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Payload Utilization in NASA's Space Launch System

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Abstract

With Space Policy Directive 1, the United States administration has directed the National Aeronautics and Space Administration's (NASA's) Human Exploration & Operations Mission Directorate (HEOMD) to return to the Moon with missions and infrastructure designed to support a sustained presence in cislunar space, with robotic and human lunar surface operations. NASA's new deep space exploration system — the super heavy-lift Space Launch System (SLS), the Orion crew spacecraft and revamped launch facilities at Kennedy Space Center (KSC) — will enable NASA and its commercial and international partners to meet this goal for human exploration of deep space. SLS is the most capable launch vehicle for these efforts, as well as for sending robotic missions deep into the solar system, or even to interstellar space. The vehicle will be available in crew and cargo configurations in progressively more powerful block variants. The initial Block 1 lift capability of at least 26 metric tons (t) to trans-lunar injection (TLI) will be followed by a more powerful Block 1B with the power to loft more than 37 t to TLI. The ultimate Block 2 variant will lift more than 45 t to TLI. For payload accommodation, the Block 1 vehicle can utilize a 5 meter (m) fairing in its cargo configuration with the crew version also able to provide berths for 6U and 12U CubeSats as secondary payloads. The Block 1B crew vehicle will provide as much volume as the space shuttle payload bay in a Universal Stage Adapter (USA) for co-manifested payloads (CPLs). Block 1B cargo vehicles will offer 8.4 m-diameter fairings in 19.1 m and possibly longer lengths, with enough volume to accommodate lunar-orbiting habitat modules and other elements of NASA's Gateway science outpost. For Mars-class payloads, larger fairings for the Block 2 cargo launcher are under consideration. For missions beyond the Earth-Moon system, SLS offers greater characteristic energy (C3) than any other launch vehicle, enabling shorter transit times or heavier payloads with more robust science packages for missions to the outer solar system. Indeed, the unmatched combination of thrust, payload volume and departure energy that SLS provides opens new opportunities for human and robotic exploration of deep space. This paper will provide an overview of the various vehicle block configurations, their capabilities and payload accommodations for sending primary, co-manifested and secondary payloads to deep space.

Keywords: NASA, Space Launch System, launch vehicles, payloads, lunar orbit, CubeSats

Acronyms/Abbreviations

National Aeronautics and Space Administration (NASA), Space Launch System (SLS), Exploration Mission-1 (EM-1), Exploration Missoin-2 (EM-2), low-Earth orbit (LEO), trans-lunar injection (TLI), metric tons (t), Human Exploration & Operations Mission Directorate (HEOMD), Exploration Ground Systems (EGS), evolved expendable launch vehicles (EELVs), EELV Secondary Payload Adapter (ESPA), distant retrograde orbit (DRO), characteristic energy (C3), Vertical Assembly Center (VAC), Interim Cryogenic Propulsion Stage (ICPS), Marshall Space Flight Center (MSFC), Stennis Space Center (SSC), Kennedy Space Center (KSC), Orion Stage Adapter (OSA), Launch Vehicle Stage Adapter (LVSA), commercial off-the-shelf (COTS), United Launch Alliance (ULA), Delta Cryogenic Second Stage (DCSS), liquid hydrogen (LH2), liquid oxygen (LOX), Vehicle Assembly Building (VAB), Launch Abort System (LAS), Launch Complex 39B (LC39B), astronomical units (AU), payload fairing (PLF), co-manifested payload (CPL), payload attach fitting (PAF), payload separation system (PSS), payload interface adapter (PIA).

1. Introduction

The first mission of the National Aeronautics and Space Administration's (NASA's) new super heavy-lift launch vehicle, the Space Launch System (SLS), and the Orion spacecraft, launching from upgraded and refurbished facilities at Kennedy Space Center (KSC), will send the Orion crew vehicle into lunar distant retrograde orbit (DRO) on a flight test known as Exploration Mission-1 (EM-1). This mission, scheduled to last about 25 days, will enable NASA to verify and

Figure 1. NASA's Block 1 Space Launch System (SLS) and Orion spacecraft

validate new systems before sending astronauts to deep space on Exploration Mission-2 (EM-2). With these exploration missions, NASA will mark the return of its human exploration programs to cislunar space for the first time since the Apollo 17 mission in 1972.

NASA plans to use the SLS Block 1 crew vehicle for the first two exploration missions. The SLS Program, managed at Marshall Space Flight Center (MSFC) in Huntsville, Alabama, U.S.A., and its prime contractors, have made substantial progress toward first launch, with several major components of the vehicle complete and delivered to the Exploration Ground Systems (EGS) Program at KSC, which has responsibility for stacking and launching the system.

With a planned path forward of progressively more powerful vehicles available in both crew and cargo configurations, SLS will provide the lift capability, payload capacity and departure energy to make the world's most demanding missions a success. In fact, SLS offers power, volume and characteristic energy (C3) that haven't been seen since the Saturn vehicles, opening options for transformative human exploration and science missions.

