

IAC-19,A5,4-D2.8,1,x51280

NASA's Space Launch System: Payload Opportunities for Lunar Exploration, Science Missions

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Abstract

Nearing its first launch, the Space Launch System (SLS), NASA's new super heavy-lift launch vehicle, offers highly energetic launches that deliver more mass and provide more volume in 8.4 m-diameter and potentially larger fairings to make a new generation of deep space missions possible. An evolvable launcher available in crew, crew with a co-manifested payload (CPL) and cargo-only configurations, SLS is a crucial capability to enable astronauts to return to the Moon, but it also offers key benefits for science missions. NASA's 21st-century return to the Moon recently received a formal name: the Artemis program. In addition to the core enabling capabilities of SLS and the Orion crew spacecraft, NASA will also enlist international and commercial partnerships for Artemis. The Agency intends to build a scientific outpost in lunar orbit, the Gateway, from which human and robotic missions to and from the surface can rendezvous. SLS will launch Orion on a series of missions leading to landing the first woman and the next man on the Moon as part of Artemis. SLS uses proven propulsion systems: two solid rocket boosters and four RS-25s engines that have been upgraded to provide more thrust and operate in the SLS environment. SLS Block 1 uses a modified Delta IV Heavy upper stage, called the Interim Cryogenic Propulsion Stage (ICPS) and lifts at least 26 metric tons (t) to trans-lunar injection (TLI). The Block 1 vehicle can also be outfitted with a 5 m-diameter fairing. Block 1B, the next major variant, also uses solid rocket boosters and RS-25 engines to achieve Earth escape velocity, but replaces the single-engine liquid hydrogen (LH2)/liquid oxygen (LOX) ICPS with a four-engine LH2/LOX Exploration Upper Stage (EUS) to increase mass to TLI to 34-37 t, depending on crew or cargo configuration. In the Block 1B crew configuration, a 10 m-tall Universal Stage Adapter (USA) connects the vehicle to Orion and can carry a CPL up to 10 t. The USA provides 286 m³ of unpressurized volume for payloads. For large payloads, 8.4 m- and 10 m-diameter cargo fairings in 19.1 m and 27.4 m lengths are possible. The ultimate SLS vehicle, Block 2, incorporates evolved boosters to reach a lift capacity of more than 45 t to TLI. The capabilities of SLS not only make new missions to the Moon possible, but also game-changing science missions, such as deployment of large-aperture space telescopes, spacecraft to the ice giants or even probes to the interstellar medium. This paper will discuss the capabilities of SLS, the vehicle's planned evolution, missions that can effectively utilize the vehicle and manufacturing status of the vehicle.

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

Acronyms/Abbreviations

NASA, Space Launch System (SLS), 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 (EELV) Secondary Payload Adapter (ESPA), distant retrograde orbit (DRO), Near-Rectilinear Halo Orbit (NRHO), characteristic energy (C3), 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), astronomical unit (AU), very local interstellar medium (VLIM), James Webb Space Telescope (JWST), Wide Field Infrared Survey Telescope (WFIRST), Large UV/Optical/IR Surveyor (LUVOIR), co-manifested payload (CPL), payload separation system (PSS), Secondary Payload Deployment System (SPDS), beyond-Earth orbit (BEO).

1. Introduction

After more than 30 years of experience living and working in low-Earth orbit (LEO) aboard the International Space Station (ISS), NASA and its international and industry partners are returning to the Moon, using it as a testbed before mounting more challenging expeditions to Mars. As part of the newly named Artemis (twin sister to Apollo) program, NASA's Space Launch System (SLS) is a critical enabling capability for returning astronauts to the Moon. After an uncrewed test flight and the first crewed lunar

flyby, elements of NASA's Gateway lunar outpost will be assembled in a Near-Rectilinear Halo Orbit (NRHO) [1]. From there, a new era of moonwalkers will begin: the Artemis generation.

SLS gives NASA the ability to launch more mass to the Moon and beyond than commercial vehicles, making possible many bold human and robotic missions. In addition to launching Orion to trans-lunar injection (TLI), SLS in its evolved variants can be fitted with large-diameter cargo shrouds, providing unmatched volume for payloads. With its proven propulsion system based on solid rocket boosters and



Figure 1. Artist's rendering of SLS Block 1B with an 8.4 m-diameter fairing on the launchpad

RS-25 engines from the Space Shuttle Program that have been modernized and upgraded for deep space missions, SLS provides highly energetic launches, to send more mass to destinations or reduce transit times. To give the vehicle additional power, engineers have planned block upgrades, such as a more powerful upper stage, incremental improvements to the boosters and increased thrust from the RS-25 engines (see Section 6).

A fairing measuring 8.4 m in diameter and 19.1 m in length will provide 621 m³ of available volume, and larger fairings are possible. For missions to the outer solar system and beyond, it is possible to add kickstage(s) above the SLS upper stage to achieve higher energy missions. In addition to providing NASA with a new capability for launching Orion and large exploration or science payloads, SLS can also carry CubeSats to deep space in unused volume in its stage adapters. SLS provides flexibility with more capability, and a wide array of missions can benefit from this unique asset.

