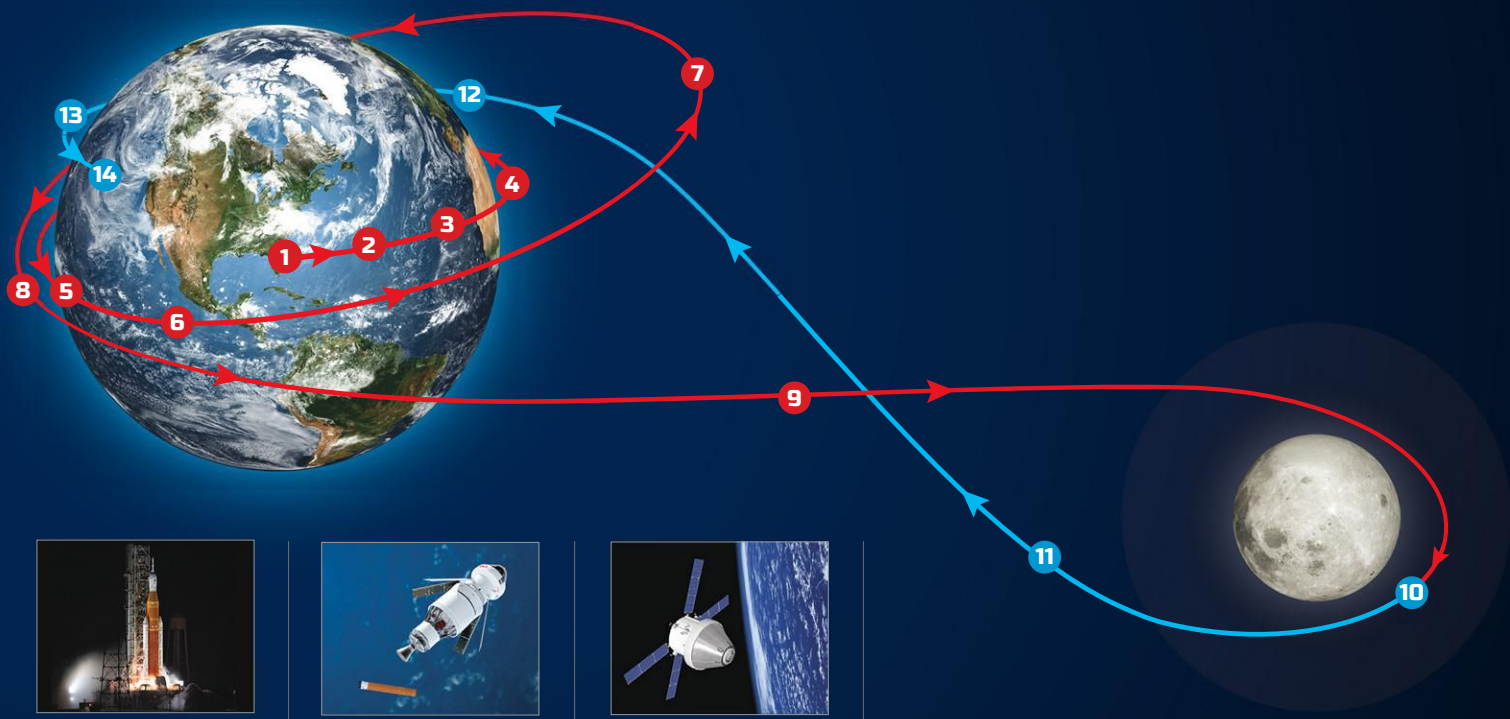
RIGHT: The AxEMU suits are designed to make it easier for astronauts to kneel down and collect samples from the Moon, as shown in testing at NASA's Johnson Space Center. AXIOM SPACE

BELOW: Axiom and Prada's lunar spacesuits were revealed Oct. 16 at the International Astronautical Congress in Milan. PRADA/AXIOM SPACE

ARTEMIS 2

EXPECTED TO FLY NO EARLIER THAN SEPTEMBER 2025, Artemis 2 will use the SLS to send a crew of four aboard an Orion spacecraft on a 10-day mission looping within 4,600 miles (7,400 km) of the Moon. The crew consists of Commander Reid Wiseman, Pilot Victor Glover, and mission specialists Christina Koch and Canadian astronaut Jeremy Hansen. Koch will be the first woman to travel to the Moon, and Hansen will be the first non-American to make the journey. The quartet have spent a total of 660 days in space on long-duration missions to the International Space Station and have 12 spacewalks between them.

