National Aeronautics and Space Administration

SPACE LAUNCH SYSTEM

REFERENCE GUIDE *for* ARTEMIS II


ARTEMIS
WISEMAN
GLOVER
KOCH
HANSEN

From the SLS Program Manager and Chief Engineer

The SLS (Space Launch System) team is excited to be flying Orion back to the Moon on NASA's heavy-lift rocket for Artemis II. This is the first crewed mission of the Artemis campaign to explore the Moon for scientific discovery, technology advancement, and to gain experience for human missions to Mars. We are proud to be a key part of that bold effort.

Astronauts from the United States and Canada will leave Earth and journey around the Moon for the first time since NASA's Apollo 17 made the trip in 1972.

The Artemis II mission is a practice run that will set the stage for future Artemis missions – humans once again landing on the lunar surface, exploring areas the Apollo astronauts did not, staying longer, learning more, and making new discoveries. It is the next step to establishing our presence on a strategically important piece of solar system real estate.

Our jobs at SLS are full of numbers that guide our work every day. As we prepare for Artemis II, our most important number is four. It reminds us daily of the four Artemis II crew members – Reid Wiseman, Victor Glover, Christina Koch, and Jeremy Hansen – the brave explorers who will lead humanity back to the Moon. We work every day to ensure SLS is safe and successful for our four brave explorers.

For SLS, the Artemis II story really began with the uncrewed Artemis I mission. The greatest reward was what the performance of that rocket told the world about the team – NASA and industry, as well as the stakeholders – that took SLS from concept to drawing board to manufacturing floor to test stand to launch in November 2022.

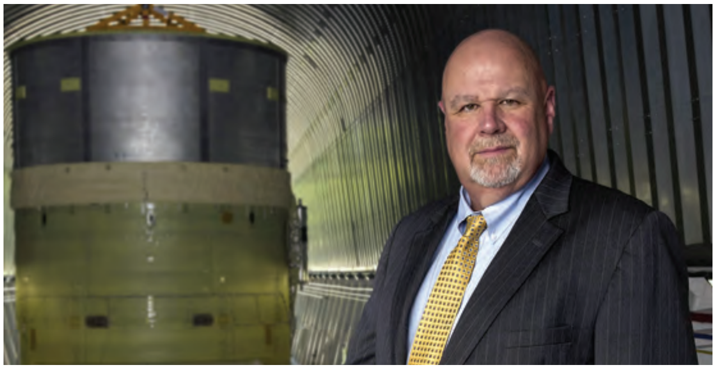
That textbook flight defied the historical odds for first flights. As you will read in more detail below, the SLS rocket, including its core stage, boosters, upper stage, flight computers, and software were exhaustively tested. As a result, the rocket performed to an incredible level, meeting every objective for the mission on its first flight.

The pre-launch activities, launch, and mission returned a treasure trove of information on how SLS performed from countdown through end-of-mission. We collected more than four terabytes of data and onboard imagery, including 31 terabytes of SLS imagery. Our months-long analysis of this comprehensive data validated the performance of the rocket and verified its capability to safely transport astronauts to the Moon. We applied the lessons learned to the rocket for Artemis II and those for future missions.

At the time of this writing, Artemis I is in the history books, and Artemis II is being readied for the launch pad. However, the work doesn't stop there. We are also laying the groundwork for future Artemis missions with the SLS core stages, engines, boosters, upper stages, and payload adapters all being built and tested. And, we continue working on improvements that will make SLS more capable and safer.

SLS is critical for achieving the next leaps in lunar exploration as the only vehicle capable of sending crews and large exploration cargoes directly to the Moon in a single launch. It represents a national strategic capability, strengthening the nation's technical and industrial base while advancing peaceful international collaboration in space. We are proud to share our story, here.

Let's go launch!



John Honeycutt, *SLS Program Manager*

Dr. John Blevins, *SLS Chief Engineer*

SLS Artemis I Post-Flight Assessment

The near-perfect flight of NASA's SLS (Space Launch System) rocket on the successful Artemis I mission verified that SLS is ready to launch its first crew on Artemis II. Engineers in the SLS Engineering Support Center (SESC) at NASA's Marshall Space Flight Center in Huntsville, Alabama, collected more than four terabytes of data and onboard imagery from SLS during pre-launch and launch phases. An additional roughly 31 terabytes of imagery data was collected from ground cameras, cameras on the rocket, and aerial cameras focused on SLS during on-pad pre-launch activities and launch.

During Artemis I, the rocket met or exceeded many of its required parameters to an accuracy of tenths or hundredths of a percent, validating its design and proving it ready to support future crewed missions. Pre-flight predictions for control performance, attitude control margin, and structural stability margins aligned closely with actual Artemis I rocket and trajectory flight performance data from liftoff through low Earth orbit insertion. During flight, planned stage separations were successful with no recontact, and stage disposals were within the required distance from land.

Other Artemis I mission highlights include:

- The solid rocket boosters performed as twins, proving to be the closest matched set that NASA has ever flown, including through all 135 space shuttle missions; the boosters hit peak thrust within 0.1 seconds of each other, performed within one-quarter of a percent of each other during ascent, and burned out within 0.4 seconds of each other
- SLS was predicted to be moving at 25,586 ft./sec. (7,799 m/sec.) when the core stage's main engines stopped; in reality, the vehicle was traveling at 25,580 ft./sec. (7,797m/sec.) at that time – incredibly close to predicted velocity
- Orbital insertion was at an altitude of 87.3 NM (162 km), and parameters were 972.6 NM (1,801 km) by 15.9 NM (29.4 km); predicted parameters were 975 NM (1,806 km) by 16 NM (30 km)
- RS-25 engine thrust was within 0.5% of pre-flight predicted values
- The 18-minute interim cryogenic propulsion stage (ICPS) translunar injection (TLI) burn pushed the rocket's velocity to more than 22,000 mph (35,406 km/h) – a record-long duration burn for any RL10 engine
- Artemis I's 10 secondary payloads were deployed after disposal burn completion, with the ICPS performing as predicted
- SLS flight software successfully executed 2,866 commands from Exploration Ground Systems (EGS) and Orion during Artemis I pre-launch and flight; internal to the rocket, from pre-launch through the end of ascent, the number of SLS flight software commands to avionics components were greater than 14 million
- The transition from Ground Launch Sequencer (GLS) to Automated Launch Sequencer (ALS) was nominal, and all ALS functions performed without issue; no avionics hardware issues occurred during flight, nor were there any trigger-level "close" calls in the abort monitor system
- There was excellent core stage liquid hydrogen and liquid oxygen closed-loop ullage control

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Preface

This document was prepared by NASA's SLS (Space Launch System) Program Office at NASA's Marshall Space Flight Center in Huntsville, Alabama, which has responsibility for design, development, testing, and engineering of SLS, NASA's operational super heavy-lift rocket that is sending astronauts to the Moon as part of the Artemis missions. The first test flight of SLS and the Orion spacecraft, Artemis I, launched from NASA's Kennedy Space Center in Florida, Nov. 16, 2022, successfully sending an uncrewed Orion to lunar orbit, demonstrating SLS prior to crewed flights.

Artemis II is also a test flight, this time with the addition of four astronauts for a 10-day mission to fly around the Moon and return safely. The mission also includes a test of rendezvous maneuvers between Orion and its expended SLS in-space stage to assess Orion's manual handling qualities in preparation for future missions that will require Orion to dock with other spacecraft.

This document is designed to serve as a general reference for the SLS rocket's initial Block 1 configuration used for NASA's early Artemis missions, as well as a summary of SLS Artemis I performance and its role for Artemis II.

In addition to providing basic facts about the SLS Block 1 rocket configured to send the Orion spacecraft to the Moon on the first three Artemis missions, this document also includes information on SLS design, capabilities, major components, and activities such as manufacturing, testing, assembly, launch, and future more capable variants of the rocket.

Dimensions, weights, and performance data used throughout this document for Artemis II are pre-launch estimates and are approximate for mission-specific, security, and proprietary reasons. They also reflect refinements based on Artemis I flight data and may vary based on differing mission requirements and the exact date and time of launch. Some basic information may be repeated from section to section to provide relevant context on a given subject without reading cover to cover.

Dimensions and measurements are provided in United States customary units as well as metric units in parentheses.

SLS launched the Artemis I mission Nov. 16, 2022.

Introduction

NASA is leading the return to the Moon through an innovative and sustainable program of exploration – the Artemis campaign. The campaign incorporates commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. NASA's SLS (Space Launch System) rocket and NASA's Orion spacecraft are critical capabilities along with the agency's Exploration Ground Systems (EGS), advanced spacesuits and rovers, the Gateway space station in lunar orbit, and the commercial human landing systems that will enable human missions of increasing complexity in deep space.

To make a new generation – the Artemis Generation – of crewed missions to the Moon possible, the SLS rocket uses proven propulsion systems consisting of space shuttle-derived solid rocket boosters and liquid-fueled engines mated to a new central core stage.

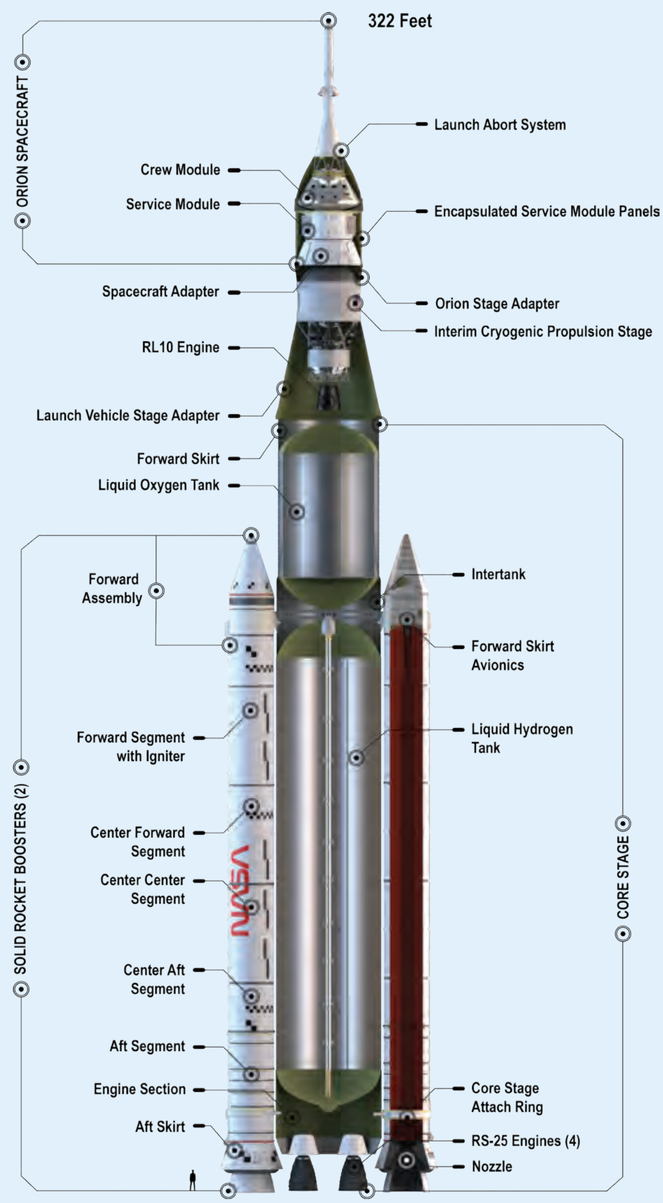
SLS uses larger solid rocket boosters than the space shuttles and liquid hydrogen/liquid oxygen-fed RS-25 engines operating at higher thrust levels than the former shuttle engines and with new controllers.

The core stage, which consists of propellant tanks, ducts, valves, avionics, and related equipment, houses the four RS-25s and provides attachment points for the boosters. Above the core stage, the conical launch vehicle stage adapter (LVSA) connects the core stage to the interim cryogenic propulsion stage (ICPS). The LVSA partially encloses the smaller-diameter stage. The Orion stage adapter (OSA), located on top of the ICPS, connects the Orion spacecraft to SLS and contains space for multiple CubeSat payloads from the science and international communities.

The first section of this guide provides a quick reference of basic dimensions and performance. The following sections go into more detail about the SLS role in Artemis missions and each of the rocket's elements, and include illustrations, photos, tables, and additional infographics.

The images and illustrations in this guide are all NASA images or used by permission. For downloadable versions of these and many other SLS images, go to: go.nasa.gov/3QgShNz

Elements of SLS and Orion



This cutaway illustration identifies the major elements of the SLS and Orion stack. From the ground up, the SLS portion consists of: twin solid rocket boosters with major components labeled, RS-25 liquid-fuel engines, central core stage with propellant tanks and flight computers, launch vehicle stage adapter, ICPS, and Orion stage adapter. Orion is atop SLS. A 6-ft. human figure is shown for comparison in the lower left.

Artemis II

Artemis II is the first crewed flight of NASA's SLS (Space Launch System) rocket and the agency's Orion spacecraft. Lasting approximately 10 days, the mission will have the four astronauts test the Orion spacecraft in a high Earth orbit before becoming the first astronauts to fly around the Moon since the Apollo 17 crew in 1972. The mission will provide critical data for the Artemis III mission – the first crewed landing on the Moon since Apollo 17.

Artemis II by the Numbers

SLS/Orion Launch Window (NLT)	No later than April 2026
Crew	4
Daily Launch Window (max)	2 hours max
Launch Azimuth	Variable 62 to 108 degrees
Insertion Orbit	15 x 1200 NM (28 x 2222 km)
Post-Perigee Raise Burn Orbit	100 x 1200 NM (185 x 2222 km)
Post-Apogee Raise Burn Orbit	0 x 40,000 NM (0 x 74,080 km)
HEO Orbit (post-PRB)	100 x 40,000 NM (185 x 74,080 km)
Earth Landing Site Weather	Fleet Training Area Hot (FLETA HOT)
Alternate Site	San Diego Up to 1200 NM (2222 km) up range
Vehicle Configuration	SLS Block 1
Mobile Launcher	Mobile launcher 1
Core Stage Engines	Heritage RS-25 "Adaptation"
Boosters	Five-segment solid
ICPS Propulsion	RL10B engine w/extendable nozzle
Orion	Crewed

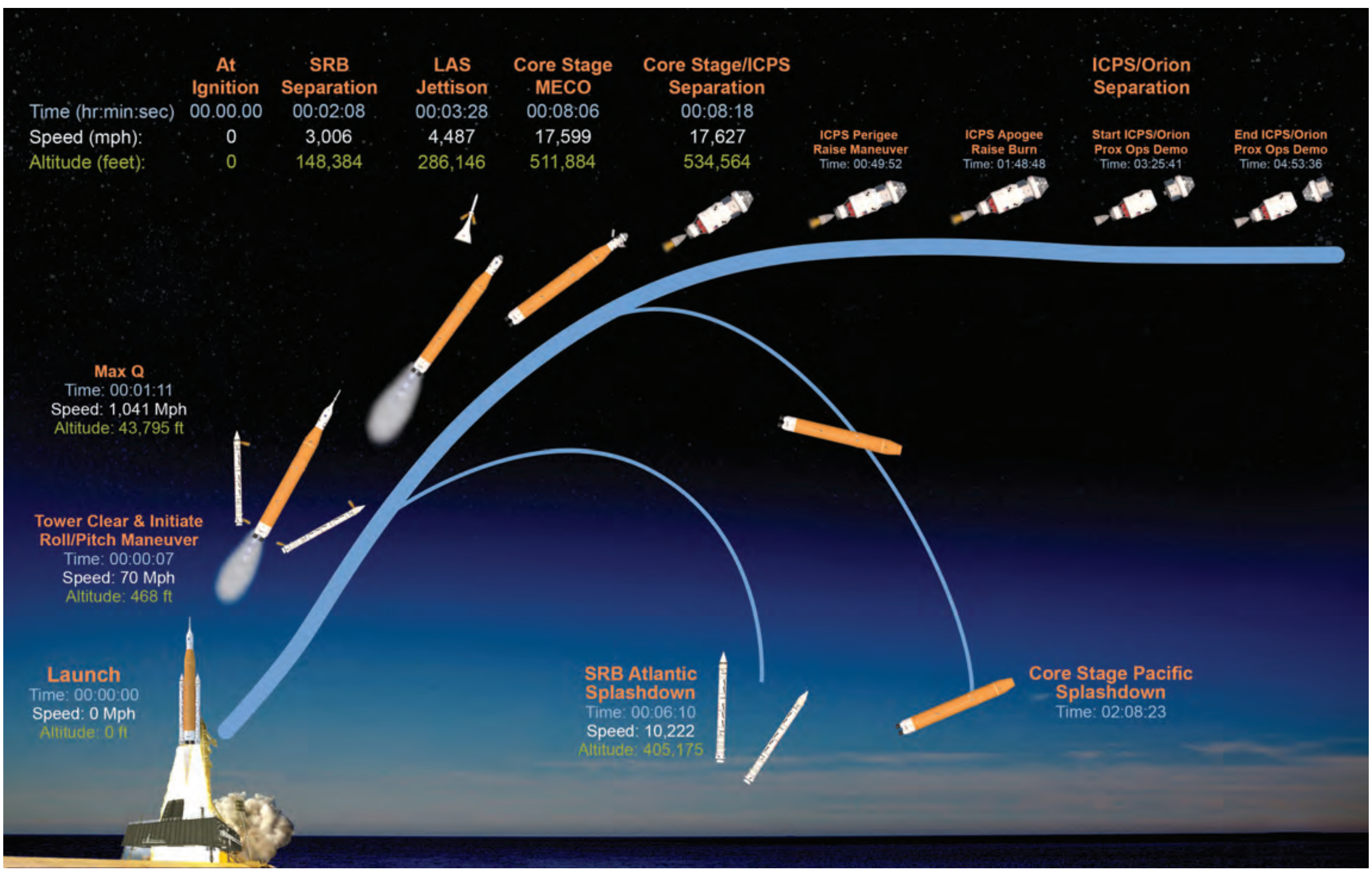
Artemis II Mission Objectives

- Evaluate crewed system performance for SLS and Orion in the deep space environment
- Perform flyby around the Moon
- Perform proximity operations demonstration with the ICPS
- Activate and checkout Orion and ground segment redundant systems
- Accomplish utilization, including payloads
- Support public outreach

Artemis II Mission Priorities

- Demonstrate ability to sustain the flight crew in the flight environment through safe return
- Demonstrate systems and operations essential to crewed lunar campaign
- Retrieve flight hardware and data
- Demonstrate emergency and off-nominal system capabilities and validate associated operations to the extent practical
- Complete remaining objectives including development test flight objectives and deploy SLS secondary payloads

Artemis II: SLS Flight Profile



Major events of the Artemis II flight are seen here, including solid rocket booster (SRB) jettison, core stage and launch vehicle stage adapter separation, and ICPS and Orion stage adapter separation from Orion. Following separation with Orion, CubeSat payloads will be released into deep space.

SLS Block 1 by the Numbers*

SLS Vehicle

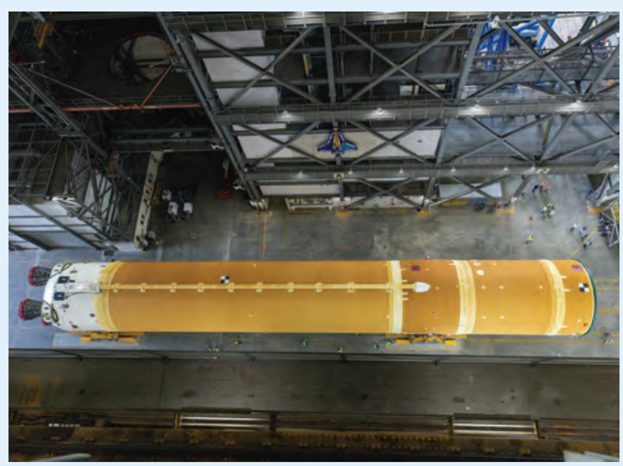
Vehicle design: Evolvable super heavy-lift
Height: 322.4 ft. (98.27 m)
Weight: 5.74 million lbs. (2,604 metric tons [t]) fueled
3.5 million lbs. (1,588 t) unfueled
Main propulsion: Four RS-25 liquid propellant engines and two five-segment solid rocket boosters
Maximum thrust: 8.8 million lbs. (39,144 kN)
Launch thrust: 8.27 million lbs. (36,787 kN)
Maximum speed: 22,670 mph (36,484 km/h) at ICPS translunar injection (TLI) main engine cutoff (MECO)
Single-launch payload to low Earth orbit:
209,439 lbs. (95 t)
Payload to TLI: > 59,525 lbs. (27 t)
Space Launch Assembly number:
(SLS only) 97M62020-003
Space Transportation Assembly number:
(SLS/Orion/secondary payloads) 97M62010-003
Exploration System number:
(SLS/Orion/secondary payloads/launch pad) 97M62000-003

The stacked Artemis I rocket, consisting of SLS and an Orion spacecraft, is seen here on the mobile launcher.

Core Stage

Contractor: Boeing
Height: 212 ft. (64.6 m) from forward skirt to engine exhaust exit plane
Diameter: 27.6 ft. (8.41 m)
Weight (without engines): 2.4 million lbs. (1,089 t) fueled,
188,000 lbs. (85.3 t) unfueled
Capacities: 537,000 gal. (2 million L),
317,000 lbs. (143.8 t) liquid hydrogen fuel;
196,000 gal. (741,941 L),
1.86 million lbs. (843.7 t) liquid oxygen oxidizer
Maximum thrust: Approximately 2 million lbs. (8,896 kN)
Burn time: 480 sec.
Artemis II completion date:
July 2024 (shipped to launch site)

**Data are approximate*



The Artemis II core stage is seen here waiting in the Vehicle Assembly Building transfer aisle at NASA's Kennedy Space Center in Florida before stacking on the mobile launcher.

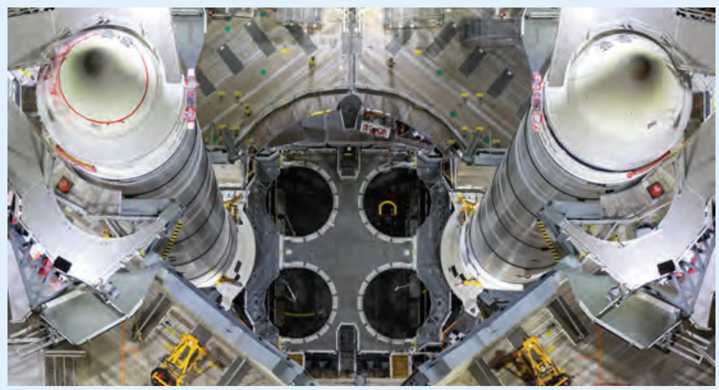
RS-25 Engines

Contractor: L3Harris Technologies
Height: 14 ft. (4.3 m)
Diameter: 8 ft. (2.4 m)
Weight (each): 7,750 lbs. (3.52 t)
Propellants: Liquid hydrogen, liquid oxygen
Thrust: 418,000 lbs. (1,859 kN) at launch; 512,300 lbs. (2,279 kN), maximum at 109 percent power level
Burn time: 480 sec.
Artemis II completion date: December 2019

The Artemis II RS-25 engines were installed in the core stage during assembly at NASA's Michoud Assembly Facility in New Orleans.

Solid Rocket Boosters

Contractor: Northrop Grumman
Height: 177 ft. (53.9 m)
Diameter: 12 ft. (3.7 m)
Weight (each): 1.6 million lbs. (726 t) loaded, 219,000 lbs. (99.3 t) empty
Solid rocket motor: Five propellant segments
Propellant: Polybutadiene acrylonitrile (PBAN)
Thrust: 3.3 million lbs. (14,679 kN) each at launch; 3.6 million lbs. (16,014 kN) each maximum
Burn time: ~126 sec.
Artemis II completion date: Motor segments July 2019, forward and aft assemblies July 2024


Artemis II five-segment solid rocket boosters were stacked on the mobile launcher at NASA Kennedy.

Interim Cryogenic Propulsion Stage (Upper Stage)

Contractor: Boeing/United Launch Alliance
Designation: Interim Cryogenic Propulsion Stage (modified Delta Cryogenic Second Stage)
Height: 45 ft. (14 m)
Diameter: 16.7 ft. (5.09 m)
Weight: 72,197 lbs. (32.748 t) fueled; 8,200 lbs (3.719 t) unfueled
Engine: L3Harris Technologies RL10B-2, RL10C-2 (Artemis II/III)
Propellants: Liquid hydrogen/liquid oxygen
Maximum thrust: 24,750 lbs. (110.1 kN)
Reaction Control System (RCS): Hydrazine
Artemis II completion date: October 2023

**Data are approximate*


The four-story Artemis II interim cryogenic propulsion stage is seen here lifted for stacking on SLS to help send Orion to the Moon.

Launch Vehicle Stage Adapter

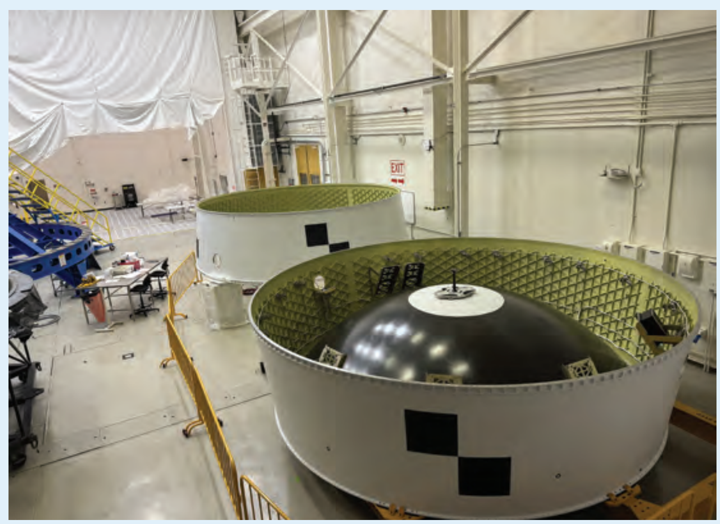
Contractor: Teledyne Brown Engineering
Height: 27.5 ft. (8.38 m)
Diameter: 27.5 ft. (8.38 m) bottom,
16.5 ft. (5.03 m) top
Weight: 10,000 lbs. (4.5 t)
Artemis II completion date:
June 2024

The Artemis II launch vehicle stage adapter at the Vehicle Assembly Building is seen here waiting to be stacked on the Artemis II rocket.