2. Evolvable, flexible architecture

NASA has Mars in its sights. Crewed expeditions to Mars are a horizon goal, and the agency is working to establish sustainable infrastructure in cislunar space as a step toward that goal. The SLS evolutionary path begins with Block 1 and evolves to Block 1B, with Block 2 ultimately providing capabilities for sending crew and infrastructure to Mars. All variants – Blocks 1, 1B and 2

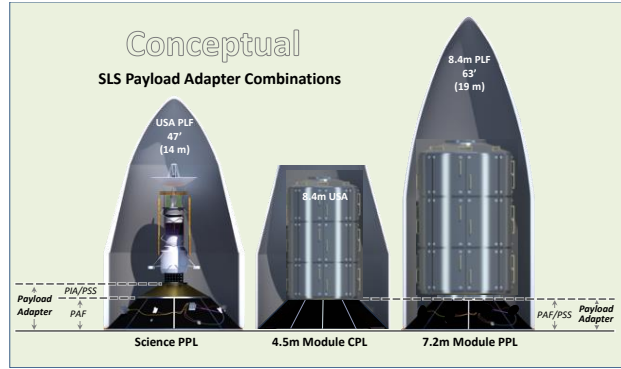


Figure 2. Sample payload configurations and payload adapters

– will be available in crew configuration to launch Orion, and cargo configuration, outfitted with fairings. In addition, Block 1B and Block 2 crew configurations have 286 m³ volume available for a co-manifested payload (CPL) in the Universal Stage Adapter (USA) -- equivalent to the volume of space shuttle’s payload bay (see Figure 7).

Blocks 1 and 1B use twin solid rocket boosters that provide more than 75 percent of thrust at liftoff and liquid hydrogen (LH2)/liquid oxygen (LOX)-fed RS-25 engines (formerly Space Shuttle Main Engines [SSMEs]). The solid-fuel boosters generate 7.2 million pounds of thrust while the RS-25s generate more than 2

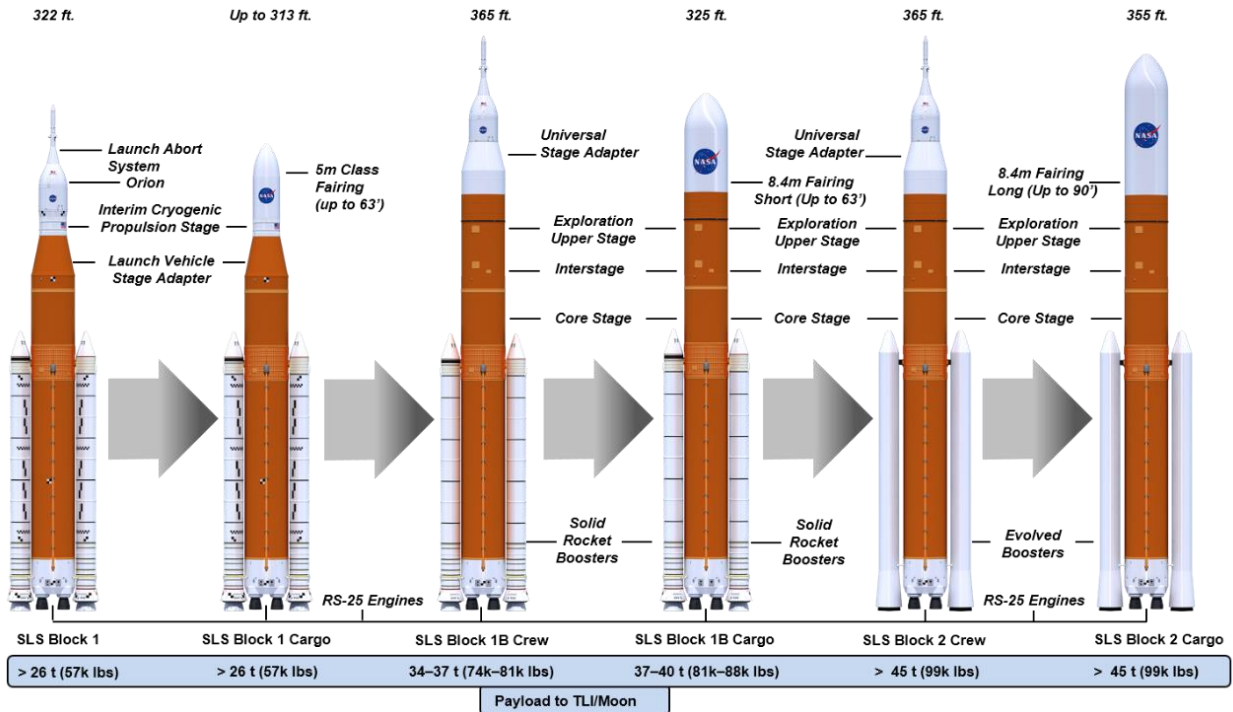


Figure 3. SLS will evolve to progressively more powerful variants and is available in crew and cargo configurations