Before departing for the Moon, Artemis 2 will enter a high-altitude 24-hour Earth orbit to check out the Orion spacecraft systems. After separating from the SLS upper stage, the crew will take manual control, turn Orion around, and approach the upper stage in a simulated docking to see how the craft handles in close quarters. Then Orion will turn around and light its Service Module engine, setting off for the Moon.



1 Launch from Kennedy Space Center, Florida. NASA

2 Solid rocket boosters, fairings, and launch abort system jettisoned. ROEN KELLY AFTER NASA

3 Core stage main-engine cutoff and separation. ROEN KELLY AFTER ESA AND NASA

4 Perigee raise burn to low Earth orbit.

5 Apogee raise burn to high Earth orbit.

6 Orion separates from ICPS and performs proximity operations demo. ROEN KELLY AFTER ESA AND NASA

7 Perigee raise burn.

8 Trans-lunar injection burn.

9 Four-day trip to the Moon on a free return trajectory.

10 Lunar flyby 6,479 miles (10,427 km) above surface.

11 Four-day return trip to Earth.

12 Crew Module separates from Service Module. ROEN KELLY AFTER NASA

13 Crew Module reenters atmosphere. ROEN KELLY AFTER NASA

14 Splashdown in the Pacific Ocean.

BACKGROUND ILLUSTRATION AND INSETS UNLESS OTHERWISE STATED: *ASTRONOMY*: ROEN KELLY

SPACECRAFT FOR LUNAR EXPLORATION

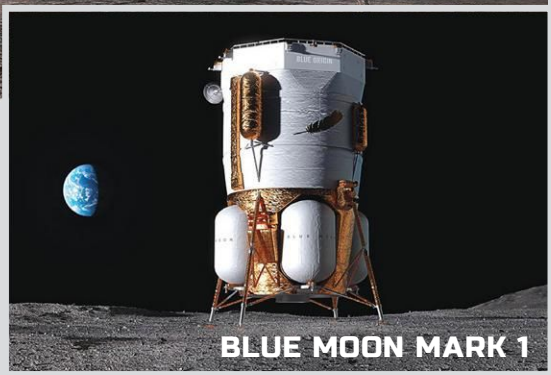
ARTEMIS WILL UTILIZE FOUR DIFFERENT SPACECRAFT TO RETURN TO THE MOON.

The cone-shaped Orion spacecraft, resembling an enlarged Apollo Command Module, will be launched by the SLS and carry four astronauts into lunar orbit to rendezvous with a lunar lander. Orion will be buttressed by the European-built Service Module, which will provide power, propulsion, and life support for the Orion.

