

# NASA's Space Launch System: Enabler for Deep Space Exploration

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## I. Abstract

NASA's SLS (Space Launch System) rocket is a super-heavy lift launch vehicle. Its current primary use is to launch crew and payloads to the Moon under the NASA-led Artemis campaign. Artemis's goal is to return astronauts to the Moon, test technologies on the lunar surface and in lunar orbit, and prepare for crewed missions to Mars.

SLS has an initial mass-to-translunar injection (TLI) single launch capability of 59,000 lbs. (27 metric tons [t]) in crewed configuration with NASA's Orion spacecraft. The vehicle produces 8.8 million pounds (39,100 kN) of thrust.

The single-launch payload capability increases significantly to more than 84,000 lbs. (38 t) on the fourth launch, which debuts the more powerful Block 1B variant featuring the larger, more capable exploration upper stage (EUS). The vehicle can send an Orion spacecraft and crew of four, along with a 10-t co-manifested payload, to the Moon on the same launch. Block 1B can also fly in a cargo-only configuration with a mass-to-TLI capability of 93,000 lbs. (42 t).

On Artemis V, the second flight of the Block 1B variant, new-production RS-25 liquid hydrogen (LH2)/liquid oxygen (LOX) engines will begin flying. The RS-25 was a key propulsion system on the space shuttle. Sixteen engines left over at the end of the Space Shuttle Program were outfitted for SLS and are flying the first four flights of the rocket. The new production engines, which take advantage of modern manufacturing technologies, will produce more thrust than the heritage engines but cost 30 percent less to produce.

The ninth SLS flight will debut the Block 2 variant, featuring more powerful solid rocket boosters. Overall vehicle thrust will increase from the Block 1B's 8.84 million pounds (39,300 kN) to Block 2's 9.44 million pounds (42,000 kN). Booster performance increases from 3.6 million pounds (16,014 kN) each to 4.2 million pounds (18,683 kN). Mass-to-TLI in crewed configuration increases to 95,000 lbs. (43 t) in a single launch and 101,000 lbs. (46 t) in cargo-only configuration.

As SLS continues moving from development to operation, steps to increase its sustainability are already being implemented. Lessons learned from the building of the first flight vehicle have significantly reduced the build time of the second unit. Beginning with the Artemis III rocket, core stage basic structures will continue to be manufactured at NASA's Michoud Assembly Facility in New Orleans. The core stage engine section will be outfitted at NASA's Kennedy Space Center in Florida, and then mated with the remaining 4/5 of the stage shipped from Michoud. The four RS-25 engines also will be installed at Kennedy. This process modification enables more hardware to be in-flow at Michoud while final outfitting of the core stage is completed at the launch site.

## II. SLS Architecture and Evolution

NASA's SLS (Space Launch System) rocket is a super-heavy lift launch vehicle designed to launch astronauts and cargo to destinations in deep space, including the Moon and Mars. SLS uses proven, reliable technologies as its

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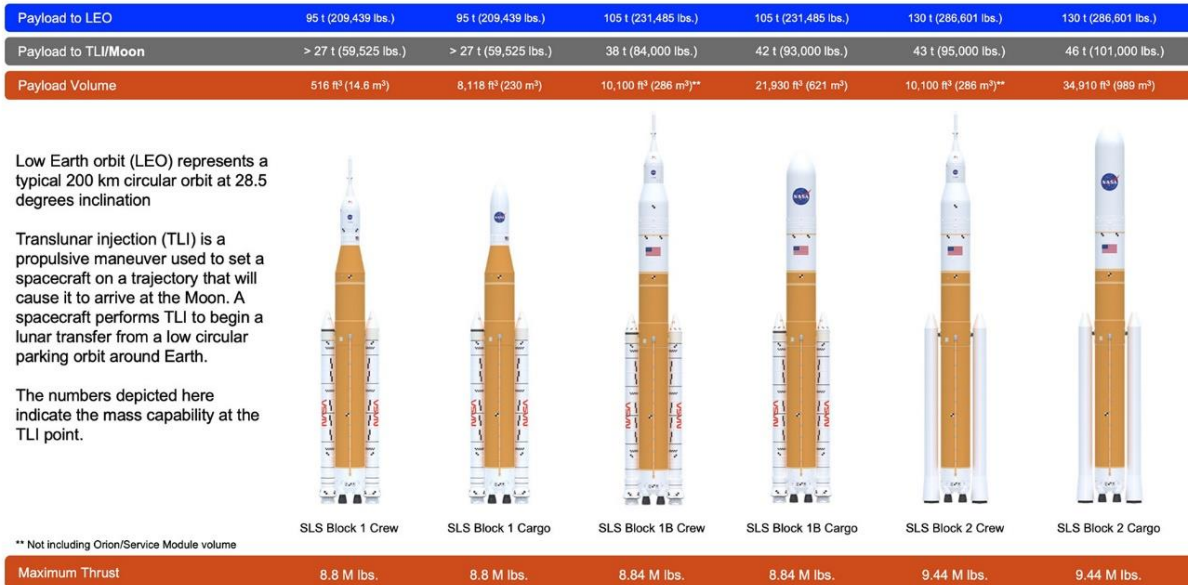
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backbone to achieve the United States’ and world’s most innovative and challenging space exploration missions. It is the only rocket in the world currently capable of launching astronauts to the Moon and other deep space destinations.