Orion Stage Adapter

Contractor: NASA's Marshall Space Flight Center
Height: 5 ft. (1.5 m)
Diameter: 18 ft. (5.5 m)
Weight: 1,800 lbs. (0.82 t)
Available volume for payloads: 516 $ft.^3$ (14.6 m^3)
Artemis II completion date:
August 2024

**Data are approximate*



The Artemis II Orion stage adapter is seen here complete and ready for CubeSats.

Secondary Payloads

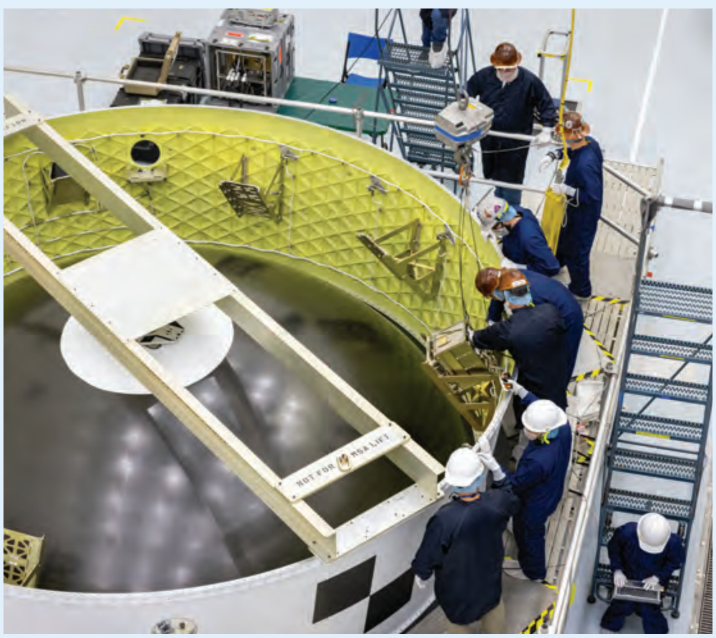
Artemis II will fly four CubeSat payloads roughly twice the size of the Artemis I CubeSats. Each fits into a volume measuring 14.4 in. (36.6 cm) x 9.4 in. (23.9 cm) x 8.8 in. (22.4 cm), not to exceed 57.3 lbs. (26 kg).

Name: ATENEA
Developer: Argentina National Space Activities Commission (CONAE)
Mission: Investigate radiation shielding, orbital design optimization, and long-range communications

Name: Space Weather CubeSat-1
Developer: Saudi Space Agency (SSA)
Mission: Measure various aspects of space weather such as radiation, solar X-rays, solar energy particles, and magnetic fields

Name: TACHELES
Developer: German Aerospace Center (DLR)
Mission: Demonstrate key in-space technologies, including electrical components, for future lunar logistics vehicles and operations

Name: K-Rad Cube
Developer: Korea AeroSpace Administration (KASA)
Mission: Measuring space radiation and its biological effect across the Van Allen radiation belts



Technicians install the Korea AeroSpace Administration (KASA) K-Rad Cube within the Orion stage adapter inside the Multi-Payload Processing Facility at NASA's Kennedy Space Center in Florida.

A technician inspects the Saudi Space Agency's Space Weather CubeSat-1 inside the Multi-Payload Processing Facility at NASA Kennedy.

SLS *and* ARTEMIS II

Artemis II will be a lunar flyby mission. Building on the success of the uncrewed Artemis I mission, which flew Nov. 16 to Dec. 11, 2022, the Artemis II test flight will be NASA's first Artemis mission with crew and will set the stage to land humans on the lunar surface on Artemis III. Launched by NASA's SLS (Space Launch System) rocket, the Artemis crew aboard their Orion spacecraft will confirm that the environmental control and life support, propulsion, navigation, and other systems operate as designed in the deep space environment.

The crew will use Orion to practice multiple maneuvers in Earth orbit, including rendezvous with the interim cryogenic propulsion stage (ICPS) as practice for the mobility required for future exploration missions. Orion will perform a translunar injection (TLI) burn to put the ship on a lunar free return trajectory in which the astronauts aboard the Orion spacecraft will fly by the Moon and use the Moon's gravity to slingshot around the lunar farside back to Earth. Like Artemis I, SLS will carry several small secondary payloads in its Orion stage adapter (OSA). These will be deployed after Orion completes the proximity operations demonstration and leaves the area.

Vehicle Integration at the Launch Site

With the manufacturing of SLS and Orion complete, components of the Artemis II launch vehicle were shipped to NASA's Kennedy Space Center in Florida where NASA's Exploration Ground Systems (EGS) team is making final installations and checks before assembling them into a launch-ready rocket as this guide was in development.

The major sections of SLS began arriving at NASA Kennedy in 2023 with the solid fuel rocket motors, followed by the core stage in 2024. Technicians began stacking the boosters on the mobile launcher in the Vehicle Assembly Building (VAB) in November 2024 and finished in February 2025. The core stage was bolted to the boosters in March 2025. The launch vehicle stage adapter (LVSA) was added in April and was integrated with the ICPS in May 2025.

The last major step before launch is testing the entire stacked Artemis II launch vehicle and confirming that the hundreds of thousands of parts from hundreds of companies across the country have been successfully assembled and mated into a flight-ready rocket. The Integrated Test and Check Out (ITCO) test series begins with SLS/Orion on the mobile launcher in the VAB at NASA Kennedy. It continues at Launch Complex 39B 4.2 miles from the VAB. The individual tests are below.

In the Vehicle Assembly Building:

The **Integrated Verification Test (IVT)** consists of powering the vehicle and utilizing reported health and status information to assess interface functionality.

The **Communications End-to-End Test (ETE)** tests all SLS and Orion communication systems that will demonstrate connections between Orion, SLS, ICPS, the Launch Control Center (LCC) at NASA Kennedy, and the Integrated Communications & Tracking Network, including Mission Control Center (MCC) at NASA's Johnson Space Center in Houston; the SLS Engineering Support Center (SESC) at NASA's Marshall Space Flight Center in Huntsville, Alabama; NASA's Goddard Space Flight Center in Greenbelt, Maryland; and satellites.

The **VAB Program Specific Engineering Test (PSET)** will check out connections, controls, and leak tests of the core stage, engines boosters, and ICPS.

The **Launch Release System (LRS) Signal Timing Test** will validate the data path from core stage flight computers to the booster ignition stage controllers, then to the LRS system on the mobile launcher.

The **Flight Safety System (FSS)** will be tested with the U.S. Space Force Space Launch Delta 45 Eastern Range for range command and receipt required by range safety regulation. This test includes installation of the flight termination system (FTS) simulators and system checkout pre-rollout, FTS end-to-end checkout for core stage and boosters, ordnance installation and mates, and mobile launcher hydrogen burn off igniter (HBOI) installation.

On Launch Pad 39B:

The **Pad Program Specific Engineering Test (PSET)** is associated with configuring the integrated SLS/Orion/ground systems for launch countdown that cannot be performed in the VAB due to safety and technical reasons. These include final vehicle ordnance/pyrotechnic testing (excluding the flight safety system). It also includes SLS and Orion pad specific testing.

The last test before launch will be a **tanking test/wet dress rehearsal (WDR)**. This consists of testing flight/ground interfaces and loading and draining of the cryogenic propellants using the new liquid hydrogen spherical tank and supporting infrastructure at Launch Complex 39B.

SLS/Orion Countdown, Launch, and Ascent

The Artemis II countdown begins more than 48 hours before launch with a "call to stations" for engineers and technicians working operations consoles and launch site infrastructure at the LCC at NASA Kennedy, the MCC at NASA Johnson, the SESC at NASA Marshall, and several contractor locations around the country.

This begins the process of readying the launch site and bringing SLS and Orion to life. Hundreds of steps – via umbilical cables on the launchpad – will turn on electrical power, bring on-line the flight computers, guidance and navigation systems, communications, and other avionics, and establish the flow of data between the launch vehicle and ground support systems. Propellant and pressurant valve positions will be checked. Once everything checks out, the launch team will give the go-ahead to begin filling the SLS core stage propellant lines and pressurant tanks. The goal is to be ready to launch when the launch window opens, providing the most efficient trajectory for intercepting the Moon.

Approximately ten hours before launch, the launch team will get a weather briefing that, along with the integrated rocket, spacecraft, and ground systems readiness, will lead to a decision to start tanking – filling the rocket with 756,000 gallons of liquid fuel and oxidizer. The four astronauts begin boarding Orion approximately four hours before launch as preparations continue.

Terminal countdown begins at T-10 minutes. In this time, SLS and Orion will switch from ground power to internal battery power. At T-33 seconds, the launch team commands SLS flight computers to begin an automated sequence of operations toward a precise time of launch.

Approximately six seconds before liftoff, the four RS-25 engines will start in sequence tenths of seconds apart and reach 100% thrust about one second before T-0. At T-0, the engines begin to ramp up to 109% thrust. At T-0, after more than 800 individual vehicle activation procedures since the call to stations, both boosters ignite, SLS-ground system umbilical connections are separated, and the rocket begins to rise.

At booster ignition, mission authority transfers from the NASA Kennedy Launch Control Team that has led the countdown to the Flight Control Team at NASA Johnson that will lead the remainder of the mission.

SLS clears the launch tower in seven seconds and initiates its roll maneuver. It reaches the speed of sound in approximately 55 seconds and, if necessary, throttles down engine thrust for about 25 seconds through the period of maximum dynamic pressure, or max Q, created as the speeding rocket pushes through the dense lower atmosphere.

Two minutes after liftoff, explosive bolts fire to separate the solid rocket boosters from the core stage, while the RS-25s are commanded down to 85 percent thrust for a few seconds to help separate the boosters cleanly before being re-commanded to 109 percent thrust. The boosters will splash down in the Atlantic Ocean about four minutes later, approximately 140 miles (225 km) off the Florida coast, north of the Bahamas.

The Orion launch abort system jettisons about three and a half minutes into flight as it is no longer needed for a safe abort by the spacecraft. SLS continues to climb, reaching maximum acceleration and maximum G forces on the crew seven minutes into the mission.

Approaching its targeted position in space, the core stage engines throttle down to engine cutoff roughly eight minutes after T-0, and core stage propellant valves begin closing. At this point, the integrated vehicle is traveling nearly 17,000 miles per hour (27,359 km/h) and is approximately 100 NM (185 km) in altitude.

Seconds later, the rocket coasts into its required target trajectory, and the Orion spacecraft and its ICPS in-space stage separate from the core stage. The core stage and launch vehicle stage adapter re-enter the atmosphere, mostly burning up. Any remaining pieces fall into the Pacific Ocean east of Hawaii, west of Baja, California.

The ICPS, which has been preparing its computers, guidance systems, and propulsion systems and engines, begins steering, establishes communications, and starts chilling its engine as Orion deploys its solar arrays and angles them slightly for onset of the ICPS first engine burn. The ICPS will place Orion and its crew in the necessary position to enable the spacecraft to reach the Moon.

About 50 minutes after launch, the ICPS fires its RL10 engine to start a 30-second perigee raise maneuver burn to raise the low point of its elliptical orbit. About an hour later, the ICPS fires its engine to begin its 20-minute apogee raise burn to raise the highest point in its elliptical orbit.

At that point, the upper stage begins safing itself by deactivating various systems. Orion separates from the stage approximately three hours and 25 minutes into the mission. Astronauts then begin manually testing Orion's controls and steering thrusters and start the proximity operations demonstration. The series of maneuvers – called the proximity operations demonstration – involves the Artemis II crew flying Orion, approaching ICPS, backing away, and maneuvering for roughly 70 minutes. As the demo concludes, Orion fires its European Service Module engine for two minutes to increase the separation distance from ICPS.

The ICPS then fires its thrusters one final time to begin its disposal burn. Following burn completion, the small breadbox-sized secondary payloads – twice that of the size of the shoebox size payloads flown on Artemis I – are ejected from the Orion stage adapter about five and a half hours into the mission. The stage's trajectory will send it to re-enter over the Pacific Ocean about 26 hours after launch.

Orion remains in high Earth orbit for about 25 hours before executing the translunar injection (TLI) burn to proceed to the Moon.

ARTEMIS II SLS MISSION EVENTS

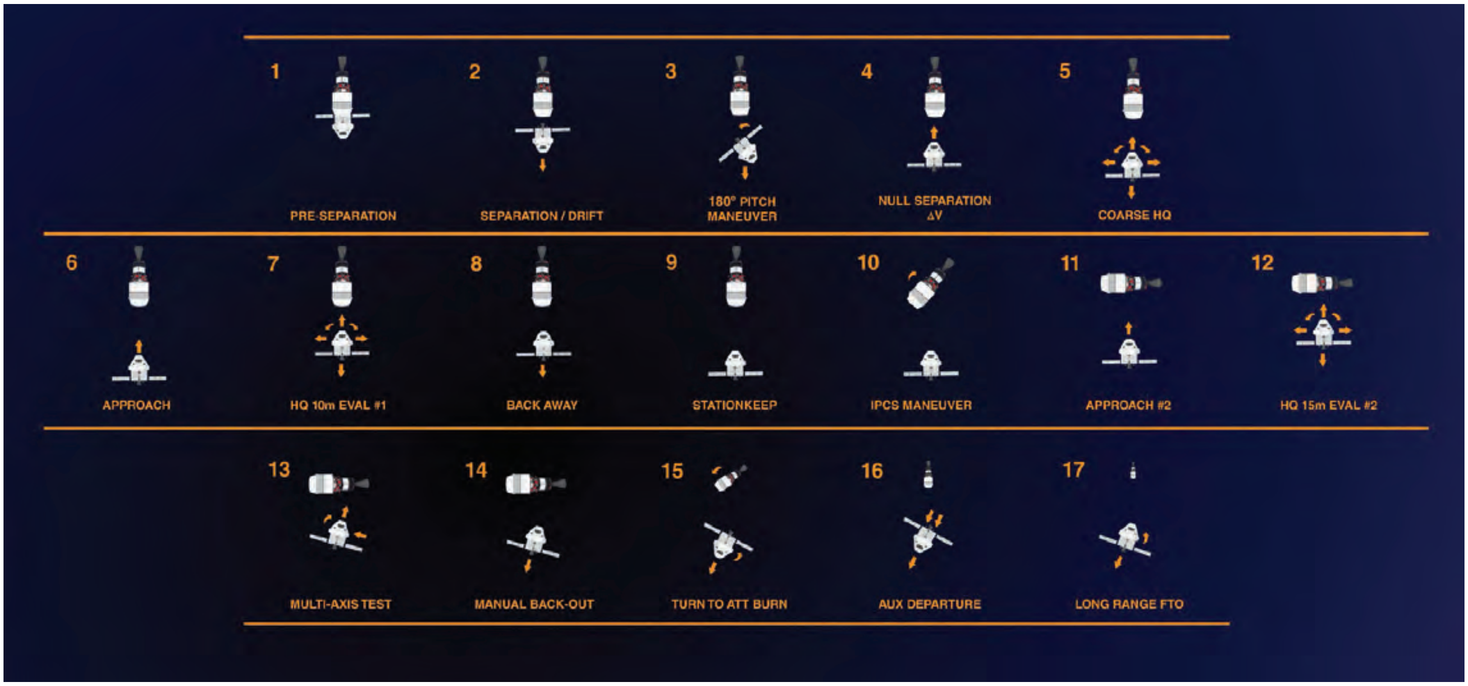
Note timings shown are approximate and will depend on specific day of launch.

	TIME hr:min:sec	SPEED (mph)	ALTITUDE (feet)	DISTANCE TRAVELED (statute miles)	DISTANCE TRAVELED (nautical miles)
Engine start	T - 00:00:06	0	0	0	0
Booster ignition engines to 109%. Core stage/ ICPS/ Orion umbilicals separate. First vertical motion. Control transferred from LCC to MCC.	0	0	0	0	0
Tower clear/initiate roll/pitch	00:00:07	70	468	0.1	0.1
Mach 1	00:00:55	710	25,745	5.1	4.4
Max dynamic pressure	00:01:11	1,041	43,795	9.1	7.9
All RS-25s commanded to 85%	00:02:04	2,989	139,757	39	34
SRB separation	00:02:08	3,006	148,384	43	37

TABLE CONTINUED					
	TIME hr:min:sec	SPEED (mph)	ALTITUDE (feet)	DISTANCE TRAVELED (statute miles)	DISTANCE TRAVELED (nautical miles)
All RS-25s commanded to 109%	00:02:08	3,006	148,384	43	37
LAS jettison	00:03:28	4,487	286,146	126	110
SRB Atlantic splashdown	00:06:10	10,222	405,175	441	383
Max acceleration/ max G	00:07:01	13,207	431,633	605	526
RS-25s throttle down to 67%	00:08:01	17,261	502,630	860	747
LAS Atlantic impact	00:08:05	17,522	509,752	879	764
Core stage MECO	00:08:06	17,599	511,884	885	769
Core stage/ICPS separation	00:08:18	17,627	534,564	944	820
ICPS perigee raise maneuver	00:49:52	14,145	7,181,309	12,053	10,473
ICPS apogee raise burn	01:46:37	18,510	701,589	26,965	23,432
Core stage Pacific splashdown	02:08:23				
ICPS/Orion separation	03:22:46	9,598	72,546,507	50,564	43,939
Start ICPS/Orion prox ops demo	03:23:36	9,552	73,128,169	50,697	44,054
End ICPS/Orion prox ops demo	04:53:36	6,460	125,055,993	62,376	54,203
Start Orion departure burn	04:53:15				
End Orion departure burn	04:55:15				
ICPS disposal burn	05:00:33	6,305	128,352,996	63,114	54,845
SPL deployment	05:20:23–05:24:23	5,896	137,337,463	65,129	56,595
Orion TLI burn	25:00:00				
ICPS splashdown	25:23:01	1,016	0	154,759	134,482

This table displays key SLS events and milestones in the Artemis II mission. The data are approximate based on pre-launch estimates. The values will also vary with launch date, time, weather conditions, and vehicle performance.

Artemis II: Proximity Operations Demonstration Sequence



Before Orion begins its lunar flyby, it will conduct a series of manual proximity operations maneuvers with the ICPS.

SLS and Related Updates for Artemis II

Artemis II retains the SLS Block 1 vehicle configuration that was used for Artemis I. The SLS core stage, engines, boosters, in-space stage, and adapters are basically unchanged from the first flight, but they incorporate mission-specific changes, as well as lessons learned.

In particular, the Artemis II ICPS incorporates several changes reflecting its larger role in the mission. The ICPS will serve as a passive target for an Orion proximity operations demonstration simulating docking maneuvers with other spacecraft for future Artemis missions although the two spacecraft will never make physical contact. The ICPS is outfitted with optical target assemblies on the outside of the stage and on the OSA diaphragm.

The stage will be inactive during the proximity operations demo. Crew will be able to monitor the stage via Orion's windows and docking camera, with telemetry voiced up from mission control. The stage will perform apogee and perigee raise burns before the rendezvous demo, while Orion will perform a final perigee raise burn and TLI burn following the demo. The ICPS will then perform a final burn and deploy its secondary payloads before an Earth atmospheric re-entry disposal above the Pacific Ocean rather than the Artemis I disposal trajectory around the Sun.

The in-space stage is equipped with a Global Positioning System in-space navigation capability. Its S-band antennas have been relocated for improved communication with the range safety system during launch. Abort triggers for the ICPS as well as core stage are enabled during launch. An emergency detection system provides the ICPS with the ability to detect, automatically respond to, and notify Orion of stage anomalies resulting in an abort condition. Other Artemis II differences associated with SLS include:

- Human rating certification
- SLS Flight Safety System adds a time delay to allow for Orion launch abort system crew escape
- Minor changes to SLS flight software reflecting Artemis II launch period and trajectory
- Core stage Power Distribution Control Unit (PDCU) updates to resolve timing issues
- Core stage self-sealing quick disconnect risk reduction change
- Strakes installed on intertank flanking booster attach points to reduce airflow-induced vibrations
- Booster separation motors rotated 15 degrees to ensure core stage clearance
- Booster separation motors have steel covers
- Booster separation will occur approximately four seconds earlier during ascent to test improved payload performance for SLS Block 1B missions; the exact timing is based on when the boosters reach a specific internal chamber pressure and thrust
- Pre-launch ITCO tests reduced from ten to seven
- Wet dress rehearsal/tanking test added to pre-launch checks instead of a core stage green run hot fire test to improve probability of launch on first attempt and minimize flight crew risk
- New secondary payloads in the OSA
- The mobile launcher at NASA Kennedy has been modified to accommodate crew and emergency egress and will also provide access to critical SLS systems including range safety flight termination system (FTS); SLS and mobile launcher have been instrumented to provide acoustic environments data to support mobile launcher 2 design
- The SLS/Orion launch window remains two hours; a new 1.2-million-gallon liquid hydrogen storage tank at the NASA Kennedy Launch Complex 39B will enable four launch attempts per week versus three for Artemis I:
  - 24 hours between first and second attempts
  - 48 hours between second and third attempts
  - 24 hours between third and fourth attempts

Artemis II Secondary Payloads

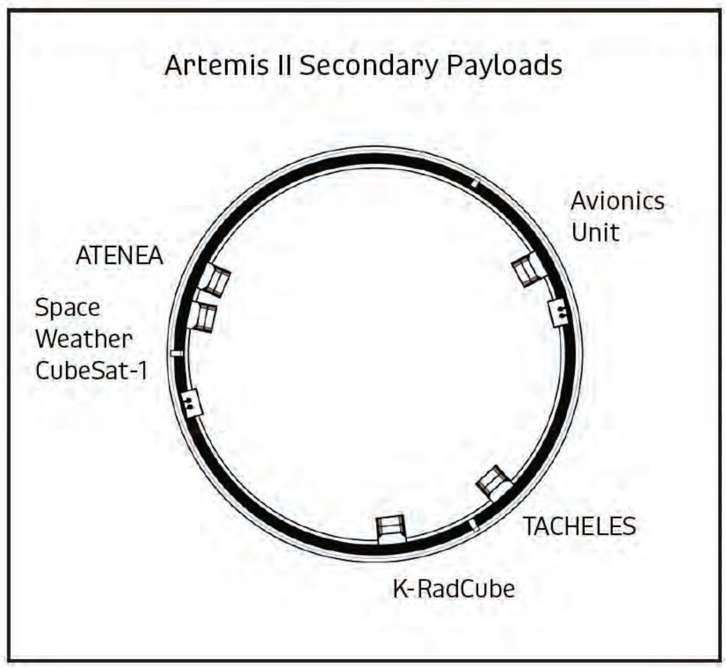
The unmatched SLS payload mass capability and the unused volume of the OSA provide a rare opportunity for small, low-cost science and technology experiments to hitch a ride on a launch with another primary mission.

The Artemis II mission will feature four 12U CubeSats from international partners as secondary payloads. These small spacecraft are twice the size of the 6U CubeSats that launched on the Artemis I mission. Following completion of the proximity operations demonstration, Orion's TLI burn to reach the Moon, and the departure burn of the ICPS, the secondary payloads will be deployed from the OSA.

The Artemis II mission is an opportunity for international partners to be involved with a deep space mission. The Artemis II CubeSats will be deployed about a third of the distance to the Moon on an Earth-return trajectory and will have the option of using propulsion systems to enter Earth orbit or conducting research during a day-long journey to Earth atmospheric re-entry. Developers are expecting to collect valuable data for their respective experiment and technology development.

Typically, secondary payload missions will be testing innovative propulsion and electronics technologies, studying space weather, analyzing the effects of radiation on organisms, and providing high-resolution imagery of Earth and the Moon.

The NEA Scout CubeSat payload was integrated into its dispenser prior to the Artemis I flight.



PAYLOAD NAME	BERTH	DESCRIPTION	DEPLOY AND DESTINATION	DEPLOYMENT TIME
ATENEA	11	A mission from the Argentina National Space Activities Commission (CONAE) that will perform several objectives including: measuring radiation doses with different shielding; measuring single photons using optoelectronic devices; collecting GPS data for orbital design optimization; and validating a long-range communications link.	Destination: Deployed in highly elliptical Earth orbit ending mission in Earth atmosphere <24hr due to no propulsion system	First secondary payload deployment occurs 2 minutes after ICPS end of mission. 00/05:29:10
TACHELES	3	Developed on behalf of the German Aerospace Center (DLR), the primary mission is to demonstrate and validate key technologies essential for lunar vehicles by highlighting their functional capabilities and performance in the space environment. TACHELES will collect measurements of crucial electrical components to determine their fitness for future lunar logistics operations.	Destination: Highly elliptical Earth orbit; plans are to use a propulsion system to raise perigee to allow for an extended service life	00/05:32:10 (3rd)
Space Weather CubeSat-1	10	A mission from the Saudi Space Agency (SSA) that will measure different aspects of space weather at a range of distances from Earth, collecting data on space radiation, solar X-rays, solar energetic particles, and magnetic fields.	Destination: Highly elliptical Earth orbit; will raise perigee to a few hundred kilometers	00/05:31:10 (2nd)
K-Rad Cube	5	A mission from the Korea AeroSpace Administration (KASA) that will utilize a Tissue-Equivalent Dosimeter to measure the space radiation environment and assess its biological effect at various altitudes across the Van Allen radiation belts.	Destination: Highly elliptical Earth orbit; will raise perigee to a few hundred kilometers	00/05:33:10 (4th)

The table above lists the Artemis II manifested payloads along with their provider, area of exploration, and a brief summary.

