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NASA's Space Launch System: Unprecedented Payload Capabilities

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ABSTRACT

As NASA turns 60 and plans to transition the International Space Station (ISS) and other low-Earth orbit (LEO) activities to commercial enterprises, the Agency's human exploration program turns its focus to deep space. With missions planned to send astronauts back to the Moon and to construct a lunar orbiting Gateway for surface access as well as science experiments and technology demonstrations, NASA requires a vehicle with capabilities for launching more mass and volume than is currently commercially available. To that end, NASA and its private sector partners are building the Space Launch System (SLS) super heavy-lift launch vehicle, which will send the new Orion crew capsule, eventually with a complement of four astronauts, to cislunar space for the first time since the Apollo Program in the 1960s and 1970s. NASA Kennedy Space Center's (KSC's) Exploration Ground Systems (EGS) Program has upgraded and refurbished ground and launch facilities to process, assemble and launch NASA's new deep space exploration system, which is managed by the Exploration Systems Development (ESD) organization in the Human Exploration and Operations Mission Directorate (HEOMD). Offering an unmatched combination of power, payload capacity and departure energy, the evolvable SLS features the world's most proven propulsion system: solid rocket boosters and RS-25 main engines with a modified Delta Cryogenic Second Stage (DCSS) cryogenic

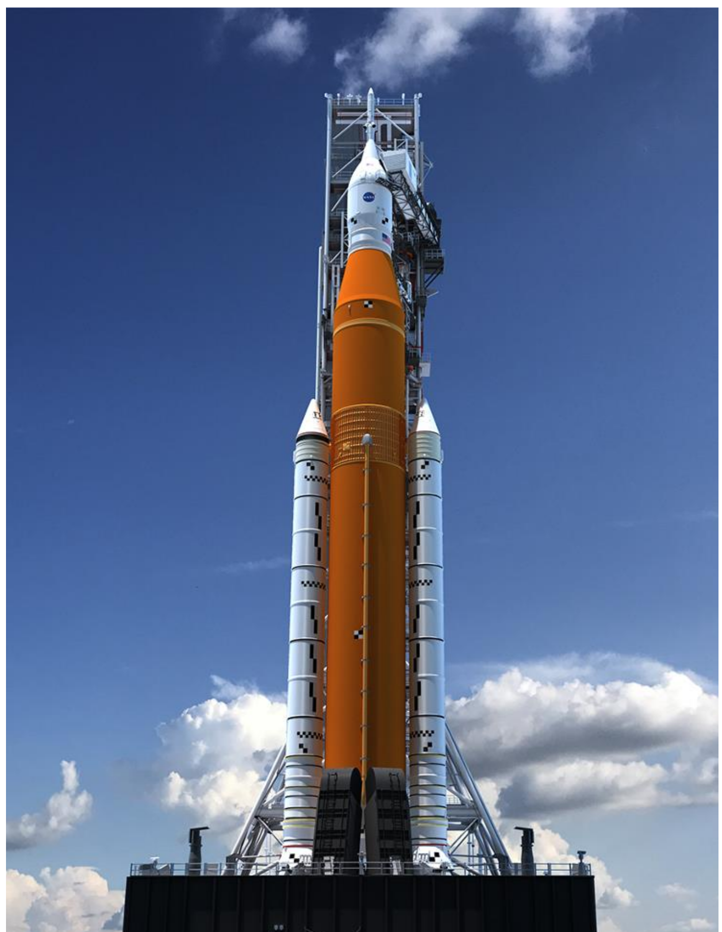


Figure 1. Artist's depiction of NASA's Space Launch System (SLS) launch vehicle, the Orion crew spacecraft and the mobile launcher (ML)

upper stage. The initial SLS configuration, Block 1, will deliver at least 26 metric tons (t) to trans-lunar injection (TLI). The second variant, Block 1B, will deliver at least 34 t to TLI in its crew configuration and at least 40 t to TLI in its cargo configuration. The Block 1 cargo vehicle will fly with an industry-standard 5 m fairing while the Block 1B cargo configuration will accommodate 8 m-diameter fairings in varying lengths. The Block 2 vehicle will incorporate upgraded boosters and possibly larger fairings for launching Mars-class payloads to deep space. Although designed to enable human exploration of deep space, the vehicle also provides game-changing benefits for large science payloads and even harnesses excess capacity to provide small satellites with access to deep space. Three flights of the Block 1 vehicle are now planned; the first vehicle, being built for a test flight known as Exploration Mission-1 (EM-1), is nearing completion at NASA and contractor sites across the United States. In fact, hardware for the second mission has also been built. This paper will provide an overview of the SLS vehicle, with a focus on its payload accommodations and the missions enabled by the unprecedented payload volume and departure energy of SLS. This paper also describes the status of the manufacturing and integration for first flight and beyond.

KEYWORDS: **NASA Space Launch System Payloads Exploration Mission-1 CubeSats Launch Vehicles**

NEW VEHICLES FOR A NEW ERA OF EXPLORATION

With commercial cargo flights regularly launching to the International Space Station (ISS) in low-Earth orbit (LEO) and commercial crew flights to the ISS expected to commence in 2019, NASA's Human Exploration and Operations Mission Directorate (HEOMD) is focused on lunar exploration in order to verify and validate new systems for living and working in deep space. Using the Moon as a stepping stone to develop technologies that will be needed to explore deeper into the solar system, NASA plans to permanently extend human presence off the Earth with a horizon goal of human exploration of the Red Planet.