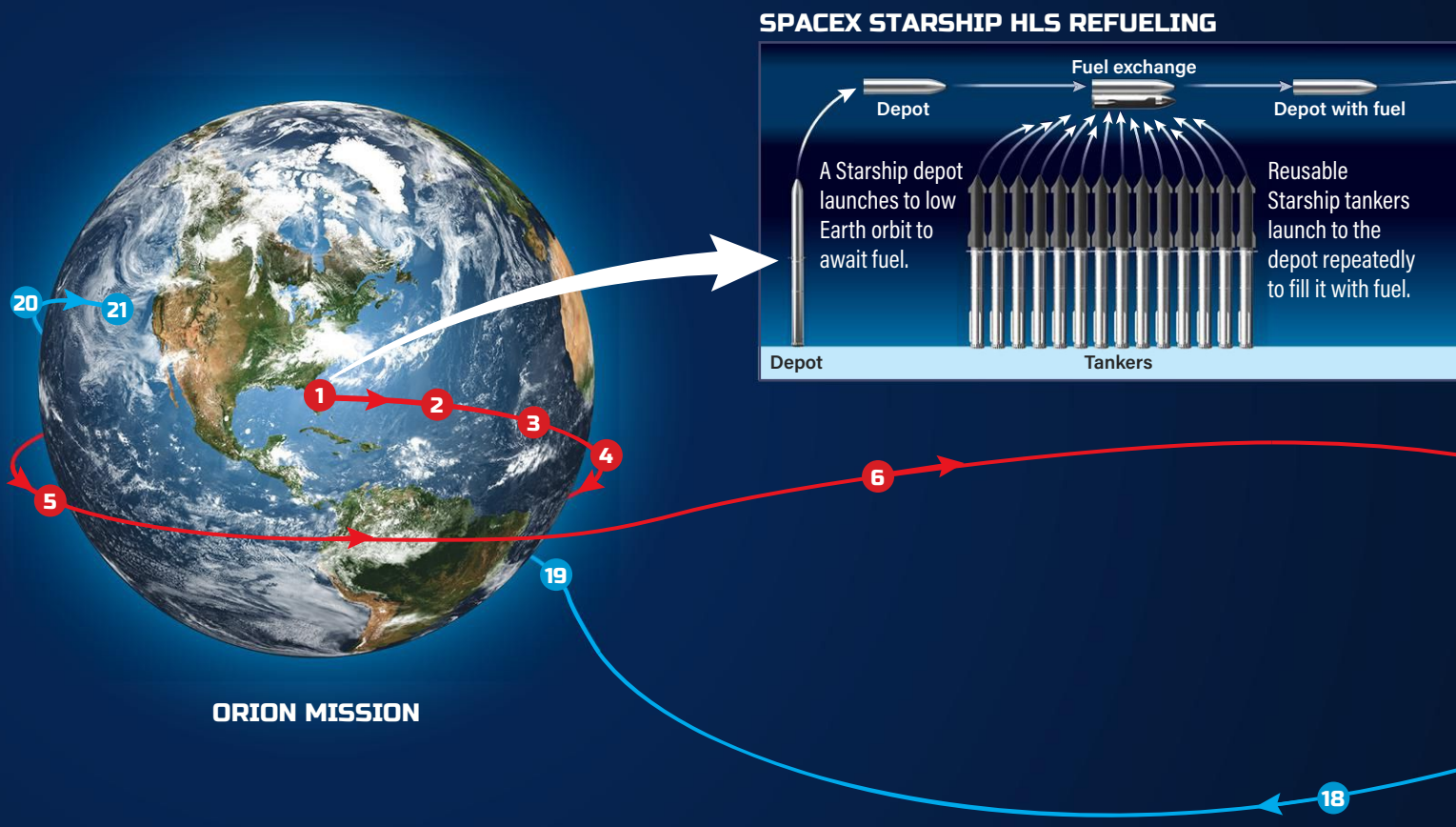
Starship HLS will be based on the current Starship undergoing Earth-orbit testing. But as it will never reenter Earth's atmosphere, it will be devoid of external heat shielding and aerodynamic control flaps. It will also feature five solar panels that extend from midship, while the ship's white coating will prevent the Sun from heating the cryogenic propellants. Heavy braking during the lunar approach with be done with the HLS's six tail-mounted, powerful Raptor engines. But to prevent them from stirring up dust and debris and potentially causing damage, they will be shut down near the lunar surface and the HLS will alight using less powerful thrusters higher up on the HLS body. The HLS will also be equipped with an airlock and elevator system to transport crew and cargo to the lunar surface nearly 100 feet (around 30 meters) below the HLS's habitable area.

Blue Origin's Blue Moon Mark 2 (above) is expected to land crews of up to four astronauts on the Moon beginning with Artemis 5. The craft features an airlock to allow access to the lunar surface without depressurizing the crew compartment. A smaller, single-use, cargo-only precursor, Mark 1, will be capable of delivering 3.3 tons (3,000 kilograms) of supplies anywhere on the Moon. A demo flight of the Mark 1 lander could launch later in 2025 and would seek to perform a pinpoint landing on the Moon's surface within 328 feet (100 m) of a designated target.

Cargo variants of Starship HLS and Blue Moon Mark 2 are also planned. Starship's cargo capacity is targeted at 100 tons (90,700 kg), though this depends on the performance of the Super Heavy booster. The Mark 2 cargo transport will deliver 22 tons (20,000 kg) of supplies to the lunar surface when configured to be reusable and 33 tons (30,000 kg) on a one-way trip. —*R.R.*



FROM TOP: BLUE ORIGIN; BLUE ORIGIN; NASA; LOCKHEED MARTIN



ARTEMIS 3

FOR THE INITIAL ARTEMIS 3 LUNAR LANDING MISSION — the first planned crewed landing on the Moon since Apollo — the SpaceX Starship Human Landing System (HLS) will be placed in lunar orbit, where it will loiter for up to 100 days awaiting the arrival of the crew aboard an Orion spacecraft.