The multi-variant launch vehicle starts with an initial 59,000 pounds (27 metric tons [t]) single launch mass-to-TLI capability in crewed configuration with NASA’s Orion spacecraft. The single launch capability increases to 84,000 pounds (38 t) on Block 1B crew and more than 95,000 pounds (43 t) in Block 2 crew. Each block also has cargo-only configurations that support higher single-launch payload capabilities than their crewed configuration counterparts. Maximum thrust on SLS starts at 8.8 million pounds (39,100 kN) on Block 1 and increases to 9.44 million pounds (42,000 kN) on Block 2 (Fig. 1).

## POWER OF SLS

### FOUNDATION FOR A GENERATION OF DEEP SPACE EXPLORATION



**Fig. 1 SLS variants will feature upgrades which will result in significant performance increases.**

The first three flights occur on the Block 1 configuration, featuring two five-segment solid rocket boosters, four RS-25 LH2/LOX engines fueled by the core stage, and the interim cryogenic propulsion stage (ICPS) as the upper stage. While the core stage was a new development stage, the RS-25 engines and solid rocket boosters are heritage hardware remaining from the Space Shuttle Program, upgraded for SLS. The ICPS is based on United Launch Alliance’s (ULA) Delta Cryogenic Second Stage (DCSS). In crewed configuration with the Orion spacecraft, the vehicle stands 322 ft. (98 m) tall and produces 8.8 million pounds (39,100 kN) of thrust.

The first substantial upgrade will be in the form of the new exploration upper stage (EUS), marking the SLS Block 1B variant. The single-engine ICPS was meant to fly only the first few flights as a key enabler of the early part of the program, helping get SLS operational and the Artemis missions underway. While based on the reliable DCSS platform, a more powerful upper stage will help take SLS to its true capability.

The EUS continues to use the RL10 engine used on the ICPS, increasing to four engines on the new stage. The stage’s thrust increases from 24,750 pounds (110 kN) to 97,360 (433 kN) and increases the single-launch payload mass-to-TLI from 59,000 pounds (27 t) in crewed configuration to 84,000 pounds (38 t). The performance increase enables NASA to launch crew and a 10-t co-manifested payload, stowed in a new universal stage adapter (USA), to the Moon on the same launch.

Along with the block upgrade’s hardware, the flight software and avionics will also be upgraded. The avionics will move from the core stage forward skirt to the EUS equipment shelf, requiring and enabling it to control the entire flight of each SLS. The software and avionics are in development.

A cargo-only variant of the Block 1B is also possible. A 62.7-foot (19.1-m) tall, 27.6-foot (8.4-m) diameter fairing is possible, providing 21,930 cubic feet (621 cubic meters) of payload volume [1]. A larger, 90-foot (27.4-m) tall, 27.6-foot (8.4-m) diameter fairing is possible, providing 34,910 cubic feet (989 cubic meters) of payload volume. A 62.7-foot (19.1-m) tall, 32.8-foot (10-m) diameter is also possible. The combination of the large payload volume with

the EUS means significant cargo can be sent to the Moon or Mars in a single launch, or large telescopes or interplanetary probes can be sent throughout the solar system. Probes can be sent to destinations in deep space years quicker than on currently available rockets.