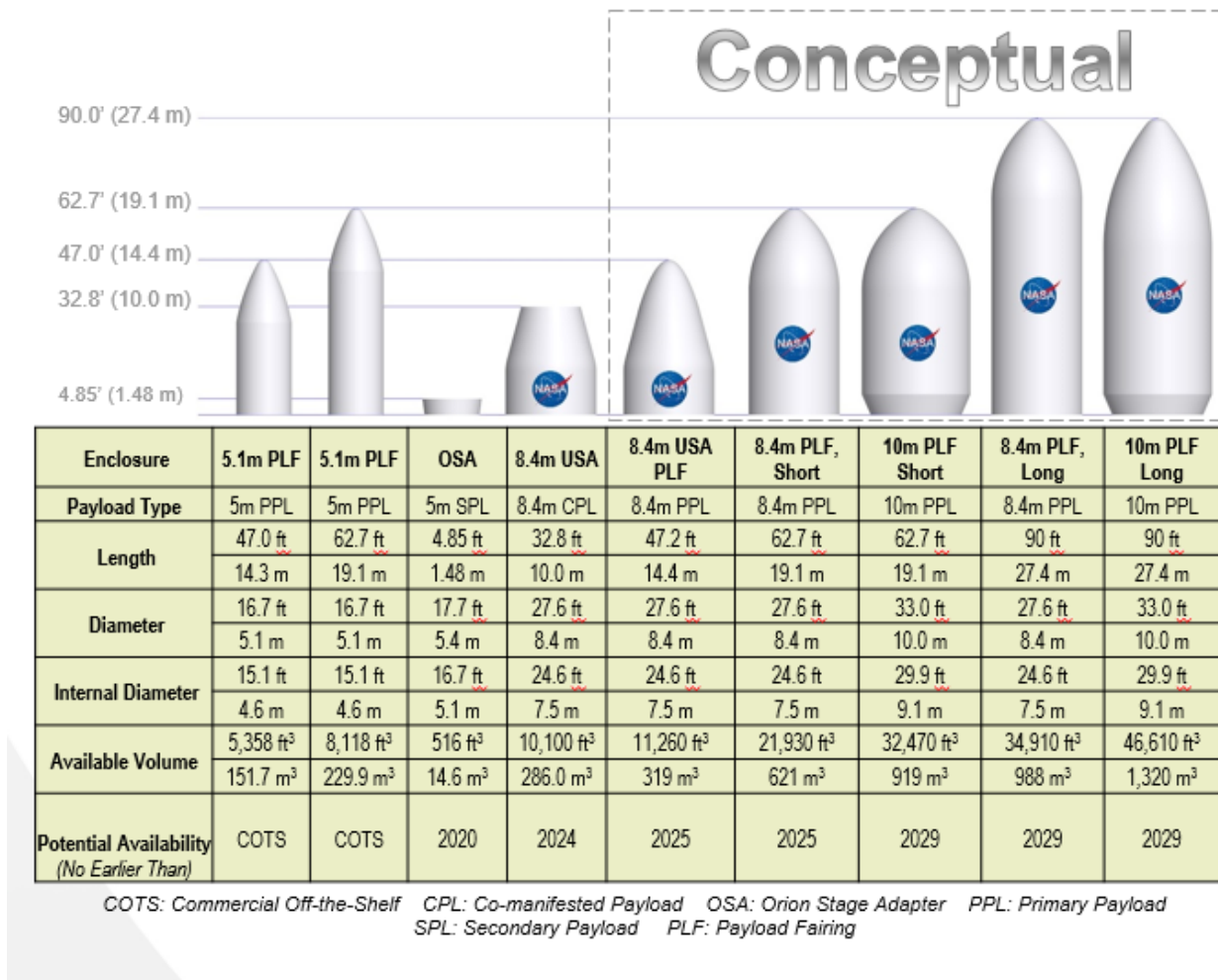


Figure 4. SLS accommodates a range of fairings to provide maximum volume for human and robotic missions

million pounds of thrust. The core stage, a new development, provides the backbone for the vehicle. The 212-foot SLS core stage is the tallest rocket stage ever to fly and comprises an engine section and boattail assembly where the four RS-25s are housed, the LH2 tank, an intertank structure, the LOX tank and a forward skirt, which contains flight computers.

For the Block 1 vehicle (both crew and cargo), the upper stage is a modified Delta Cryogenic Second Stage (DCSS), called the Interim Cryogenic Propulsion Stage (ICPS). The ICPS is a single-engine LH2/LOX system that generates 24,750 pounds of thrust. The Block 1 vehicle with the ICPS lifts at least 26 t to TLI. Block 1 can be outfitted with a 5 m-diameter, 14.3 m-tall fairing, providing 177.6 m³ of available volume for payloads.

For Block 1B and Block 2 (crew and cargo), the ICPS will be replaced by the four-engine LH2/LOX

Exploration Upper Stage (EUS), which will generate 96,000 pounds of thrust. Block 1B in the crew configuration will lift at least 34 t to TLI. The USA has volume for CPLs in the Block 1B and Block 2 crew configurations; up to 10 t is possible in the 286 m³ volume. For the cargo configuration, Block 1B can potentially accommodate 8.4 m-diameter fairings in 19.1 m and 27.4 m lengths.

The ultimate variant, Block 2, will use evolved boosters, the EUS and other incremental improvements to lift more than 45 t to TLI. The EUS will provide in-space propulsion. In addition to the 8.4 m fairings flown on Block 1B, for Block 2, fairings 10 m in diameter are also being studied. At 27.4 m long, a 10 m-diameter fairing will provide an unprecedented 1,320 m³ of volume for payloads.

Mission planners are also studying configurations with additional upper stages. Kickstage options are possible in the 8.4 m- and 10 m-diameter 27.4 m long fairings, which would enable several exciting science missions. These architectures are promising for enabling missions to the Kuiper Belt or the very local interstellar medium (VLIM) within reduced timelines and possibly with greater mass/more robust science packages (see Section 8).