2. Cornerstone of NASA's Deep Space Exploration System

SLS is not one launcher. Rather, it's a system of launch vehicles suitable for a variety of super heavy-lift missions to a variety of destinations beyond low-Earth orbit (LEO). The major variants, Block 1, Block 1B and Block 2, provide incrementally improved lift capabilities; each block variant will be available in crew and cargo configurations. Cargo configurations will utilize payload fairings (PLFs) in a variety of sizes, from industry-standard 5-meter (m) diameter to 8.4-m diameter, with larger diameter fairings under evaluation.

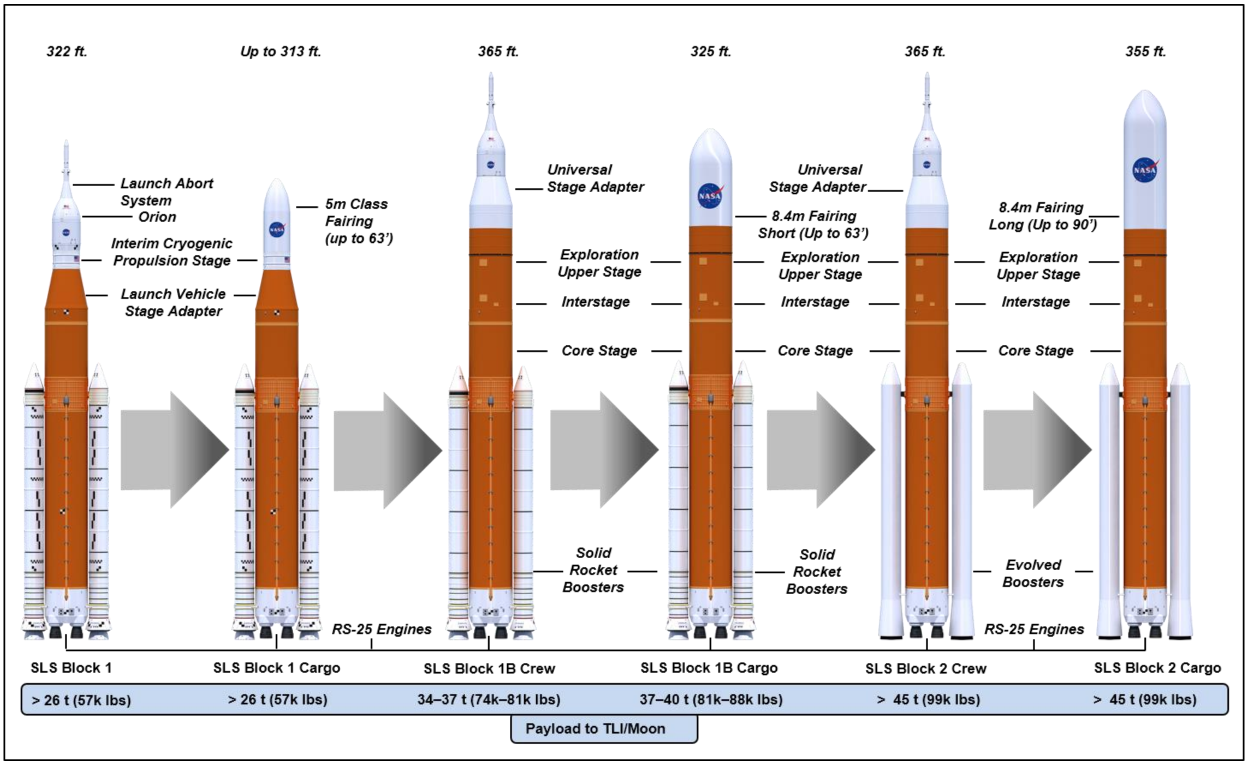


Figure 2. The evolutionary block upgrade path for SLS

For all vehicles in the series, primary propulsion will be supplied by two boosters and four liquid hydrogen/liquid oxygen (LH2/LOX)-fueled RS-25 engines. For the first two variants, Block 1 and Block 1B, the boosters and engines are derived from the Space Shuttle Program but upgraded to meet more stringent SLS performance requirements and more extreme operating environments. An all-new core stage will house the propellant tanks, the four RS-25 engines, the flight computers and provide the attach points for the boosters. Towering 64.6 m, the SLS core stage is the largest rocket stage ever constructed in terms of volume and length and required the world's largest spacecraft welding tool, the Vertical Assembly Center (VAC), for joining the sections. The VAC was installed at NASA's historic Michoud Assembly Facility near New Orleans, Louisiana, U.S.A., and the friction-stir welding tool has produced a series of test and flight hardware for the first two missions. The upper stage and payload sections of the vehicles, in addition to required adapters, will vary according to block configuration and will be discussed below. To meet its ultimate lift capability of at least 45 t to TLI, Block 2 will feature upgraded boosters for maximum performance.