The Space Launch System (SLS) architecture will support a variety of missions and payloads to cislunar space and beyond. Vehicle designers have plotted a block upgrade path to bring progressively more capable vehicles online for increasingly challenging missions that will usher in this new era of deep space exploration. Each block is scheduled for availability in crew and cargo configurations, with the initial Block 1 crew vehicle slated for the first test flight, known as Exploration Mission-1 (EM-1).

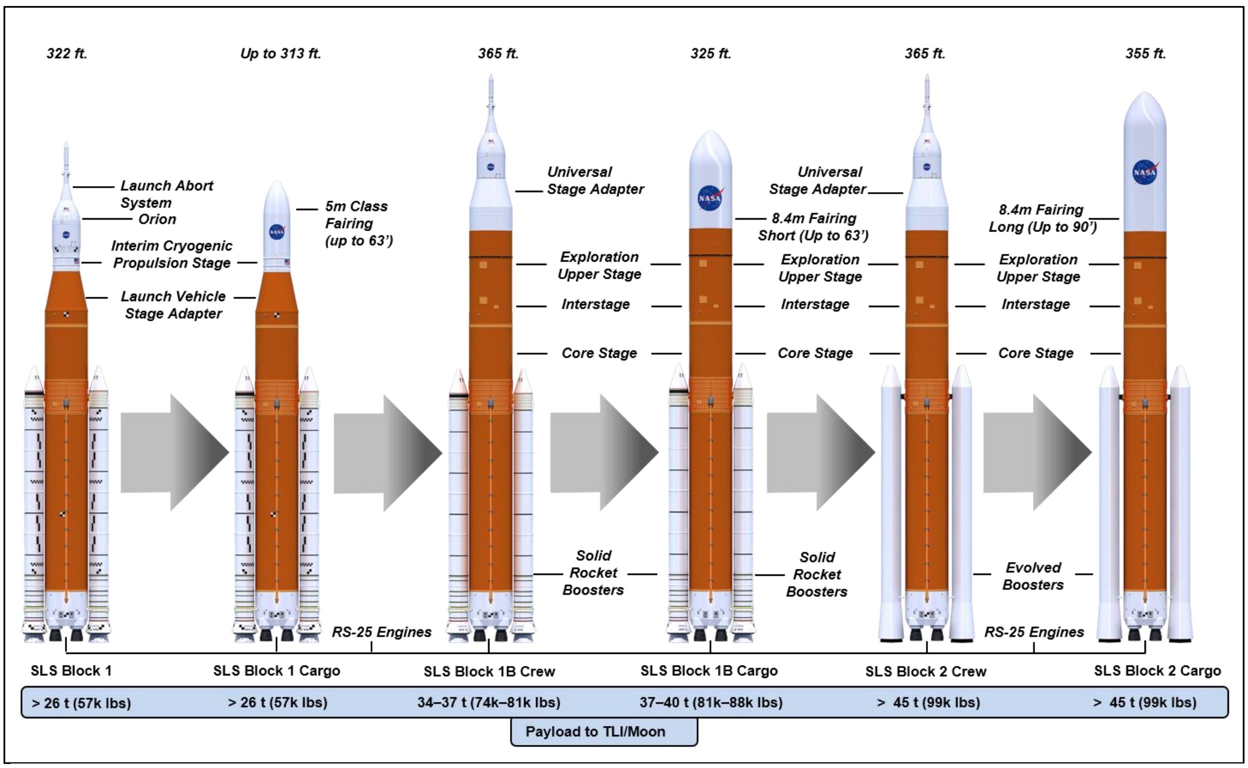


Figure 2. SLS will evolve to lift more mass and provide more volume for deep space payloads

The Block 1 vehicle is currently planned for the first three missions with Exploration Mission-2 (EM-2) slated to return astronauts to cislunar space for the first time since Apollo 17 in 1972. Science Mission-1 (SM-1) will utilize a 5 m fairing on the Block 1 cargo configuration to launch the Europa Clipper mission on a direct trajectory to the Jovian system. Block 1 will be capable of lifting at least 26 metric tons (t) to trans-lunar injection (TLI). Block 1B will employ a more powerful upper stage: a four-engine liquid hydrogen (LH2)/liquid oxygen (LOX) Exploration Upper Stage (EUS), to increase capability to 34 to 40 t to the lunar vicinity, depending on crew or cargo configuration. The crewed version will be able to take co-manifested payloads in the 8-10 t range along with a fully outfitted Orion to the Moon, giving NASA the capability to launch crew and cargo together to maximize launch resources and support Gateway buildup. Block 1B cargo flights can utilize an 8.4 m-diameter fairing in 19.1 m or 27.4 m lengths. Block 2 flights will raise mass capability to at least 45 t to TLI. Fairings larger than 8.4 m in diameter are under consideration for this vehicle, which will utilize upgraded boosters to increase performance.