3. SLS Block 1 capabilities

The initial capability to fly is SLS Block 1 (with ICPS) in the crew configuration, which will send Orion to TLI. For its first flight, Artemis I (formerly Exploration Mission-1), the Block 1 vehicle will send an uncrewed Orion to a Distant Retrograde Orbit (DRO) around the Moon for a thorough checkout. The mission is expected to last 25-45 days, with its primary objective being to test Orion's new heat shield design at lunar return velocity. In addition to objectives involved in testing SLS in its flight environment, the mission also includes deployment of 13 6U CubeSats into deep



Figure 5. Solid rocket boosters are complete for Artemis I; seven are complete for Artemis II mission

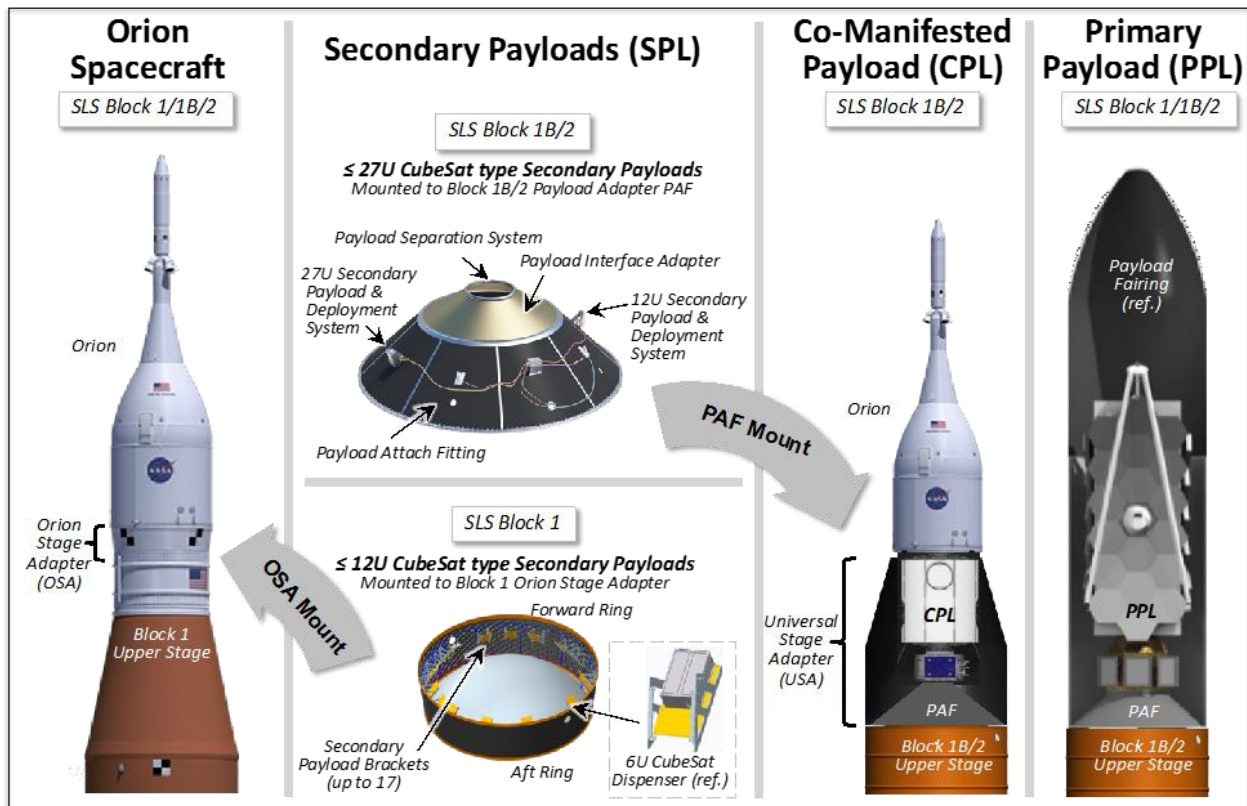
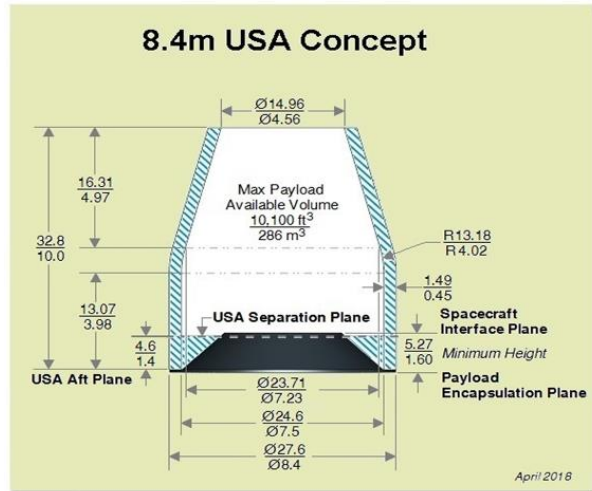