Getting the Starship to the Moon will involve a complex scheme of refueling spacecraft in orbit. First, a fuel-depot version of Starship will be placed in orbit using the SpaceX Super Heavy booster. Next, a series of up to 20 reusable tanker spacecraft launched by the Super Heavy booster will fill the fuel depot with 2 million pounds (910,000 kg) of liquid methane and liquid oxygen. The Starship HLS will subsequently launch, refuel from the depot, then boost to lunar orbit.

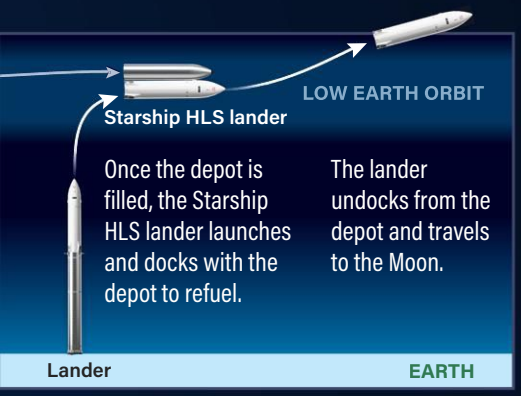
The crew of four astronauts will launch separately, in the Orion spacecraft atop NASA's SLS rocket, and travel to lunar orbit to rendezvous and dock with Starship HLS. Two of the crew members will transfer to Starship HLS, which will transport them to the lunar surface, and land near the south pole. Up to four moonwalks are planned during the 6.5-day stay. Instruments carried to the surface will investigate the seismic and physical properties of the Moon. After liftoff, the Starship HLS will rendezvous with the orbiting Orion, and all four astronauts will return to Earth aboard the Orion.

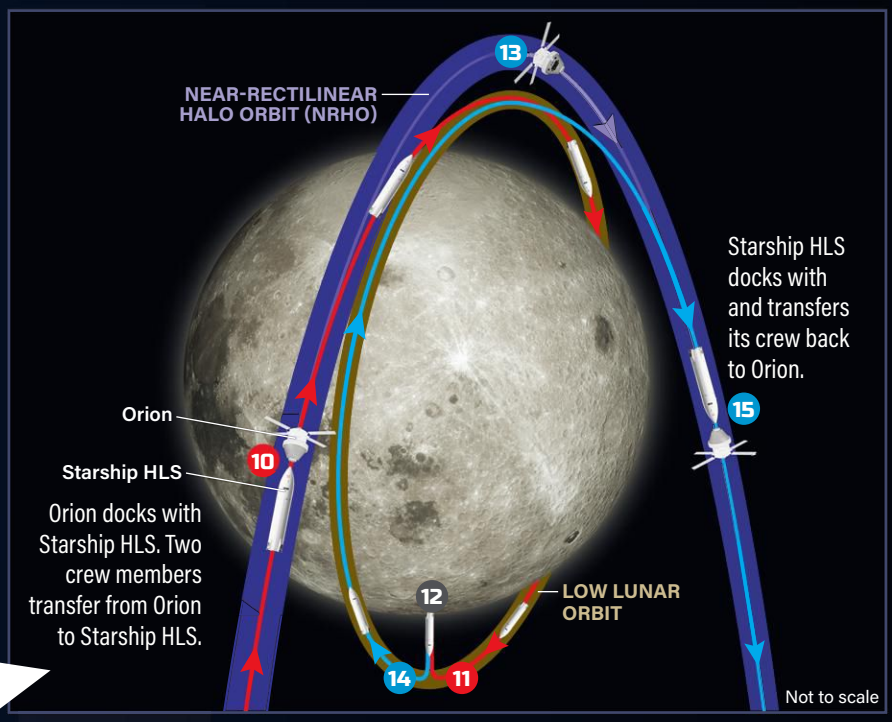
Although published timelines call for Artemis 3 to land on the Moon by the end of 2026, NASA's internal baseline for the landing has been pushed back to February 2028. Many engineering milestones must be met before the flight is approved. These include resolving unexpected pitting and erosion suffered by the Orion spacecraft's heat shield on Artemis 1 as well as challenges faced by Axiom Space in developing the Artemis lunar spacesuit. A history of previous ambitious spaceflight programs suggests it is prudent to manage expectations and expect Artemis 3 to finally fly in late 2028.