SLS BACKGROUND

NASA's SLS (Space Launch System) rocket is the primary crew transportation for the Artemis campaign as a part of NASA's framework for deep space exploration, including the Orion spacecraft, Exploration Ground Systems, advanced spacesuits and rovers, the Gateway in lunar orbit, and commercial human landing systems. SLS is the world's most capable rocket. No other rocket can send the Orion spacecraft, crew, and supplies directly to the Moon in a single launch.

SLS provides a unique capability to deliver exploration-class mass and volume for both human and robotic exploration to the Moon, Mars, and the outer planets.

SLS was established by the NASA Authorization Act of 2010. The program was created at NASA's Marshall Space Flight Center in Huntsville, Alabama, in 2011 and received funding in fiscal year 2012. SLS is the world's first exploration-class launch vehicle since the Apollo Program's Saturn V.

NASA's Exploration Systems Development Mission Directorate is developing SLS, as well as the Orion crew spacecraft, managed at NASA's Johnson Space Center in Houston, and Exploration Ground Systems at NASA's Kennedy Space Center.

SLS Design: Chosen from Thousands of Options

Super heavy-lift has been validated by numerous NASA and external studies. As NASA looked toward the space shuttle's retirement, the agency focused on a return to human deep space exploration and the needed super heavy-lift capability to make those missions a reality.

In defining the vehicle that would become SLS, NASA evaluated thousands of combinations of attributes such as propulsion systems; stages; boosters; performance; development and operations cost; mission complexity, reliability, and risks; and the ability to maintain critical industry base skills. The design selected became SLS – evolvable, capable of accommodating crew or cargo configurations, powered by a proven propulsion system, and providing a safe, human-rated launch capability.

The Artemis II core stage is seen here being lowered between the SLS solid rocket boosters in the Vehicle Assembly Building. The SLS design uses a proven propulsion system of solid rocket boosters and liquid-fueled RS-25 engines to launch more payload to the Moon than any rocket since the Saturn V.

SLS benefits from NASA's half-century of experience with efficient liquid oxygen and liquid hydrogen propellants. It also benefits from advances in technology and manufacturing practices. Further, by using common design elements, the SLS interfaces with the ground systems at NASA Kennedy, the Orion spacecraft, and future payloads will remain consistent over time, reducing complexity of deep space missions.

The SLS operational plan takes advantage of resources established for the space shuttle, including the workforce, manufacturing processes, tooling and facilities, transportation logistics, launch infrastructure, and liquid oxygen/liquid hydrogen propellants. By using heritage shuttle engines and boosters upgraded for SLS, the program saved the time and cost typical in developing new propulsion systems, and the SLS Program conducts flights with proven, reliable engine and booster hardware transferred from the Space Shuttle Program.

SLS's payload capability enables it to send large payloads to the Moon in a single launch. With the largest payload mass and volume of any currently operational rocket, SLS represents greater safety, less risk, and increased probability of mission success in the dynamic, unforgiving environments of spaceflight. More mass and volume translates into fewer launches, which reduces overall mission and architecture complexity and risk.

On the ground, it translates into simpler hardware design and less transportation, storage, processing, launch operations, and launch pad turnaround activities. SLS was designed for the most challenging deep space missions involving strategic commitments of national resources, national prestige, and human life. SLS represents the best balance of mission performance, safety, cost, and risk.

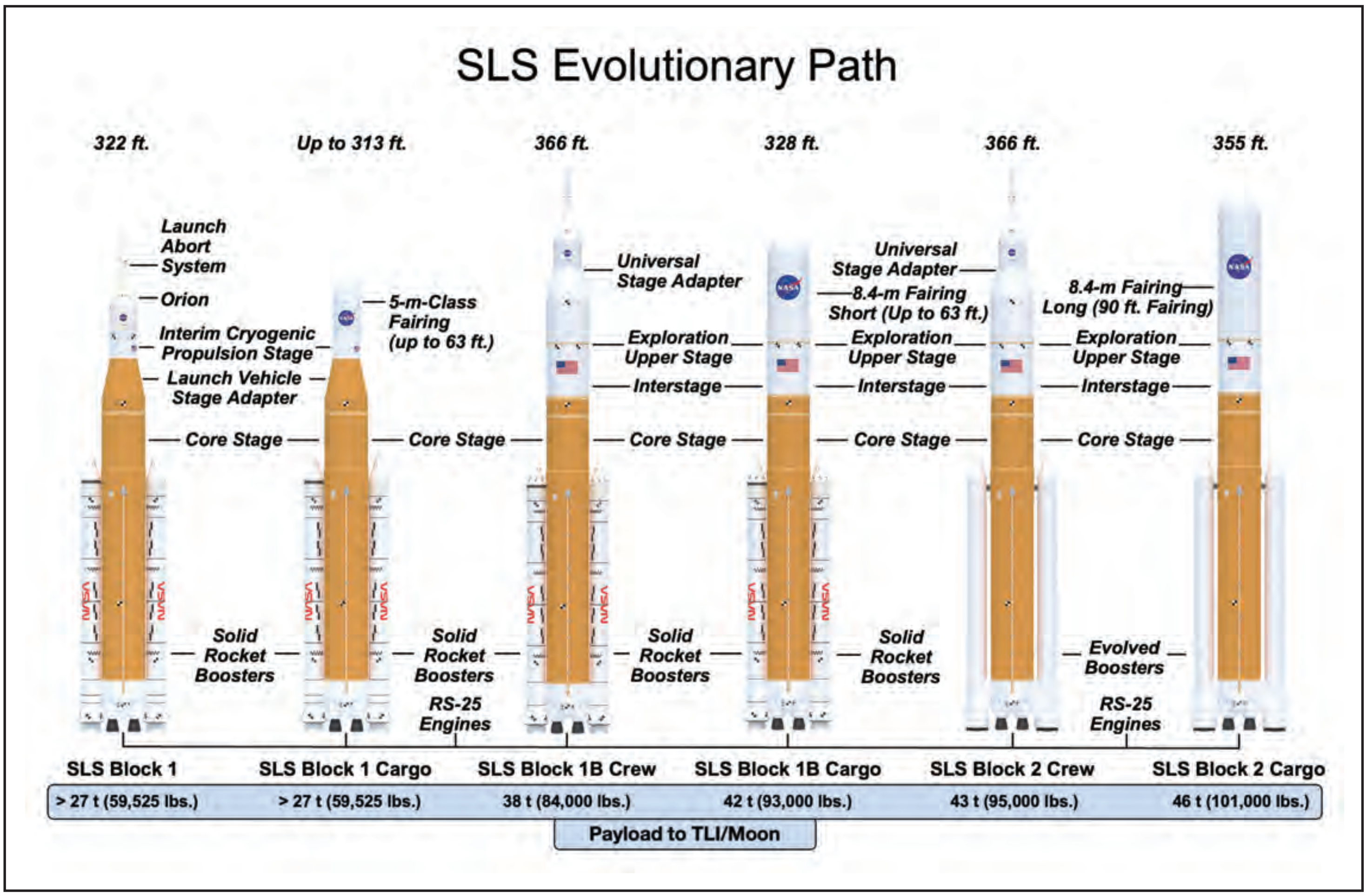
Dedicated ground test RS-25 engines were fired at NASA's Stennis Space Center in Bay St. Louis, Mississippi, to qualify engines to specific SLS operating conditions.

Common Elements and Evolvability

SLS evolvability supports a robust resumption of human exploration beyond low Earth orbit and an expeditious growth path as exploration missions become more complex and demanding.

All variants of the basic SLS design are based on common propulsion components:

- A central core stage housing propellant tanks, engines, avionics, and attach points for a pair of solid rocket boosters
- Four liquid propellant engines powered by cryogenic liquid hydrogen and cryogenic liquid oxygen from the core stage
- Two solid-propellant, side-mounted booster rockets that provide the majority of thrust and steering for the rocket during the first two minutes of flight, after which they are jettisoned
- An in-space upper stage fueled by liquid hydrogen and liquid oxygen



SLS Block 1 with an Orion spacecraft will launch the first three Artemis missions. Following Artemis III, SLS will evolve to a more powerful Block 1B configuration with the new exploration upper stage, replacing the interim cryogenic propulsion stage. The ultimate variant, Block 2, will incorporate evolved boosters to increase payload mass to translunar injection (TLI) to at least 101,000 lbs. (46 t).

Each succeeding SLS block variant grows more capable through upgrades to the engines, boosters, and upper stage, providing a flexible platform for a variety of human and robotic deep space missions, rather than requiring development of entirely new rockets to increase performance. In addition to flying Orion, SLS can also be outfitted with wide-diameter payload fairings in varying lengths.

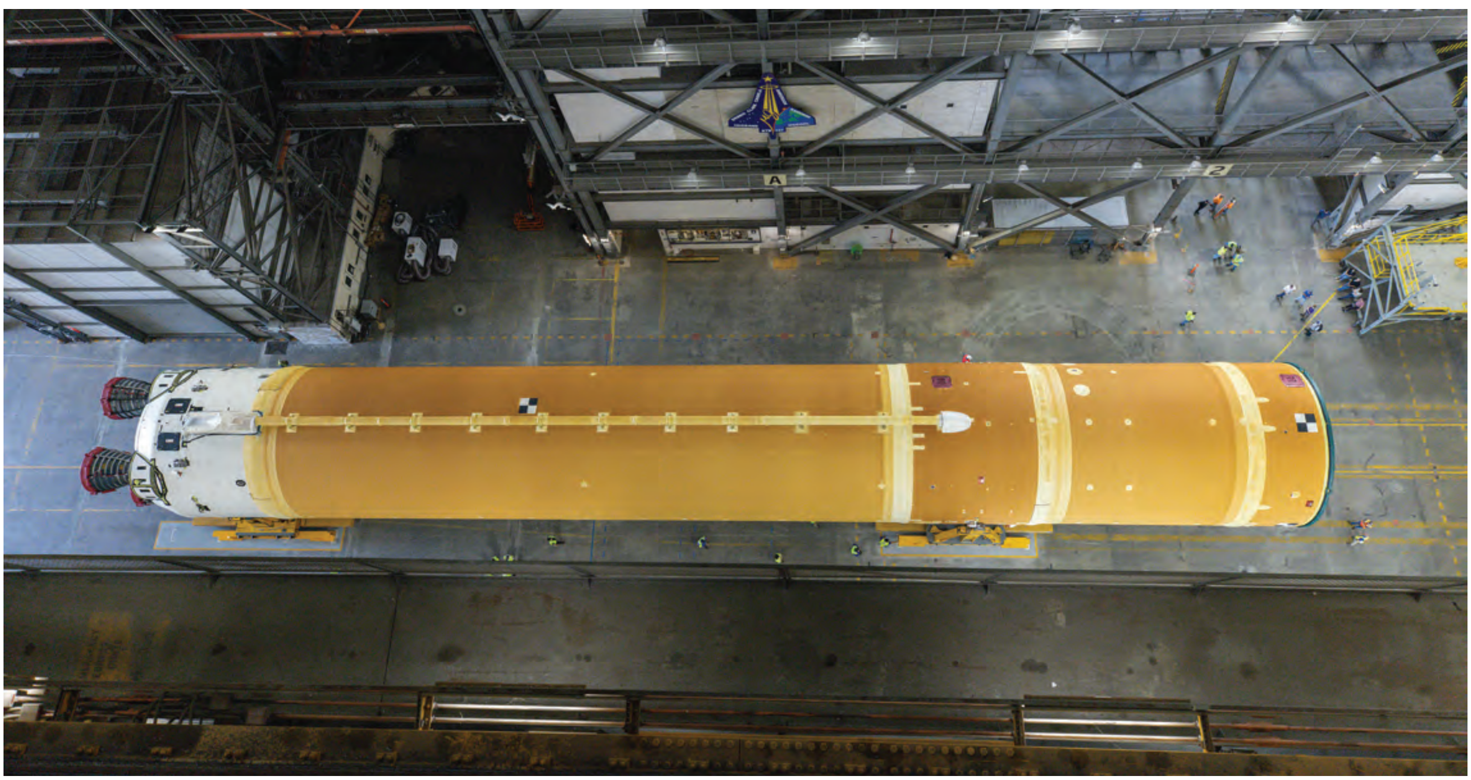
SLS Block 1 was used in Artemis I and will launch Artemis II and III. Beginning on Artemis IV, SLS will evolve to a more powerful Block 1B configuration with the new exploration upper stage (EUS) replacing the interim cryogenic propulsion stage (ICPS).

The ultimate variant, Block 2, will incorporate evolved boosters to increase payload mass to TLI to at least 101,000 lbs. (46 t).

Block 1 towers 322.4 ft. (98.27 m) and weighs 5.74 million lbs. (2,604 t) fueled. During ascent, the rocket generates 8.8 million lbs. (39,144 kN) of thrust – more than the Saturn V that launched the Apollo missions to the Moon. SLS will transport approximately 59,525 lbs. (27 t) to translunar injection (TLI).

The core stage, manufactured by Boeing at NASA's Michoud Assembly Facility in New Orleans, serves as the backbone of the SLS rocket. The core stage propellant tanks hold 537,000 gal. (2 million L) of cryogenic liquid hydrogen and 196,000 gal. (741,941 L) of cryogenic liquid oxygen. Total propellant weight is 2.2 million lbs. (998 t). The stage operates for approximately 480 seconds, after which separation from the ICPS, Orion stage adapter (OSA), and Orion will occur.

The core stage engine section contains four RS-25 engines manufactured by L3Harris Technologies and transferred from the Space Shuttle Program with new controllers and minor modifications for SLS requirements.



The 212-ft. (64.6-m) core stage for Artemis II is seen in the transfer aisle of the Vehicle Assembly Building in preparation for lifting and integration on the mobile launcher. Manufactured by Boeing at NASA's Michoud Assembly Facility in New Orleans, the stage houses the four RS-25 engines, propellant tanks, and flight computers. Too large to ship over land, the SLS core stage is transported by NASA's barge Pegasus from NASA Michoud to NASA Kennedy over water for integration with the rest of the vehicle.

The five-segment solid rocket boosters are based on the space shuttle four-segment boosters and made by Northrop Grumman. The solid propellant motors are cast in Promotory, Utah, and shipped to NASA Kennedy. The forward and aft assemblies are manufactured and assembled at NASA's Booster Fabrication Facility at NASA Kennedy. The SLS boosters also use hardware transferred from the Space Shuttle Program, including steel cases, nose cones, frustums, aft skirts, and more. The SLS solid rocket boosters are the largest and most powerful solid rocket boosters ever built for spaceflight. In addition to the extra propellant segment, the SLS boosters incorporate new insulation, avionics, modified propellant grain design, and nozzle design.

The upper stage on the SLS Block 1 is the ICPS, a commercial stage modified for the SLS mission. The ICPS is powered by a liquid hydrogen/liquid oxygen system with a single L3Harris Technologies RL10 engine. It also contains the avionics to fly the mission after core stage separation until Orion separates from the ICPS. The stage is manufactured by Boeing/United Launch Alliance (ULA) in Decatur, Alabama.

The ICPS is partially enclosed by a launch vehicle stage adapter (LVSA), which has a separation system that fires to separate itself and the core stage from the ICPS and Orion. On top of the ICPS, the Orion stage adapter connects the Orion spacecraft to SLS. The adapter will also carry and deploy four 12U CubeSats during the Artemis II mission.

SLS: SUPER HEAVY-LIFT ROCKET FOR GAME-CHANGING SPACE EXPLORATION MISSIONS

- Block 1 in its crew configuration (with Orion) will transport more than 209,000 lbs. (95 t) to low Earth orbit and more than 59,000 lbs. (27 t) to TLI
- Block 1B's crew variant will launch more than 231,000 lbs. (105 t) to low Earth orbit and more than 83,000 lbs. (38 t) to TLI
- Block 2 in the crew configuration will carry more than 286,000 lbs. (130 t) to low Earth orbit and more than 94,000 lbs. (43 t) to TLI
- The design for each variant's cargo version is capable of launching thousands more pounds to low Earth orbit and TLI compared to its crew variant
- SLS with a 27.6-ft. (8.4-m)-diameter payload fairing offers immense volume for large payloads, such as habitat modules, space telescopes, and interplanetary probes; additional stages can even be encapsulated with a spacecraft to make high-energy missions to the outer planets possible
- The ultimate Block 2 design in its cargo configuration can launch more than 101,000 lbs. (46 t) to TLI and more than 80,000 lbs. (36 t) to Mars

More Powerful Rockets for Future Missions

The initial SLS Block 1 rocket configuration was used for Artemis I and is manifested for the Artemis II and III missions. The Block 1B variant will follow the Block 1 rocket design. The Block 1B variant incorporates several upgrades to improve SLS performance, allowing the rocket to launch larger and heavier payloads to deep space destinations.

The primary increase in performance for the Block 1B rocket will come from replacing the single-engine ICPS with the new, more powerful four-engine EUS. SLS Block 1B uses the same core stage and twin five-segment solid rocket boosters as the Block 1 rocket. New-production RS-25 engines, which will debut on Artemis V, will cost 30 percent less to manufacture. They will provide SLS with almost 40,000 pounds (178 kN) more thrust than the shuttle-heritage RS-25 engines on the first four Artemis missions, which translates to 992 extra pounds (0.45 t) of payload to the Moon.

The Block 2 variant retains the core stage, RS-25 engines, and EUS but replaces the Block 1 steel case booster motor design with a lighter composite case, new propellant formulation, and other upgrades that increase overall payload performance.

Super Heavy Lifting on the Ground: SLS Transportation, Logistics, and Pathfinders

NASA has not built a rocket on the scale of SLS, able to take astronauts and cargo to the Moon, since the Saturn V rocket of the Apollo Program in the 1960s and 1970s.

For SLS, engineers had to adapt existing ground support vehicles and equipment and develop a variety of full-scale "pathfinders" – simulators – to pave the way for safe, smooth handling, lifting, and shipping operations.

For transportation, the Artemis II SLS relied on specialized ground support equipment (GSE). This is a set of modular equipment ranging from smaller brackets, shackles, and pins that secure the giant rocket hardware to the slow, flatbed motorized transports, such as the self-propelled modular transporters and multi-purpose transportation systems that move rocket components between buildings, test stands, and transportation vehicles.

Like the flight hardware that depends on it, the ground support equipment was designed and built to exact specifications, and its uses – and instructions for those uses – are documented in detail. Every move is carefully choreographed by the operations teams that use it.

Pathfinders mimicking shape, size, weight, center of gravity, and handling interfaces, provided realistic practice handling, lifting, and transport operations using newly designed ground support equipment at NASA Michoud, NASA's Stennis Space Center in Bay St. Louis, Mississippi, and NASA Kennedy before teams worked with the Artemis I core stage. Ground support equipment continues to play a critical role in safely and securely moving large SLS components around factory floors and test and launch facilities.

The Dynamic Demonstration Unit allows workers to practice handling the SLS core stage.

An Artemis II booster segment is seen here being lifted from its ground support equipment transportation cradle and readied for lifting with its "four point lifting beam" in the VAB.

NASA's barge Pegasus is the largest vehicle used to transport SLS elements as well as the core stage pathfinder. Pegasus ferried the Artemis I and Artemis II core stages from NASA Michoud, where they were manufactured, to NASA Kennedy. Pegasus also transported the Artemis I and II launch vehicle stage adapters from NASA Marshall to NASA Kennedy.

Pegasus was designed and built in 1999 to transport space shuttle external tanks from NASA Michoud to NASA Kennedy. It replaced the Poseidon and Orion barges that were used to carry Saturn rocket stages and hardware for the Apollo Program. Pegasus was modified in 2014 to carry the longer SLS core stage. A 115-ft. (35-m) section was removed and replaced with a 165-ft. (50-m) section capable of carrying more weight and lengthening Pegasus from 260 ft. (79 m) to 310 ft. (94 m). Pegasus has no engines and instead is moved by tugboats and towing vessels.

ULA uses its R/S RocketShip, formerly the Delta Mariner, to transport the ICPS from its rocket factory in Decatur, Alabama, to the Delta Operations Center near NASA Kennedy prior to stacking in the Vehicle Assembly Building.

Engineers test drove a self propelled modular transporter used to carry the SLS core stage at NASA Michoud.

A lifting fixture called a "spider" is seen here attached to the Artemis II core stage in the VAB.

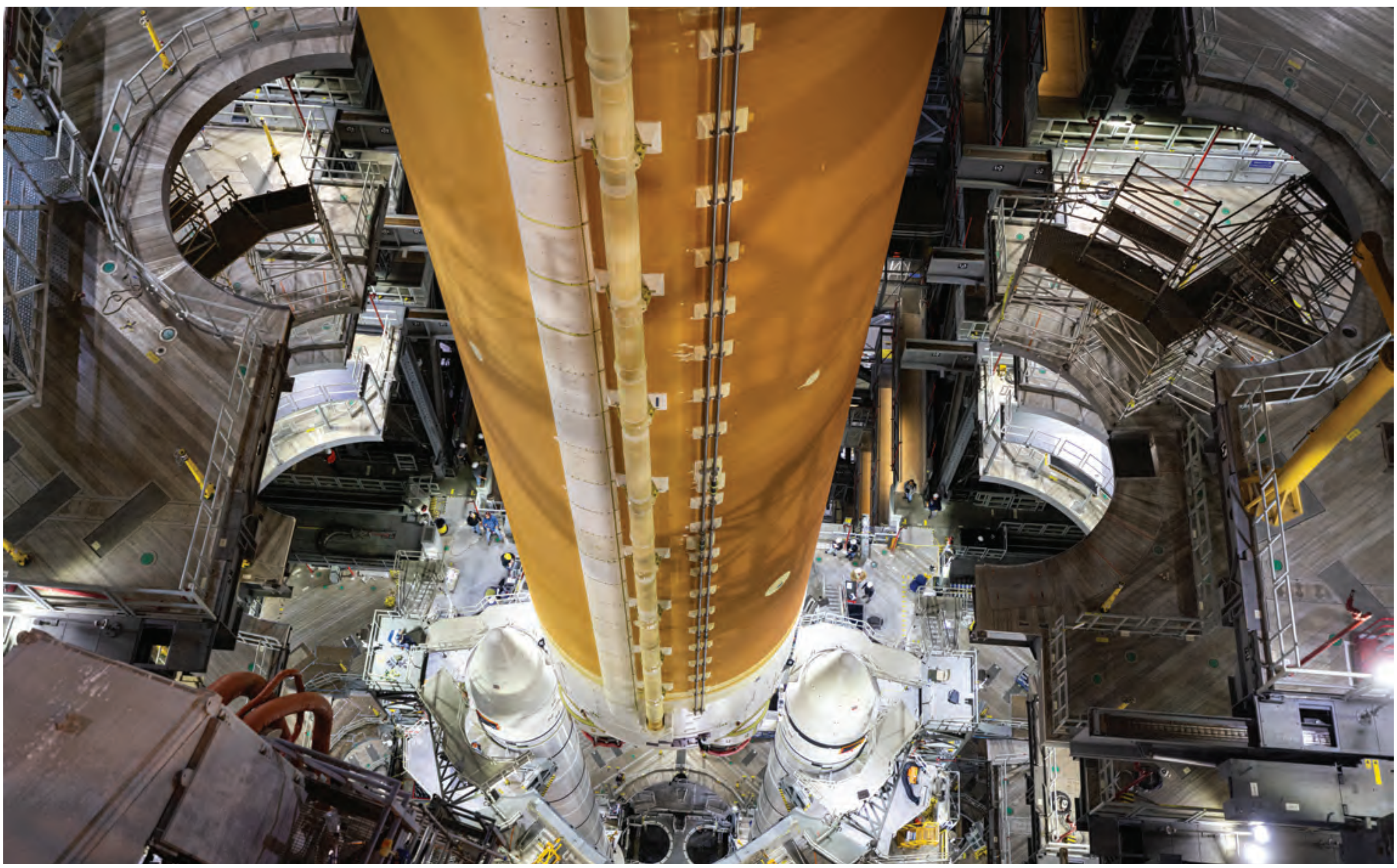
NASA's Pegasus barge carrying the Artemis II SLS core stage arrived at NASA Kennedy turn basin wharf in July 2024.

Thermal Protection System

SLS has several distinctive external features. The orange color of the core stage is the thermal protection system, or spray-on foam insulation. This insulation, along with other materials such as cork, provides thermal protection for every part of the rocket, although it is most visible on the core stage. The insulation is flexible enough to move with the rocket but rigid enough to take the aerodynamic pressures as SLS accelerates from 0 to 17,400 mph (28,003 km/h) and soars to more than 100 NM (185 km) above Earth in just 8 minutes.

The cryogenic propellants (liquid hydrogen and liquid oxygen) that power the RS-25 engines must stay extremely cold to remain liquid. Hydrogen must remain at -423 degrees Fahrenheit (-253 degrees Celsius) and oxygen at -297 degrees Fahrenheit (-183 degrees Celsius). If temperatures rise too high, the propellant will become a gas and must be vented overboard. The insulation helps minimize losses that require the stage to be replenished during countdown.