NASA'S NEW EXPLORATION MISSIONS

The first step in NASA's plans to develop systems for deep space exploration is the launch of EM-1, the first integrated mission of SLS and Orion, which will lift off from launch pad 39B at Kennedy Space Center (KSC). For EM-1, an SLS Block 1 crew configuration will send an uncrewed Orion on a 25.5-day mission to a distant retrograde lunar orbit (DRO) with the primary objective to test and validate new systems and procedures. Flight objectives include validation of thermal protection, control and data systems; testing deep space maneuvers, communications and tracking; demonstrating landing and recovery operations in preparation for future crewed missions; testing motion imagery systems; and deploying 13 6U secondary payloads from the Orion Stage Adapter (OSA) following the TLI burn and separation from the Orion spacecraft.

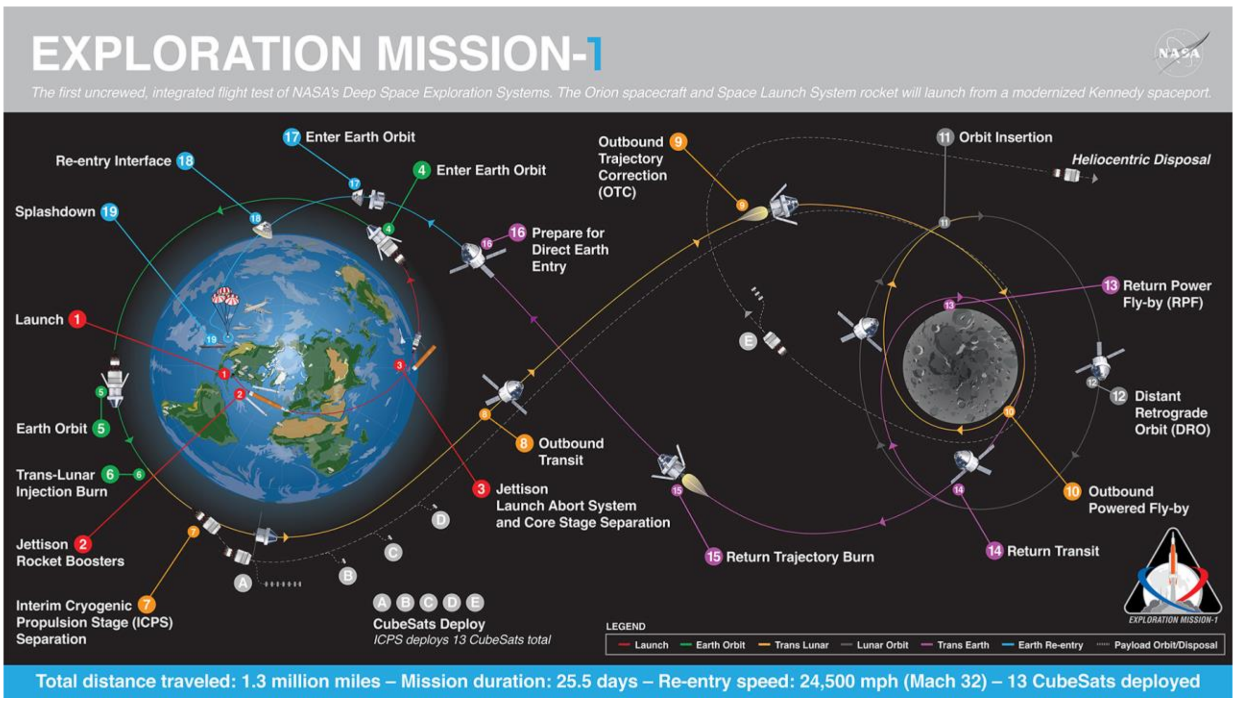


Figure 3. Overview of the first integrated flight of SLS and the unscrewed Orion spacecraft, Exploration Mission-1 (EM-1)

The 13 6U-class CubeSat payloads manifested on EM-1 are being developed by a diverse array of academic, industry and international partners, as well as projects within NASA. These secondary payloads, which will carry out a variety of scientific experiments and technology demonstrations (see Table 1), will deploy in several locations along the upper stage disposal trajectory. Seven payloads will be deployed after the upper stage, known as the Interim Cryogenic Propulsion Stage (ICPS), has cleared the first Van Allen Radiation Belt. About 90 minutes after clearing the first radiation belt, another payload will be released and one more is scheduled to be deployed soon after the ICPS has cleared both radiation belts. About one hour after passing through both radiation belts, another payload will be deployed. The final three payloads will be deployed after the ICPS passes the Moon and enters its heliocentric disposal orbit.

For EM-2, the second Block 1 mission using the crew configuration, SLS will send the Orion spacecraft with four astronauts to cislunar space. To meet human rating requirements, the ICPS will be modified to include an emergency detection system. Because SLS has been designed from the ground up for human exploration of deep space, no other significant changes are expected to meet the human-rating certification.