While Block 1B is flying, new RS-25 engines will be brought online. The engine, used on the space shuttle and now SLS, has flight-proven success. Between ground and flight operations, teams have more than 1 million seconds of hot fire experience with the engine. As the engines for the first four flights are heritage engines from the Space Shuttle Program, new engines will be needed beginning with Artemis V. In April 2024, the new production engines completed a two-part, 24-test hot fire test series to certify the design and components. The first production engine is scheduled to be complete in early 2025. It will then undergo an acceptance hot fire test at NASA's Stennis Space Center in Bay St. Louis, Mississippi, before being installed on its core stage.

The new engines take advantage of modern manufacturing technologies like additive manufacturing, enabling prime contractor L3Harris Technologies to significantly reduce the time, cost, and complexity of production. Teams at NASA's Marshall Space Flight Center in Huntsville, Alabama, are doing significant research into additive manufacturing of the nozzle's channel walls, which would further reduce the production time and cost of liquid rocket engines. About 70 percent of its components have been redesigned, simplified, and improved, yielding an engine that can be produced quicker, is 30 percent more affordable, and operates at two percent higher thrust than the 16 shuttle heritage engines that will power the first four flights.

The third SLS variant, called SLS Block 2, features evolved solid rocket boosters. As the heritage space shuttle steel booster cases will run out following the eighth flight of SLS, new boosters featuring composite cases will debut on the ninth flight. Other upgrades to the boosters will include new propellant, new insulation, and new thrust vector control systems to handle the wider nozzle and increased power. The boosters further increase SLS's capability. Maximum vehicle thrust increases to 9.44 million pounds (42,000 kN), and the mass-to-TLI increases to 95,000 lbs. (43 t) in crewed configuration and 101,000 (46 t) in cargo-only configuration.

### **III. Artemis I Flight Data**

The Artemis I mission, launched November 16, 2022, was a test flight of the rocket (Fig. 2). The mission sent an uncrewed Orion spacecraft on a 25-day mission around the Moon into a distant retrograde orbit about the Moon and back. Data collected from the launch were analyzed over the course of the following months to learn as much about the behavior of the vehicle in the flight environment as possible. On the debut flight, SLS performed incredibly close to pre-flight predictions, including:

- Targeted prelaunch predicted velocity was 25,586.43 ft./sec. (7,798.74 m/sec.). Actual Earth orbital insertion velocity was 25,579.86 ft./sec. (7,796.74 m/sec.) – a difference of 6.58 ft./sec. (2.00 m/sec.) or 0.026 percent.
- Targeted apogee was 975 nautical miles (1,569.1 km). Actual Earth orbital insertion apogee altitude was 972.6 nautical miles (1,564.4 km). This difference of 2.4 nautical miles (4.667 km) was just 0.25 percent from the preflight prediction.
- The booster 50-psi separation signal, which is based on measurements during the tailoff pressure, was sent to each booster within 0.04 seconds of each other. Data indicate that the booster pair are the closest match pair ever flown, including through all 135 space shuttle missions.
- The core stage's 999 sensors and 45 miles (72 km) of cable executed all functions nominally.
- The interim cryogenic propulsion stage (ICPS) set a record for longest duration burn of the RL10 engine during the translunar injection burn at approximately 18 minutes.
- The flight software performed as designed.



**Fig. 2 Artemis I launch November 16, 2022.**

#### **IV. Current Hardware Progress**

After thorough review of the data, teams concluded that performance was sufficient to fly crew on the second flight – NASA’s Artemis II mission, which will send four astronauts on a lunar flyby mission aboard an Orion spacecraft. The mission is targeted to fly no later than April 2026. SLS hardware for the mission is largely complete and at NASA’s Kennedy Space Center in Florida.

The Artemis II core stage completed manufacture at NASA’s Michoud Assembly Facility outside New Orleans. The stage was shipped to Kennedy in July 2024 on NASA’s Pegasus barge and transported into the Vehicle Assembly Building. Teams are finalizing work on it. When complete, the stage will be ready for stacking on the mobile launcher with the solid rocket boosters.