Materials engineers qualified the third-generation, orange-colored spray-on foam insulation to meet the harsh environments that the SLS will experience. At the same time, they made the foam more environmentally friendly. When the foam is applied, it gives the rocket a light-yellow color that the Sun's ultraviolet rays eventually "tan," giving the SLS core stage its signature orange color.



The SLS gets its signature orange color when its spray-on foam insulation darkens with exposure to sunlight.

Livery and Photogrammetric Markings

In addition to the SLS core stage's distinctive orange color, several other markings are visible on the outside of the rocket. The most visible are the national and agency livery markings such as "USA," the U.S. flag, the NASA "meatball" and "worm" logos, and the ESA (European Space Agency) logo.

The Artemis II SLS, Orion crew spacecraft, and the mobile launcher are painted with a variety of black and white checkerboards, squares, and circles. These photogrammetric markings serve as imagery references for engineering photo and video documentation and post-flight analysis of SLS attitude and position relative to ground structure during liftoff and ascent. Markings range in size from 0.2 in. (0.5 cm) in diameter to 3 x 3 ft. (0.9 x 0.9m). On the solid rocket boosters, some of the markings are a multi-checkered pattern measuring 24 x 130 in. (0.61 m x 3.3 m).

For Artemis II, the number and placement of the markings are almost identical to those of Artemis I – 176 for Artemis II versus 178 for Artemis I. For Artemis II, SLS has 122 total markings and Orion has 54.

Some of the markings are visible only to the internal cameras that capture separation and jettison events. The LVSA has eight internal markings, ICPS has four. The forward bay of the European Service Module has 30, the spacecraft adapter has 12, and spacecraft adapter jettison panels have 12 markings.

Notable additions for Artemis II are two optical target assemblies to aid astronauts during the proximity operations rendezvous activity – one mounted on the outside of ICPS and one on the diaphragm inside the OSA.

Engineers are interested in every movement of the rocket, both independently and in relation to the mobile launcher, in every phase of flight, from the launch pad to its return to Earth. Most of the markings will be used during separation events, such as liftoff from the mobile launcher, boosters from the core stage, core stage/LVSA from the ICPS, and ICPS/OSA from Orion and its service module.

The imagery markings help to characterize these movements, and the data will feed back into computer models to understand actual versus predicted movements.

Workers are seen here painting the red NASA "worm" logo on the side of an Artemis II solid rocket booster motor segment at NASA Kennedy.

Every key launch event and its marking were analyzed for placement in relation to SLS built-in cameras and ground cameras. Key considerations were where to place onboard and mobile launcher cameras to survive the harsh launch and ascent environments, as well as where ground cameras are located.

SLS has four cameras on the engine section that look forward, two on the intertank looking aft and two inside the launch vehicle stage adapter to capture the ICPS separation event. The engine section cameras are forward-facing and have a tilt of 10 degrees and a pan of 0 degrees. The aft facing intertank cameras have a tilt of 2.5 degrees and a pan of 5 degrees. There are more than 150 ground cameras used for inspecting or monitoring the vehicle during launch. A few of those are for public affairs purposes, but most of them provide imagery to engineers. Airborne and ship-based imagery is also used during re-entry and recovery of Orion.

Instrumentation and Vehicle Telemetry

One of the most important products generated by any mission is flight data collected on the ground and in flight. That information is used to validate the design and computer models of predicted performance, and to assess any differences or anomalies with implications for future missions. For SLS, much of that flight data will be generated by sensors placed throughout the rocket on the outside and inside, and measurements from the engines, boosters, core stage, and ICPS.

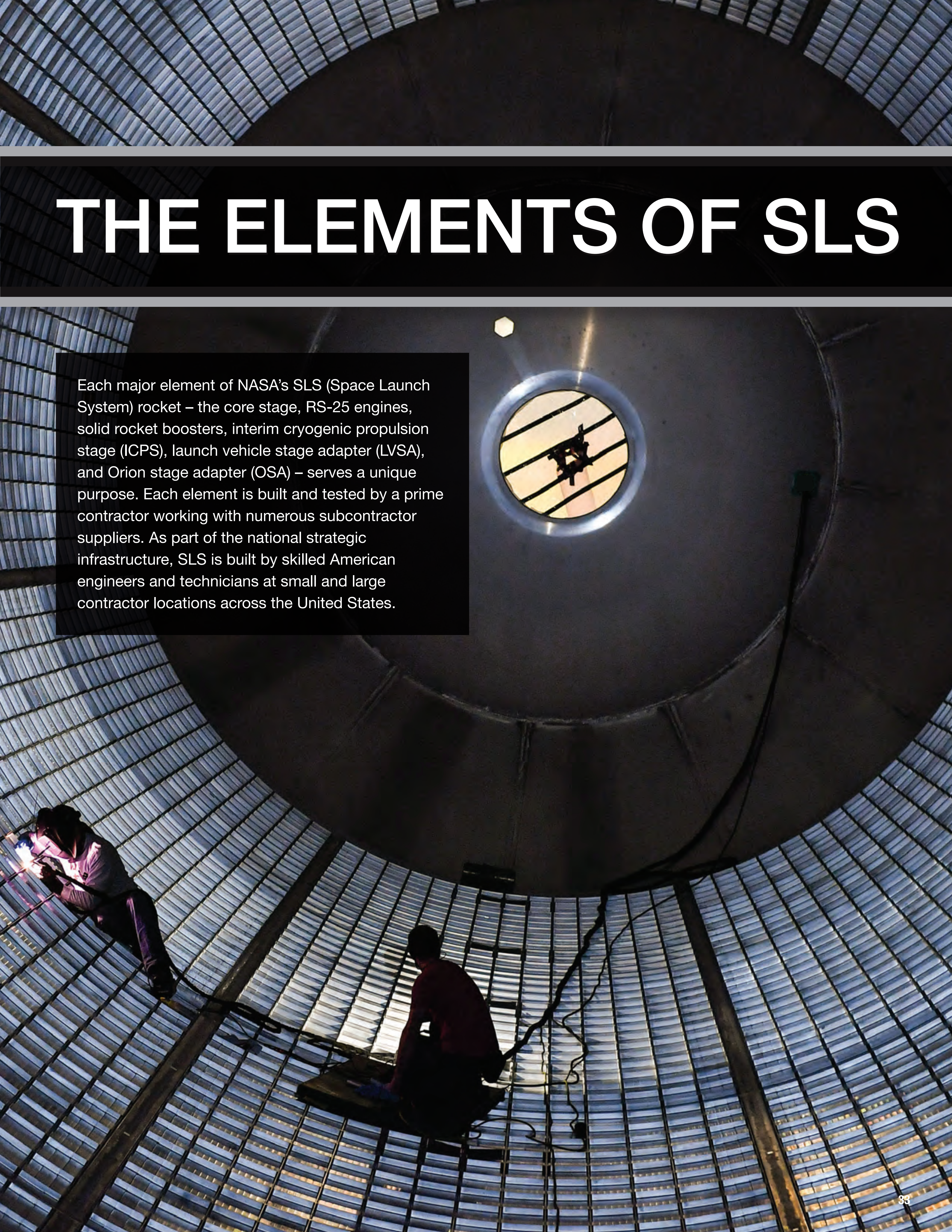
That data and instrumentation to capture the data is divided into three categories: operational flight instrumentation, engineering flight instrumentation, and development flight instrumentation. Operational data is hardware and/or software required to operate the vehicle. Engineering data is hardware or software data mainly used for post-flight performance analysis. Developmental data is used to increase confidence in the computer models – predictions – of how the vehicle should perform.

As with Artemis I, the Artemis II SLS will transmit data from more than 27,000 sources to the ground for analysis. Of those, more than 20,000 channels will be operational and engineering data with the rest devoted to development data. Each element – core stage, engines, boosters, payload, command telemetry, and imagery – has a specified allocated bandwidth for transmission during flight.

All this data will be collected and analyzed to ensure SLS is the most reliable, highest-performing, and safest rocket that NASA has ever developed. Engineers will rigorously test all the systems in deep space because Artemis II will set the stage for Artemis III, the first human Moon landing since the Apollo Program.

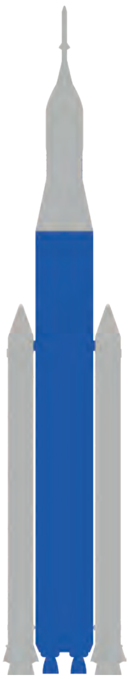
Part of the Kennedy Uplink Station, the S-band ground tracking system at NASA Kennedy provides crucial tracking and communication capabilities following liftoff of SLS and Orion.

THE ELEMENTS OF SLS



Each major element of NASA's SLS (Space Launch System) rocket – the core stage, RS-25 engines, solid rocket boosters, interim cryogenic propulsion stage (ICPS), launch vehicle stage adapter (LVSA), and Orion stage adapter (OSA) – serves a unique purpose. Each element is built and tested by a prime contractor working with numerous subcontractor suppliers. As part of the national strategic infrastructure, SLS is built by skilled American engineers and technicians at small and large contractor locations across the United States.

Core Stage



Overview

The SLS core stage is manufactured at NASA's Michoud Assembly Facility in New Orleans, where the Apollo Program's Saturn rocket stages and the space shuttle's external tanks were manufactured. Boeing, as the prime contractor for the SLS core stage, is responsible for the design, manufacturing, and testing of the stage. The core stage is the tallest single rocket stage NASA has ever flown. It measures approximately 212 ft. (64.6 m) tall and 27.6 ft. (8.41 m) in diameter (excluding thermal protection system foam and flanges). Its fully fueled weight, excluding engines, is 2.4 million lbs. (1,089 t).

The SLS core stage contains four RS-25 engines, their liquid hydrogen and liquid oxygen propellant supply, and the avionics and software that control SLS operation and flight until the core stage separates from the ICPS. It is literally the core of SLS, supporting other stages, spacecraft, and payloads atop its upper-most section and serving as the attach point for the two solid rocket boosters.

The core stage is designed to operate for the entire approximately 480-second launch from ground to Earth orbit, reaching speeds of nearly Mach 23 and more than 530,000 ft. (161.5 km) in altitude before it separates from the ICPS, OSA, and Orion spacecraft.

The core stage is a major new development for the SLS Program, while other key elements, such as the RS-25 engines, solid rocket booster structures, and ICPS have previous spaceflight experience.

Legacy Hardware

A key goal of the SLS design was to reuse space shuttle components or design within shuttle heritage experience where possible. For example, the core stage has the same diameter as the shuttle external tank and the propellant feedlines, and the fill and drain ducts were sized around heritage joints and existing valves.

Major Sections

The core stage is made up of 10 major barrel sections, four dome sections, and seven rings. Each cylindrical barrel section consists of eight aluminum panels which vary in length and height depending on the section.

Those panels are friction-stir welded or bolted vertically and horizontally to form the five major sections of the core stage:

- Engine section
- Liquid hydrogen tank
- Intertank
- Liquid oxygen tank
- Forward skirt

The SLS core stage, the tallest rocket stage NASA has ever built, is seen here being lowered between the Artemis II boosters in the Vehicle Assembly Building.

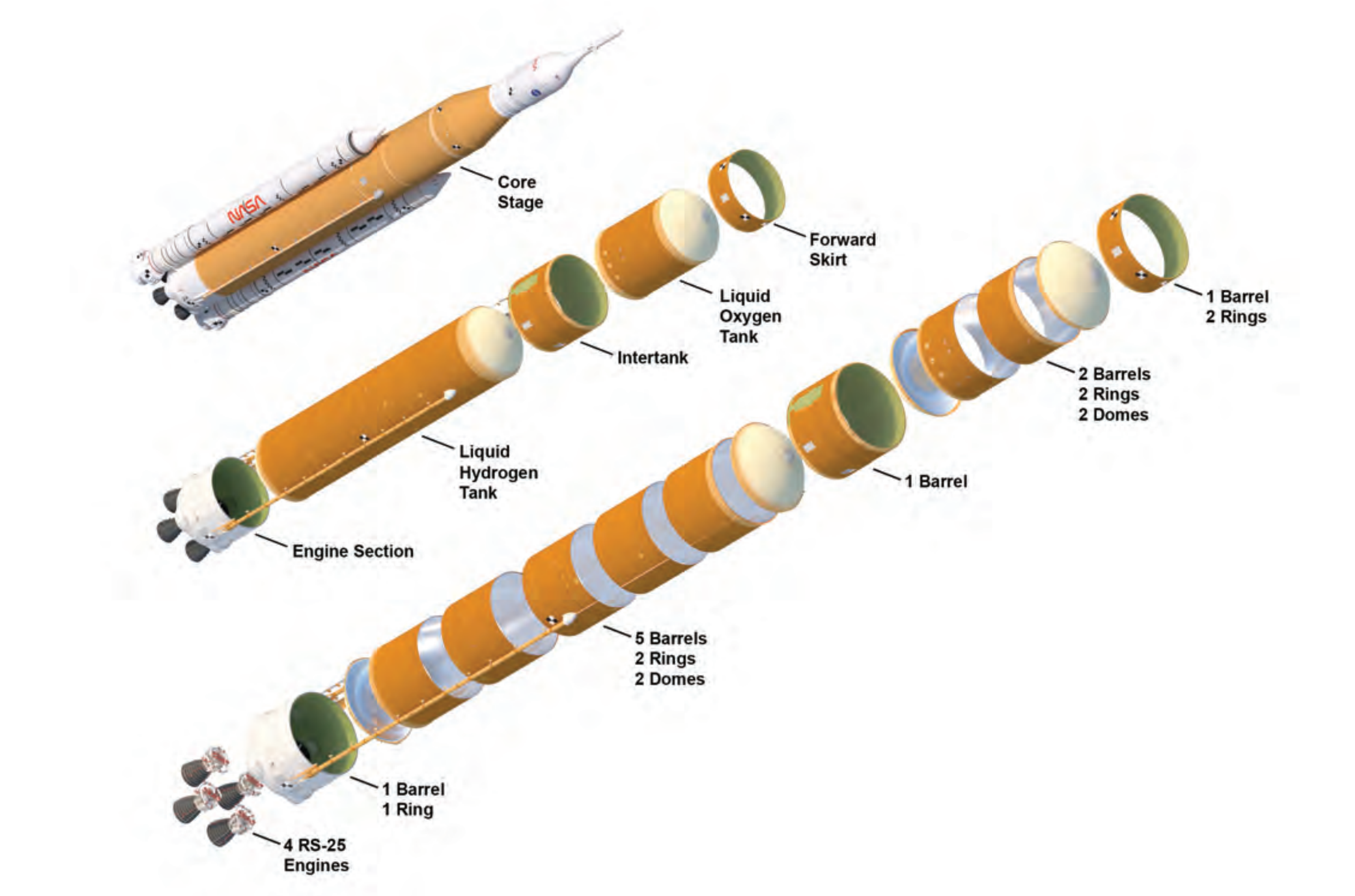
Engine Section

Beginning at the bottom, or aft end, of the stage, the engine section houses four RS-25 main engines, the engine thrust structure, propellant ducts, various avionics systems, and engine thrust vector control systems, and serves as the aft attach point for the two solid rocket boosters.

The engine section consists of a single barrel section 27.6 ft. (8.41 m) in diameter and 22.5 ft. (6.86 m) tall. It consists of welded aluminum isogrid panels. An aerodynamic boattail fairing at the bottom channels airflow and protects the engines from extreme temperatures during launch.

Liquid Hydrogen Fuel Tank

The liquid hydrogen fuel tank is 27.6 ft. (8.41 m) in diameter and 130 ft. (39.6 m) tall. It consists of five welded barrel sections each 22 ft. (6.7 m) tall and two end domes. The aft end of the liquid hydrogen tank includes four liquid hydrogen feedlines to the RS-25 engines. The tank has a capacity of 537,000 gal. (2 million L) of liquid hydrogen.



The SLS core stage is comprised of 10 barrel sections, four dome sections, and seven rings as shown in this illustration of the core stage major components.

Intertank

The intertank separates the upper hemispherical dome of the liquid hydrogen tank from the lower hemispherical dome of the liquid oxygen tank and serves as the forward attach point for the boosters. The intertank measures 27.6 ft. (8.41 m) in diameter and 21.8 ft. (6.64 m) tall. It contains a thrust structure to carry loads imparted by the solid rocket boosters during ascent. The intertank also contains several avionics components, including two rear-facing cameras. The intertank is the only section that is bolted together instead of welded on the core stage. This provides an added layer of strength to help carry the loads of the boosters' weight and thrust.

Workers at NASA's Michoud Assembly Facility in New Orleans are shown here preparing to join the core stage liquid hydrogen tank (left) to the core stage forward assembly (right) comprising the forward skirt, liquid oxygen tank, and intertank.

Liquid Oxygen Tank

The liquid oxygen tank is 27.6 ft. (8.41 m) in diameter and 51 ft. (16 m) tall. It consists of two 15.6-ft. (4.75-m) barrel sections made from isogrid aluminum panels and two domes. Liquid oxygen is fed to the engine section and engines through a pair of "downcomer" ducts that exit the intertank on opposite sides and run down the core stage. The liquid oxygen tank has a capacity of 196,000 gal. (741,941 L). The thermal protection system on the tank minimizes boiloff of the -297 degrees Fahrenheit (-183 degrees Celsius) liquid oxygen. Gaseous oxygen is vented overboard.

The Artemis II core stage liquid oxygen tank is seen here completing cleaning and prepares to move to another area for spray insulation at NASA Michoud.

Forward Skirt

The forward skirt is located at the top of the core stage. It connects the core stage to the Integrated Spacecraft/ Payload Element. The aluminum isogrid structure is 27.6 ft. (8.41 m) in diameter and 10.4 ft. (3.17 m) tall. It houses the majority of the vehicle's avionics and has connections to launch pad utility umbilicals, the vehicle stabilization system that helps secure SLS to the mobile launcher, access doors, vent system, pressurant lines, and antennas.

The Artemis II core stage forward skirt is seen here undergoing outfitting at NASA Michoud.

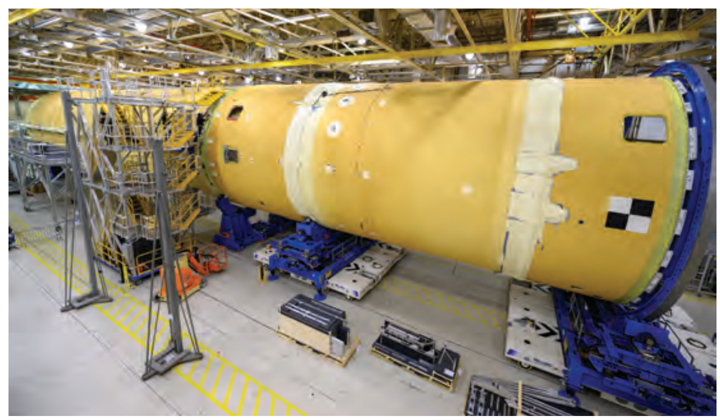
Main Propulsion System

The main propulsion system in the core stage consists of the ducts, valves, and other equipment that supply and control the flow of liquid hydrogen and liquid oxygen propellants, as well as gaseous helium and nitrogen pressurants for valve actuation and line/volume purges. To accomplish those functions, the main propulsion system has four subsystems:

- Liquid oxygen
- Liquid hydrogen
- Pressurization
- Ground System Supplied Pneumatics (pre-launch)

Major drivers in the design of the main propulsion system included the main propellant tank configuration, main engine configuration, reliability and affordability, mission requirements, and component mounting. For example, the main propulsion system flow rates and interfaces were designed around the RS-25 engine configuration and the need to supply propellants to the engines under temperature and pressure conditions required by the engines. The orientation of the engine hydrogen and oxygen feedlines in the engine section determined the feed system layout for the main propulsion system.

Workers are seen here moving the Artemis II core stage engine section at NASA Michoud.



Workers are seen here connecting feedlines and other external components to the fully assembled Artemis II core stage at NASA Michoud.

Artemis II Updates

Based on Artemis I lessons learned, the core stage Power Distribution Control Unit (PDCU) has been updated to resolve timing issues during countdown. A self-sealing quick disconnect was added to the thrust vector control system to reduce leak risk. Strakes approximately 7.5 feet (2.3 m) long are installed on intertank flanking booster attach points to reduce airflow-induced vibrations.

Prior to the successful Artemis I test flight, extensive testing on the materials and manufacture of the core stage and its elements proved the stage to be capable of performing its role on SLS. For more information about the manufacturing, testing, and checkout of the core stage, please refer to the core stage section in the Artemis I Reference Guide.

Engineers at NASA Michoud inserted 360 bolts to connect the forward assembly to the liquid hydrogen tank to make up the bulk of the core stage.

Core Stage Fun Facts

- There are 562 cables in the core stage; the largest number of cables – 231 – are located in the engine section
- There are 45 mi. (72 km) of cabling in the core stage and more than 18 mi. (29 km) in the engine section alone
- There are 775 independent sensors that have wire routing to them
- There are approximately 100,000 clamps and ties securing wires and cables throughout the core stage
- The liquid hydrogen tank shrinks about 6 in. (15 cm) in length and 1 in. (2.54 cm) in diameter when filled with cryogenic fuel
- The liquid oxygen tank shrinks approximately 1.5 in. (3.8 cm) in length and 0.5 in (1.3 cm) in diameter when filled with cryogenic propellant
- To compensate for those changes, everything that attaches to them – ducts, vent lines, systems tunnel, brackets, etc. – must be connected by accordion-like bellows sections, slotted joints, telescoping sections, or ball joint hinges
- Roughly 14,500 fasteners need to be drilled and filled in the intertank
- The flight computer uses the same class microprocessor as the original Macintosh PowerBook G3, somewhere between a Pentium II and Pentium III; however, the operating system is much more sophisticated
- Each flight computer is rated to operate over a temperature range of -11 to 97.7 degrees Fahrenheit (-24 to 36.5 degrees Celsius)

RS-25 Engines

Overview

Four RS-25 engines power SLS for its eight-minute climb to Earth orbit, together with a pair of solid rocket boosters that operate for the first two minutes of ascent. The RS-25 was formerly used as the Space Shuttle Main Engine (SSME) and flew successfully on 135 space shuttle missions.

The RS-25s have accumulated more than 3,000 starts and one million seconds of ground and flight hot fire experience.

The RS-25, manufactured by L3Harris Technologies, is the most efficient rocket engine in its class, allowing heavier payloads to be carried without increasing the rocket's size.

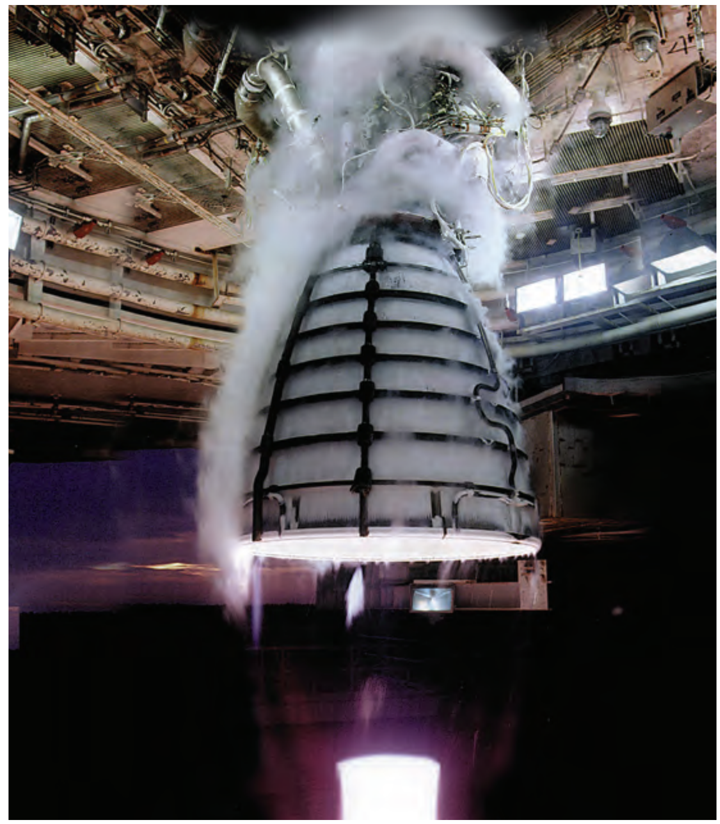
The RS-25 is a staged-combustion cycle engine that produces approximately 500,000 lbs. (2224 kN) of thrust. Each engine has an onboard computer that automatically controls start and shutdown, thrust ranging from 65 percent to 109 percent, propellant mixture ratio, and engine health. It was that power, efficiency, and reliability – as well as the knowledge and experience base – that led to selection of the RS-25 for SLS.

Each engine is roughly 14 ft. (4.3 m) tall, 8 ft. (2 m) in diameter, and weighs approximately 7,750 lbs. (3.52 t).

The first four SLS missions are powered by 14 flight-proven engines and two new engines assembled from shuttle-era engine components.

Legacy Hardware

Upgrades to the engines include development of new engine controllers and software and the addition of nozzle insulation to protect them from booster exhaust due to the engine and booster nozzles being located roughly in the same plane. New RS-25 engines now in manufacturing will be available for the fifth and subsequent missions.



The RS-25s have been upgraded with new controllers that were hot fire tested prior to the Artemis I flight.

Operations and Performance

The operations of the SLS RS-25s differ from operations during the Space Shuttle Program. Each shuttle mission used three engines, while each SLS mission uses four. Shuttles routinely operated with SSMEs throttled to 104.5 percent, or roughly 491,150 lbs. (2,185 kN) of thrust. Each SLS engine operates at 109 percent thrust – approximately 512,300 lbs. (2,279 kN) maximum thrust in a vacuum.