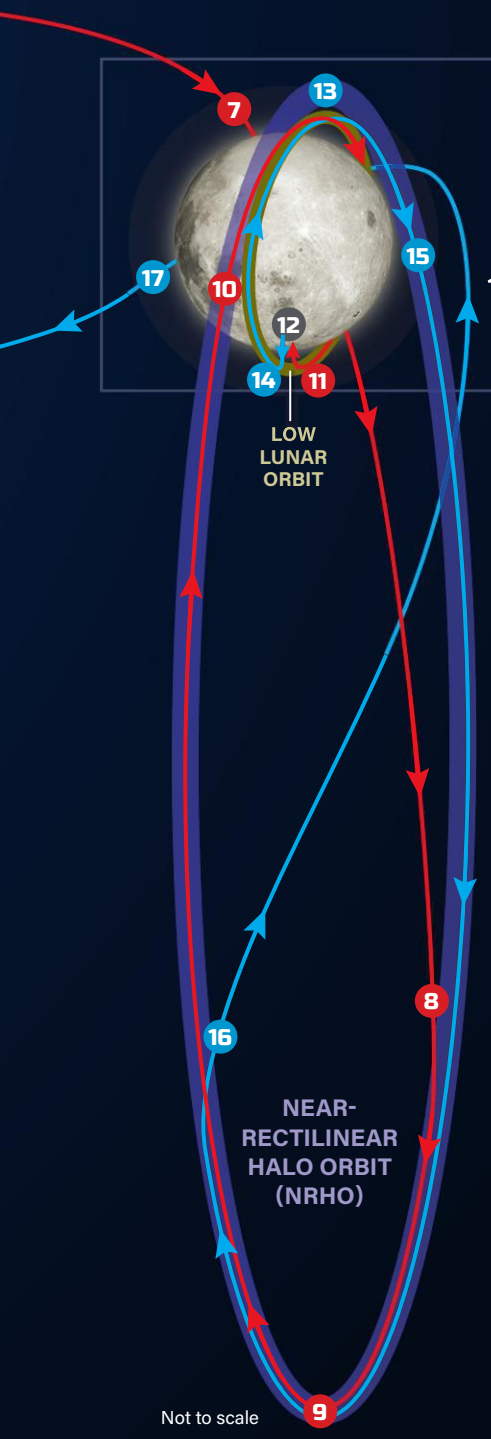
A critical variable in the Artemis scheme is the apparent underperformance of the SpaceX Super Heavy rocket. Instead of 100 tons (90,000 kg) of cargo or fuel being placed in orbit, the currently achievable figure is closer to 50 tons (45,000 kg). Unless rectified, this will necessitate perhaps twice as many tanker spacecraft launches, extending the filling of the fuel depot spacecraft to an unwieldy six-month process. A Starship in-orbit refueling demo is expected in 2025.

The current performance of the Super Heavy is not fatal to Artemis, but it could delay the program's lunar landings by up to five years. It will likely take longer than that for SpaceX to perfect the higher-performance Raptor 3 engines that will restore the Super Heavy booster to its baseline of placing 100 tons into Earth orbit.

BACKGROUND ILLUSTRATION AND INSETS UNLESS OTHERWISE STATED: *ASTRONOMY*: ROEN KELLY







1 SLS launches from Kennedy Space Center, Florida.

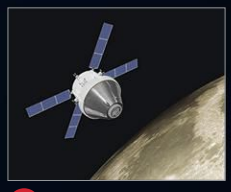
2 Solid rocket boosters, fairings, and launch abort system jettisoned.
ROEN KELLY AFTER NASA

