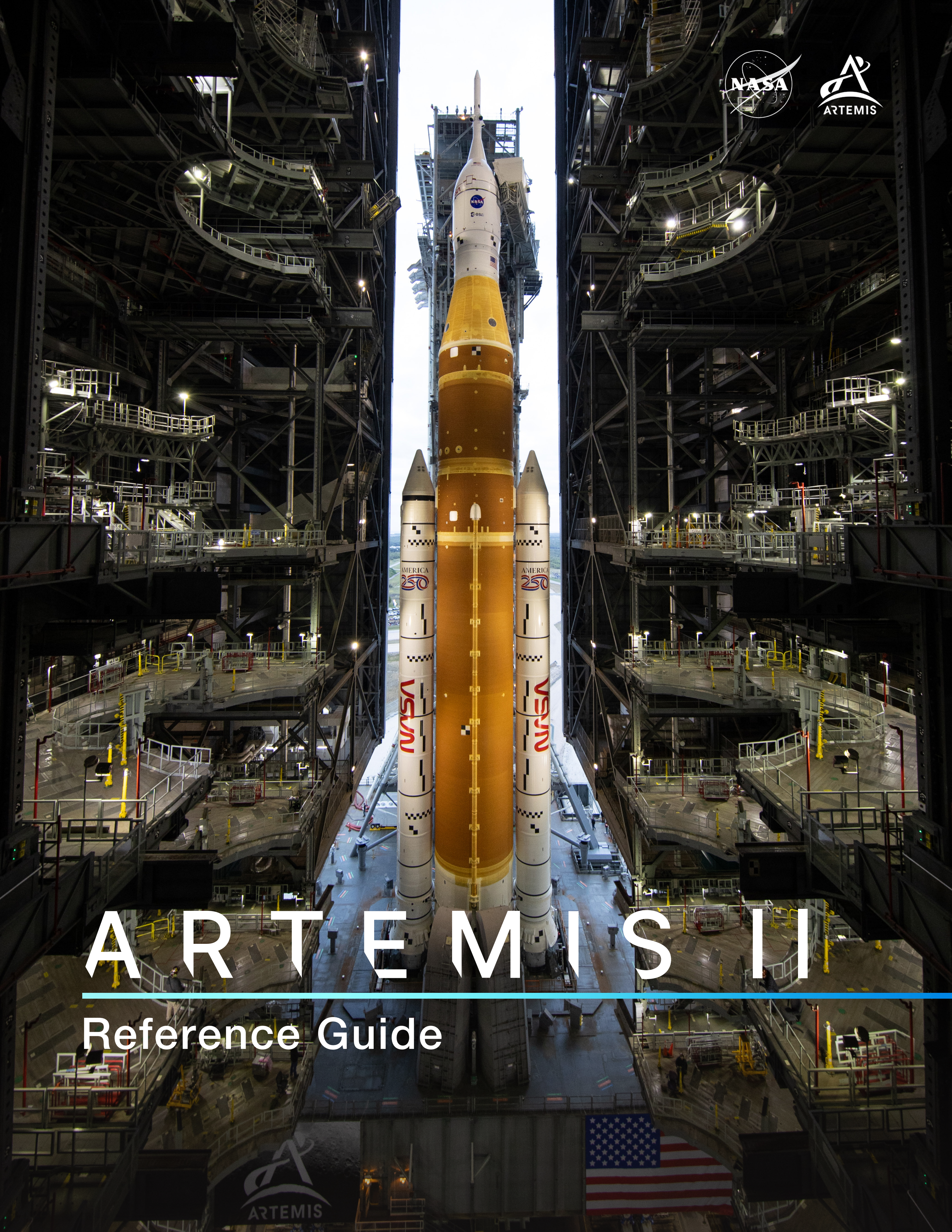


ARTEMIS II

Reference Guide

CONTENTS

FOREWORD

Dr. Lori S. Glaze

Associate Administrator (Acting)
Exploration Systems Development
Mission Directorate

We are ready for Artemis II to enable NASA to set course to explore the Moon, marking a new era of human spaceflight and deep space exploration.

By harnessing the capabilities of NASA's SLS (Space Launch System) rocket, Orion spacecraft, and ground systems, the Artemis II mission will send NASA astronauts Reid Wiseman, Victor Glover, Christina Koch, and CSA (Canadian Space Agency) astronaut Jeremy Hansen on an approximately 10-day, 685,000-plus-mile journey around the Moon and back.