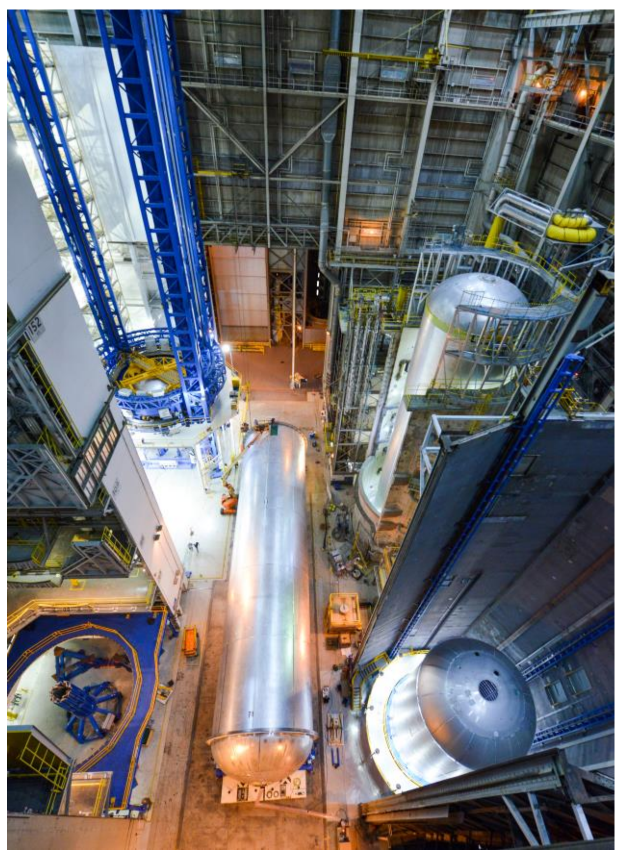


Figure 3. SLS propellant tanks manufactured at Michoud Assembly Facility

3. Initial Capability: SLS Block 1

The first vehicle to fly will be the Block 1 crew variant, which will send an uncrewed Orion to a lunar

Distant Retrograde Orbit (DRO) for the first mission, EM-1. The EM-1 vehicle is nearing completion. The four RS-25 engines have been hot-fire tested at Stennis Space Center (SSC) and upgraded with state-of-the-art computerized controllers. The EM-1 engines stand ready for integration with the core stage. The five-segment solid rocket motors, of a similar design to shuttle-era solid motors but 20 percent more powerful with an additional propellant segment and different grain geometry, as well as new case insulation and avionics, are also complete for the first flight. Technicians are completing refurbishment on the forward and aft booster assemblies; avionics testing is underway. One section of the core stage, the forward skirt, is complete and the other parts of the stage are undergoing final installation of internal subsystems. Then, the major sections of the stage will be joined at Michoud to create the EM-1 vehicle's core stage. Forward work on the EM-1 vehicle, in addition to joining the sections of the core stage, includes integrating the four RS-25 engines into the stage and shipping the stage to SSC for a "green run" hot-fire test.

Above the core stage, a single-engine LH2/LOX-based Interim Cryogenic Propulsion Stage (ICPS) will provide the burn to send Orion to TLI during EM-1. Essentially an off-the-shelf United Launch Alliance (ULA) Delta Cryogenic Second Stage (DCSS), the ICPS required a few modifications for EM-1: lengthening the LH2 tank, adding hydrazine bottles for attitude control and a few minor avionics changes. The Program delivered the ICPS to EGS well ahead of schedule and it stands ready for integration with the rest of the vehicle.

Two adapters connect the ICPS to the core stage below it and Orion's spacecraft adapter above it. Technicians are putting the finishing touches on the Launch Vehicle Stage Adapter (LVSA) at MSFC; the Orion Stage Adapter (OSA) is complete and has been delivered to KSC. For the EM-1 test flight, the OSA provides payload berths for 13 6U smallsats and one avionics unit. These secondary payloads will be released into deep space following separation of Orion from the ICPS along its disposal trajectory. The SLS Program provided a secondary payload deployment system consisting of mounting brackets for commercial off-the-shelf (COTS) dispensers, cable harnesses and the avionics unit. For future missions, the system is capable of supporting up to 17 CubeSats in a combination of 6U and 12U configurations.

The Block 1 cargo configuration will use an ICPS upper stage and an industry-standard 5 m-diameter fairing. This configuration is under consideration for a