3 Solid rocket boosters, fairings, and launch abort system jettisoned.
ROEN KELLY AFTER NASA

4 Perigee raise burn to low Earth orbit.

5 Trans-lunar injection burn.

6 Four-day trip to the Moon.



7 Outbound powered lunar flyby 69 miles (111 km) above surface.

8 Lunar orbit insertion burn.

9 Rendezvous with Starship HLS.

10 Lander undocking and separation.

11 Lander descends to surface.

12 Week-long lunar surface exploration.

13 Orion remains in lunar orbit.

14 Starship HLS ascends to low lunar orbit.

15 Starship HLS rendezvous and docking with Orion.

16 Orion undocks and performs trans-Earth injection burn.

17 Return powered flyby 69 miles (111 km) above surface.

18 Final return trajectory correction burn.

19 Crew Module separates from Service Module. ROEN KELLY AFTER NASA

20 Crew Module reenters atmosphere.
ROEN KELLY AFTER NASA

21 Splashdown in the Pacific Ocean. NASA

NEW ROCKETS FOR THE MOON

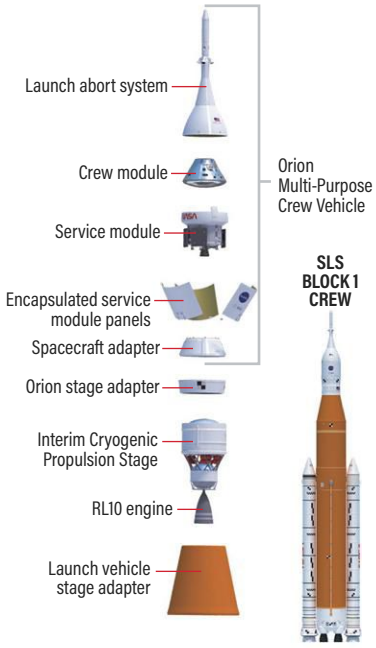
THE ARTEMIS PROGRAM WILL RELY ON a fleet of rockets and crewed vehicles. These include NASA's Space Launch System (SLS), the SpaceX Starship/Super Heavy system, and the Blue Origin New Glenn.

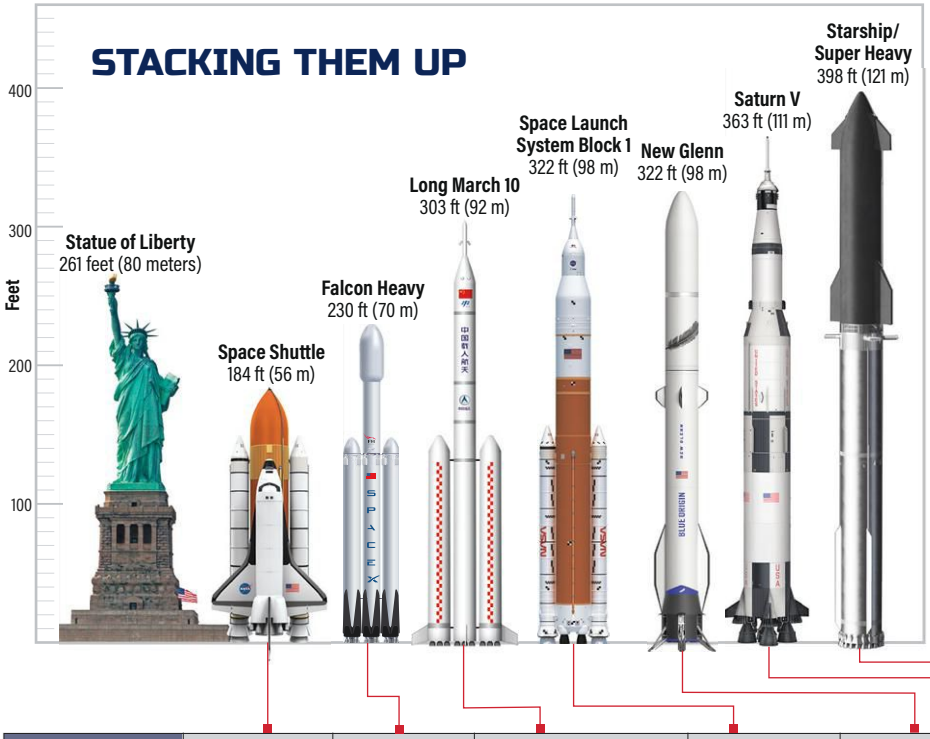
NASA's 322-foot-tall (98 m) SLS will send the crewed Orion spacecraft into lunar orbit to join the awaiting lunar landing craft. The SLS consists of a core booster utilizing four repurposed RS-25 engines from NASA's retired space shuttle, and two nonrecoverable uprated solid rocket boosters (SRB), also adapted from the shuttle.