Figure 6. Payload accommodations in SLS block variants

space. Along with its primary mission, SLS can accommodate 6U or 12U CubeSats when mass and volume are available. On the first two Block 1 flights, CubeSats will be housed in the Orion Stage Adapter (OSA), which connects the core stage to Orion's spacecraft adapter. The SLS program supplies a Secondary Payload Deployment System (SPDS) in the OSA, which includes mounting brackets, cable harnesses, a vibration isolation/mitigation system and an avionics unit (AU) that controls deployment. CubeSats can begin deployment after the vehicle separates from Orion and the ICPS inserts itself into a heliocentric disposal trajectory. Ridesharing on SLS flights gives CubeSats rare access to deep space and the opportunity to incorporate and test propulsion systems. The Artemis I CubeSat manifest includes several missions to the Moon that may return data to inform future Artemis missions [2]. Currently, the program is also evaluating proposals for CubeSats in 6U and 12U form factors for a limited number of slots on the Artemis II flight [3]. Artemis II will be an approximately 10-day mission that will see the return of astronauts to cislunar space for the first time since Apollo on a hybrid free return trajectory. The Artemis II astronauts will travel farther from Earth than any humans have ever gone before.

4. Manufacturing status

The Block 1 crew vehicle designated for Artemis I is nearing completion, with all elements manufactured and several complete and delivered to Exploration Ground



- Available Payload Dynamic Envelope
 - Fairing Envelope (attenuation)
 - Minimum Payload Adapter (PLA) Envelope
- All dimensions in Feet
 • Height of the spacecraft separation/interface plane depends on spacecraft/PLA attach diameter and PLA cone angle
 • Spacecraft appendages projecting below spacecraft interface plane may be permitted; coordinate with SLS/SPIE

Figure 7. The Universal Stage Adapter (USA) on SLS Block 1B, crew configuration, offers as much volume for payloads as a 5 m fairing

Systems (EGS) at Kennedy Space Center (KSC), which has responsibility for integrating and launching the SLS/Orion stack. The five-segment solid rocket motors are 20 percent more powerful than the solid rocket



Figure 8. Technicians at Micoud Assembly Facility have joined the 212-foot SLS core stage for the Artemis I flight



Figure 9. All five components of the Artemis II core stage are manufactured, including the LH2 tank

boosters used on the space shuttle. The motors are complete for Artemis I at prime contractor Northrop Grumman's facilities in Utah; they will ship to KSC in 2020. At KSC, Northrop Grumman is completing refurbishment and upgrades on the forward and aft booster assemblies. Those elements are scheduled to be delivered to EGS in 2020.

The four RS-25 engines designated for Artemis I have been hot-fire tested at Stennis Space Center (SSC) and upgraded with state-of-the-art controllers. The engines are currently being integrated with the core stage at NASA's rocket factory, Michoud Assembly Facility, near New Orleans. The 212-foot SLS core stage is a new development and has presented several challenges in manufacturing. Prime contractor Boeing has now completed manufacturing the stage, which has five major components: an engine section and boat tail assembly that house the four RS-25s, the LH2 tank, an



Figure 10. Block 1B payload adapter manufacturing demonstration article

intertank structure, the LOX tank and the forward skirt, where the flight computers are located. The engine section proved the most challenging component to outfit for flight and was the final element to be completed. Boeing mated all five of the components in 2019, and the stage is scheduled to ship from Michoud to SSC in late 2019. At SSC, the stage, with the four RS-25s integrated, will undergo a series of qualification tests known as "Green Run." Green Run will feature a number of "firsts," including the first time the propellant tanks are filled, the first end-to-end flow test of propellants and other fluids through the complete stage, the first operational test of stage avionics, and the first time four RS-25 engines are fired simultaneously.

The Artemis I ICPS will provide the approximately 20-minute burn to send Orion to TLI. The stage is complete and awaiting integration at KSC. The ICPS, built by United Launch Alliance (ULA) and Boeing, required some modifications for SLS's Artemis I flight: lengthening the LH2 tank, adding hydrazine bottles for attitude control and minor avionics changes. For Artemis II, the ICPS will require an emergency detection system to monitor abort conditions and communicate any abort recommendations to the Orion spacecraft. In addition, for the Artemis II flight, Orion's service module will provide the TLI burn while the ICPS will perform three burns: perigee raise maneuver, apogee raise burn and disposal burn.

In the Block 1 vehicle, two adapters connect the ICPS to the core stage below it and Orion's spacecraft adapter above it. The Artemis I OSA is complete and has been delivered to EGS. The OSA was delivered with the SPDS installed and tested. The Artemis I Launch Vehicle Stage Adapter (LVSA) is in final processing at Marshall Space Flight Center (MSFC) and expected to ship to KSC in 2020.

Next year promises many exciting milestones toward integration and launch. In addition to the Green Run test campaign and the booster motor segments

shipping to KSC, the Program should complete its Design Certification Review (DCR) and will continue work toward a Certification of Flight Readiness (CoFR). Additionally, launch monitoring facilities at KSC and MSFC should finish outfitting. Training and simulation activities are underway and will continue until close to the time for launch.

The second Block 1 vehicle, which will send astronauts in Orion on a lunar flyby free return mission, has several elements manufactured. All 10 motor segments for the solid rocket boosters are cast with propellant; seven are complete. Two RS-25 engines have completed processing and all controllers have been hot-fired at SSC. Boeing has manufactured all five components of the Artemis II core stage at Michoud. Panels have been machined for the LVSA and OSA and work on the ICPS is in progress at ULA facilities under an undefinitized contract action (UCA), with procurement expected to be complete in the next few months. A smaller manifest of 6U and 12U CubeSats is expected for Artemis II; proposals can be submitted through November 4, 2019 through NASA's CubeSat Launch Initiative (CSLI) Program [3].