The RS-25 uses a staged-combustion engine cycle that burns liquid hydrogen and liquid oxygen propellants at very high pressure. These engines operate in temperature extremes from -423 degrees Fahrenheit (-253 degrees Celsius) to 6,000 degrees Fahrenheit (3,316 degrees Celsius) and at pressures exceeding 7,000 psi (48,263 kPa).

The engine was certified by ground testing during the shuttle program to operate at the higher thrust, though it was never used operationally.

With SLS, the RS-25 will experience several additional differences in performance requirements and operating environments. The SLS engine compartment is colder because it is located directly below the liquid hydrogen fuel tank instead of the separate arrangement of the shuttle orbiter and external tank. The SLS engines face higher liquid oxygen inlet pressures due to the higher position of the liquid oxygen tank relative to the engines as compared to the shuttle and external tank.

Unlike the space shuttle, SLS will not reuse its RS-25s as the core stage size, as well as altitude and speed at main engine cutoff (MECO), make recovery impractical without significant sacrifice in payload-carrying capability. SLS is designed to launch the most ambitious space exploration missions and requires maximum performance.

Design Features

During ascent, the engines are gimballed through two planes by hydraulic actuators to produce vehicle pitch, yaw, and roll.

Key design features that contribute to the RS-25's high performance:

- Its cryogenic liquid hydrogen and liquid oxygen propellants, which are more efficient than hydrocarbon engines
- Its staged-combustion operating cycle, in which propellants are burned twice, first in preburners then in the main combustion chamber, and its two high pressure turbopumps (liquid oxygen and liquid hydrogen) fed by two low-pressure pumps, creating higher main combustion chamber pressures

Additionally, the engine nozzles are also subjected to a hotter launch environment due to their location closer to the SLS booster exhaust nozzles compared to a location farther above the booster exhaust nozzles on the space shuttle. Operationally, pre-launch engine conditioning is different because of those environments, and the engine throttling and gimballing profiles during ascent are different due to vehicle acceleration and trajectory profile.

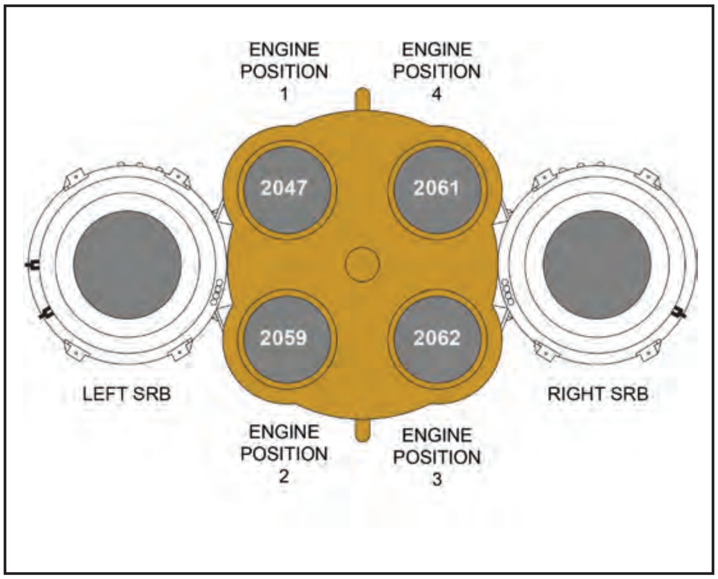
The SLS engines start approximately six seconds before booster ignition at T-0 using a staggered start: engine 1, engine 3, engine 4, then engine 2. The approximate thrust profile is:

- Engines start in series about 6 seconds prior to booster ignition
- Engines reach 100 percent of rated power level about one second before booster ignition
- Engines throttled to 109 percent rated power level at booster ignition (T-0)
- At ~T+55 seconds, engines can be throttled down to lessen stress on the rocket during maximum dynamic pressure (max Q)
- At ~T+81 seconds, throttle back up to 109 percent rated power level
- At ~T+123 seconds, throttle down to 85 percent rated power level (booster separation “bolt bucket” to reduce stress on attach struts and frangible bolts)
- At ~T+132 seconds, throttle back up to 109 percent rated power level following booster separation
- At ~T+421 seconds, throttle back as needed to reduce acceleration forces (max g level)
- At ~T+476 seconds, throttle back to 67 percent rated power level
- At ~T+483 seconds, main engine cut off (MECO)

Artemis II Updates

There were no significant changes in the Artemis II engines since Artemis I. The Artemis II RS-25 engines are serial numbers: 2047, 2059, 2061, and 2062. The Artemis III engines serve as backups in the event an engine must be replaced for any reason. The protocol was exercised for Artemis II. Engine 2061, originally scheduled to launch on Artemis III, was brought forward when hydraulic leaks were found on Engine 2063. The engine controllers on all four engines were also replaced, due to a problem discovered during testing.

Prior to the successful Artemis I test flight, extensive testing on the materials and manufacture of the RS-25s proved the engines to be capable of performing its role on SLS. For more information about the manufacturing, testing, and checkout of the RS-25 engines, please refer to the RS-25 Engines section in the Artemis I Reference Guide.



This illustration shows the Artemis II engine serial numbers and their position in the core stage relative to the boosters.

The RS-25 engines helped launch the Artemis I mission Nov. 16, 2022.

Flight History of Artemis II RS-25 Engines

Engines installed on the Artemis II core stage are serial numbers 2047, 2059, 2061, and 2062. Engines 2047, 2059, and 2061 were reconfigured for SLS and accepted for flight without additional acceptance testing, having flown previously. Engine 2062 is a new engine assembled from spare components made during the Space Shuttle Program. It was test fired in 2019. All four engines were stored at NASA's Stennis Space Center in Bay St. Louis, Mississippi, until they were needed for integration into the Artemis II core stage. All meet the SLS engine life requirements of four starts and 1,700 seconds operation time remaining. The three veteran RS-25s slated for Artemis II have a rich history in NASA's Space Shuttle Program flying to low Earth orbit. They are veterans of these successful space shuttle missions.

Engine 2047:

- **STS-91**: June 2 – June 12, 1998, Discovery, closed out the Shuttle-Mir Program, first Alpha Magnetic Spectrometer flight
- **STS-96**: May 27 – June 6, 1999, Discovery, first docking to the ISS (International Space Station), 45th spacewalk in shuttle history.; deployed Starshine satellite from cargo bay
- **STS-98**: Feb. 7 – Feb. 20, 2001, Atlantis, delivered and attached the Destiny Laboratory Module to ISS
- **STS-99**: Feb. 11 – Feb. 22, 2000, Endeavour, deployed Shuttle Radar Topography Mission mast to gather data
- **STS-106**: Sept. 8 – Sept. 20, 2000, Atlantis, unloaded nearly 3 tons of cargo, spacewalk to connect ISS cables
- **STS-104**: July 12 – July 24, 2001, Atlantis, Quest airlock attached to Unity, 66th spacewalk in shuttle history and 23rd for ISS assembly
- **STS-109**: March 1 – March 12, 2002, Columbia, Hubble Space Telescope servicing mission featuring five spacewalks
- **STS-112**: Oct. 7 – Oct. 18, 2002, Atlantis, deployed S1 integrated truss and crew and equipment translation air cart for ISS
- **STS-115**: Sept. 9 – Sept. 21, 2006, Atlantis, installation of P3 and P4 truss segments on ISS; first spacewalk astronaut campout in the Quest airlock to shorten pre-breathe time
- **STS-118**: Aug. 8 – Aug. 21, 2007, Endeavour, 22nd shuttle flight to ISS, installed a 7,000-pound (3,175 kg) storage platform using only shuttle and station arms, installed S5 truss, gyroscope, and external stowage platform 3
- **STS-123**: March 11 – March 26, 2008, Endeavour, delivered Japanese Kibo Logistics Module and Canadian Dextre robot system to ISS
- **STS-126**: Nov. 14 – Nov. 30, 2008, Endeavour, delivered equipment to ISS via reusable logistics module
- **STS-128**: Aug. 28 – Sept. 11, 2009, Discovery, delivered Leonardo Multipurpose Logistics Module and Lightweight Multi-Purpose Experiment Support Structure Carrier to ISS, 30th shuttle mission dedicated to assembly and maintenance of ISS
- **STS-132**: May 14 – May 26, 2010, Atlantis, delivered Integrated Cargo Carrier and Russian Mini Research Module to ISS
- **STS-135**: July 8 – July 21, 2011, Atlantis, 33rd and final Atlantis and Space Shuttle Program mission, delivered more than 9,400 (4,264 kg) pounds of spare parts, equipment, and other supplies in Raffaello Multi-Purpose Logistics Module including 2,677 pounds (1,214 kg) of food

Engine 2059:

- **STS-117**: June 8 – June 22, 2007, Atlantis, deployed S3 and S4 ISS starboard trusses with photovoltaic radiator and third set of solar arrays on ISS
- **STS-122**: Feb. 7 – Feb. 20, 2008, Atlantis, crew transfer
- **STS-125**: May 11 – May 24, 2009, Atlantis, last HST servicing mission, installed two new instruments and repaired two others, replaced gyroscopes and batteries, added new insulation panels
- **STS-130**: Feb. 8 – Feb. 21, 2010, Endeavour, delivered/installed the final U.S. module, Tranquility module, and cupola to ISS
- **STS-134**: May 16 – June 1, 2011, Endeavour, Endeavour's final flight, delivered Alpha Magnetic Spectrometer-2 and spare parts to ISS

Engine 2061:

- **STS-130**: Feb. 8 – Feb. 21, 2010, Endeavour, delivered Tranquility node and cupola to ISS.
- **STS-134**: May 16 – June 1, 2011, delivered alpha Magnetic Spectrometer-2 and critical supplies to ISS, last flight of Endeavour.

Engine 2062:

- New, assembled from STS heritage flight spares

RS-25 Fun Facts

- The thrust provided by the SLS RS-25 engines could keep eight Boeing 747s aloft
- The RS-25 is so powerful that it could power 846,591 mi. (1,362,456 km) of residential streetlights – a street long enough to go to the Moon and back, then circle the Earth 15 times
- Four RS-25 engines push the SLS rocket 73 times faster than an Indianapolis 500 race car travels
- The RS-25 could provide twice the power needed to move all 10 existing Nimitz-class aircraft carriers at 30 knots
- The RS-25 generates about 20 percent more thrust at sea level than comparable kerosene engines using the same amount of hydrocarbon fuels
- The RS-25 exhaust is clean, superheated water vapor
- In the RS-25, coolant travels through the main combustion chamber in two milliseconds, increasing its temperature by 400 degrees Fahrenheit (204 degrees Celsius)
- Pressure within the RS-25 is equivalent to an ocean depth of three miles – about the same distance where Titanic lies below the surface of the Atlantic Ocean
- Together, the SLS's four RS-25 engines gobble propellant at the rate of 1,500 gal. (5,678 L) per second during their eight minutes of operation – more than enough to drain an Olympic-size swimming pool during launch
- Hot gases exit the RS-25's nozzle at 9,600 mph (15,450 km/h) – 13 times the speed of sound, or fast enough to go from Los Angeles to New York City in 15 minutes

Engine 2062 was test fired at NASA Stennis before being assigned to Artemis II.

Solid Rocket Boosters

Overview

NASA's Space Launch System (SLS) boosters, manufactured by Northrup Grumman, are the largest, most powerful solid rocket boosters ever to fly. Two five-segment boosters support the entire weight of the SLS vehicle and Orion, including an astronaut crew and payloads. The two boosters operate for the first two minutes of flight, providing 75% of the total thrust required to launch the SLS. Each SLS booster is 177 ft. (53.9 m) tall, 12 ft. (3.7 m) in diameter, and weighs 1.6 million lbs. (726 t) when filled with solid propellant.

The propellant on the SLS Block 1 rocket boosters consists of polybutadiene acrylonitrile (PBAN), ammonium perchlorate, and aluminum powder. Standing 17 stories tall and burning more than 11,023 pounds (5 t) of propellant each second, each booster generates more thrust than 14 four-engine jumbo commercial airliners.

Legacy Hardware

The SLS boosters are derived and upgraded from the four-segment space shuttle solid rocket boosters, with numerous design, manufacturing, and testing improvements for increased performance, efficiency, and safety. For the first eight flights, the SLS Program uses repurposed heritage hardware from the Space Shuttle Program, including-forward structures, metal cases, aft skirts, and thrust vector control elements.

This image shows a close-up of the Flight Support Booster-2 solid rocket motor, poised for a full-scale ground test at Northrop Grumman's Utah test facility.

Design Features

The major difference between the shuttle and SLS boosters is the addition of a fifth solid propellant segment to the four-segment shuttle booster, allowing SLS to send more weight to translunar injection (TLI) than the shuttle lofted to low Earth orbit.

The larger SLS motor burns about three seconds longer and has more than 200,000 lbs. (890 kN) additional thrust. Other new design features of the SLS booster include:

- New manufacturing processes
- New nozzle design three inches larger in diameter than the shuttle nozzle throat to support increased thrust
- Modified propellant formulation with lowered burn rate
- New grain design with 12-fin forward segment
- New asbestos-free insulation and liner configuration
- New avionics and control systems
- Improved nondestructive evaluation processes
- Aft booster attach rings moved 20 ft. (6 m) aft from the space shuttle external tank location to allow them to attach to the core stage engine section rather than the liquid hydrogen tank

The SLS booster is optimized for a single use, to launch heavier payloads, and reduce operational costs associated with the space shuttle's reusable booster ocean-based recovery, post-launch assessment, and continued flight hardware refurbishment. To that end, parachutes and other recovery features have been removed from the SLS booster and recovery resources and infrastructure have been excessed/decommissioned. Deletion of the recovery systems translated into a reduction of approximately 20,000 lbs. which allows for an increase of 0.9 t additional payload to TLI, the maneuver that sends Orion to the Moon.

Major Assemblies

Each SLS booster includes the following three major assemblies:

- Forward assembly
- Motor assembly
- Aft assembly

Forward Assembly

The forward skirt assembly includes the nose cone, frustum with four solid fuel booster separation motors (BSMs), and forward skirt. The forward skirt houses booster avionics, the flight termination system, and core stage attach support posts that carry most of the static and flight loads for the SLS stack.

Motor Assembly

The motor assembly is made up of five segments. Each segment is comprised of two steel cases joined together and filled with rubbery propellant. Beginning from the top of the motor, the segments are:

- Forward segment
- Center forward segment
- Center center segment
- Center aft segment
- Forward segment

The forward segment contains the igniter that fires the length of the hollow motor segments to ignite all segments simultaneously. The segments, once ignited, burn from the center of the propellant grain outward until all propellant is consumed.

The forward attach struts are also located on the forward segment.

The aft motor segment is attached to an ablative exhaust nozzle that can be gimballed to steer the rocket. It contains the aft attach struts.

Booster Separation Motors

In addition to the booster motor, Northrop Grumman also produces the booster separation motors (BSM) used to push the boosters away from SLS at motor burnout. Each booster has four separation motors in the nose and four on the aft skirt for a total of 16 on the vehicle.

Aft Assembly

The aft assembly on each booster consists of the aft skirt, the thrust vector control system for the booster, and four solid booster separation motors. The thrust vector control system in the aft skirt gimbals the exhaust nozzle to steer the rocket. Throughout the duration of their burn cycle, the boosters provide approximately 75 percent of the steering for the SLS vehicle.

This image shows the Artemis II crew and Northrop Grumman technicians with the Artemis II forward assemblies in the Booster Fabrication Facility at NASA's Kennedy Space Center in Florida.

Artemis II booster aft assemblies are seen here on the the mobile launcher in NASA Kennedy's Vehicle Assembly Building.

Operations and Performance

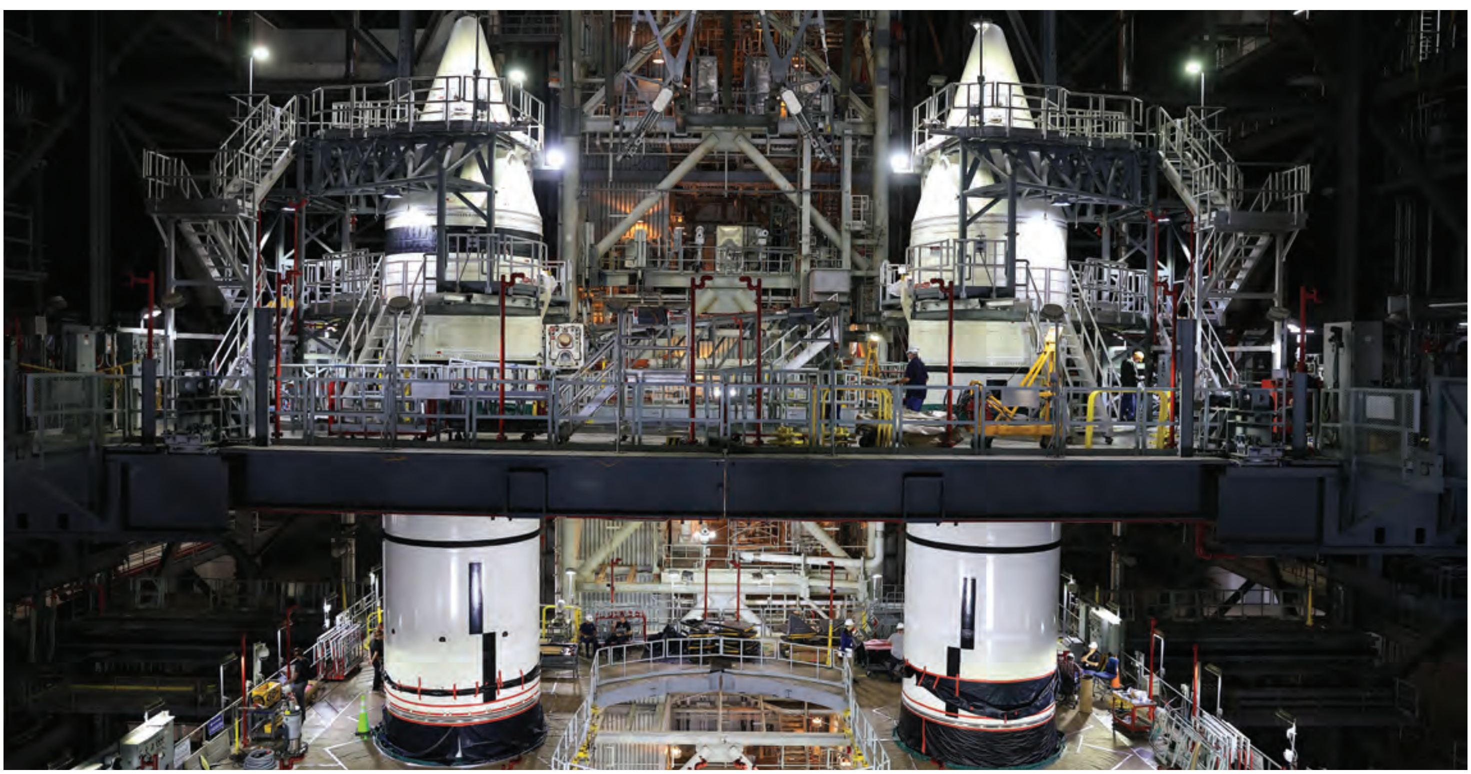
Several seconds after the RS-25 engines start and get up to full thrust, booster ignition occurs at T-0 seconds and the vehicle lifts off the mobile launcher platform and begins its ascent. The propellant grain within each motor segment has a specific geometric design to optimize thrust and burn time. It is designed to provide a maximum 3.6 million lbs. (16,014 kN) thrust for roughly 25 seconds, ramping down to about 2.8 million lbs. (12,455 kN) thrust as SLS passes through max Q, and then ramping up to about 3.3 million lbs. (14,679 kN) of thrust before beginning to tail off at about T+90 seconds.

Booster separation occurs at about 2 minutes into flight as the vehicle is traveling at 148,384 ft. (45.2 km) in altitude and at Mach 4.3 or more than 3,000 mph. In order to separate from the vehicle, pyrotechnically activated separation bolts on the booster attach struts fire and all eight BSMs at the top and bottom of each booster fire to push the empty boosters safely away from the core stage. Each booster separation motor generates about 20,000 lbs. (89 kN) of thrust for just under 1 second. The boosters splash down in the Atlantic Ocean approximately 5.5 minutes after launch.

Artemis II Updates

For Artemis II, the BSMs have been rotated 15 degrees to provide the boosters additional clearance from the core stage when jettisoned. Additionally, booster separation will occur approximately four seconds sooner than on Artemis I to test improved payload performance for the SLS Block 1B missions. The BSM cover material was changed from aluminum to steel to add protection against any debris during launch.

The Artemis I booster design included a barrier/cap ply insulation layer inside the solid rocket motor metal cases. Analysis and testing indicated that the insulation was structurally more reliable without the barrier/cap ply layer, so it was deleted from the design and a single-layer insulation design was certified for flight on Artemis II and subsequent missions. For more information about the manufacturing, testing, and checkout of the boosters, please refer to the Solid Rocket Boosters section in the Artemis I Reference Guide.

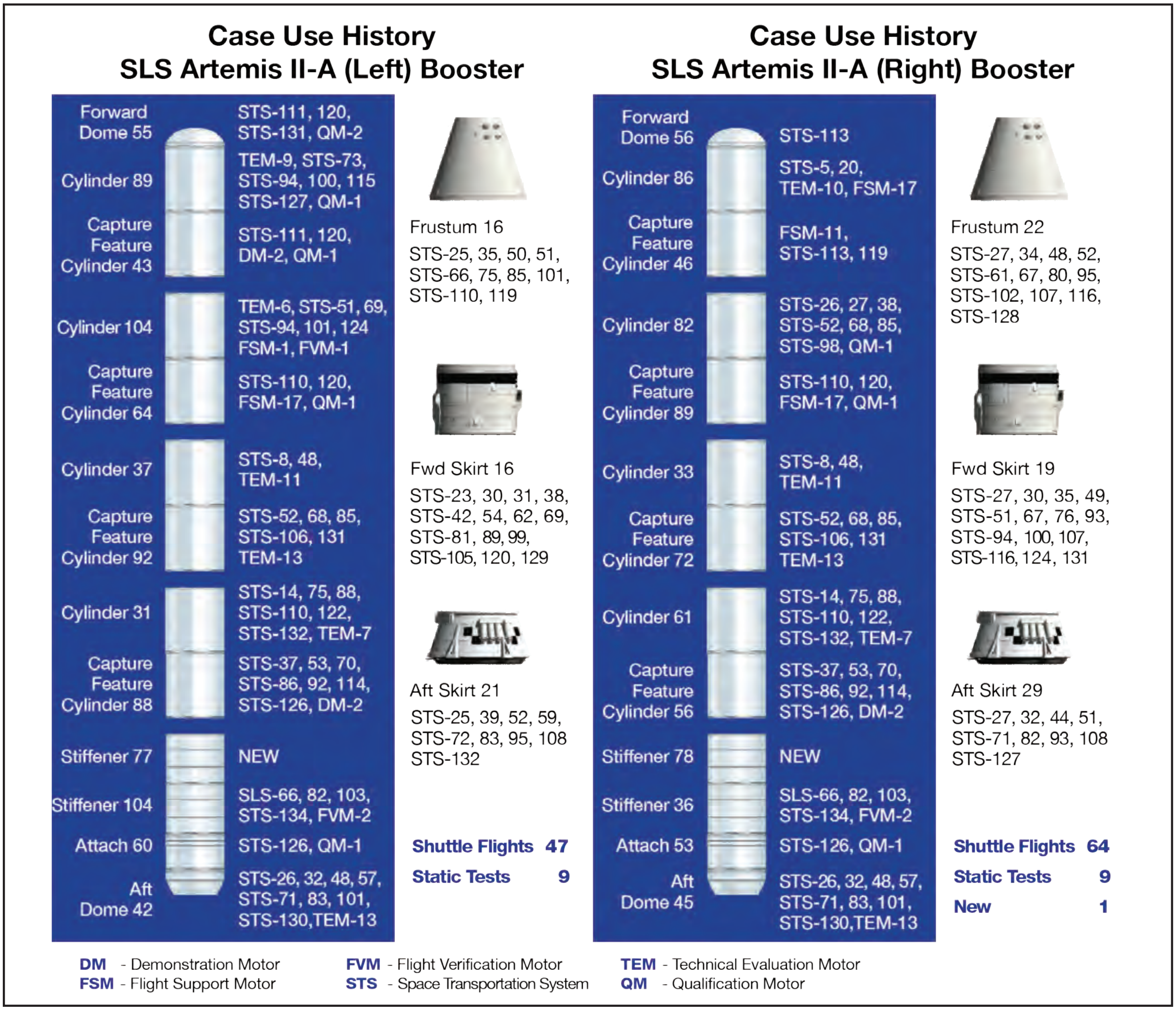


The five-segment SLS solid rocket boosters generate 7.2 million lbs. (32,027 kN) of thrust – more than 75 percent of the rocket's total thrust for the first two minutes of flight.

Flight History of the SLS Booster Structures

Several missions' worth of space shuttle booster hardware was transferred to the SLS Program for its early missions, while Northrop Grumman restarted booster manufacturing, incorporating several new features. The charts below summarize the shuttle flight history behind each of the Artemis II booster components. The cylinders, domes, capture features, aft domes, frustums, forward skirts, and other shuttle-era booster components used to build the Artemis II boosters have supported 84 different space shuttle missions. Left booster hardware flew on 47 shuttle missions and was used in nine tests.