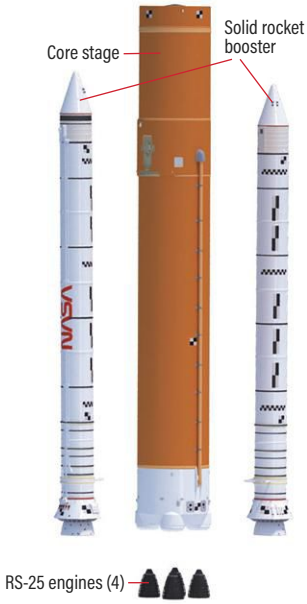
The first four SLS flights will expend the 16 remaining space shuttle RS-25 main engines, and the first eight SLS missions will expend the remaining shuttle SRBs. Subsequent missions will utilize newer uprated engines now under development.

The initial configuration of SLS makes use of an upper stage modified from a Delta rocket built by United Launch Alliance. Called the Interim Cryogenic Propulsion Stage, it will be replaced by an uprated upper stage on Artemis 4. This will allow SLS launches to bring additional Lunar Gateway modules, riding piggyback on the Orion crewed spacecraft.

It is clear that the longevity of the SLS booster will be limited due to its staggering cost — currently estimated as high as $2 billion per launch — and its low flight rate. Currently, there is not enough SLS hardware to support an annual launch rate and the required SLS upgrades for Artemis 4 may delay that mission until late 2028. There are hopes that SLS could launch various future robotic space probes to lower the unit cost to as low as $1 billion per flight, but it is difficult to attract users for such an expensive vehicle. Eventually, more affordable reusable commercial launch capabilities will render the SLS obsolete, and it will vanish from the spaceflight manifest. *—R.R.*







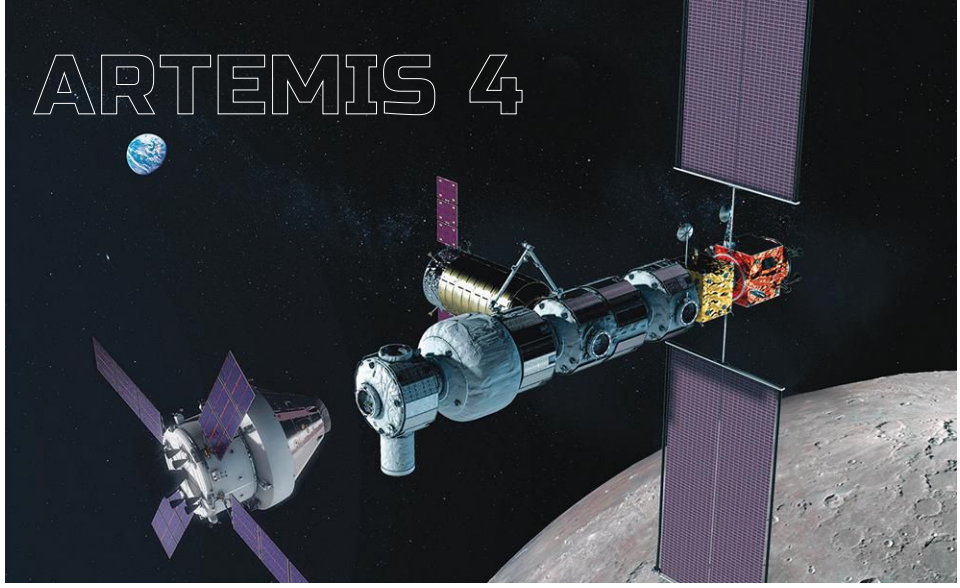
Manufacturer	Rockwell et al.	SpaceX	China Academy of Launch Vehicle Technology	Boeing et al.	Blue Origin	Boeing et al.	SpaceX
Weight	4,500,000 lbs (2 million kg)	3,126,000 lbs (1,421,000 kg)	4,826,000 lbs	5,750,000 lbs (2.6 million kg)	Undisclosed	6,200,000 lbs (2.8 million kg)	11,000,000 lbs (5 million kg)
Liftoff thrust	7,800,000 lbs (35 million N)	5,100,000 lbs (23 million N)	5,900,000 lbs (26 million N)	8,800,000 lbs (39 million N)	3,850,000 lbs (17.2 million N)	7,600,000 lbs (34 million N)	16,700,000 lbs (74 million N)
Lunar payload	N/A	35,000 lbs (16,000 kg)	59,500 lbs (27,000 kg)	59,500 lbs (27,000 kg)	15,000 lbs (7,000 kg)	96,000 lbs (43,500 kg)	150 tons (with low Earth orbit refueling)
Fuel	LH_2/LOX/Solid propellant	RP-1/LOX	RP-1/LOX	LH_2/LOX/ Solid propellant	Methane/LOX	RP-1/LOX/LH_2	Methane/LOX
Reusable	Partially	Yes	No	No	Yes	No	Yes
Cost per launch	$1,500,000,000	$90,000,000	Unknown	$2,000,000,000	$68,000,000 (estimated)	$1,500,000,000 (adjusted for inflation)	$100,000,000 (estimated)