Beyond Artemis II, Northrop Grumman is processing booster segments for a third flight set of



Figure 7. Five RL-10 upper stage engines are complete for future SLS missions

boosters, Aerojet Rocketdyne has completed RL-10 engines for the ICPS and restarted production of the RS-25 engines. Boeing has produced weld confidence articles for the EUS and MSFC has fabricated a payload adapter manufacturing demonstration article.

5. SLS Block 1 cargo with 5 m fairing

In addition to the Block 1 crew vehicles designated for the first few Artemis flights, the Block 1 configuration with the ICPS upper stage can be fitted with an industry-standard 5 m-diameter fairing. Industry-standard payload interfaces and accommodations in the Block 1 cargo vehicle can streamline payload development processes. The Block 1

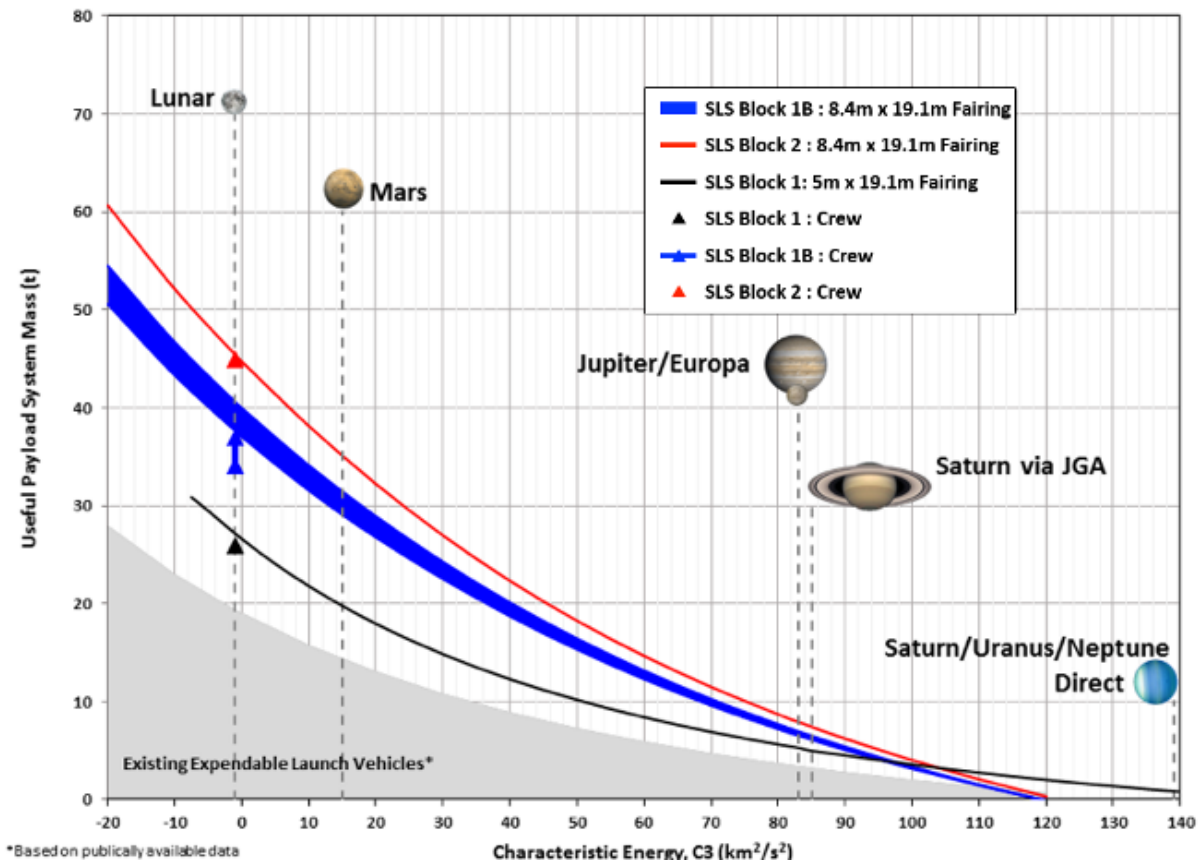


Figure 8. SLS can deliver a range of useful payload mass to deep space destinations

cargo model, with its high C3 values to the outer planets can deliver large mass to destinations such as the gas giants with reduced transit time (see Figure 11). For a notional Jovian insertion mission, for example, SLS offers a launch with C3 energy sufficient to eliminate the Venus-Earth-Earth gravity assist (VEEGA) trajectory that commercial vehicles require, reducing cruise time from more than six years to less than three years.

6. SLS Block 1B

SLS Block 1B uses the same core stage design as the Block 1 vehicles. To improve performance, the solid rocket boosters and four RS-25 engines will on-ramp new technologies, with the newly manufactured RS-25 engines upgraded to perform at 111 percent of shuttle-era operational power levels. The primary means of increasing mass to beyond-Earth orbit (BEO) will be through the 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 the lunar vicinity, depending on crew or cargo configuration. The EUS will provide both ascent/circularization and in-space transportation for payloads.