It has been more than 50 years since humans have traveled beyond low Earth orbit. Over the ensuing decades, our world has changed, our dreams and aspirations have grown, and our technological capabilities have advanced at an astounding pace.

Since the successful test flight of Artemis I, teams of NASA engineers and specialists have painstakingly analyzed every piece of data from that mission. The lessons we have learned and implemented give us confidence that the Artemis II SLS rocket and Orion spacecraft will be the most capable deep space system ever flown.

When launched, Artemis II will be the culmination of years of planning, technology development, hardware testing, crew training, public investment, and seamless coordination among NASA's commercial and international partners.

But Artemis II is more than a steppingstone to the Moon, Mars, and beyond. It is a critical mission of scientific discovery and technology innovation. During flight, our astronauts in space and support teams around the globe will gather vital data on human health, make firsthand observations of the lunar far side, and practice flight maneuvers necessary for NASA's return to the lunar surface under Artemis III.

This mission builds upon America's proud legacy of Apollo, the space shuttle, and the International Space Station. But the time has come for NASA to blaze new trails and extend our reach to exciting and unexplored frontiers. We go to the Moon not as momentary visitors, but rather as bold pioneers committed to the ongoing exploration of the lunar surface and, for the first time ever, the Moon's South Pole region.

Ultimately, what we build, test, and discover at the Moon will teach us how to live and work on another world as we prepare for human missions to Mars.

Artemis II and future missions at the Moon will also energize innovation across our technology base, enhance our ability to conduct science across all disciplines, and secure American leadership in space for generations to come.

This is a proud and powerful moment for NASA and our nation. We have challenged ourselves to go farther, and we have met that challenge together. As you read through this reference guide, I encourage you to look beyond the facts and figures. Take time to appreciate the many thousands of people who have given their skills, ingenuity, and unwavering commitment to the mission and the goals of NASA.

Artemis succeeds because of humanity's shared vision of a better tomorrow and a more prosperous future. We are honored to have you join us on this adventure.

Sincerely,

Lori

The last quarter Moon is pictured above Earth's atmosphere from the International Space Station as it soared 260 miles over the Pacific Ocean southwest of Panama. (NASA)

Artemis

Purpose

The Artemis campaign heralds a Golden Age of exploration and innovation for NASA and its partners. America is leading the way into the cosmos, preparing humanity to live and work on the Moon, and paving the way for a crewed mission to Mars.

This reference guide provides detailed descriptions of the systems and subsystems for the Artemis II mission, including program overviews, technical elements, testing, and management roles and facilities for the SLS (Space Launch System) rocket, Orion spacecraft, and associated Exploration Ground Systems.