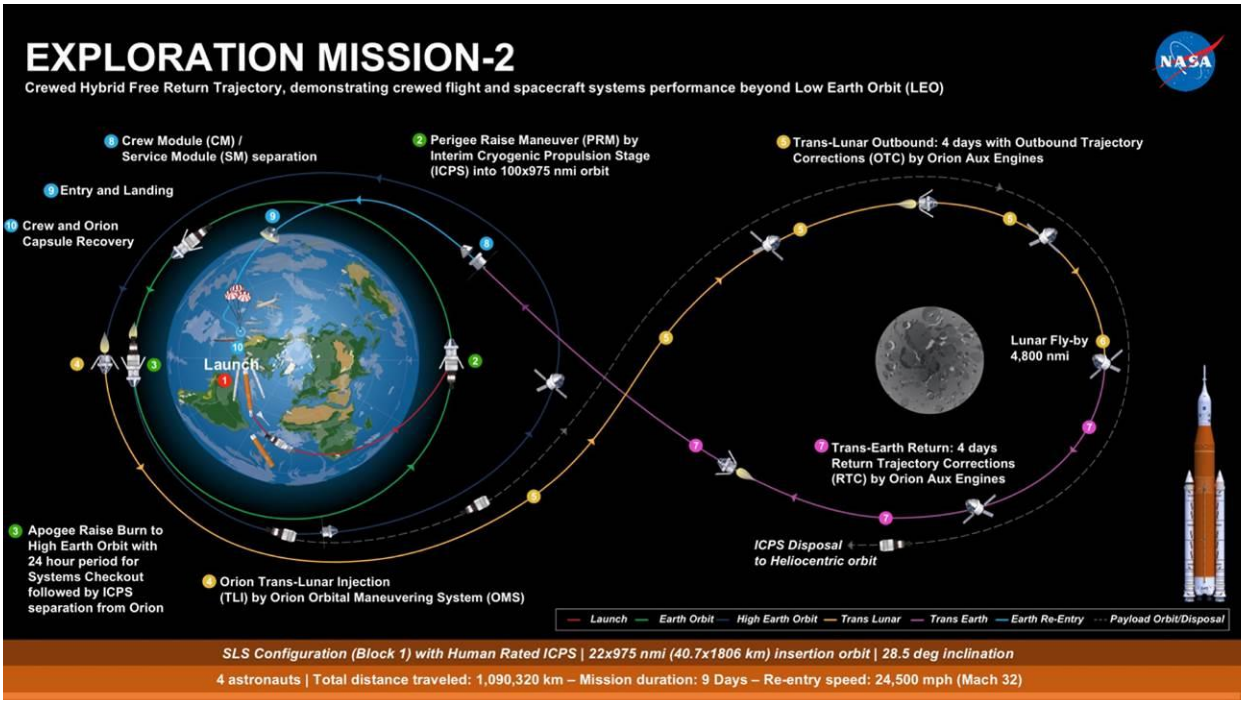


Figure 4. Mission overview for Exploration Mission-2 (EM-2), scheduled to be the first NASA mission to send astronauts around the Moon since Apollo 17

The mission to launch the Europa Clipper probe to Jovian space, SM-1, will also utilize a Block 1 vehicle, with a 5 m-diameter fairing. At the time of writing, procurement was in progress for the cargo shroud, payload adapter, separation system and other associated hardware. Use of industry-standard payload interfaces and accommodations in the Block 1 cargo vehicle will streamline development for Europa Clipper mission planners and engineers.

All SLS vehicles will be stacked in KSC's historic Vehicle Assembly Building (VAB), where the Exploration Ground Systems (EGS) Program has removed the platforms used to assemble space shuttles and replaced them with 10 new work platforms extending nearly to the top of the 160-m tall High Bay 3, where SLS and Orion, with its Launch Abort System (LAS), will be integrated. The new system will launch from Launch Complex 39B at KSC on a mobile launcher (ML) that has also been upgraded to meet SLS and Orion requirements. In fact, the EGS Program recently completed installation of all umbilicals on the ML for EM-1 and tested the ML by rolling it out to the launch pad and back into the VAB.

Table 1. Summary of EM-1 6U Secondary Payload Missions

Payload	Developer(s)	Sponsor	Destination	Mission
ArgoMoon	Argotec	Agenzia Spaziale Italiana (ASI)	Geocentric orbit with high eccentricity and apogee close to the Moon	Photograph the ICPS, CubeSat deployment, the Earth and Moon using HD cameras and advanced software imaging recognition
Biosentinel	NASA Ames, NASA	NASA Advanced	Heliocentric orbit via	Use yeast as a biosensor