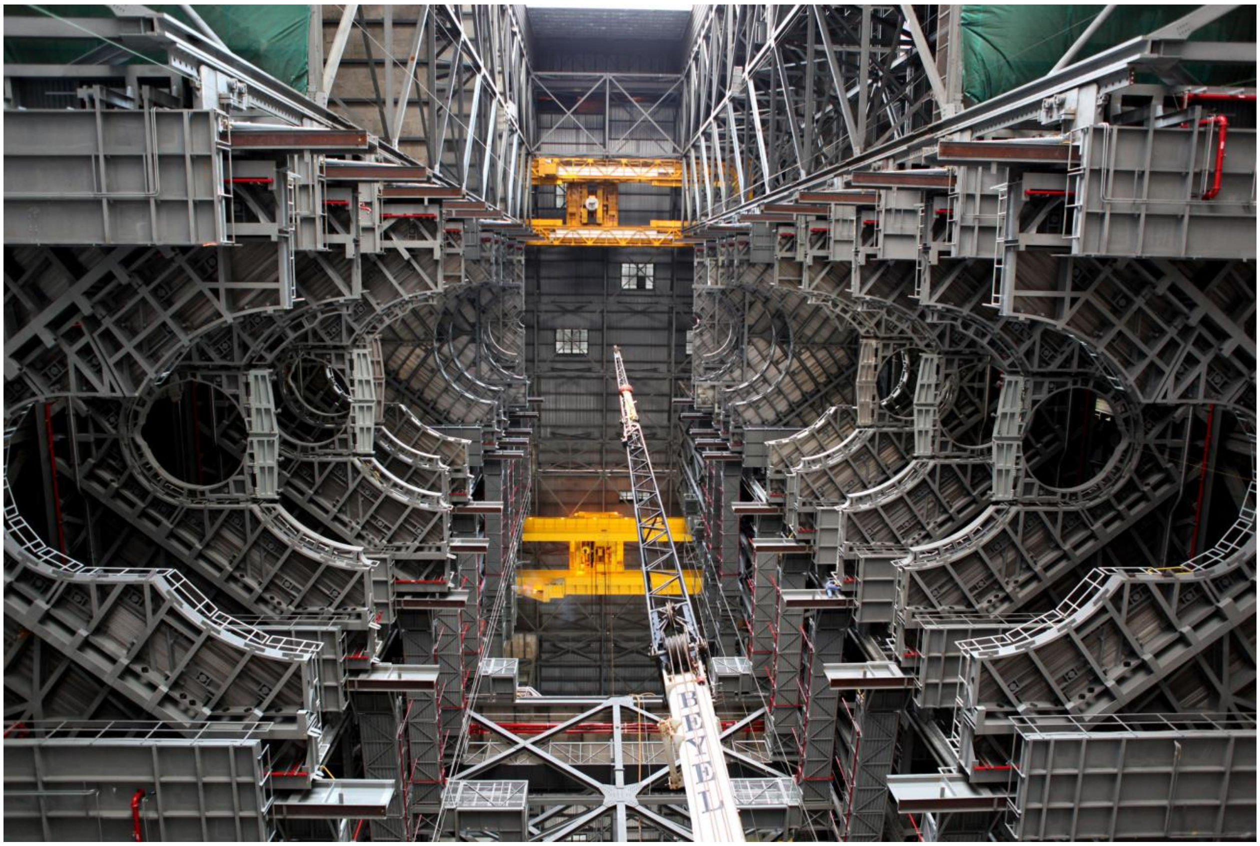


Figure 2. New work platforms have been installed in Kennedy Space Center's Vehicle Assembly Building for stacking the SLS vehicles

launch sending the "Europa Clipper" probe on a direct trajectory to the icy Jovian moon. At the time of writing, procurement was underway 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 processes for Europa Clipper mission planners and engineers.

All Block 1 vehicles will be stacked in KSC's historic Vehicle Assembly Building (VAB), where the EGS Program has removed the platforms used to stack space shuttles and replaced them with 10 new platforms. The new work platforms soar 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 (LC39B) at KSC on Mobile Launcher (ML) 1, which has also been refurbished for SLS and Orion. In fact, the EGS Program recently completed installation of all umbilicals on the ML for EM-1.

4. Interim Capability: SLS Block 1B

SLS Block 1B will use the same core stage design, with only minor modifications, as the Block 1 vehicles. To improve performance, the solid rocket boosters and four RS-25 engines will incorporate new technologies, with the four RS-25 engines expected to perform at 111 percent of shuttle-era maximum power levels. The primary means of increasing mass to TLI will be through a new upper stage, termed the Exploration Upper Stage (EUS). This four-engine LH2/LOX stage will team with the newly manufactured RS-25s and upgraded boosters to allow SLS to deliver between 34 to 37 t of payload to cislunar space, depending on crew or cargo configuration. The EUS will provide both ascent/circularization and in-space transportation for payloads. The Block 1B capability is scheduled to come into service beginning with the fourth SLS flight and will launch from a second ML at KSC's LC39B.

The Block 1B crew vehicle can accommodate Orion and a co-manifested payload (CPL) in the Universal Stage Adapter (USA), which provides as much volume for payloads as industry-standard 5 m fairings. The Program anticipates lift capability of up to 10 t for CPLs, which will typically separate from the EUS between five and eight hours post-launch, after reaching a safe distance from the crew vehicle.

The USA can offer various sizes of access doors to facilitate a variety of payloads and an interior surface compatible with acoustic treatments to meet environmental requirements. Once on orbit, after Orion separates from the USA, the USA separates in a "canister" fashion (in contrast to typical fairing "sector" separations). The canister separation scheme results in