Artemis Overview

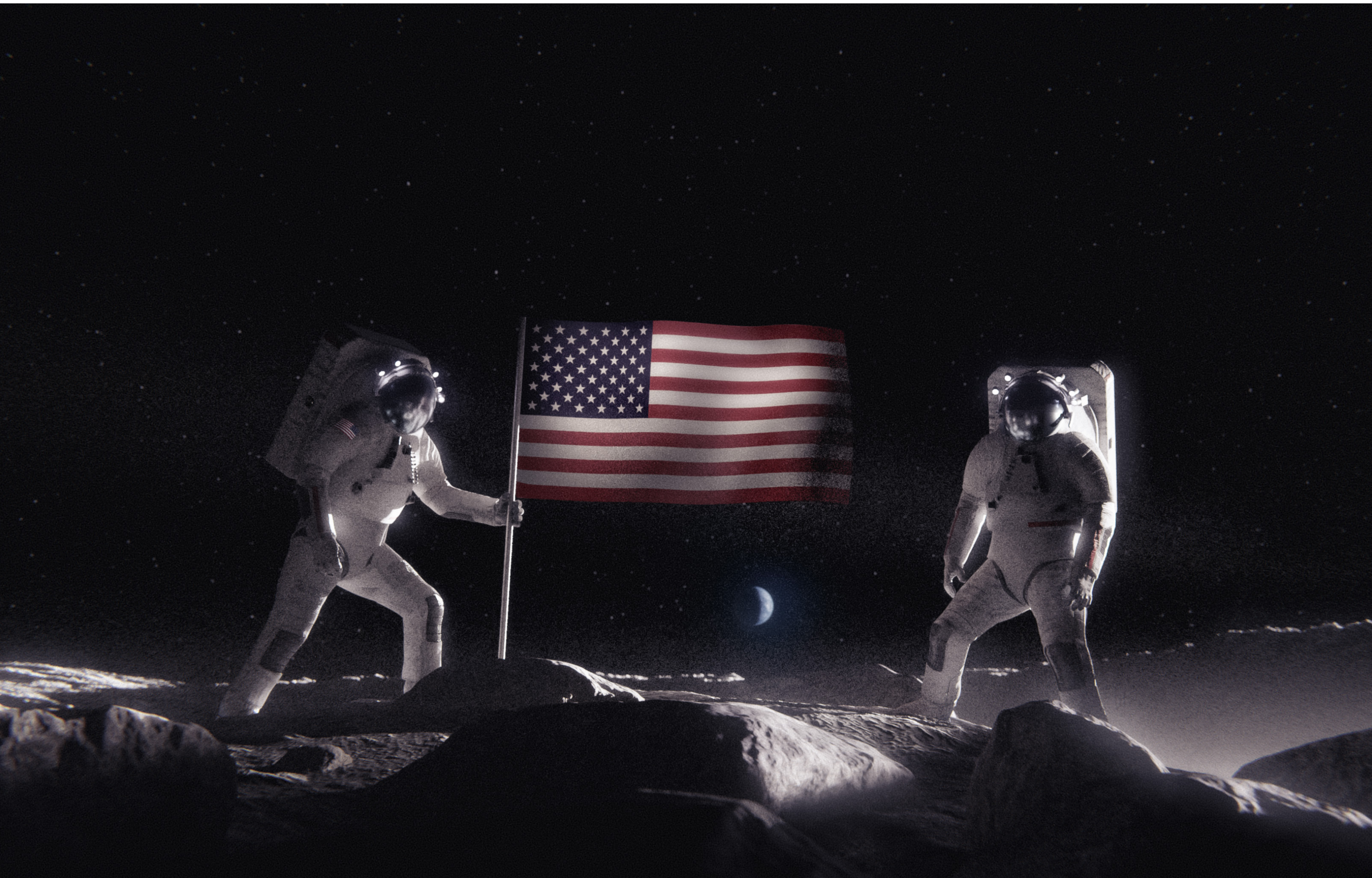
Along with robotic missions, human-led Artemis missions will unveil more of the Moon than ever before. The lunar South Pole is an area shrouded in mystery but enticing in its scientific potential.

For more than 25 years, astronauts have lived and worked in low Earth orbit aboard the International Space Station. Now, through NASA's Artemis missions, astronauts will learn how to live and work farther away from Earth, for longer periods of time.

NASA is investing in a long-term exploration campaign of the Moon, which will lead to Mars, connecting near-term achievements with the technologies, science, and partnerships necessary for sending the first people to another planet.

Artemis returns American astronauts to the Moon in order to stay. Each flight fulfills a methodical list of test objectives that build an enduring presence in deep space. It is the foundation of our future among the stars, and that future begins now.

This artist's concept shows two Artemis astronauts planting a new American flag at the lunar South Pole. (NASA/Daniel O'Neal) ▼



Artemis I

Following liftoff on Nov. 16, 2022, NASA spent nearly 26 days rigorously testing its foundational deep space exploration systems — the SLS rocket, Orion spacecraft, and Exploration Ground Systems — during Artemis I. It was a monumental moment for NASA, the United States, the agency's international partners, and all of humanity.

During, the record-breaking mission, the Orion spacecraft traveled more than 1.4 million miles on a path around the Moon before returning safely to Earth, cooling off with a splash in the Pacific Ocean west of Baja California.

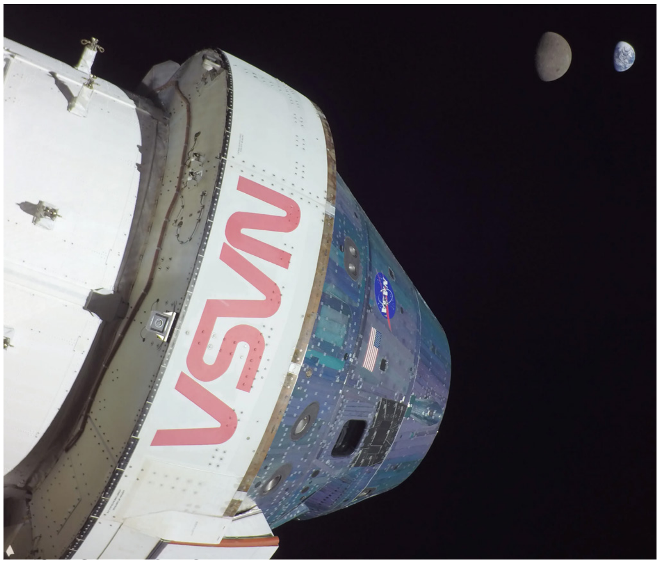
Orion stayed in space longer than any spacecraft designed for astronauts has done without docking to a space station. While in a distant lunar orbit, Orion surpassed the record for distance from Earth by a spacecraft designed to carry humans, previously set during Apollo 13, by traveling nearly 270,000 miles from Earth to intentionally stress its systems before they could be validated for crew.