	Johnson, Loma Linda University Medical Center, University of Saskatchewan	Exploration Systems (AES)	lunar flyby	to evaluate the effects of ambient space radiation on DNA
Cislunar Explorers	Cornell University	NASA Cube Quest Challenge, sponsored by NASA's Science Technology Mission Directorate (STMD) Centennial Challenges	Lunar orbit	Demonstrate use of an inert water-based propulsion system for lunar gravity assists capture in lunar orbit; compete in NASA's Deep Space Derby
CubeSat to Study Solar Particles (CuSP)	Southwest Research Institute, NASA Goddard	NASA Science Mission Directorate (SMD)	Deep space	Study the sources and acceleration mechanisms of solar and interplanetary particles in near-Earth orbit
EQUilibriUm Lunar-Earth point 6U Spacecraft (EQUULEUS)	University of Tokyo	Japanese Aerospace Exploration Agency (JAXA)	Earth-Moon L2 point	Demonstrate trajectory control techniques within the Sun-Earth-Moon region and conduct imaging Earth's plasmasphere
Lunar IceCube	Morehead State University, NASA JPL, NASA Goddard, BUSEK	NASA Next Space Technologies for Exploration Partnerships (NextSTEP)	Lunar orbit	Search for water (and other volatiles) in ice, liquid and vapor states using infrared spectrometer
Lunar Flashlight	NASA JPL	NASA AES	Lunar orbit	Search for ice deposits using near-infrared band lasers
Lunar-Polar Hydrogen Mapper (LunaH-Map)	Arizona State University	NASA SMD	Lunar orbit	Perform neutron spectroscopy to characterize abundance of hydrogen in permanently shaded craters
LunIR	Lockheed Martin Space Systems	NASA NextSTEP	Heliocentric orbit via lunar flyby	Use a miniature high-temperature Mid-Wave Infrared (MWIR) sensor to characterize the lunar surface
Near Earth Asteroid (NEA) Scout	NASA Marshall	NASA AES	NEA within ~1.0 AU of Earth	Detect target NEA, perform reconnaissance and close proximity imaging
Outstanding MOon exploration TEchnologies demonstrated by Nano Semi-Hard Impactor (OMOTENASHI)	Institute of Space and Astronautical Science (ISAS)/JAXA	JAXA	Lunar surface	Develop world's smallest lunar lander and observe lunar radiation environment
Team Miles	Miles Space, LLC	NASA Cube Quest Challenge, sponsored by STMD Centennial Challenges	Deep space	Demonstrate propulsion using plasma thrusters and autonomous flight using an onboard computer system; compete in NASA's Deep Space Derby
University of Colorado-Earth Escape Explorer (CU-E^3)	University of Colorado in Boulder	NASA Cube Quest Challenge, sponsored by STMD Centennial Challenges	Deep space	Demonstrate use of solar radiation pressure for propulsion; compete in NASA's Deep Space Derby

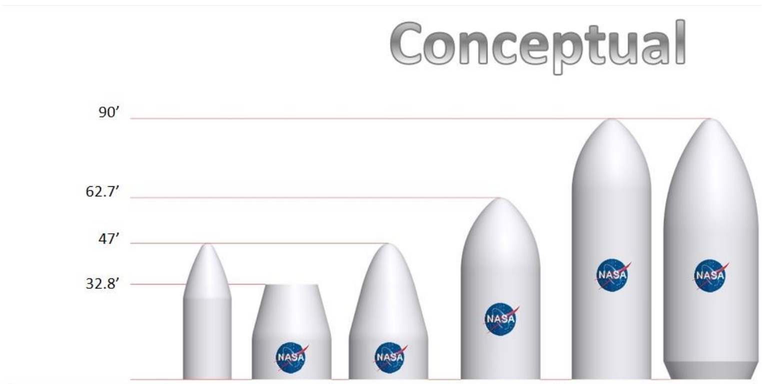
FUTURE MISSIONS AND PAYLOAD CAPABILITIES

Enabling Sustained Lunar Operations

NASA's vision for exploring deep space is being informed by the *Global Exploration Roadmap*,[1] which articulates the objective, goals, benefits and strategies for cooperative international exploration. The *Roadmap* is a product of the International Space Exploration Coordination Group (ISECG), consisting of 14 space agencies, including NASA, from nations around the world. The Roadmap, which identifies Mars as "the driving goal of human exploration," is a living document updated via an ongoing series of meetings between partner agencies and other stakeholders.

Early in the 2020s, NASA plans to construct a lunar orbiting Gateway in Near Rectilinear Halo Orbit (NRHO)[2]. The Gateway can be used as a staging point for missions to the lunar surface and as a platform for destinations in deep space, providing a flexible human exploration architecture. Notionally, initial functionality will include a Power and Propulsion Element (PPE); habitation; an airlock to enable docking and extra-vehicular activity (EVA); and logistics for cargo delivery, science utilization, exploration technology demonstrations and potential commercial utilization. SLS will launch astronauts in the Orion crew vehicle along with co-manifested payloads in the Block 1B vehicle to help establish the Gateway.

The PPE is scheduled to launch first, on a commercial vehicle. For Exploration Mission-3 (EM-3), and the inaugural flight of the Block 1B crew vehicle, SLS is slated to carry a European Space Agency (ESA)-provided ESPRIT module and a U.S.-developed utilization module – a small habitat and logistics module – as a co-manifested payload with Orion. The ESPRIT module will provide a science airlock and additional communications, and refueling for the PPE. The Block 1B crew vehicle will accommodate co-manifested payloads in the Universal Stage Adapter (USA), which provides as much volume for payloads as commercial 5 m-diameter fairings. Co-manifested payloads will typically separate from the EUS after reaching a safe distance from Orion, typically five to eight hours after launch. The USA will separate in a "canister" fashion rather than a "sector" separation. The canister separation scheme results in the upper 85 percent of the USA structure, with the Orion spacecraft adapter still attached, being jettisoned as a single, circumferential ring. The non-separable 15 percent of the USA structure remains with the EUS. Similar to evolved expendable launch vehicles (EELVs), the mechanical interface between the SLS Block 1B launch vehicle and a co-manifested payload is a payload adapter consisting of up to three components: a payload attach fitting, a payload separation system and a payload interface adapter. Choice of a particular payload adapter depends on mission needs.