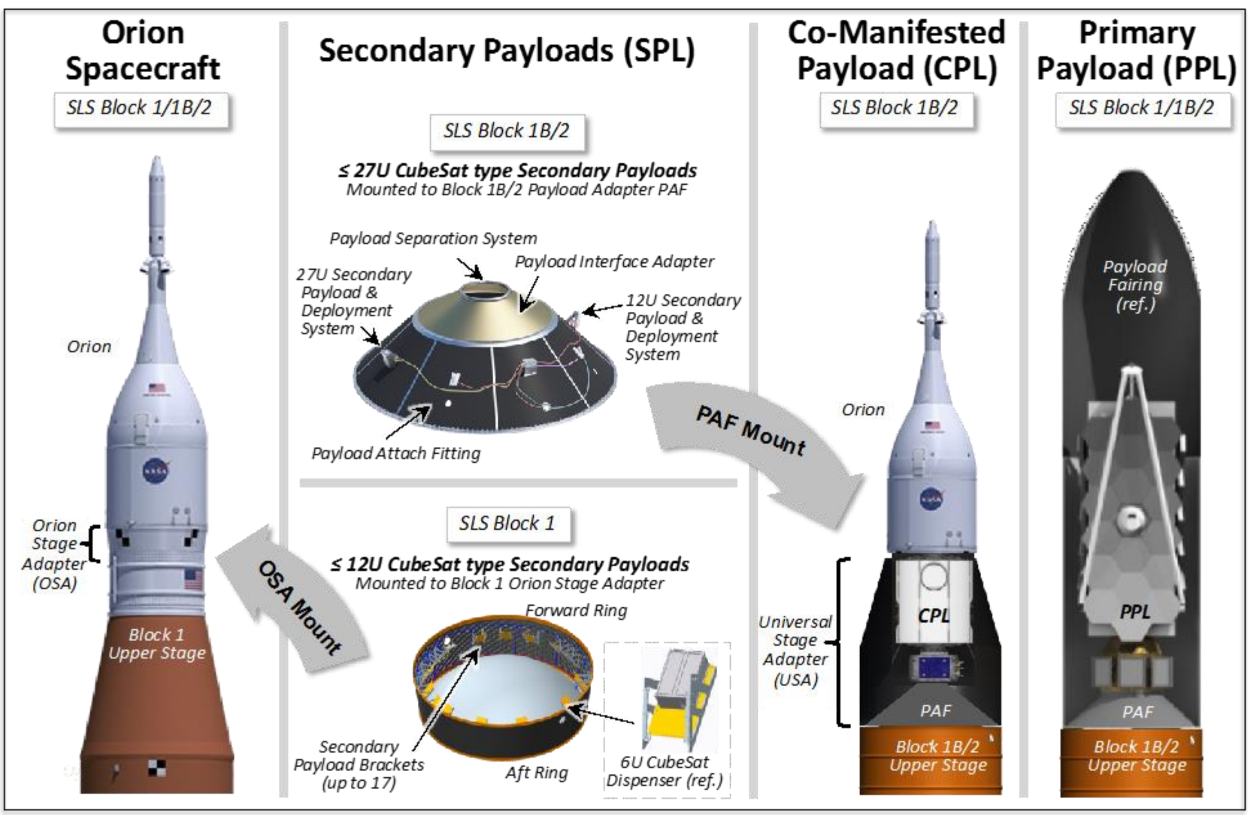


Figure 3. Notional payload accommodations for primary, co-manifested and secondary payloads in SLS Block 1B and Block 2 crew and cargo configurations

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; its height is less than the payload adapter separation plane in order to facilitate CPL extraction by Orion, or separation as an independent system.

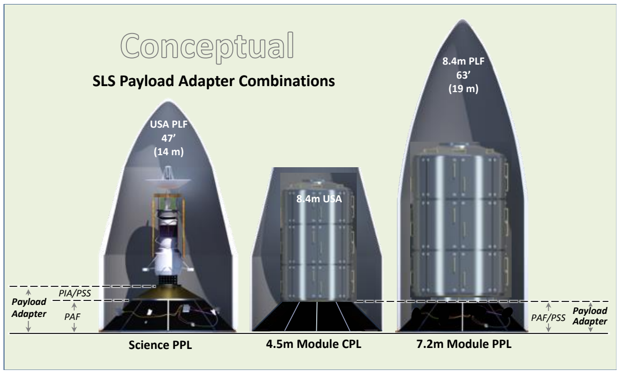


Figure 6. SLS Block 1B payload adapter components

Similar to evolved expendable launch vehicles (EELVs), the mechanical interface between the SLS Block 1B launch vehicle and a primary payload or CPL is a payload adapter consisting of up to three components as shown in Figure 6. Choice of a particular payload adapter is mission-dependent.

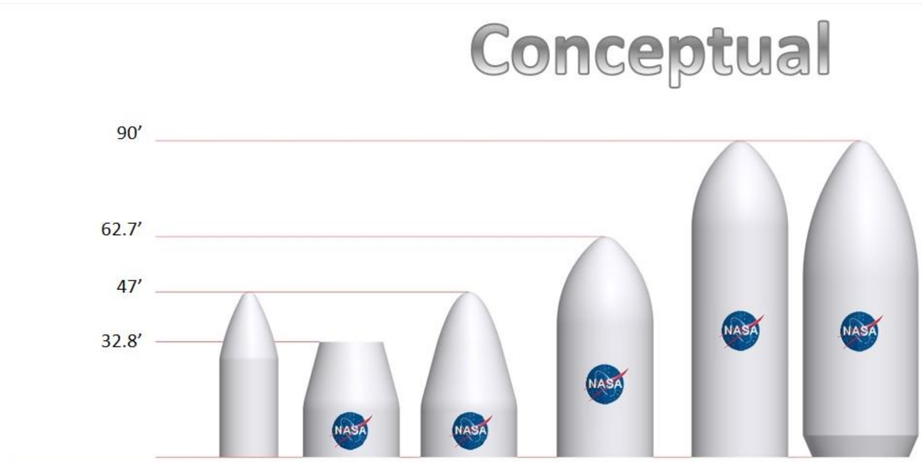
A payload attach fitting (PAF) is a structural/service interface to the 8.4 m-diameter SLS EUS forward adapter. The PAF can be configured with a payload interface adapter (PIA) and/or a payload separation system (PSS) to accommodate different spacecraft or payload interfaces. The PIA is an optional interface between the PAF and the spacecraft or payload that maximizes available volume. The PIA accommodates a PSS, which is a structural separation interface for a spacecraft or payload mounted on the PAF or PIA. Depending on the interface diameter required, it can support a variety of COTS separation systems (e.g., D1666 or 1666VS) or a new-development separation system.