Right booster hardware flew on 64 missions and was used in nine ground tests. The most-flown components of the Artemis II boosters are the left- and right-hand forward skirts with 14 total flights each that supported the maiden flight of Endeavour (STS-49) and the last space shuttle night launch (STS-130) among other missions. The component with the earliest flight is cylinder 86 that supported STS-5 in 1982. Cylinder 64 and stiffener 36 are the most recently used components, supporting STS-134, the final flight of Endeavour, in 2011. Components from the first and last flights of Endeavour support Artemis II.



SLS Solid Rocket Boosters Fun Facts

- The SLS solid rocket boosters are 177 ft. (53.9 m) tall, taller than the Statue of Liberty from base to torch
- Each booster is 12 ft. (3.7 m) in diameter
- The boosters are the first element to be installed on the mobile launcher
- The weight of the entire 5.74 million lb. (2,604 t) rocket rests on the booster aft skirts
- Each booster weighs 1.6 million lbs. (726 t) when loaded with propellant
- Each booster burns approximately 11,023 lbs. (5 t) of propellant a second
- Each booster generates 3.6 million lbs. (16,014 kN) of thrust, more thrust than 14 four-engine jumbo commercial airliners
- During the first two minutes of flight, the boosters provide more than 75 percent of the total SLS thrust
- During hot fire testing in the Utah desert, the booster motor burns so hot that sand hit by the nozzle exhaust turns to glass
- The boosters operate for approximately 2 minutes and are then jettisoned into the Atlantic Ocean
- Once all the propellant in the solid rocket boosters has burned, a total of 16 small solid rocket motors, called booster separation motors, in the forward and aft sections of each booster, fire simultaneously to safely push the boosters away from the SLS rocket
- All 16-booster separation motors fire within approximately 0.68 seconds of each other; if their heat energy were converted to electric power, the two solid rocket boosters firing for two minutes would produce 2.3 million KWh of power, enough to supply power to more than 92,000 homes for a full day

The completed Artemis II boosters are shown stacked on the mobile launcher in the Vehicle Assembly Building at NASA Kennedy before integrating the other elements of SLS and Orion.

Integrated Spacecraft/Payload Element

Overview

The SLS Block I configuration was used for Artemis I and will be used for the Artemis II and III missions. The Integrated Spacecraft/Payload Element for the SLS Block I crew configuration is located above the core stage and below the Orion spacecraft.

Major Elements

The Integrated Spacecraft/Payload Element includes elements for in-space propulsion, adapters, and a separation system. Additionally, it includes a deployment system for secondary payloads.

On Artemis I, the interim cryogenic propulsion stage (ICPS) burned for a record-breaking 18 minutes to provide the final boost necessary to send Orion to fly to the Moon. However, on Artemis II, Orion will fire its service module engine to make the final translunar injection burn to complete the journey to the Moon.

The launch vehicle stage adapter (LVSA) partially encloses the ICPS and connects with the larger core stage below.

A crane is seen here lowering the launch vehicle stage adapter onto the SLS core stage in the Vehicle Assembly Building at NASA's Kennedy Space Center in Florida.

Interim Cryogenic Propulsion Stage

Overview

The 45-ft. (13.7-m)-tall, 16.7-ft. (5.09-m)-diameter ICPS is a modified Delta Cryogenic Second Stage, a proven upper stage used on ULA's (United Launch Alliance) Delta IV family of launch vehicles. The ICPS is built in a collaborative partnership by Boeing and ULA at ULA's rocket factory in Decatur, Alabama. After completion, it's shipped to ULA's Delta Operations Center at Cape Canaveral Space Force Station in Florida on ULA's R/S Rocketship cargo ship for final checkout prior to stacking in the Vehicle Assembly Building (VAB) at NASA's Kennedy Space Center in Florida.

Design Features

Modifications to the Delta stage for the Block 1 SLS missions include lengthening the liquid hydrogen tank by 18.4 in. (46.7 cm), adding a second hydrazine bottle for attitude control, a new navigation system, Orion and launch vehicle stage adapter electrical and mechanical interfaces, a modified liquid hydrogen vent and relief valve, an RL10 in-flight helium injector purge to support engine restart, and RL10 qualification to SLS environments.

Power

The stage is powered by liquid hydrogen and liquid oxygen, feeding a single L3Harris Technologies RL10C-2 engine producing 24,750 lbs. (110.1 kN) of thrust. The RL10 has been in use for more than 50 years to launch numerous military, government, and commercial satellites into orbit and send spacecraft to every planet in the solar system.

Proximity Operations

During Artemis II, Orion and ICPS will orbit Earth three times, with the ICPS firing once to maintain Orion's path and firing a second time to raise the spacecraft to a high-Earth orbit. After the Orion spacecraft separates from the SLS upper stage, Artemis II astronauts will use targets added to ICPS as visual markers to "test drive" Orion to simulate future rendezvous and docking operations with other Artemis components such as human landing systems and the Gateway lunar space station. A disposal burn after proximity operations will send ICPS on a trajectory to deploy secondary payloads before reentering Earth's atmosphere above the Pacific Ocean for disposal.

Artemis II Updates

Hardware improvements to the ICPS include a Teflon seal added to the liquid hydrogen and liquid oxygen umbilicals to make filling and draining the cryogenic propellant from the vehicle safer. Having upgraded from the RL10B-2 engine flown on Artemis I, enhancements made to the L3Harris Technologies RL10C-2 engine include adding a dual engine igniter and netting that helps contain debris shedding from the engine nozzle.

For Artemis II, ULA repurposed its Emergency Detection System (EDS) avionics box (which was proven during launches of the Atlas V rocket carrying Boeing's Starliner) to provide Artemis crews with protection against hazards that might arise from off-nominal conditions before and during flight. Addition of this avionics box is a key step in human-rating the ICPS for Artemis II. The EDS will monitor critical systems during launch and alert Orion on the need to abort from the SLS rocket if a catastrophic problem is predicted. The added Communication Bus Protocol Operator (CBPO) acts as an interface to send vehicle health updates to Orion.

Prior to the successful Artemis I test flight, extensive testing on the materials and manufacture of the ICPS proved the element to be capable of performing its role on SLS. For more information about the manufacturing, testing, and checkout of the ICPS, please refer to the ICPS section in the Artemis I Reference Guide.

The Artemis III ICPS is seen here being moved at ULA's Delta Operations Center prior to stacking.

Launch Vehicle Stage Adapter

Overview

The cone-shaped launch vehicle stage adapter (LVSA) partially encloses the ICPS and provides the interface between the 27.6-ft. (8.41-m)-diameter core stage and 16.7-ft. (5.09-m)-diameter ICPS. The adapter is 27.5 ft. (8.38 m) tall, and is built at NASA Marshall by Teledyne Brown Engineering.

Design Features

Hatches in the adapter allow technicians access to the ICPS during processing at NASA Kennedy. The LVSA also protects avionics and electrical devices in the ICPS from extreme vibration and acoustic conditions during launch and ascent.

A pneumatically actuated frangible joint assembly at the top of the LVSA separates the ICPS, Orion stage adapter, and Orion from the core stage and LVSA during ascent.

Cameras inside the adapter provide engineers with data on its performance and location in space after the core stage and LVSA separate from the ICPS and Orion. The LVSA stays attached to the core stage and they are disposed through Earth atmospheric re-entry over the Pacific Ocean.

Artemis II Updates

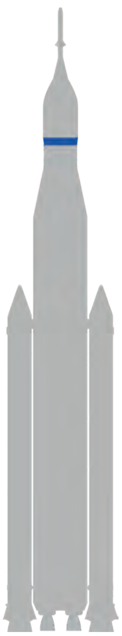
There were no significant design changes for Artemis II's LVSA, although improvements were made to the electrical cable harness routing that connects the core stage flight control system with the LVSA's separation system, ICPS flight computers, and the Orion spacecraft.

Prior to the successful Artemis I test flight, extensive testing on the materials and manufacture of the LVSA proved the element to be capable of performing its role on SLS. For more information about the manufacturing, testing, and checkout of the LVSA, please refer to the LVSA section the Artemis I Reference Guide.

The LVSA partially encloses the ICPS and contains the pyrotechnic system to separate itself and the core stage from the ICPS and Orion spacecraft.

Manufactured by Teledyne Brown Engineering at NASA's Marshall Space Flight Center in Huntsville, Alabama, the Artemis II LVSA is seen here leaving the center on the Pegasus barge for NASA Kennedy.

Orion Stage Adapter



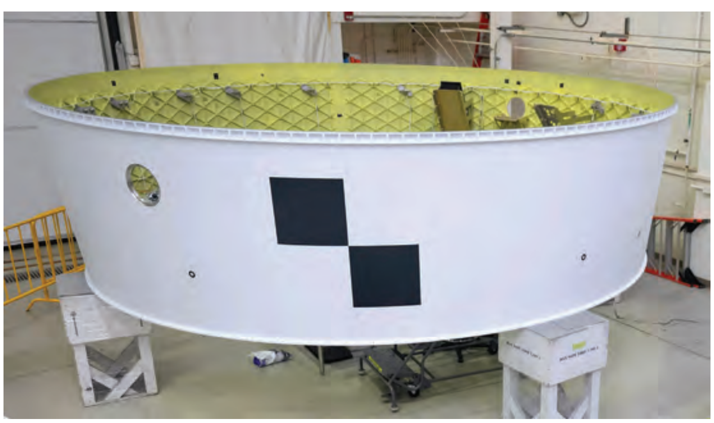
Overview

The highest SLS element in the SLS stack, the Orion stage adapter (OSA), connects the ICPS to the Orion spacecraft. OSA is 18 ft. (5.5 m) in diameter, 5 ft. (1.5 m) tall, and is made of lightweight aluminum. The adapter is manufactured by NASA's Marshall Space Flight Center in Huntsville, Alabama.

Design Features

The adapter contains a diaphragm that provides a barrier to prevent gases – such as hydrogen – generated during launch from entering Orion. For Artemis II, the OSA will also carry small secondary payloads, called CubeSats.

SLS provided a comprehensive secondary payload deployment system for the CubeSats, including mounting brackets for commercial-off-the-shelf dispensers, cable harnesses, a vibration isolation system, and an avionics unit.



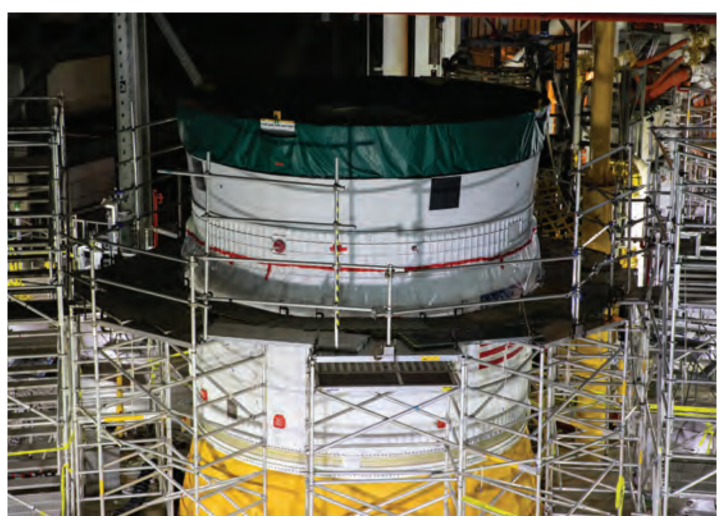
Seen here is the completed Orion stage adapter awaiting deliver from NASA Marshall to NASA Kennedy. The brackets to hold the dispensers for the CubeSat payloads and avionics unit are visible.

Artemis II Updates

The Artemis II OSA's brackets and dispensers have been updated to support five 12U CubeSats rather than the 10, 6U CubeSats Artemis I deployed. Following separation from Orion and after the proximity operations demonstration, when the crewed spacecraft is a safe distance away, the avionics unit in the Orion stage adapter secondary payload deployment system will send the signals to release the payloads at pre-selected times. Following secondary payload deployment, the Orion stage adapter remains attached to the ICPS and enters an Earth atmospheric disposal trajectory.

A centerline docking target has been mounted on the Artemis II OSA diaphragm for use by the astronauts during the proximity operations demonstration intended to test Orion's handling capabilities.

Prior to the successful Artemis I test flight, extensive testing on the materials and manufacture of the OSA proved the element to be capable of performing its role on SLS. For more information about the manufacturing, testing, and checkout of the OSA, please refer to the OSA section in the Artemis I Reference Guide.



The OSA is the final element of SLS to be stacked before the Orion spacecraft is added. The Artemis I OSA was covered to protect the mission's secondary payloads prior to the addition of the Orion spacecraft.

SLS Avionics and Software

The SLS core stage, engines, boosters, and interim cryogenic propulsion stage (ICPS) all have computers and software that monitor and control their functions. The avionics in the engines, boosters, and ICPS are connected to the flight avionics in the core stage. The core stage flight computers use data from the distributed avionics systems in the boosters, engines, and throughout the core stage to control the rocket and carry out its mission. During Artemis I, the avionics system also transmitted vehicle performance data to controllers on the ground. During Artemis II and future missions, this data will also be transmitted to the crew in Orion.

Core stage avionics and flight software serve as the "brains" of the rocket. They contain and execute the commands to prepare and launch SLS, route data and commands to the stage, distribute power, produce navigation and flight control data, produce range safety tracking data, execute flight termination commands, produce motion imagery, provide telemetry to ground systems, synchronize and process data, monitor stage conditions, and receive/execute flight safety commands.

Core stage avionics consist of four main subsystems:

- Flight control
- Telemetry
- Flight safety
- Electrical power

Core stage avionics equipment is distributed among the forward skirt, intertank, and engine section in the core stage.

Three flight computers and four power, data, telemetry, and navigation systems are located in the forward skirt. Each of the three flight computers uses three microprocessors and executes the same software for redundancy.

The intertank houses 26 avionics systems for power, power distribution, data receiving/handling, telemetry, and vehicle camera control. The engine section contains 10 avionics systems related to engine monitoring and vehicle navigation.

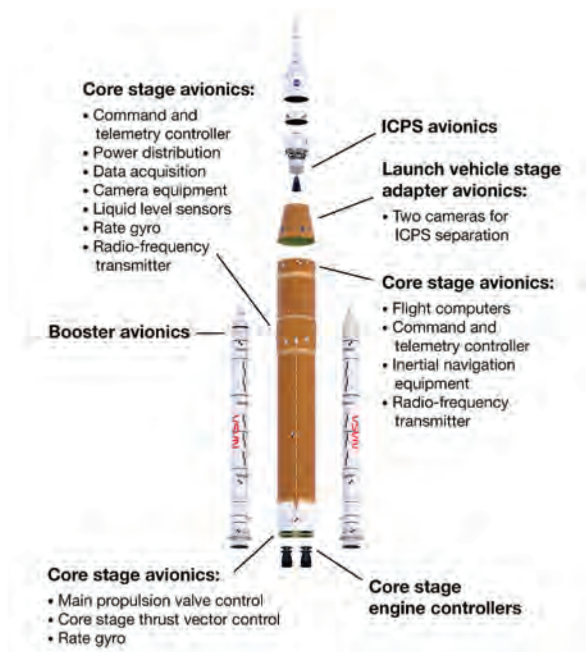
SLS flight software provides the pre-flight and flight software functions necessary for on-pad pre-launch procedures, launch, and ascent of SLS up through ICPS separation. The software was developed at NASA Marshall.

The flight control system, led by three redundant flight computers, monitors the rocket's condition, senses vehicle motion, generates navigation and control data, actuates main propulsion system valves, monitors the main propulsion system and engine controls, and routes flight-critical commands to engine thrust vector control systems and controllers. The flight computers have 256 MB of RAM each.

The core stage telemetry system includes radio and ethernet communications with the ground, telemetry control, engineering and development flight instrumentation, and a motion imagery system.

Incorporated for public safety, the flight safety system provides range tracking data and controls the rocket's self-destruct function located in the core stage and boosters.

The avionics power system distributes ground power, stores ground power for flight, and provides data to ground control centers.



Avionics throughout the elements of SLS monitor the rocket's health and control the flight.

MANAGEMENT ROLES *and* FACILITIES

NASA's SLS (Space Launch System) rocket is managed and supported by NASA Headquarters in Washington, D.C., and multiple NASA field centers across the nation. The Exploration Systems Development Mission Directorate oversees NASA's human exploration programs in and beyond low Earth orbit.

Marshall Space Flight Center

NASA's Marshall Space Flight Center in Huntsville, Alabama, is home to the SLS Program Office and manages all areas of the program, including planning, procurement, development, testing, evaluation, production, and operation of the integrated vehicle. NASA Marshall also develops and tests the flight software in-house.

The program office is also supported by Resident Management Offices (RMOs) at NASA field centers and industry partner sites. The RMOs conduct engine testing, are responsible for integration and launch, and coordinate SLS technical and operations expertise with the Exploration Ground Systems (EGS) Program.

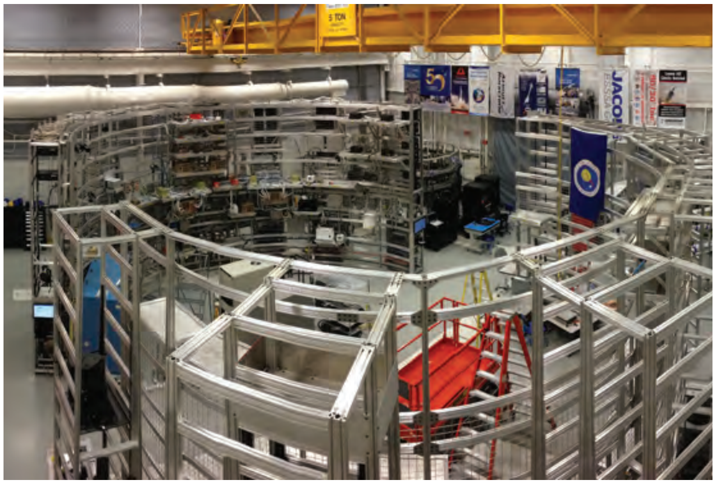
Unique Test Facilities

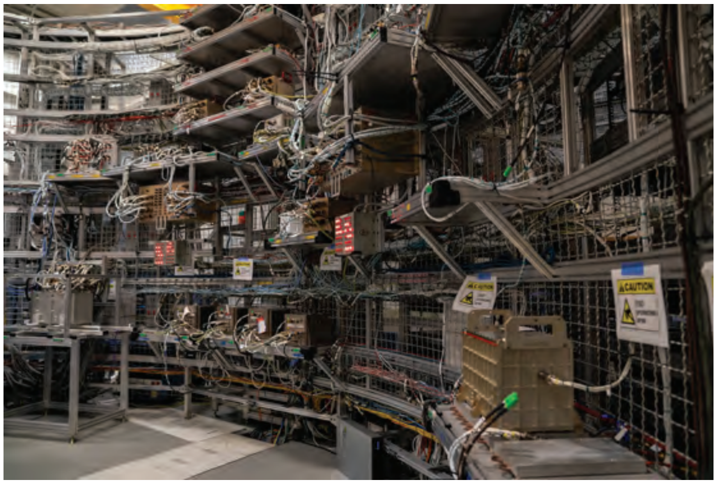
Several NASA Marshall facilities support SLS. Building 4693 is a twin-tower open structure built to perform structural testing on a liquid hydrogen tank test article. Measuring 221 ft. (67.3 m) tall, the tower reuses the foundation of a former Saturn rocket test stand. For structural testing on the SLS core stage liquid hydrogen tank structural test article, 38 hydraulic pistons were used to impart simulated flight loads on the tank, while more than 3,900 sensors measured temperature, deflection, strain, pressure, sound, and imagery.

Building 4697 is an L-shaped open tower structure built to test the core stage liquid oxygen tank structural test article. Soaring 90 ft. (27.4 m) tall, the stand used 24 hydraulic pistons and more than 2,700 sensors to conduct 32 structural loads tests on the liquid oxygen tank structural test article.

Special test equipment consisting of two open-structure towers were built in Building 4619 to test core stage engine section and intertank structural test articles. The engine section tower measures 58 ft. (18 m) tall and the intertank tower measures 62 ft. (19 m) high. The engine section was subjected to 49 tests monitored by approximately 3,000 sensors. The intertank underwent 42 tests monitored by approximately 3,000 sensors.

The Systems Integration Lab/Systems Integration Test Facility allows engineers to test software with hardware in the loop. This allows them to fully simulate the integration of systems in virtual space prior to hardware manufacturing and test flight. Engineers in the lab also create and run end-to-end simulation environments in support of the entire project life cycle, including requirements development and analysis, as well as early prototyping, testing, and verification. These unique capabilities ensure that software and hardware integrate seamlessly before rocket manufacturing and assembly.





The Systems Integration Lab/Systems Integration Test Facility at NASA Marshall is a full-scale mockup of flight-like avionics systems for the solid rocket boosters and core stage where engineers can test hardware and software integration prior to manufacture and flight.

Supporting Launch Operations

The SLS Engineering Support Center (SESC), located in the Huntsville Operations Support Center at NASA Marshall, allows engineers specializing in the engines, boosters, core stage, avionics, and upper stage to monitor the rocket's propulsion and other systems during the countdown and flight. The teams in the SESC leading up to and during launch analyze and monitor temperatures, pressures, flow rates, stresses, and other types of telemetry from the rocket. SESC teams also produce flash reports for the Mission Management Team and report on and archive data for additional study in the weeks and months after launch.

The SESC supports the Launch Control Center (LCC) at NASA Kennedy and the Flight Operations Directorate team located at the Mission Control Center at NASA's Johnson Space Center in Houston, performing in-depth analyses to help mission leadership evaluate any anomalies and solutions.

The SESC facility, which once served a similar purpose for both the Apollo and Space Shuttle Programs, has been updated with new communication and data equipment that provide greater data throughput and more voice communications channels. It also has the capability to reach out to SLS contractor organizations around the nation for additional expertise and attention to any issues. The SESC is staffed by a team from the SLS Program, NASA Marshall engineering teams, and SLS contractors.

The Natural Environments Branch at NASA Marshall characterizes terrestrial, space, and planetary natural environments in support of the SLS Program and other projects and programs across NASA. The Natural Environments Branch has been collecting detailed atmospheric data from the Earth's surface and aloft at NASA Kennedy since the Apollo Program. The branch collects this data and develops weather databases for use by NASA and commercial customers to support spacecraft and launch vehicle programs in three major areas: system requirements design, verification and validation, and mission operations.

In addition to supporting SLS design and verification, the branch supports mission operations by generating complete atmospheric profiles for use in verifying SLS trajectory and loads constraints due to atmospheric wind conditions prior to launch.

For SLS and the Artemis missions, the Natural Environments Branch also supports the Day of Launch Initialization Load Update. This update collects and uses day-of-launch atmospheric winds and temperature to design and verify the SLS flight profile in order to minimize loads (stresses) on the vehicle to ensure a safe flight.

On launch day, NASA Kennedy and the Space Launch Delta 45 Eastern Range update weather data. The NASA Marshall Natural Environments Branch uses the data to generate a profile of wind, temperature, density, and pressure at 100-ft. (30.5-m) intervals from the surface to 600,000 ft. (183 km). NASA Johnson inputs that data into software to generate a flight guidance profile that is then validated by independent teams at NASA Johnson and NASA Marshall before sending those files to the launch team at NASA Kennedy for upload onto SLS flight computers to translate into engine throttling and steering commands that minimize wind stresses on the rocket.

NASA Marshall's SESC is networked to NASA Kennedy, NASA Johnson, and contractor locations nationwide to provide engineering support for SLS testing and launch operations.

On launch day, NASA Marshall's Natural Environments Branch measures temperature, wind speeds, and more at NASA Kennedy to provide data inputs critical to defining final flight trajectories.

NASA's Michoud Assembly Facility

For more than half a century, NASA’s Michoud Assembly Facility in New Orleans has been America’s rocket factory, the nation’s premier site for manufacturing, assembling, and checkout of large-scale space structures and systems.

The government-owned manufacturing facility is one of the largest in the world, with 43 acres of manufacturing space under one roof — a space large enough to contain more than 31 football fields. NASA Marshall manages NASA Michoud; commercial firms and NASA contractors use several areas of the facility. NASA Michoud employs several key new manufacturing technologies and approaches to produce the SLS core stage:

- Lean manufacturing approaches with a production footprint about half of what was used to manufacture the space shuttle’s external tank; the SLS production workforce is also less than half of the external tank program headcount
- Friction stir welding, providing stronger, lighter structures produced without welding defects; core stage welded barrel sections used to assemble the rocket tanks are produced in less than half the time compared to space shuttle external tank production
- Horizontal, single cell, robotically controlled application of spray-on foam insulation
- Spun dome technology for dome caps, reducing complexity associated with gore panels

NASA Michoud is managed by NASA Marshall and is the world's premier rocket factory and one of the largest manufacturing facilities in the world, with 43 acres under one roof.

The Artemis II core stage liquid hydrogen tank is seen here readied for the next production phase at NASA Michoud.

Manufactured at NASA Michoud, the Artemis II liquid oxygen tank seen here will hold up to 196,000 gallons of liquid oxygen cooled to -297 degrees Fahrenheit.