NASA continues to learn from the data received during that test flight, helping to improve the hardware and systems crews will rely on for Artemis II and beyond.

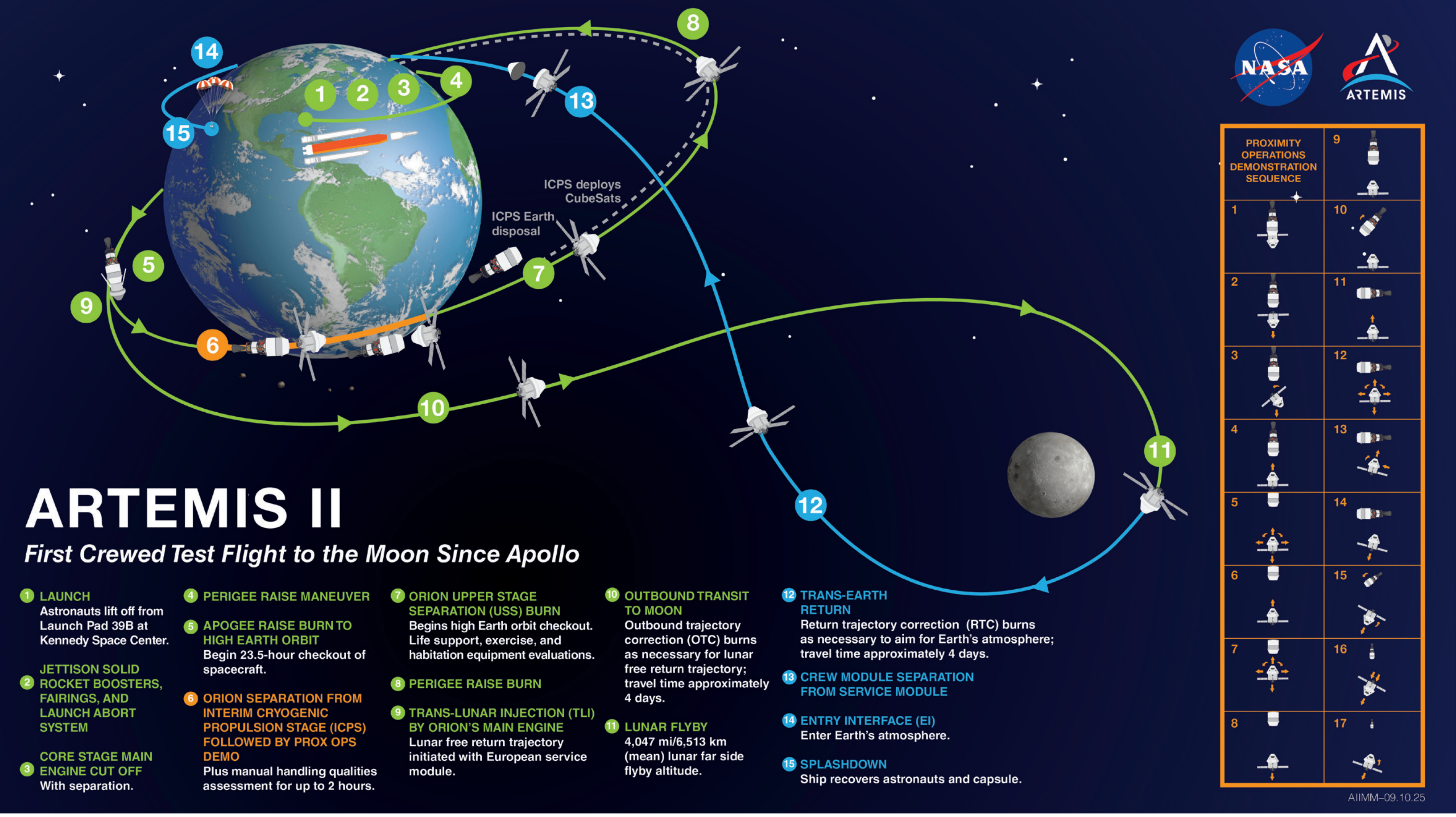
The first Artemis flight set new performance records and continues to serve as the standard for how the agency will make deep space exploration attainable for this generation's explorers.