Enclosure	5.1m PLF	8.4m USA	8.4m USA PLF	8.4m PLF, Short	8.4m PLF, Long	10m PLF
Type	5m PPL	8.4m CPL	8.4m PPL	8.4m PPL	8.4m PPL	10m PPL
Length	47.0 ft	32.8 ft	47.2 ft	62.7 ft	90 ft	90 ft
	14.3 m	10.0 m	14.4 m	19.1 m	27.4 m	27.4 m
Diameter	16.7 ft	27.6 ft	27.6 ft	27.6 ft	27.6 ft	32.8 ft
	5.1 m	8.4 m	8.4 m	8.4 m	8.4 m	10.0 m
Internal Diameter	15.1 ft	24.6 ft	24.6 ft	24.6 ft	24.6 ft	29.9 ft
	4.6 m	7.5 m	7.5 m	7.5 m	7.5 m	9.1 m
Available Volume	6,274 ft^3	10,100 ft^3	11,260 ft^3	21,930 ft^3	34,910 ft^3	46,610 ft^3
	177.6 m^3	286.0 m^3	319 m^3	621 m^3	988 m^3	1,320 m^3
Potential Availability *(No Earlier Than)*	COTS	2022	2023	2023	2024	2028

COTS: Commercial Off-the-Shelf CPL: Co-manifested Payload PPL: Primary Payload PLF: Payload Fairing

Figure 5. SLS offers unmatched volume for payloads

For possible secondary payloads in the Block 1B crew configuration, rideshare opportunities for up to 21 smallsats 6U, 12U and larger may be offered on the USA payload adapter. The SLS Program is also evaluating user demand for payload accommodations in a propulsive EELV Secondary Payload Adapter (ESPA) ring configuration.

The Block 1B cargo configuration can accommodate payloads using an 8.4 m diameter fairing in varying lengths (see Figure 5). The greater payload volume and mass that SLS provides can decrease the need for miniaturization and simplify the spacecraft design, as well as reduce risk.

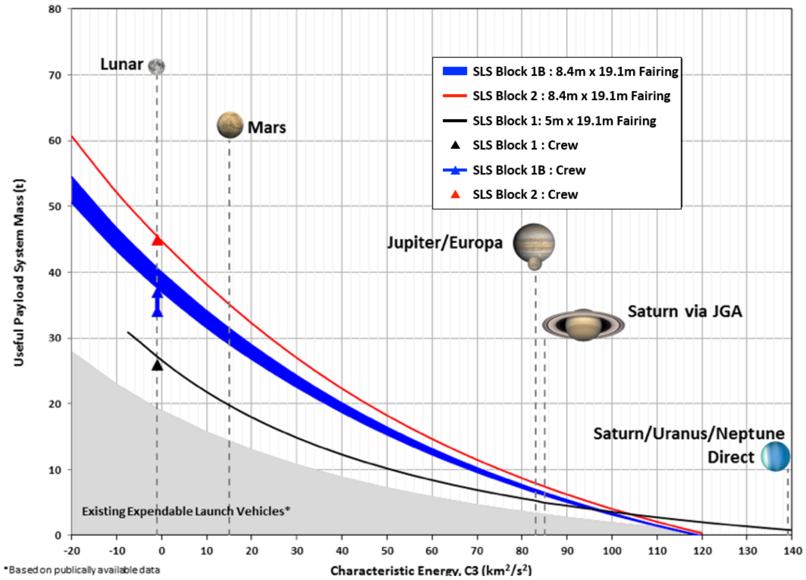


Figure 6. SLS vehicles can deliver a range of useful payload mass, shown here as a C3 curve

Missions to the Outer Planets

SM-1, the Europa Clipper mission scheduled to launch on the Block 1 cargo vehicle, provides an example for the benefits of the superior SLS departure energy to shorten cruise time, permitting faster data return. For SM-1, SLS will propel the probe directly to Jovian space, eliminating the seven-plus-year Venus-Earth-Earth gravitational assist trajectory a commercial vehicle would require to send the spacecraft to Europa. With the Block 1 SLS vehicle, transit to Europa will be less than three years. In addition to faster data return, a shorter outbound cruise time means simplified mission design and reduced operational costs. A follow-on Europa lander mission could also benefit from the superior performance of SLS, not for decreased transit time, but for increased mass, using a gravitational-assist trajectory to deliver a larger, more capable scientific payload with a launch mass of 16 t. The earlier data return of the Clipper mission launched on SLS will also better inform the lander study, potentially paving the way for historic discoveries.

Looking farther into the solar system, mission planners could utilize the unique capabilities of SLS to send a small probe to the giant ice worlds of Uranus and Neptune to investigate the atmospheric and magnetic properties and conduct flybys of larger moons. SLS can send spacecraft on direct trajectories to these systems also, opening new horizons for exploration with faster data return for investigators.