At NASA Michoud, six major multi-function assembly/welding tools developed for SLS have resulted in a greater than 80 percent reduction in tooling from shuttle external tank production. This reduced tooling also minimizes hardware handling, reducing complex hardware lifting operations by more than 70 percent. The new tools in NASA's rocket factory include:

- The Circumferential Dome Weld Tool, which performs circumferential friction-stir welds in the production of dome assemblies for the SLS core stage cryogenic tanks
- The Gore Weld Tool performs vertical conventional friction stir welds in the production of gore assemblies for the SLS core stage tanks (gores are preformed aluminum alloy dome segments that are welded together to make the dome)
- The Circumferential Dome Weld and Gore Weld tools are special tooling for the Enhanced Robotic Weld Tool, which is used to make dome components for SLS
- The Vertical Weld Center is a friction-stir-weld tool for wet and dry structures on the SLS core stage; it welds barrel panels together to produce whole barrels for the two pressurized tanks, the intertank, the forward skirt, and the engine section; it stands about three stories tall and weighs almost 300,000 pounds (136 t)
- The Segmented Ring Tool uses a friction-stir-weld process to produce segmented support rings for the SLS core stage; the rings connect and provide stiffness between domes and barrels
- The Vertical Assembly Center is where domes, rings, and barrels are joined to complete the tanks or dry structure assemblies; the tool also performs nondestructive evaluation on the completed welds; this tool measures 170 ft. (51.8 m) tall and 78 ft. (24 m) wide and is one of the world's largest welding tools

Seeking production efficiencies after Artemis I, NASA Marshall and NASA Kennedy, along with Boeing signed an agreement in 2022 to use available facilities at NASA Kennedy for final core stage vertical assembly and integration beginning with Artemis III. Structurally complete engine sections from NASA Michoud are to be shipped to NASA Kennedy for internal equipment installation, followed by mating with the top 4/5 of core stages from NASA Michoud and RS-25 engines processed at NASA Stennis.

The gore weld tool at NASA Michoud is used to weld domes for the SLS core stage propellant tanks.

NASA's Stennis Space Center

As the nation's largest propulsion test site, NASA's Stennis Space Center in Bay St. Louis, Mississippi, plays a major role in testing for SLS, just as it did for Saturn rockets and space shuttle vehicles.

The Fred Haise Test Stand was used to conduct multiple tests of RS-25 developmental engines to ensure the modified flight engines will operate to SLS requirements and environments. It was also used to green run test two new RS-25 engines, as well as new engine controllers for all 16 shuttle engines transferred from the Space Shuttle Program. The hot fire tests for the new engines and controllers also were conducted on NASA Stennis's Fred Haise Test Stand. In 2017, NASA began using the stand to test RS-25 engines with newly designed parts made with advanced technology, such as additive manufacturing or 3D printing, for a new generation of engines for the fifth SLS flight and beyond.

Newer engines will have the same high performance as the upgraded engines used for early Artemis missions but with anticipated manufacturing cost savings of more than 30 percent.

The Fred Haise Test Stand is a single-position, vertical-firing facility, which means that it can accommodate one rocket engine at a time fired in an upright position with thrust directed downward. The stand was constructed from December 1964 to February 1967. The first test of an RS-25 rocket engine for SLS was conducted on the Fred Haise Test Stand Jan. 9, 2015. On April 4, 2019, NASA Stennis completed testing of all 16 RS-25 main engines that will help launch the first four SLS missions.

Technicians at NASA Stennis are seen preparing an RS-25 engine at the Fred Haise Test Stand.

The stand extends 58 ft. (18 m) below ground and 158 ft. (48.2 m) above ground. It can withstand rocket engine thrust up to about 1.1 million lbs. (4,893 kN) of force; the thrust limit is known as the maximum dynamic load.

The Thad Cochran Test Stand at NASA Stennis features dual, vertical-firing test positions, designated B-1/B-2, built in the 1960s. The B-1 position is designed for single-engine testing. The B-2 position is built to accommodate rocket stage testing. The B-2 position underwent major refurbishment and modification to conduct the SLS Artemis I core stage Green Run test series to ready the stage for integration and flight.

The Thad Cochran Test Stand is anchored in the ground with 144 ft. (43.9 m) of steel and concrete. As constructed, the soft core of the B-2 position of the stand was about 290 ft. (88.4 m) tall. The new steel superstructure added for testing SLS extends that height to almost 350 ft. (107 m), ranking the stand as one of the tallest structures in the state of Mississippi.

NASA Stennis test stands are linked by a 7.5-mile (12-km) canal system used for transporting rocket stages and liquid propellants. Support facilities for NASA Stennis test stands include a test control center for each complex; data acquisition facilities; a large High Pressure Gas Facility to supply pressurized nitrogen, helium, hydrogen, and air; an electrical generation plant that provides power for engine tests to avoid potential disruptions in the power grid; and a High Pressure Industrial Water Facility that features large diesel pumps, as well as a new electric pump, and a 66-million-gal. (250-million-L) reservoir.

The main derrick crane atop the B-2 Test Stand was extended 50 ft. (15 m) with an increased load rating of 390,00 pounds (177 t) to lift the Artemis I SLS core stage, which is larger and heavier than the earlier Saturn V stages.

More than 32,500 5/32-inch holes drilled in the B-2 Test Stand flame deflector direct more than 240,000 gal. (908,000 L) of water a minute to cool engine exhaust during a test. Another 92,000 gal. (348,000 L) of water per minute is sprayed through 92 nozzles to provide vibro-acoustic suppression protection to the core stage during testing. More than 100 water nozzles are arrayed across the test stand to provide a curtain of water across the facility, if needed, to prevent damage in the event of a fire or cryogenic spill.

NASA Stennis provides unique facilities, such as the Thad Cochran Test Stand pictured here, for testing SLS RS-25 engines, controllers, and rocket stages.

INDUSTRY PARTNERS

Truly America's rocket, over the course of NASA's SLS (Space Launch System) Program more than 2,400 companies from 48 states have contributed to designing, developing, manufacturing, testing, and supporting SLS, the rocket that will return NASA's human spaceflight program to the Moon. Several prime contractors head up the manufacturing, test, and assembly of the major elements of SLS, but they in turn are supported by hundreds of smaller suppliers across the U.S.

L3Harris Technologies

L3Harris Technologies is the prime contractor for the four powerful RS-25 engines used to help propel each SLS mission. The four liquid hydrogen/liquid oxygen-fed RS-25 engines produce more than 2 million lbs. (8,896 kN) of thrust. The RS-25 contract is managed out of the company's Canoga Park, California, facility, which is also where most of the design work and component fabrication takes place.

Assembly and testing occur at the company's facility located at NASA's Stennis Space Center in Bay St. Louis, Mississippi. In addition to the RS-25 engines, the company also provides propulsion that will be used throughout the Artemis missions.

L3Harris Technologies designs, manufactures, and tests the RL10 engine that propels the interim cryogenic propulsion stage (ICPS) in West Palm Beach, Florida. A suite of propulsion for NASA's Orion spacecraft is manufactured in Redmond, Washington. The company's subsidiary, ARDE, located in Carlstadt, New Jersey, builds the oxygen and nitrogen (nitrox) tank for the life support system on Orion and five composite overwrapped pressure vessels that store high-pressure helium to inflate Orion's flotation system upon water landing.

Industry partner L3Harris, headquartered in Melbourne, Florida, supplies RS-25 engines for the SLS core stage and RL10 engines for the ICPS.

Boeing

Boeing is the prime contractor for the design, development, testing, and production of the SLS core stage and ICPS, as well as development of the flight avionics suite. Boeing built and tested the core stage for the first two Artemis missions, and production for the Artemis III, IV, and V stages is underway, including the exploration upper stage (EUS), a more powerful in-space stage for NASA's Block 1B and ultimate Block 2 variants.

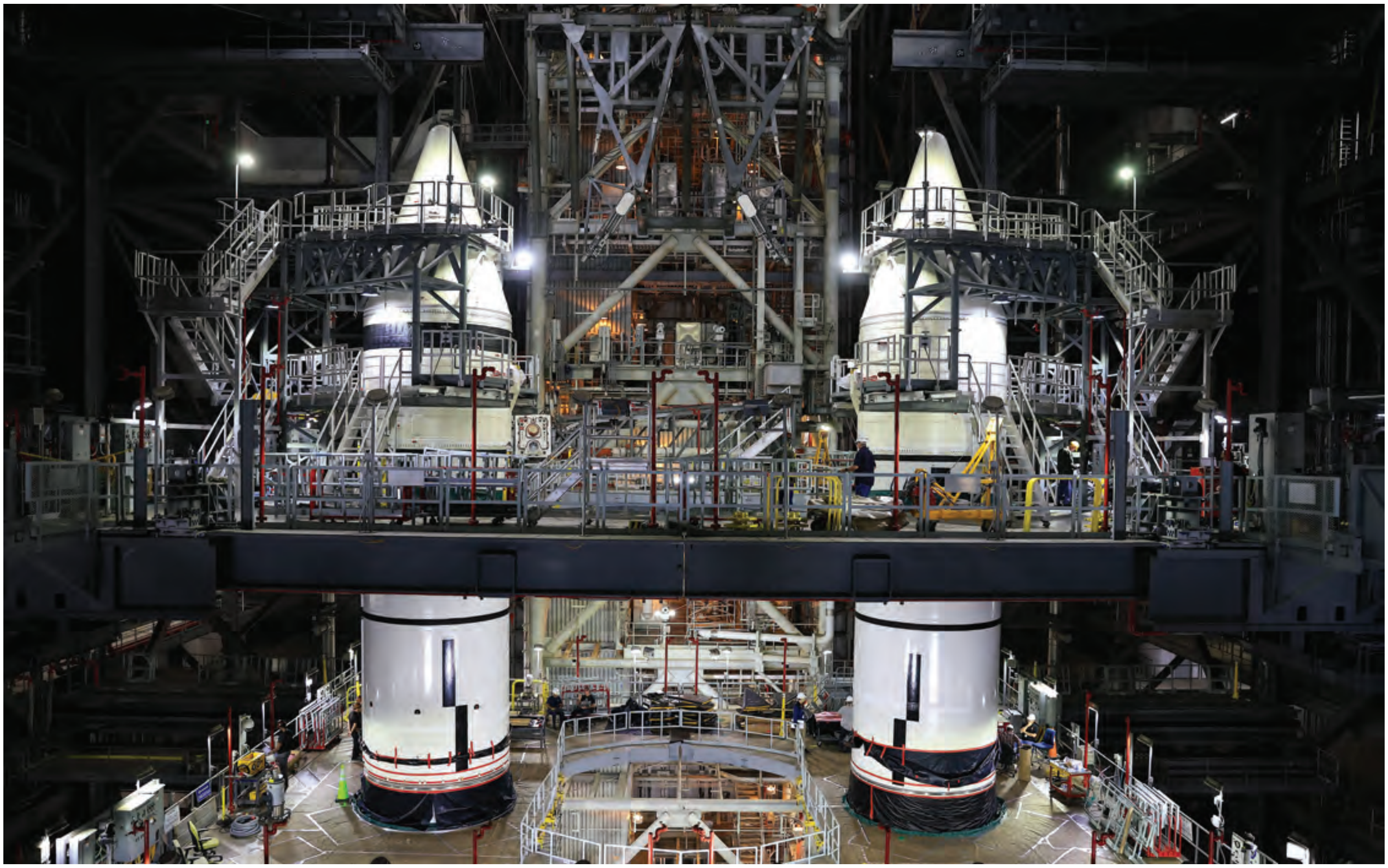
The Boeing SLS Program is managed by the company's Space and Launch division in Huntsville, Alabama, and employs Boeing's workforce in Huntsville, at NASA's Michoud Assembly Facility in New Orleans, NASA's Kennedy Space Center in Florida, at other Boeing sites, and with suppliers across the country. The Boeing Exploration Launch Systems office supports NASA on strategy and policy for space exploration programs procured by NASA's Marshall Space Flight Center in Huntsville, Alabama.

Boeing is the prime contractor for the SLS core stage, manufactured at NASA Michoud, and the ICPS, manufactured by United Launch Alliance (ULA).

Northrop Grumman

Northrop Grumman is the prime contractor for the design, development, testing, and production of the twin solid rocket boosters that provide more than 75 percent of initial thrust for SLS. Building on the knowledge and flight-proven hardware from the Space Shuttle Program, the new five-segment design features enhanced technologies and incorporates 25 percent more propellant to make these the largest rocket boosters ever built for flight. Additionally, Northrop Grumman provides 16 booster separation motors, designed to push the spent solid rocket boosters away from the core stage, for each launch.

The Northrop Grumman Northern Utah team manages the production and testing of the SLS solid rocket boosters, with teams at NASA Kennedy, as well as in Huntsville, Alabama, overseeing various components and providing on-site support. Northrop Grumman also produces the launch abort motor and the attitude control motor for the Orion spacecraft's Launch Abort System. The abort motor is manufactured and tested out of the company's Promontory and Bacchus, Utah, facilities, and work on the attitude control motor is based in Elkton, Maryland.



Northrop Grumman manufactures the SLS solid rocket boosters, as well as two of the three solid motors used in the Orion spacecraft's launch abort system.

Teledyne Brown Engineering

Teledyne Brown Engineering, based in Huntsville, Alabama, has been a leader in innovative products, systems, integration, operation, and manufacturing for the space industry for more than 65 years. Teledyne Brown provides engineering, technical support, and hardware for the launch vehicle stage adapter (LVSA).

The LVSA is manufactured using the friction-stir welding tools in the Advanced Weld Facility at NASA Marshall. It is the largest piece of the current SLS configuration built at NASA Marshall. In addition to the Artemis II adapter, Teledyne Brown delivered the launch vehicle stage adapter structural test article for Artemis I in 2016, delivered the Artemis I adapter for flight, and has completed the Artemis III adapter.

Teledyne Brown Engineering is the lead contractor for the launch vehicle stage adapter that has a pneumatically activated frangible joint that separates it and the core stage from the ICPS, Orion stage adapter, and Orion spacecraft during flight.

United Launch Alliance

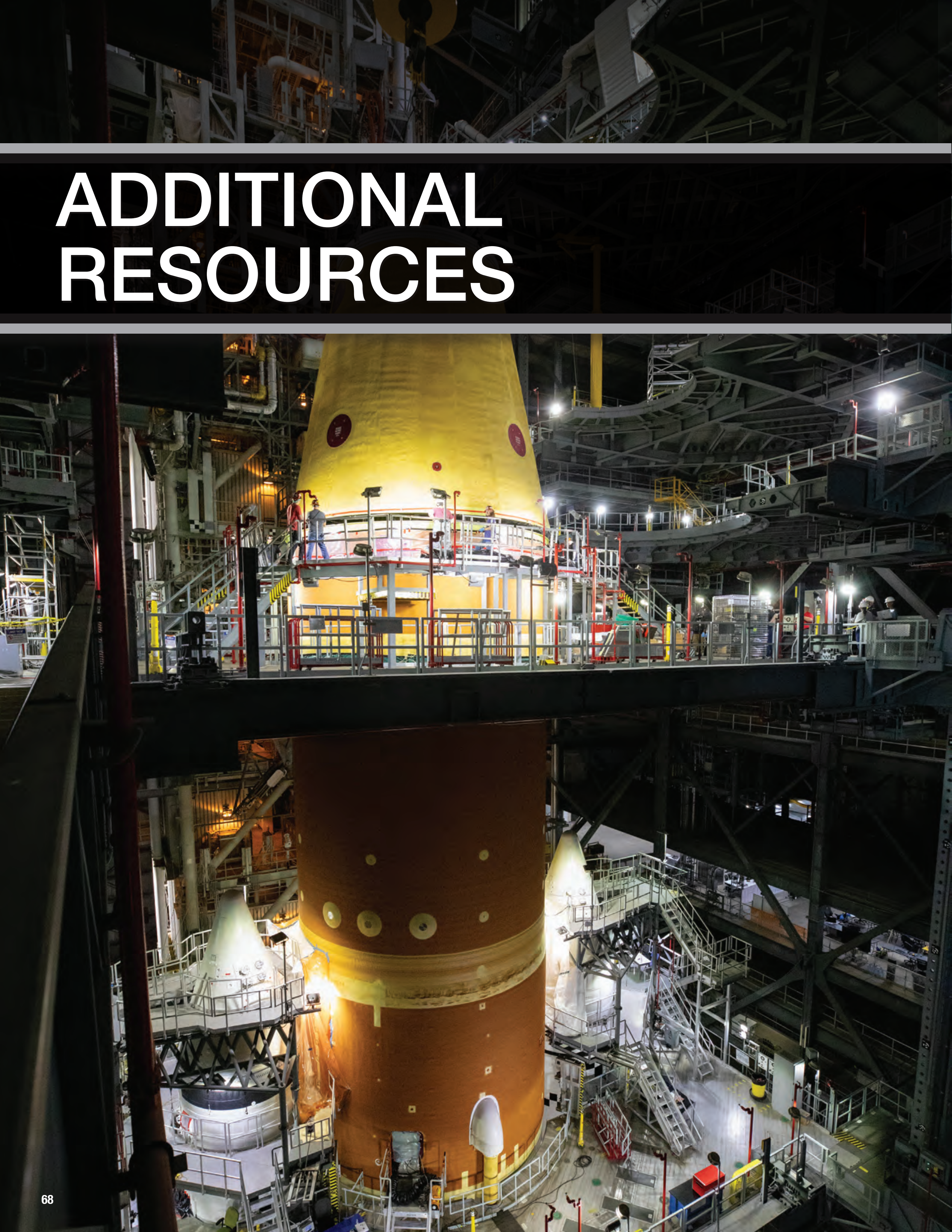
United Launch Alliance (ULA) worked collaboratively with Boeing to develop and build the 5-m (16-ft.)-diameter ICPS for Artemis I, II, and III. The interim cryogenic propulsion stages (ICPS) were manufactured in ULA's Decatur, Alabama, manufacturing facility. The ICPS is a modified version of the ULA 5-m (16-ft.) Delta Cryogenic Second Stage, which has flown 24 times with 100 percent mission success.

With more than a century of combined heritage between Boeing and Lockheed Martin, ULA is the nation's most experienced and reliable launch service provider. ULA has successfully delivered more than 140 missions to orbit that aid meteorologists in tracking severe weather, unlock the mysteries of our solar system, provide critical capabilities for troops in the field, deliver cutting-edge commercial services, and enable GPS navigation.

ULA's program management, engineering, test, and mission support functions are headquartered in Denver, Colorado. Manufacturing, assembly, and integration operations are located at Decatur, Alabama, and Harlingen, Texas. Launch operations are located at Cape Canaveral Space Station in Florida and Vandenberg Space Force Base in California.

ULA supplies the ICPS, which is based on the Delta Cryogenic Second Stage, for the SLS Block 1 rocket.