A bird's eye view of the Artemis I launch shows one of the rocket's solid rocket boosters shortly after ignition. (NASA/Chris Coleman, Kevin Davis)

During Artemis I, the Orion spacecraft reached a maximum distance from Earth when it was 268,563 miles away from our home planet. (NASA)



At 12:40 p.m. EST on Dec. 11, 2022, Orion splashed down in the Pacific Ocean west of Baja California, completing its 25.5-day mission beyond the Moon. (NASA/Josh Valcarcel)



During Artemis II, over the course of about 10 days, four astronauts will confirm all of the spacecraft's systems operate as designed with people aboard in the actual environment of deep space. The mission paves the way to land the next Americans on the Moon on Artemis III. (NASA) ▲

Artemis II

The Artemis II test flight will be NASA's first mission with crew under Artemis.

The SLS rocket will launch the Orion spacecraft and its crew into space with a set of research and flight objectives to meet. Many of these will be completed as Orion flies two elliptical orbits around Earth to ensure Orion's systems are working as expected before committing to a trip around the Moon.

At the beginning of a 24-hour highly elliptical orbit, the crew will take control of Orion for about two hours while mission control monitors from Houston, executing targeting maneuvers to gather performance data and experience to prepare for Artemis III operations. The remainder of the orbit will be spent checking out the Orion environmental control and life support system — one primary aim for the mission.

Teams recover the Crew Module Test Article — a full-scale mock-up of the Orion spacecraft — as they practice Artemis recovery operations during Underway Recovery Test-12 aboard USS Somerset off the coast of California on March 29, 2025. During the test, NASA and Department of War teams practice recovery procedures for NASA's Artemis II mission around the Moon, which will conclude with splash-down in the Pacific Ocean. (NASA/Bill Ingalls) ▲

The Artemis II crew will travel approximately 4,700 miles beyond the far side of the Moon, evaluating their spacecraft's performance, practicing emergency procedures, and testing the radiation shelter. From their unique vantage point, the crew will see Earth and the Moon from Orion's windows, with the Moon close in the foreground and Earth nearly a quarter-million miles in the background.

The mission is expected to last approximately 10 days. The spacecraft will rely on gravity to be pulled home, re-entering Earth's atmosphere at 30 times the speed of sound and splashing down in the Pacific Ocean.

From left to right, NASA astronauts Christina Koch, Reid Wiseman, Victor Glover, and and CSA (Canadian Space Agency) astronaut Jeremy Hansen play the board game "Sorry" inside the Neil A. Armstrong Operations and Checkout Building at NASA's Kennedy Space Center in Florida on Aug. 11, 2025. During launch day, NASA flight crews have a tradition of playing a board or card game before leaving the crew quarters ahead of launch until the commander loses so that the commander burns off all his or her bad luck before the flight. (NASA) ▲

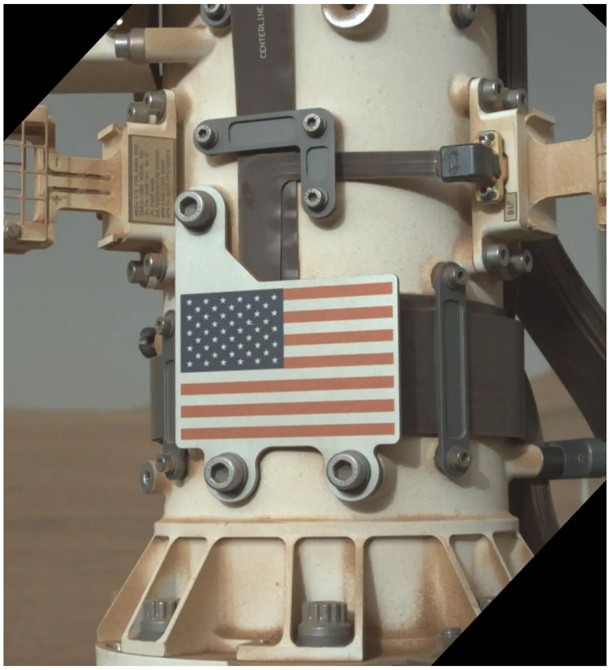
The Artemis II crew is shown inside the Neil A. Armstrong Operations and Checkout Building at NASA's Kennedy Space Center in Florida in front of their Orion crew module on Aug. 8, 2023. From left are: Jeremy Hansen, mission specialist; Victor Glover, pilot; Reid Wiseman, commander; and Christina Hammock Koch, mission specialist. (NASA/Kim Shiflett) ▲