Astrophysics Missions

In the field of astrophysics, the unmatched payload volume in SLS fairings, whether an 8.4 m or potentially larger fairing, facilitates launch of large-aperture telescopes that could reveal the universe's earliest formative events or potential life on exoplanets. SLS could be used to deploy telescopes potentially as large as 16 m to make ultra-high-contrast spectroscopic observations of exoplanets or image the first galaxies. Such a capability would address a need identified in the 2013 NASA astrophysics roadmap, "Enduring Quests, Daring Visions." A space telescope larger than the James Webb Space Telescope could be engineered to utilize the largest fairing under study – a 10 m-diameter, 27.4-m long fairing. Such a telescope could be stationed at a Sun-Earth Libration Point to allow scientists to explore the universe, characterize supermassive black holes, investigate the history of hundreds of galaxies and uncover the secrets of

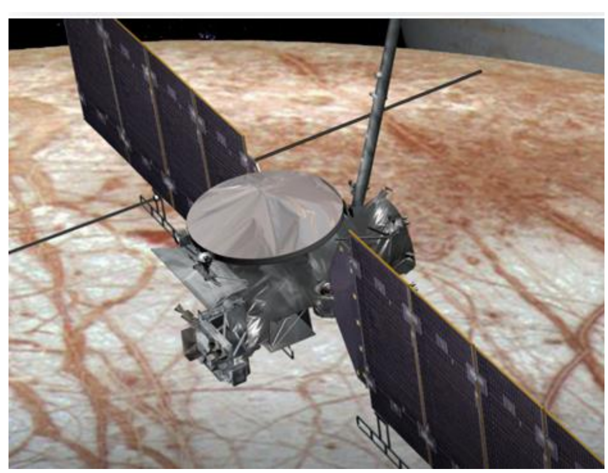


Figure 7. SLS can send the "Europa Clipper" probe to the icy Jovian moon using a direct trajectory

dark matter. The SLS Program has an *SLS Mission Planner's Guide* available in a downloadable PDF format, to provide basic technical details on the SLS system[3].

SLS PROGRAM STATUS

In the last year, the SLS Program and its contractors and suppliers have made significant progress manufacturing the Block 1 crew vehicle for EM-1. Completed elements of the vehicle include:

- Two complete solid rocket motor sets
- Four RS-25 engines with upgraded engine controllers
- ICPS upper stage
- OSA
- Core stage forward skirt

Forward work includes continued outfitting of the EM-1 core stage with internal subsystems and finishing the booster forward and aft assemblies, the Launch Vehicle Stage Adapter (LVSA) and flight software. Avionics and structural testing of full-scale hardware is well underway.

Solid Rocket Boosters

Supplying more than 75 percent of liftoff thrust (about 32,000 kilonewtons [kN]), the SLS solid rocket boosters are the largest ever built for flight. The boosters leverage the designs and manufacturing processes established for the Space Shuttle Program, but incorporate key upgrades to meet SLS performance requirements. The shuttle-era solid-fuel motor design used four segments; the SLS booster incorporates a fifth segment for 20 percent more power. Insulation between the case and the propellant is new and asbestos-free for safer handling on the ground. Propellant grain geometry has a new design and the avionics system is new.

Figure 8. Five full-scale solid rocket motors have been test-fired to support flight certification

The Program has conducted five full-scale static test firings on the path to qualification for flight. At prime contractor Northrop Grumman facilities in Utah, all 10 EM-1 motor segments are complete; they will ship to KSC via rail at a later date. At KSC, installation of the thrust vector control (TVC) system in the aft skirts is also complete. Work continues on the forward assemblies, with recent application of the thermal protection system. Avionics testing continues at MSFC and contractor sites.

Figure 9. The 10 segments that will comprise the EM-1 motors are complete

With the EM-1 solid motors close to completion, work is progressing on the motors for the second mission. Seven motor segments have been cast for the second flight and several nozzle structures have been fabricated. Looking farther ahead, NASA and Northrop Grumman are conducting trade studies to determine future design improvements that will provide additional vehicle performance.

RS-25 Engines

In addition to two solid rocket boosters, SLS uses four Aerojet Rocketdyne RS-25 main engines, integrated into the core stage, to reach escape velocity. Leveraged from the Space Shuttle Program, each engine supplies 512,000 pounds of vacuum thrust at 109 percent rated power versus the shuttle engines' standard thrust of 104.5 percent. The RS-25s will operate for the entire eight-minute trip to orbit. SLS benefits from an extensive engine database of more than one million seconds of flight and ground test time, including 135 shuttle missions. For EM-1, the engines have been upgraded with new controllers, which have been hot-fire tested on development engines at Stennis Space Center (SSC). The engines are ready for integration with the core stage. They will ship from SSC to Michoud Assembly Facility near New Orleans, Louisiana, USA, where technicians will integrate them into the engine section of the integrated core stage. From there, the core stage will ship to SSC for a full-duration test firing known as "Green Run" prefaced by a series of modal structural tests. After the Green Run test series, the stage will ship to KSC for build-up with the solid rocket boosters, upper stage, adapters and Orion.

Figure 10. The four RS-25 engines for EM-1 are ready for integration with the core stage

Looking beyond EM-1, engine controllers for the second flight have been manufactured and are currently being hot-fire tested at SSC. The SLS Program has enough engines in inventory for four flights and has contracted with Aerojet Rocketdyne to restart production of the RS-25 for future flights. The production restart engines incorporate numerous technological and manufacturing improvements aimed at reducing production costs by 30 percent. In fact, "smart-manufactured" components, such as a 3D-printed pogo accumulator, have already been incorporated onto development engines and are being hot-fire tested along with the new controllers.