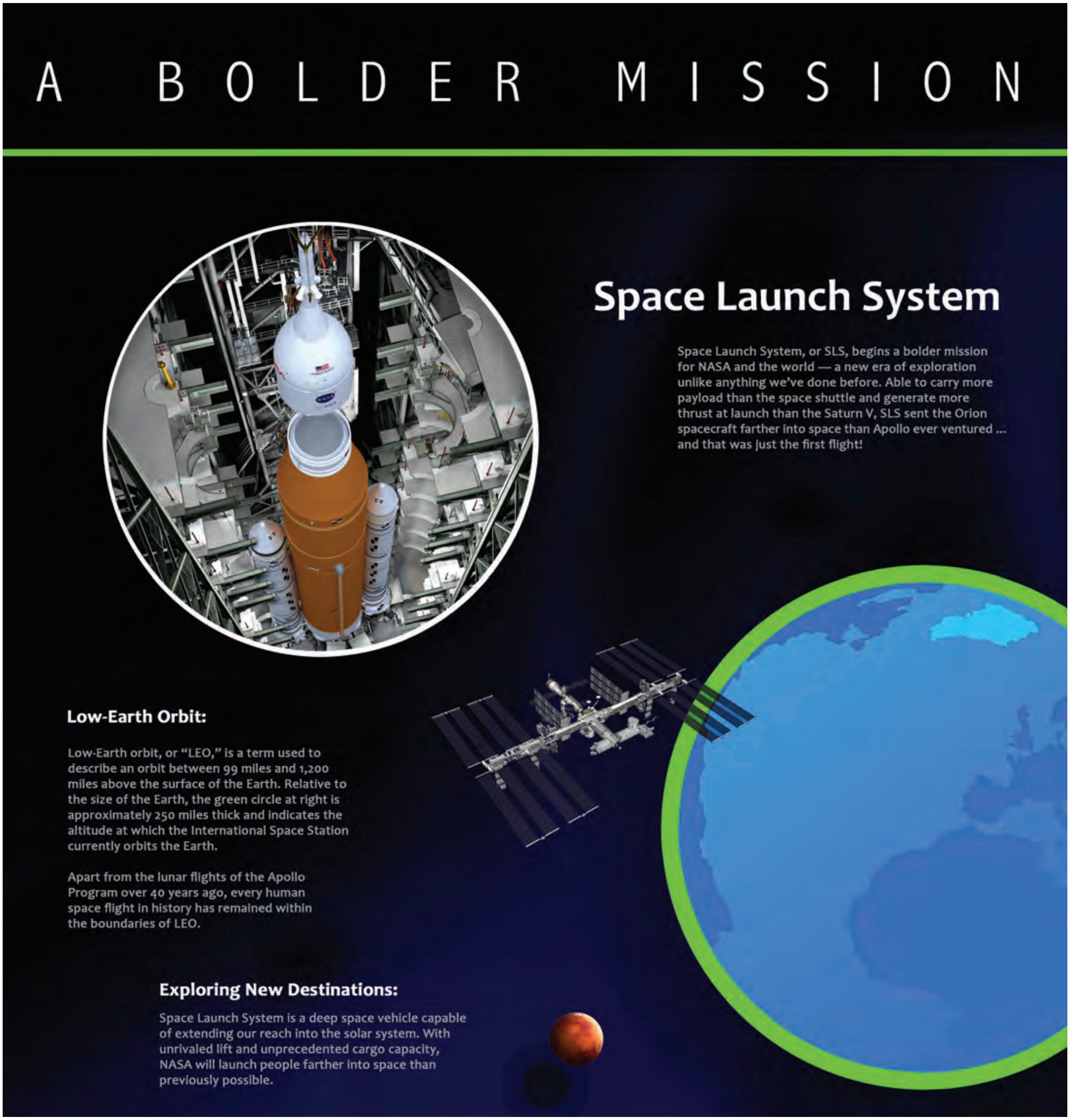
ADDITIONAL RESOURCES

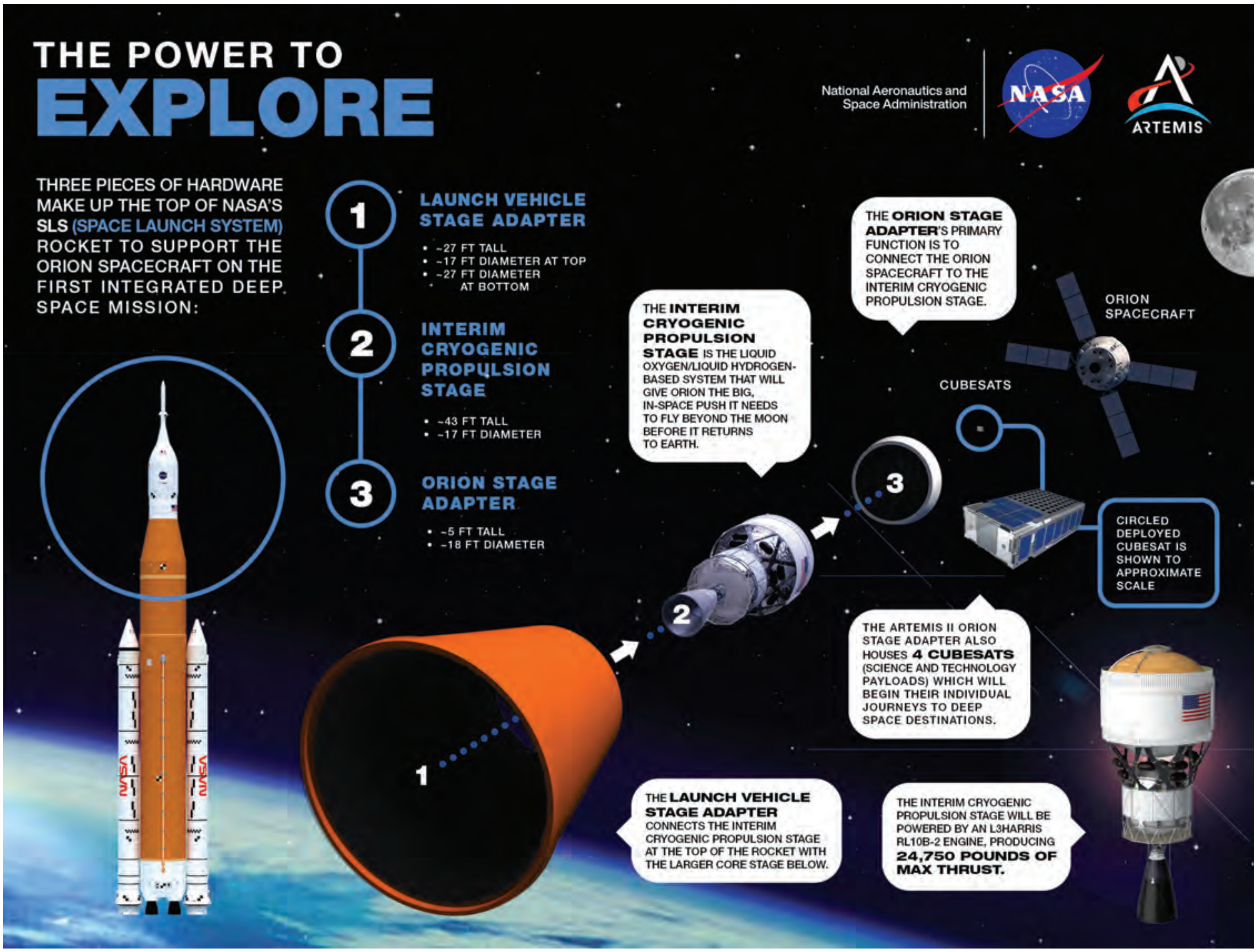


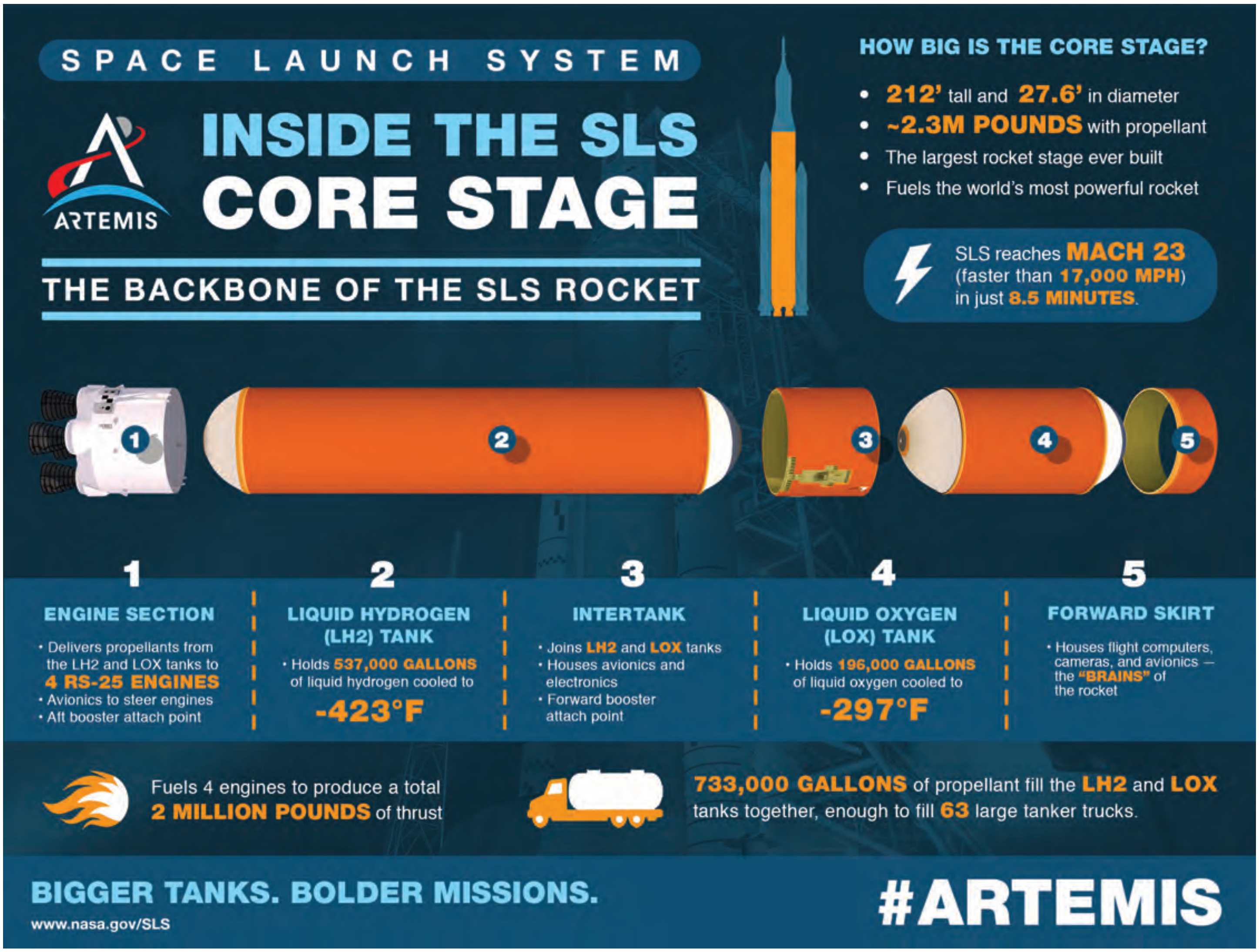
Understanding SLS: Infographics

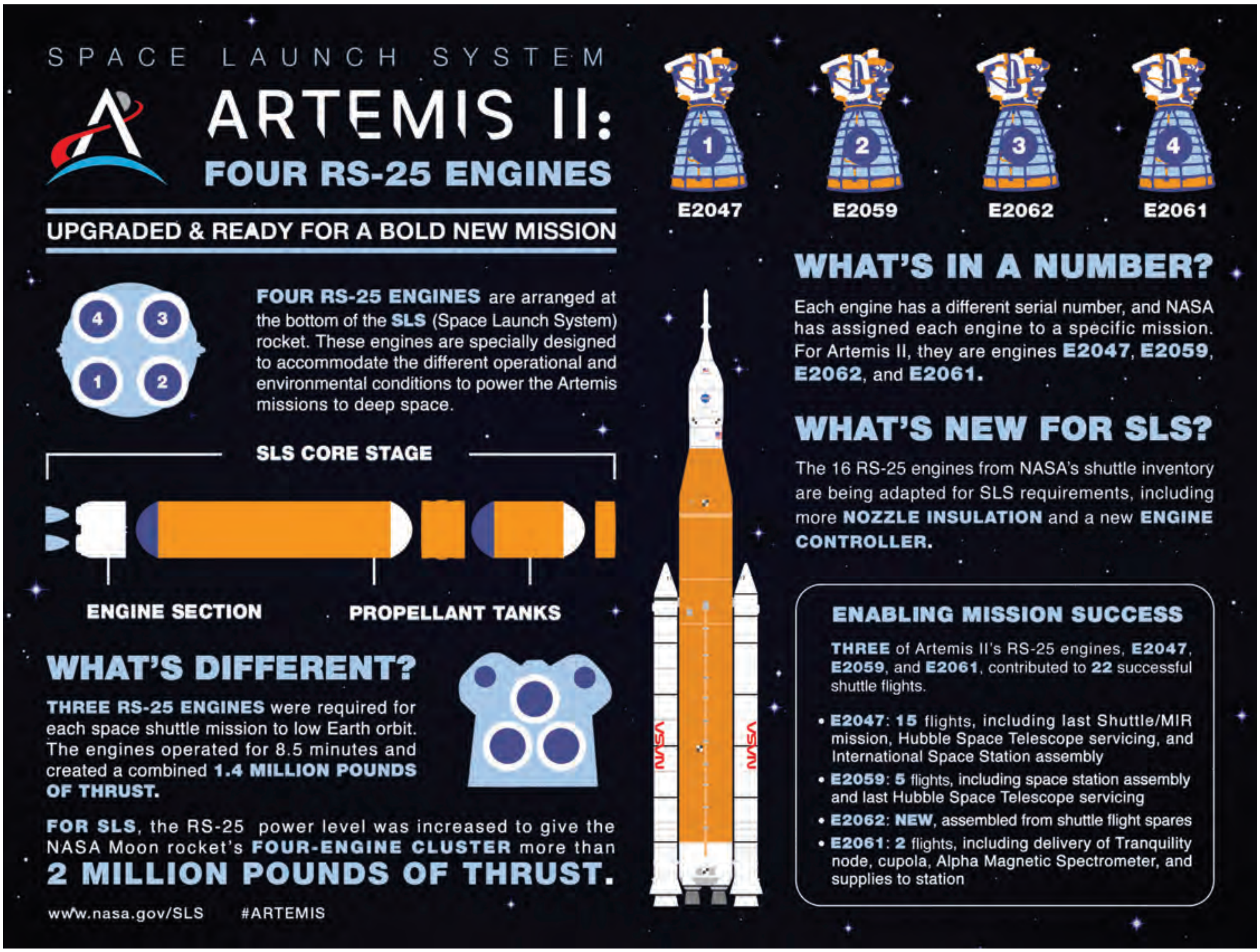
In addition to the Quick Facts in the front of this document, selected SLS infographics below will help you understand SLS and its unique capabilities to enable continuous, ongoing human exploration of the Moon through the Artemis program.

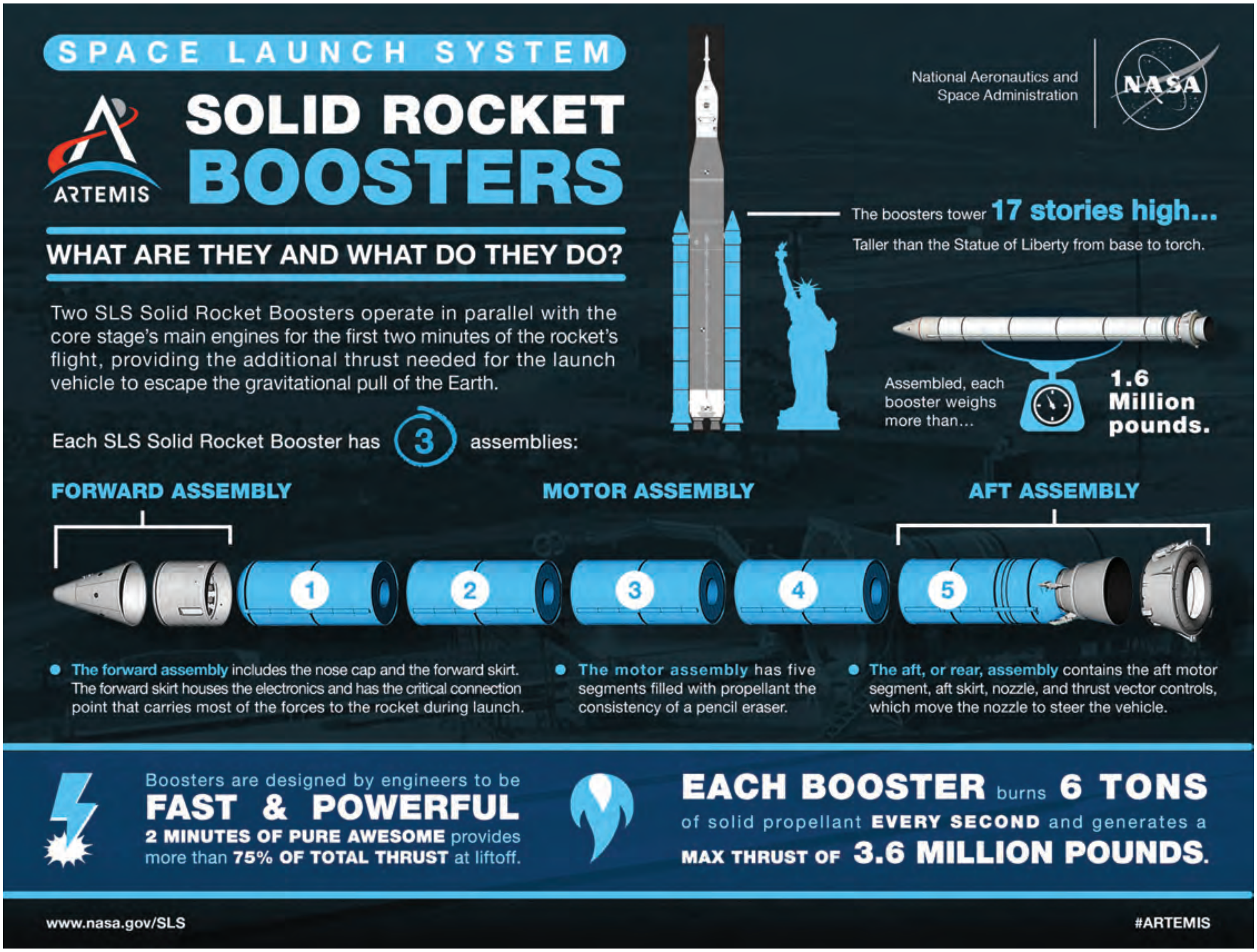
Additional infographics describing SLS design, capabilities, testing, and more are available on the SLS web site at https://www.nasa.gov/gallery/space-launch-system-infographics/.

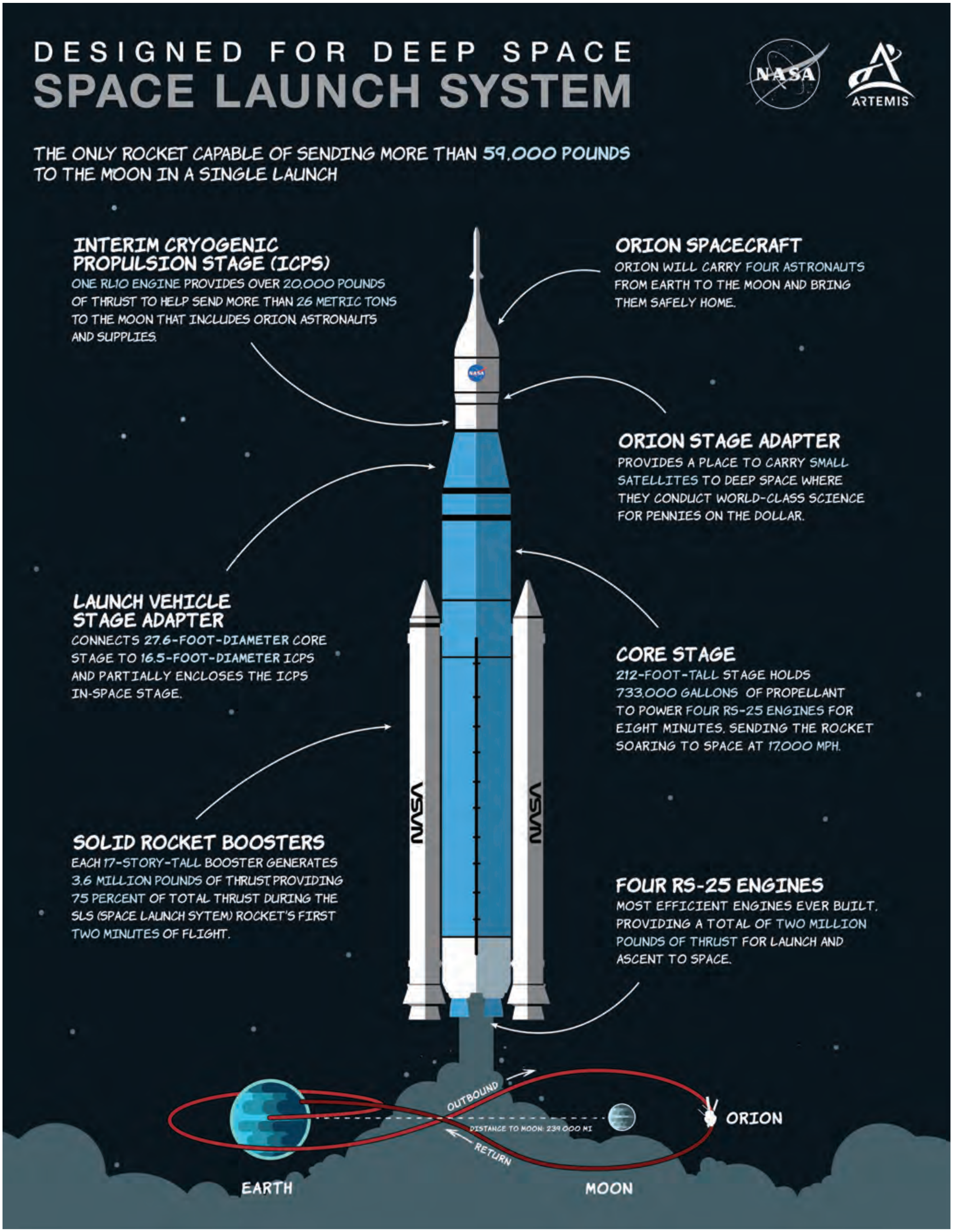



THE POWER TO
EXPLORE
National Aeronautics and Space Administration
NASA
ARTEMIS
THREE PIECES OF HARDWARE MAKE UP THE TOP OF NASA'S SLS (SPACE LAUNCH SYSTEM) ROCKET TO SUPPORT THE ORION SPACECRAFT ON THE FIRST INTEGRATED DEEP SPACE MISSION:
1 LAUNCH VEHICLE STAGE ADAPTER
• ~27 FT TALL
• ~17 FT DIAMETER AT TOP
• ~27 FT DIAMETER AT BOTTOM
2 INTERIM CRYOGENIC PROPULSION STAGE
• ~43 FT TALL
• ~17 FT DIAMETER
3 ORION STAGE ADAPTER
• ~5 FT TALL
• ~18 FT DIAMETER
THE INTERIM CRYOGENIC PROPULSION STAGE IS THE LIQUID OXYGEN/LIQUID HYDROGEN-BASED SYSTEM THAT WILL GIVE ORION THE BIG, IN-SPACE PUSH IT NEEDS TO FLY BEYOND THE MOON BEFORE IT RETURNS TO EARTH.
THE ORION STAGE ADAPTER'S PRIMARY FUNCTION IS TO CONNECT THE ORION SPACECRAFT TO THE INTERIM CRYOGENIC PROPULSION STAGE.
ORION SPACECRAFT
CUBESATS
CIRCLED DEPLOYED CUBESAT IS SHOWN TO APPROXIMATE SCALE
THE ARTEMIS II ORION STAGE ADAPTER ALSO HOUSES 4 CUBESATS (SCIENCE AND TECHNOLOGY PAYLOADS) WHICH WILL BEGIN THEIR INDIVIDUAL JOURNEYS TO DEEP SPACE DESTINATIONS.
THE LAUNCH VEHICLE STAGE ADAPTER CONNECTS THE INTERIM CRYOGENIC PROPULSION STAGE AT THE TOP OF THE ROCKET WITH THE LARGER CORE STAGE BELOW.
THE INTERIM CRYOGENIC PROPULSION STAGE WILL BE POWERED BY AN L3HARRIS RL10B-2 ENGINE, PRODUCING 24,750 POUNDS OF MAX THRUST.
1
2
3


SPACE LAUNCH SYSTEM
ARTEMIS
INSIDE THE SLS
CORE STAGE
THE BACKBONE OF THE SLS ROCKET
HOW BIG IS THE CORE STAGE?
• 212' tall and 27.6' in diameter
• ~2.3M POUNDS with propellant
• The largest rocket stage ever built
• Fuels the world's most powerful rocket
SLS reaches MACH 23 (faster than 17,000 MPH) in just 8.5 MINUTES.
1
2
3
4
5
1
ENGINE SECTION
• Delivers propellants from the LH2 and LOX tanks to 4 RS-25 ENGINES
• Avionics to steer engines
• Aft booster attach point
2
LIQUID HYDROGEN (LH2) TANK
• Holds 537,000 GALLONS of liquid hydrogen cooled to
-423°F
3
INTERTANK
• Joins LH2 and LOX tanks
• Houses avionics and electronics
• Forward booster attach point
4
LIQUID OXYGEN (LOX) TANK
• Holds 196,000 GALLONS of liquid oxygen cooled to
-297°F
5
FORWARD SKIRT
• Houses flight computers, cameras, and avionics — the "BRAINS" of the rocket
Fuels 4 engines to produce a total 2 MILLION POUNDS of thrust
733,000 GALLONS of propellant fill the LH2 and LOX tanks together, enough to fill 63 large tanker trucks.
BIGGER TANKS. BOLDER MISSIONS.
www.nasa.gov/SLS
#ARTEMIS


SPACE LAUNCH SYSTEM
ARTEMIS II:
FOUR RS-25 ENGINES
UPGRADED & READY FOR A BOLD NEW MISSION
FOUR RS-25 ENGINES are arranged at the bottom of the SLS (Space Launch System) rocket. These engines are specially designed to accommodate the different operational and environmental conditions to power the Artemis missions to deep space.
SLS CORE STAGE
ENGINE SECTION
PROPELLANT TANKS
WHAT'S DIFFERENT?
THREE RS-25 ENGINES were required for each space shuttle mission to low Earth orbit. The engines operated for 8.5 minutes and created a combined 1.4 MILLION POUNDS OF THRUST.
FOR SLS, the RS-25 power level was increased to give the NASA Moon rocket's FOUR-ENGINE CLUSTER more than
2 MILLION POUNDS OF THRUST.
www.nasa.gov/SLS
#ARTEMIS
E2047
E2059
E2062
E2061
WHAT'S IN A NUMBER?
Each engine has a different serial number, and NASA has assigned each engine to a specific mission. For Artemis II, they are engines E2047, E2059, E2062, and E2061.
WHAT'S NEW FOR SLS?
The 16 RS-25 engines from NASA's shuttle inventory are being adapted for SLS requirements, including more NOZZLE INSULATION and a new ENGINE CONTROLLER.
ENABLING MISSION SUCCESS
THREE of Artemis II's RS-25 engines, E2047, E2059, and E2061, contributed to 22 successful shuttle flights.
• E2047: 15 flights, including last Shuttle/MIR mission, Hubble Space Telescope servicing, and International Space Station assembly
• E2059: 5 flights, including space station assembly and last Hubble Space Telescope servicing
• E2062: NEW, assembled from shuttle flight spares
• E2061: 2 flights, including delivery of Tranquility node, cupola, Alpha Magnetic Spectrometer, and supplies to station


SPACE LAUNCH SYSTEM
ARTEMIS
SOLID ROCKET BOOSTERS
WHAT ARE THEY AND WHAT DO THEY DO?
Two SLS Solid Rocket Boosters operate in parallel with the core stage's main engines for the first two minutes of the rocket's flight, providing the additional thrust needed for the launch vehicle to escape the gravitational pull of the Earth.
Each SLS Solid Rocket Booster has 3 assemblies:
National Aeronautics and Space Administration
NASA
The boosters tower 17 stories high...
Taller than the Statue of Liberty from base to torch.
Assembled, each booster weighs more than...
1.6 Million pounds.
FORWARD ASSEMBLY
MOTOR ASSEMBLY
AFT ASSEMBLY
1
2
3
4
5
The forward assembly includes the nose cap and the forward skirt. The forward skirt houses the electronics and has the critical connection point that carries most of the forces to the rocket during launch.
The motor assembly has five segments filled with propellant the consistency of a pencil eraser.
The aft, or rear, assembly contains the aft motor segment, aft skirt, nozzle, and thrust vector controls, which move the nozzle to steer the vehicle.
Boosters are designed by engineers to be
FAST & POWERFUL
2 MINUTES OF PURE AWESOME provides more than 75% OF TOTAL THRUST at liftoff.
EACH BOOSTER burns 6 TONS of solid propellant EVERY SECOND and generates a MAX THRUST OF 3.6 MILLION POUNDS.
www.nasa.gov/SLS
#ARTEMIS


DESIGNED FOR DEEP SPACE
SPACE LAUNCH SYSTEM
NASA
ARTEMIS
THE ONLY ROCKET CAPABLE OF SENDING MORE THAN 59,000 POUNDS TO THE MOON IN A SINGLE LAUNCH
INTERIM CRYOGENIC PROPULSION STAGE (ICPS)
ONE RL10 ENGINE PROVIDES OVER 20,000 POUNDS OF THRUST TO HELP SEND MORE THAN 26 METRIC TONS TO THE MOON THAT INCLUDES ORION, ASTRONAUTS AND SUPPLIES.
ORION SPACECRAFT
ORION WILL CARRY FOUR ASTRONAUTS FROM EARTH TO THE MOON AND BRING THEM SAFELY HOME.
ORION STAGE ADAPTER
PROVIDES A PLACE TO CARRY SMALL SATELLITES TO DEEP SPACE WHERE THEY CONDUCT WORLD-CLASS SCIENCE FOR PENNIES ON THE DOLLAR.
LAUNCH VEHICLE STAGE ADAPTER
CONNECTS 27.6-FOOT-DIAMETER CORE STAGE TO 16.5-FOOT-DIAMETER ICPS AND PARTIALLY ENCLOSES THE ICPS IN-SPACE STAGE.
CORE STAGE
212-FOOT-TALL STAGE HOLDS 733,000 GALLONS OF PROPELLANT TO POWER FOUR RS-25 ENGINES FOR EIGHT MINUTES, SENDING THE ROCKET SOARING TO SPACE AT 17,000 MPH.
NASA
NASA
SOLID ROCKET BOOSTERS
EACH 17-STORY-TALL BOOSTER GENERATES 3.6 MILLION POUNDS OF THRUST, PROVIDING 75 PERCENT OF TOTAL THRUST DURING THE SLS (SPACE LAUNCH SYTEM) ROCKET'S FIRST TWO MINUTES OF FLIGHT.
FOUR RS-25 ENGINES
MOST EFFICIENT ENGINES EVER BUILT, PROVIDING A TOTAL OF TWO MILLION POUNDS OF THRUST FOR LAUNCH AND ASCENT TO SPACE.
OUTBOUND
DISTANCE TO MOON: 239,000 MI
RETURN
ORION
EARTH
MOON

ACRONYM LIST

ACRONYM	DEFINITION
EGS	Exploration Ground Systems
ESA	European Space Agency
EUS	Exploration Upper Stage
GSE	Ground Support Equipment
ICPS	Interim Cryogenic Propulsion Stage
ISS	International Space Station
ITCO	Intergrated Test and Check Out
LAS	Launch Abort System
LCC	Launch Control Center
LVSA	Launch Vehicle Stage Adapter
Max Q	Maximum Dynamic Pressure
MECO	Main Engine Cutoff
OSA	Orion Stage Adapter
PBAN	Polybutadiene Acrylonitrile
SESC	SLS Engineering Support Center
SLS	Space Launch System
SSME	Space Shuttle Main Engine
STS	Space Transporation System
TLI	Translunar Injection
ULA	United Launch Alliance

Links

For more information about SLS, visit:

https://x.com/nasaartemis

https://www.facebook.com/NASAArtemis/

http://youtube.com/nasa

https://www.instagram.com/nasaartemis/

NOTES

NOTES

National Aeronautics and Space Administration

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www.nasa.gov

SLS-5558