The Block 1B crew vehicle can accommodate Orion and a CPL in the 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 Orion crew vehicle.

Similar to commercial vehicles, the mechanical interface between the SLS Block 1B vehicle and a primary payload or CPL is a payload adapter consisting of up to three components as shown in Figure 2. Choice of a particular payload adapter is mission-dependent.

A payload adapter is a structural/service interface to the 8.4 m-diameter SLS EUS forward adapter. The payload adapter can be configured with a payload interface adapter (PIA) and/or a payload separation system (PSS) to accommodate different spacecraft or

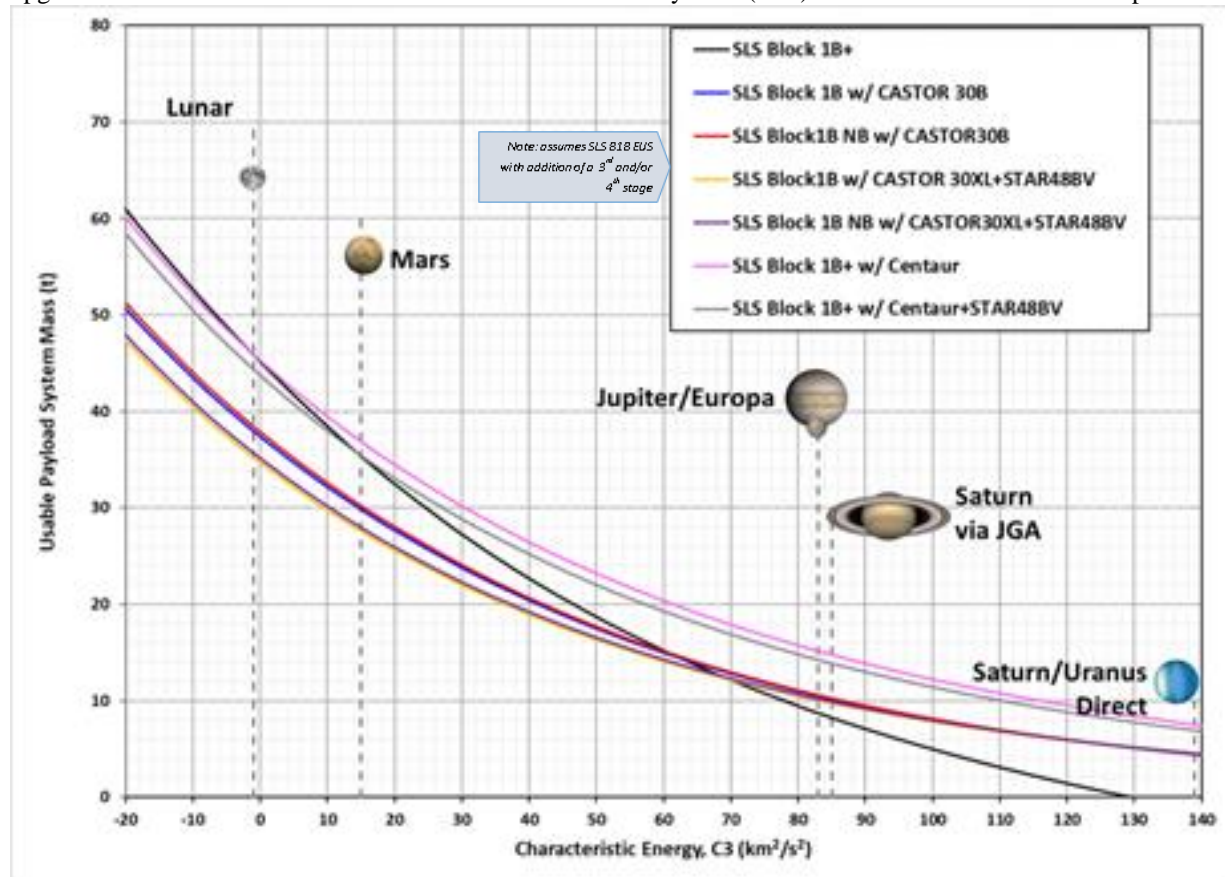


Figure 9. Mass to destination using the SLS Exploration Upper Stage (EUS) and optional third stages and kickstages

payload interfaces. The PIA is an optional interface between the adapter and the spacecraft/payload that maximizes available volume. The PIA accommodates a PSS, which is a structural separation interface for a spacecraft or payload mounted on the adapter or PIA. Depending on the interface diameter required, it can support a variety of commercial off-the-shelf (COTS) separation systems (e.g., D1666 or 1666VS) or a new-development separation system.

For smallsats, rideshare opportunities for up to 21 smallsats in varying sizes may be offered on a payload adapter in the USA (see Figure 6). Depending on the requirements of primary or CPLs, deployment of larger “ring payloads,” similar to those currently flown on an Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) ring, might be possible. Propulsive ESPA-class capabilities are also being evaluated.

The Block 1B cargo configuration can accommodate payloads using an 8.4 m diameter fairing in 19.1 m and 27.4 m lengths. As with CPLs on the Block 1B crew configuration, the EUS forward adapter provides an interface for various payload fairings and payload adapters.