Figure 11. The EM-1 liquid hydrogen (LH2) tank under construction at Michoud Assembly Facility

Core Stage

The 64.6 m-tall, 8.4 m-diameter core stage is the SLS Program's all-new development, being manufactured by prime contractor Boeing at Michoud, where the space shuttle external tanks and the first stages of the Saturn 1, 1B and V vehicles were built. The core stage comprises five major assemblies: the engine section, the LH2 tank, intertank, the LOX tank and the forward skirt. The forward skirt is complete. All of the other major components are constructed and in various stages of subsystem installation. At the time of writing, work was scheduled to commence on the first of three major joins required to assemble the final stage. Working vertically, technicians will complete the forward join by mating the LOX tank to the intertank and then the forward skirt to the LOX-intertank assembly. Following completion of the forward join, the aft join, also executed vertically, will consist of mating the LH2 tank to the engine section (with engines previously integrated) and boat tail fairing. Once each of those major joins are complete, the two sections will be bolted horizontally to complete the first core stage.

Integrated Spacecraft/Payload Element

Above the core stage, the Integrated Spacecraft/Payload Element (ISPE) comprises the LVSA, ICPS and OSA on the Block 1 crew vehicle. The LVSA partially covers the ICPS and adapts the diameter of the vehicle between the 8.4 m core and the 5 m ICPS. The adapter was built at Marshall Space Flight Center's (MSFC's) Advanced Weld Facility using a combination of robotic and vertical weld tools. The LVSA is currently nearing completion, with thermal protection applied and technicians working on installation of cameras, cable routing and an environmental control system. Forward work on the LVSA includes installation of the pneumatic actuation system and mating with the frangible joint assembly.

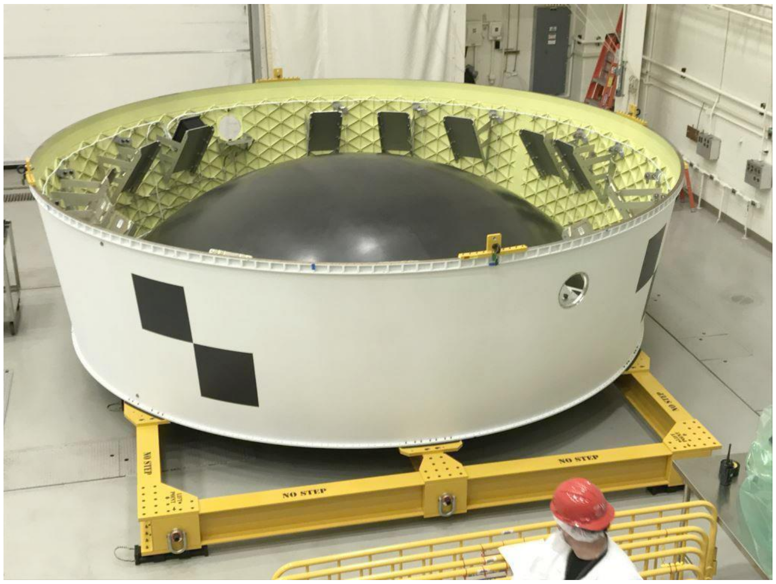


Figure 12. The Orion Stage Adapter (OSA), prior to shipping to Kennedy Space Center (KSC), showing the mounting brackets for the secondary payload dispensers and avionics unit

The ICPS upper stage engine, a single-engine LH2-LOX system based on the United Launch Alliance (ULA) DCSS, was completed and delivered to the EGS Program in 2017. Procurement is in progress for additional ICPS elements for the EM-2 and SM-1 flights.

The other adapter, the OSA, connects SLS to Orion's spacecraft adapter and provides the accommodations for the 13 EM-1 CubeSats and the Secondary Payload Deployment System (SPDS) that the SLS Program supplies. Also complete and delivered to EGS, the OSA includes mounting brackets, cable harnesses and the avionics unit that's part of the SPDS. A diaphragm protects Orion from gases generated during launch. With the EM-1 OSA complete, managers are working on long-lead procurement items for the second OSA build. In addition, for the first Block 1B vehicle, MSFC has conducted development work on the payload adapter, and a contract has been awarded to Dynetics, Inc., of Huntsville, Alabama, USA, for production of the USA.

CONCLUSION

With 18 years of experience living and working full-time in LEO aboard the ISS, NASA, with the help of its international partners, is focused on advancing technologies to sustainably live and work in cislunar space. Providing NASA with an unparalleled capability to launch more mass and volume with greater departure energy, SLS will enable a new era of human deep space exploration. Three Block 1 SLS missions, launching from new facilities at KSC, will see NASA rigorously test out its new deep space exploration system in the first flight before putting astronauts back in lunar orbit on the second exploration mission. The third Block 1 flight will launch the Europa Clipper probe directly to Jovian space where amazing discoveries await scientists who will review their data years earlier than possible if launched on a commercial vehicle. Following the Block 1 flight, Block 1B, available in crew and cargo configurations, will send astronauts in the Orion spacecraft to NASA's lunar Gateway outpost, along with co-manifested and possibly secondary payloads. The ultimate Block 2 variant will be needed for exploration of Mars. Deep space exploration is an endeavor that will require not only engineering and technology development; it will require cooperation among the world's space agencies, commercial companies, academia and more. NASA envisions its role as a systems integrator, defining an open architecture that meets objectives and streamlines international cooperation. Working together, discovery awaits.

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