The solid rocket booster propellant segments were transported via train from prime contractor Northrop Grumman’s Utah manufacturing facilities in late 2023 and are now stacked on the mobile launcher. Stacking of the segments began in November 2024 and concluded February 19 with the joining of the forward assemblies (Fig. 3).

The ICPS for Artemis II is complete at prime contractor United Launch Alliance’s facilities at Cape Canaveral in Florida. The launch vehicle stage adapter, which will connect the ICPS to the core stage, was shipped from Marshall in August 2024 on the Pegasus barge. The Orion stage adapter has been outfitted with the brackets for the secondary payloads. It is targeted to arrive via truck at Kennedy from Marshall in Spring 2025.



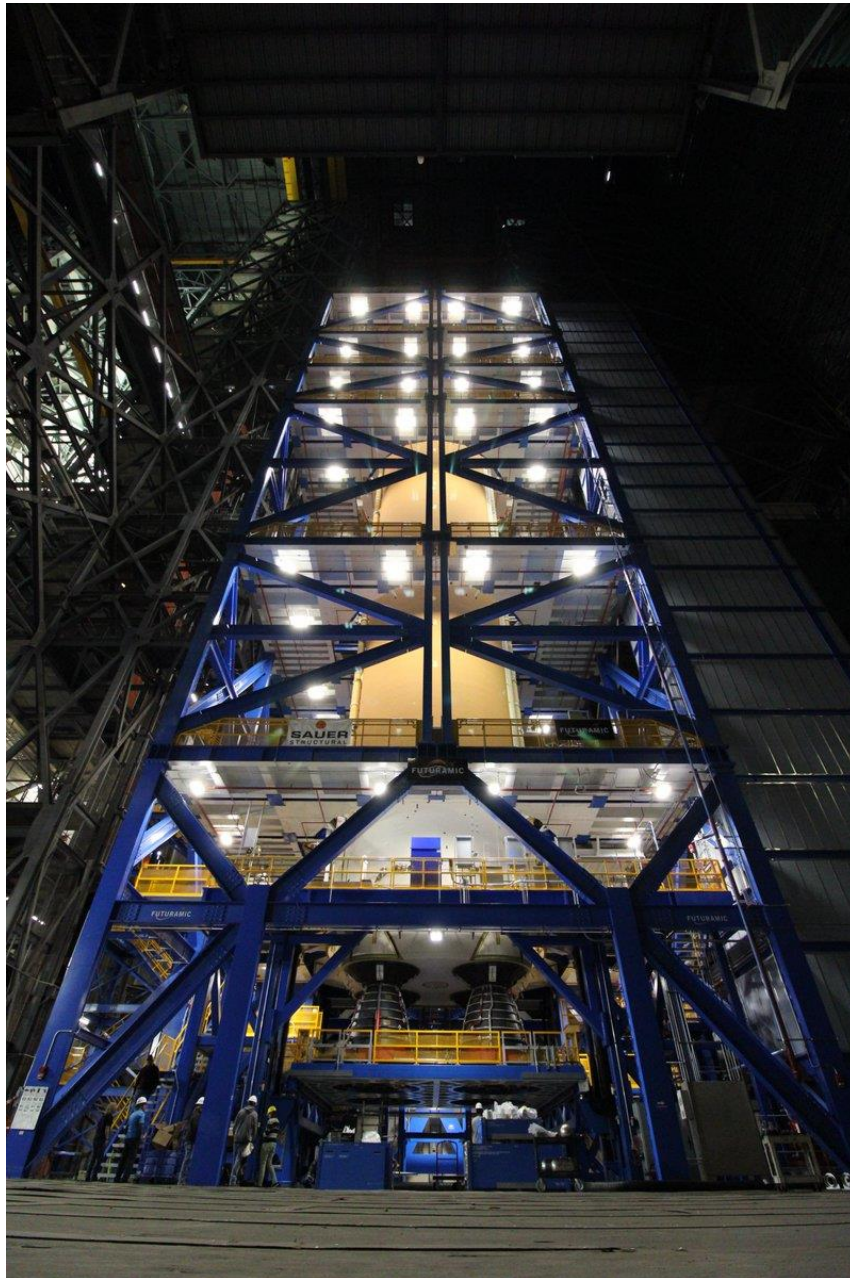
**Fig. 3 Artemis II solid rocket boosters completed stacking February 19.**

In addition to preparations for the Artemis II mission, significant progress is being made on the launch vehicles for Artemis III, IV, V, and beyond.