7. Ultimate Capability: SLS Block 2

The eventual Block 2 crew variant will use evolved boosters to maximize performance, enabling the vehicle to place more than 45 t in lunar orbit. The Block 2 vehicle has the potential to carry up to 10 m fairings with a volume of up to 1,300 m³, several times greater than any currently available fairing, making new missions possible and streamlining design of deep space spacecraft. This configuration will also take advantage of future developments in technology, while providing unique enabling capabilities for human Mars missions.

8. Benefits for science missions

SLS offers substantial benefits to mission scientists, primary investigators, spacecraft designers and mission planners with the capability to launch more mass, provide greater volume and highly energetic launches compared to commercial vehicles. Greater payload volume and mass can decrease the need for miniaturization and complex deployments, simplifying spacecraft and reducing risk. Reducing cruise time by enabling injection into direct trajectories without gravitational assists lowers operational costs, can eliminate the need to design for inner solar system conditions and increases spacecraft’s useful life. More energetic launches that reduce outbound cruise time can allow more robust science packages on payloads and quicker data return, which can translate into programmatic benefits.

SLS can accommodate primary payloads, payloads co-manifested with Orion and smallsats in several form



Figure 14. Concept of LUVOIR A space telescope in SLS 8.4 m-diameter, 27.4 m-long fairing

factors. Program managers are actively engaged with the science community to understand demand and provide information on the unique capabilities of the system. An *SLS Mission Planner's Guide* is available in a downloadable PDF format to provide basic technical details on the system [4].

While SLS is designed to enable human exploration of the solar system with the Moon as a testbed, many missions will benefit from the mass, volume and departure energy that SLS provides, including planetary science, astrophysics, heliophysics, planetary defense and commercial endeavors.

8.1 Lunar and Martian 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 capabilities of SLS Block 1B will enable NASA to send Orion and a CPL, such as a habitat or logistics module, to the Gateway in a single launch. 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.

With the construction of the lunar Gateway and proving out deep space technologies as an intermediate step, Mars remains NASA's 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 from the Gateway using a fully evolved Block 2 SLS vehicle. Large-volume habitat modules and rovers will require the large-diameter 8.4 m and 10 m cargo shrouds.

8.2 Missions to the Gas Giants

The Europa Clipper mission to Jupiter 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 the probe into Jovian space, reducing transit to Europa to less than three years. The shorter cruise phase means the spacecraft needs less radiation shielding and saves mass, which can translate to more mass and volume available for the science payload. If a follow-on Europa lander mission comes to fruition, that mission could use the performance of SLS for increased mass, delivering a payload in the 16 t range. In addition, enabling earlier science return of the Clipper mission can inform the lander study.

8.3 Missions to the Ice Giants

Looking farther into the solar system, scientists could utilize the unique capabilities of SLS to send probes to the ice giants to investigate the atmospheric and magnetic properties and conduct flybys of larger satellites. In the coming decades, there are no trajectories that would allow a single spacecraft to fly by both Uranus and Neptune. SLS can enable a single launch with dual spacecraft. Initially both spacecraft would travel on a similar trajectory; the crafts would eventually vector toward the different destinations [5]. A solid-fuel motor kickstage can be included in the SLS staging architecture to enable high enough C3 to reach the planets [5]. The dual-spacecraft launch using SLS and a kickstage could enable reduced flight times and/or increased useful mass delivered to the planets. These options can allow additional trade-offs between cost and science and provide programmatic benefits [5].



Figure 10. Concept of Interstellar Probe packaged with solid-motor kickstage

8.4 Astrophysics

In the field of astrophysics, the Block 1B capabilities and volume in co-manifested and 8.4 m-diameter cargo shroud options provide significant benefits for large-aperture space telescopes. After the James Webb Space Telescope (JWST) launches, the Wide Field Infrared Survey Telescope (WFIRST) is scheduled to come online. WFIRST could fly as a CPL on a Block 1B launch, again providing cost and programmatic benefits.

Looking farther into the future, telescopes such as the Large UV/Optical/IR Surveyor (LUVOIR) can benefit from Block 1B's capabilities. LUVOIR has a larger "A" concept and a smaller "B" concept [6]. The LUVOIR A concept in the 8.4 m-diameter 27.4 m-long fairing is shown in Figure 11. Mission planners are exploring using a co-manifested launch for the LUVOIR B mission.

8.5 Kuiper belt and interstellar medium missions

SLS could be used for a solar system escape mission with a spacecraft with mass similar to a New Horizons mission but with greatly reduced transit times. Such a mission would require an innovative trajectory design [7]. McNutt *et al.* believe extremely large launch C3s in the range of 200 km²/s² to 350 km²/s² should be possible using SLS [9]. By using a Jupiter gravity assist, travel times of 25 to 35 years to 200 AU could be achieved. 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 [9].

9. Conclusion

With the first Block 1 crew vehicle nearing completion and the Artemis I test flight SLS, Orion and ground systems squarely within view, a new generation of deep space exploration is dawning – the Artemis generation. SLS will give NASA the capability to send astronauts to the Moon in Orion 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, test, demonstrate and innovate off-planet 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 and exciting missions, whether that be sending a CPL of significant size and volume along with Orion to the Gateway or launching a flagship science mission as a cargo-only flight deep into the solar system. The mass, volume and departure energy of SLS provide scientists, spacecraft designers and mission planners with new and

unique opportunities for astrophysics, planetary science and other ambitious missions. SLS puts once-out-of-reach missions with larger science packages or reduced cruise times now squarely with the science community's reach.

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