For secondary payloads, rideshare opportunities for up to 21 smallsats up to 27U in size may be offered on the payload adapter in the USA. Depending on the requirements of PPLs or CPLs, it might also be possible to deploy larger "ring payloads," similar to those currently flown on an EELV Secondary Payload Adapter (ESPA).

The Block 1B cargo configuration can accommodate payloads using an 8.4 m diameter fairing in varying lengths. As with CPLs on the Block 1B crew configuration, the EUS forward adapter provides an interface for various payload fairings and payload adapters.

5. Ultimate Capability: SLS Block 2

The eventual Block 2 crew variant will use an advanced booster to maximize performance, enabling the vehicle to place at least 45 t in lunar orbit. This configuration will also take advantage of future developments in technology, while providing unique enabling capabilities for human Mars missions. Fairings larger than 8.4 m diameter in varying lengths are being evaluated. The Block 2 vehicle has the potential to carry



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 4. SLS accommodates a range of fairings

10 m fairings with a volume of up to 1,800 m^3, several times greater than any currently available fairing, making new missions possible and streamlining design of deep space spacecraft.

6. System Benefits and Outreach

SLS offers substantial benefits to spacecraft designers and mission planners in terms of greater mass, volume and departure energy than EELVs can provide. These primary benefits make possible a variety of secondary benefits too. For example, greater payload volume and mass can decrease the need for miniaturization and origami-like deployments, thus simplifying the spacecraft design cycle, as well as complexity and risk. Reducing transit time by enabling a direct trajectory without gravitational assists reduces mission risk and operational cost, and can eliminate the need to design for inner solar system conditions.

Program managers envision an eventual flight processing throughput capacity of two to three SLS flights per year, making flight opportunities available to NASA mission directorates, international partners, private industry, academia and other government agencies. SLS can accommodate primary payloads, CPLs and secondary payloads and is actively engaged with the science community to understand demand and provide information on the unique capabilities of the evolvable system. 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, including configurations: https://ntrs.nasa.gov/search.jsp?R=20170005323.

7. Mission Opportunities

While the primary purpose of SLS is to enable human exploration of the solar system with the Moon as a foundational proving ground, a myriad of mission types will benefit from the mass, volume and departure energy that SLS provides, including planetary science, astrophysics, heliophysics, planetary defense and commercial endeavors.

7.1 Lunar Missions

NASA's Human Exploration & Operations Mission Directorate (HEOMD) has outlined plans for a new lunar orbiting science outpost, the Gateway, to be constructed in the 2020s. The Gateway will serve as a proving ground for technology and science missions to both better understand the Earth-Moon system and inform future missions to Mars and deeper into the solar system. The superior lift and payload volume abilities of SLS Block 1B will enable the Agency to send Orion and a CPL, such as a habitat module or a reusable lunar lander for astronauts, to the Gateway in a single launch. Opportunities for international collaboration on Gateway components that will go to the outpost as CPLs will enhance international cooperation while commercial vehicles have a role to play providing logistics flights and delivery of other elements. For deploying more massive Gateway infrastructure, Block 1B cargo flights featuring the 8.4 m fairing in varying lengths will be available in the 2020s. The super heavy-lift capability of SLS may yield a significant mass margin that can be used to carry additional consumables or secondary payloads in 6U, 12U or larger sizes.