FROM LEFT TO RIGHT: STUART MONK/DREAMSTIME; NERTHUZ/DREAMSTIME AND ROEN KELLY; SUBHAN BAGHIROV/DREAMSTIME; ROEN KELLY; NASA; BLUE ORIGIN; NASA; SPACEX; NASA

TOP TO BOTTOM: NASA's Space Launch System lifts off from Launch Complex 38B at Kennedy Space Center Nov. 16, 2022, on Artemis 1. NASA/JOEL KOWSKY

The SpaceX Starship/Super Heavy combination is a rocket of astonishing proportions. Fully stacked, the stainless steel rocket stands 30 feet (9 m) wide and 398 feet (121 m) high. With 33 methane-burning Raptor engines, Super Heavy has more than double the thrust of Apollo's Saturn 5. To recover Super Heavy for reuse, SpaceX will catch the booster in mid-air with moving arms on the rocket's launch tower. This process was tested successfully during a test flight Oct. 13, 2024. SPACEX

The first components of the reusable Blue Origin New Glenn rocket stand at Cape Canaveral for testing and integration prior to a maiden flight scheduled for late 2024. New Glenn will refuel on-orbit and transport the Blue Origin Blue Moon lunar lander to the Gateway in support of Artemis 5 and later missions. BLUE ORIGIN



The Lunar Gateway, a small space station in a six-day lunar orbit, will be used as staging point for the Artemis 4 and later lunar landings. In this artist's rendering, an Orion craft approaches for docking. NASA

STARTING WITH ARTEMIS 4, a small space station called the Lunar Gateway will circle the Moon in a six-day orbit and serve as a staging point for lunar landings. The initial two Gateway modules will be launched aboard a SpaceX Falcon Heavy rocket. The Artemis 5, 6, and 7 missions will piggyback additional Gateway modules with the Orion spacecraft.

Mission planning for Artemis 4 depends on Artemis 3's timeline. Current public announcements call for launching no earlier than September 2028; a more realistic date is late 2029. Artemis 4 will use the uprated SLS Block 1A rocket, which will have an additional 33,000 pounds (15,000 kg) of payload capacity allowing it to carry the International Habitation Module (I-Hab) being developed by the European and Japanese space agencies. The I-Hab, along with the modules previously launched by the Falcon Heavy, will establish a functional Lunar Gateway outpost. As with the previous mission, the Starship HLS will launch first, rendezvous with the Lunar Gateway, and await the arrival of Orion and the Artemis 4 crew. Two astronauts will then perform the second Artemis lunar landing aboard the Starship HLS. Then all crew members will return to Earth aboard the Orion craft.

ARTEMIS 5 — and beyond

TENTATIVELY PLANNED for launch no earlier than March 2030, Artemis 5 will feature the first use of Blue Origin's Blue Moon lander, which will be launched to the Lunar Gateway by a Blue Origin New Glenn rocket. Four astronauts will launch aboard an Orion spacecraft on an SLS rocket which will also carry an additional module for the Lunar Gateway. At the Gateway, two astronauts will transfer to the Blue Moon for a south pole landing near a prepositioned rover, called the Lunar Terrain Vehicle (LTV). The LTV will be the first use of a lunar rover on the Moon since Apollo 17 in 1972. After returning to the Gateway, the pair will join the other two crew members aboard the Orion for their return to Earth.

If these initial Artemis lunar landings go well, future landings will follow at roughly one-year intervals. Each will utilize the Lunar Gateway to transfer crew from Orion to either a Starship HLS or Blue Moon lander.

There are currently serious technical and financial challenges along Artemis' path to the Moon. The optimistic public schedules will certainly become fiction. But as long as there is a national will to return to the Moon hand-in-hand with international partners, these obstacles can be overcome and more human footprints will join those left on the Moon half a century ago by the heroes of the Apollo era.

Robert Reeves *is an accomplished astrophotographer and author, with a passion for lunar photography and science.*