- The Artemis III core stage primary structures, including the LH2 and LOX tanks, are structurally complete at Michoud. The tanks are in the process of having their thermal protection systems applied.
- The solid rocket booster segments for Artemis III are all cast and stored at prime contractor Northrop Grumman's Utah facilities.
- The Artemis III engine section and engine section boattail and Artemis IV engine section are at Kennedy.
- Weld confidence articles, structural test articles, and flight hardware components for the new EUS are being manufactured and tested.
- New production RS-25 engines for Artemis V and beyond are being made by prime contractor L3Harris. These new engines take advantage of modern manufacturing technologies and streamlined processes, resulting in an engine that is 30 percent more affordable with a small increase in thrust compared to heritage space shuttle engines.
- A test program to certify the new production engines at Stennis completed in April 2024.
- Flight software for the SLS Block 1B variant is in development.
- A full-scale hot fire test of the evolved solid rocket booster for Block 2 is targeted for summer 2025.

## **V. Increasing Efficiency and Flow**

In December 2024, High Bay 2 in the Vehicle Assembly Building at Kennedy completed retrofitting of a new vertical workstation. This new workstation enables teams to access the entire core stage for processing and integration. Prior to the workstation, the work was done with the stage in the horizontal position, significantly limiting access and requiring periodic rotation of the stage. The Artemis II core stage was the first to take advantage of the vertical access, and areas of work were completed weeks ahead of schedule (Fig. 4).



**Fig. 4 Artemis II core stage undergoes final processing in High Bay 2.**

Full integration of the first two core stages was performed at Michoud. Beginning with Artemis III, the engine section and RS-25s will be integrated at Kennedy. The change enables more core stages to be concurrently in flow at Michoud and Kennedy.

Work is ongoing to establish pad access to portions of the launch vehicle that currently have to be serviced inside the Vehicle Assembly Building. This pad access will enable quicker turnarounds between wet dress rehearsals and launch and may prevent rolling back to the Vehicle Assembly Building for some repairs.

## **VI. Powering Artemis and Enabling Discovery**

SLS will launch large segments of the agency's Gateway lunar orbiting outpost. Gateway will be composed of multiple modules, including the Lunar I-Hab module which will launch on Artemis IV and the Lunar View refueling

module that will launch on Artemis V. The modules will be co-manifested payloads with Artemis crews on the Orion spacecraft. The missions will both be crewed landing missions with Gateway assembly happening concurrently. SLS's capability enables these missions, which reduces the number of launches to accomplish the objectives.

In addition to co-manifested payloads, all variants possess the capability to launch CubeSats as secondary payloads [2]. On Artemis I, 10 6U secondary payloads were launched inside the Orion stage adapter. Artemis II will launch multiple 12U CubeSats, developed by international partners. The Block 1B and Block 2 variants include a new mounting structure for CubeSats. Called the Nest, the ring-like structure will fit inside the payload adapter fairing, and CubeSats will be manifested on missions that have mass and volume availability (Fig. 5).



**Fig. 5 The payload adapter (left) and universal stage adapter (right) will be able to house large co-manifested payloads as well as CubeSat secondary payloads on the Block 1B and Block 2 variants. Note the Nest ring inside the top opening of the payload adapter.**

SLS's role in the Artemis campaign will enable significant discoveries as astronauts explore the Moon both from the lunar surface and from the Gateway in lunar orbit. As previously discussed, it is possible for SLS to fly cargo-only missions to the Moon or other destinations throughout the solar system. SLS has significant departure energy, enabling the launch of massive telescopes and spacecraft [3,4]. The vehicle can also launch smaller payloads and get them to their destinations quicker than currently operational launch platforms.

## VII. Summary

SLS is designed for human safety, and selection of proven propulsion technology and success on the Artemis I mission positions it to play a critical role in Artemis II and future missions. Using SLS, astronauts will launch to the Moon in the Orion spacecraft, transport modules of the Gateway lunar orbiting outpost, and perform historic missions that will ultimately lay the foundation for crewed missions to Mars. SLS is an enabling piece of the architecture and will fly missions for the nation and world for decades to come.

## VIII. References

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