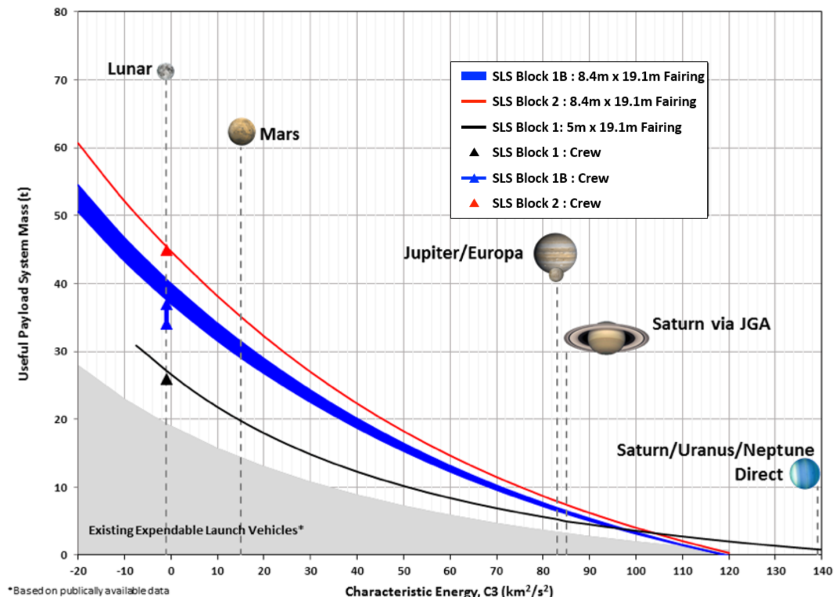


Figure 8. SLS vehicles can deliver a range of useful payload mass, shown here in the form of a C3 curve

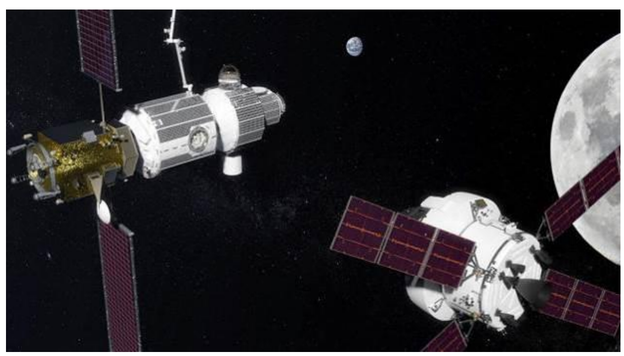


Figure 9. SLS can deliver the Orion crew vehicle and co-manifested payloads (CPLs) to NASA's lunar Gateway

7.2 Mars Missions

With the construction of the lunar Gateway and proving out deep space technologies as an intermediate step, Mars remains an Agency – and international – horizon goal. In addition to sending astronauts to the Moon to expand knowledge of working in deep space environments, SLS may be used to launch future missions to Mars using a fully evolved Block 2 SLS vehicle.

7.3 Missions to the Outer Planets

Science Mission-1 (SM-1), the Europa Clipper mission notionally launching on the Block 1 cargo vehicle, provides a case study for utilization of the superior SLS departure energy to shorten cruise time, enabling faster data return and simpler mission design. SLS can directly inject this flagship science mission into Jovian space, eliminating the seven-to-eight-year Venus-Earth-Earth gravitational assist trajectory a Delta IV Heavy would require to send the spacecraft to Jupiter's icy ocean moon. With the Block 1 SLS vehicle, transit to Europa will be less than three years, providing earlier science return and reduced operational costs. In addition, a shorter outbound cruise phase means the spacecraft needs less radiation shielding and saves mass, which can translate to a more robust science payload. If a follow-on Europa lander mission comes to fruition, that mission could use the performance of SLS, not for decreased transit time, but for increased mass, using a gravitational-assist trajectory to deliver a large payload with a launch mass of 16 t. In addition, the earlier science return of the Clipper mission will inform the lander study.

Looking farther into the solar system, scientists 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 satellites. SLS can send spacecraft on direct trajectories to these systems also, opening new horizons for exploration with faster data return for investigators.

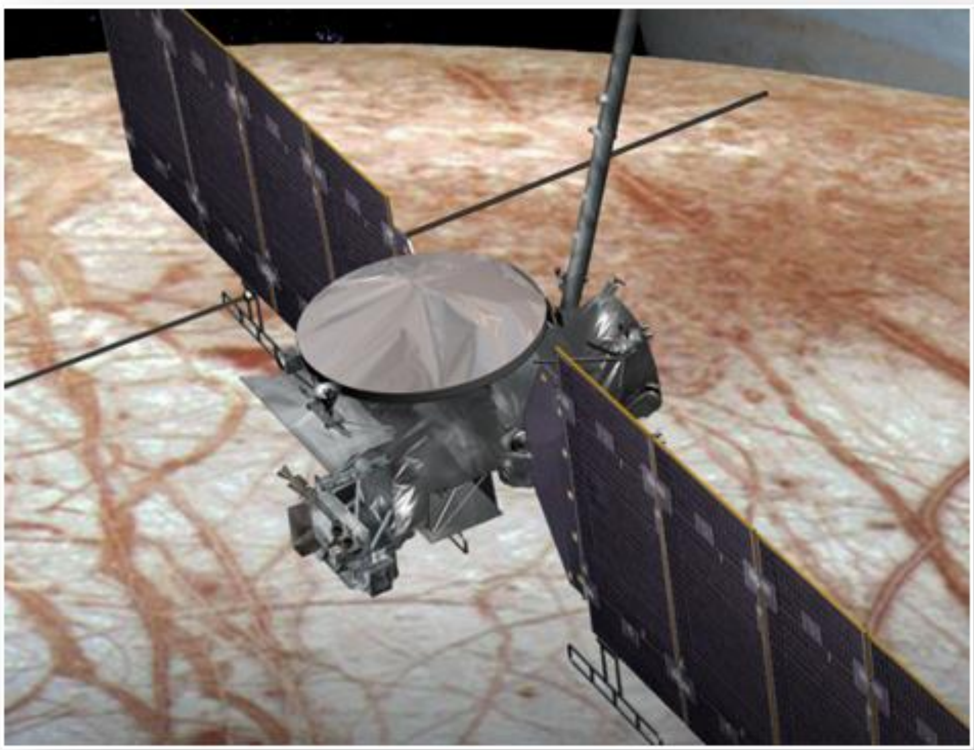


Figure 10. SLS can launch the "Europa Clipper" on a direct trajectory to Jovian space, without gravity assists

7.4 Astrophysics Missions

In the field of astrophysics, the unmatched payload volume in SLS fairings, whether 8.4 m or potentially larger fairing, facilitates launch of large-aperture telescopes that could put a view of cosmic dawn – or life on exoplanets – within our reach. The unmatched payload volume of 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 dark matter.

7.5 Interstellar Medium Missions

SLS could be used to send a small probe to interstellar space, in concert with a skillfully designed mission, to explore the interstellar medium. Maximizing the staging efficiency to reduce flight times could enable a project goal of achieving 1,000 AU in 50 years. Mission concepts include investigation of the interstellar medium and its influence on the solar system, and the characterization of interstellar gas, low-energy cosmic rays, dust and magnetic fields.

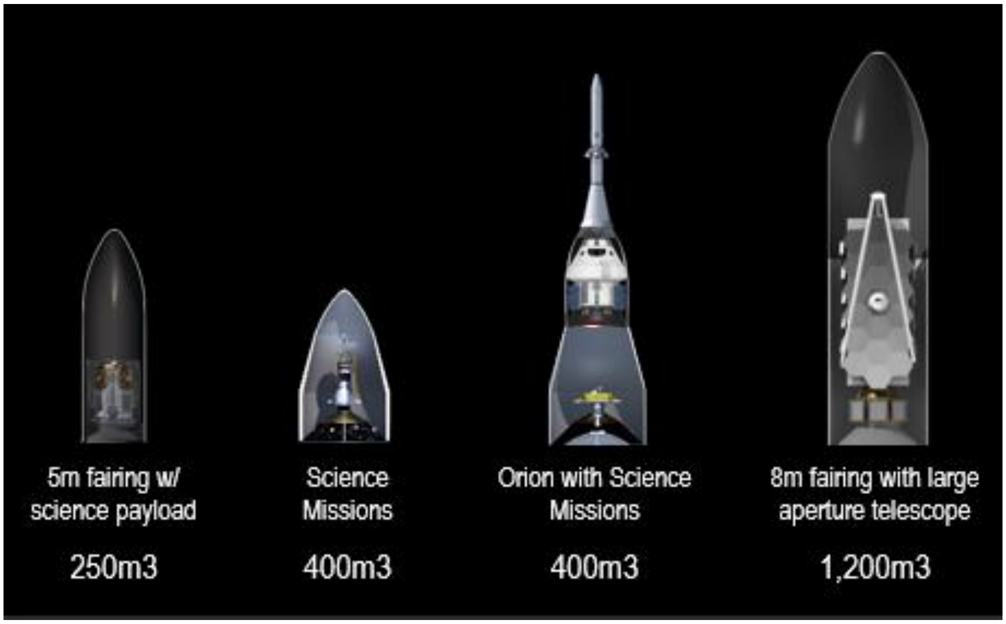


Figure 11. SLS provides unique benefits for a number science missions

Using the Sun as a gravitational focus in order to study features on distant exoplanets is another mission concept that SLS could enable. Einstein's Theory of General relativity predicts that light bends around a massive object – such as the Sun. However, the effect is tiny and only observable at significant distance from objects of enormous mass. Consequently, the focal point of a solar lens must be at least 550 AU distant, beyond Pluto's orbit and past the Kuiper Belt, which extends a mere 50 AU. SLS could be used to deploy a telescope at the focal line of the gravitational lens in order to study a distant exoplanet in unprecedented detail.

7. Conclusion

With the first Block 1 crew vehicle nearing completion and the EM-1 test flight of NASA's new deep space exploration system squarely within view, a new era of deep space exploration is dawning. With SLS, Orion and EGS, NASA will once again have the capability to send astronauts to the Moon and safely return them to Earth. This lunar exploration campaign of the 2020s, however, will be a sustained and cooperative effort among NASA and its partners to live, explore, investigate, demonstrate and innovate off-planet operations using the lunar Gateway. Technologies developed for lunar exploration will be tested with an eye toward Mars and the rest of the solar system.

With SLS, NASA has a vehicle with a clear evolutionary path to meet the nation's most demanding missions, whether that's sending astronauts in the capable Orion crew vehicle to the Gateway along with a CPL of significant size and volume, or whether it's launching a flagship science mission as a cargo-only flight deep into the solar system. The mass, volume and departure energy SLS provides presents spacecraft designers and mission planners with new and unique opportunities for astrophysics, planetary science, *in situ* exploration, sample return and other ambitious missions. Larger science packages and reduced cruise times put many once out-of-reach missions within reach, in our lifetimes.

The answers to the most profound questions about the cosmos may be within our reach.