Artemis III and Beyond

Artemis III will see Orion and a crew of four once again travel to the Moon — this time to make history by landing the first humans at the lunar South Pole region.

After Artemis III, NASA will work with commercial and international partners to launch additional crewed missions to the Moon and establish a long-term, more permanent foothold in deep space.

NASA is mastering capabilities for mission longevity far from Earth. By building a flexible exploration architecture with applications for more than one world, NASA will gain the knowledge necessary to go further into the solar system and land American astronauts on Mars.



The U.S. flag adorns an aluminum plate mounted at the base of the mast, or “head,” of NASA’s Perseverance Mars rover. This image of the plate was taken on June 28, 2025 (the 1,548th day, or sol, of the mission), by the WATSON (Wide Angle Topographic Sensor for Operations and eNgineering) camera on the end of the rover’s robotic arm. (NASA/JPL-Caltech/MSSS) ▲

NASA is leaving the warm confines of low Earth orbit to venture to the Moon, Mars, and beyond. In this image, Jakarta, Indonesia, with a metropolitan population of about 32.6 million, and fishing boats illuminated on the Java Sea, are pictured from the International Space Station as it orbited 261 miles above the Indian Ocean. (NASA) ▼

Artemis II NASA astronauts (left to right) Reid Wiseman, Victor Glover, and Christina Koch, and CSA (Canadian Space Agency) astronaut Jeremy Hansen stand in the white room on the crew access arm of the mobile launcher at Launch Pad 39B as part of an integrated ground systems test at NASA's Kennedy Space Center in Florida on Sept. 20, 2023. (NASA/Frank Michaux) ▲

Artemis II Science

With Artemis II, NASA is taking the science of living and working in space beyond low Earth orbit. While the test flight will help confirm the systems and hardware needed for human deep space exploration, the crew will be serving as both scientists and volunteer research subjects, completing a suite of experiments that will allow NASA to better understand how human health may change in deep space environments. Results will help the agency build future interventions, protocols, and preventative measures to best protect astronauts on future missions to the lunar surface and to Mars.

Science on Artemis II will include seven main research areas:

ARCHeR: Artemis Research for Crew Health and Readiness

NASA's Artemis II mission provides an opportunity to explore how deep space travel affects sleep, stress, cognition, and teamwork — key factors in astronaut health and performance. While these effects are well-documented in low Earth orbit, they've never been fully studied during lunar missions.

Artemis II astronauts will wear wristband devices that continuously monitor movement and sleep patterns throughout the mission. The data will be used for real-time health monitoring and safety assessments, while preflight and postflight evaluations will provide deeper insights into cognition, behavior, sleep quality, and teamwork in the unique environment of deep space and inside the Orion spacecraft.

The findings from the test flight will inform future mission planning and crew support systems, helping NASA optimize human performance for the next era of exploration on the Moon and Mars.

Immune Biomarkers

Saliva provides a unique window into how the human immune system functions in a deep space environment. Tracing changes in astronauts' saliva from before, during, and after the mission will enable researchers to investigate how the human body responds to deep space in unprecedented ways.

Dry saliva will be collected before, during, and after the mission. It will be blotted onto specialized paper in pocket-sized booklets since equipment needed to preserve wet saliva samples in space — including refrigeration — will not be available due to volume constraints. To augment that information, wet saliva and blood samples will be collected before and after the mission.

With these wet and dry saliva samples, scientists will gain insights into how the astronauts' immune systems are affected by the increased stresses of radiation, isolation, and distance from Earth during their deep space flight. They also will examine whether otherwise dormant viruses are reactivated in space, as has been seen previously on the International Space Station with viruses that can cause chickenpox and shingles.

The information gathered from this study, when combined with data from other missions, will help researchers develop ways to keep crew members safe and healthy as we explore farther and travel for longer periods on deep space missions.

AVATAR: A Virtual Astronaut Tissue Analog Response

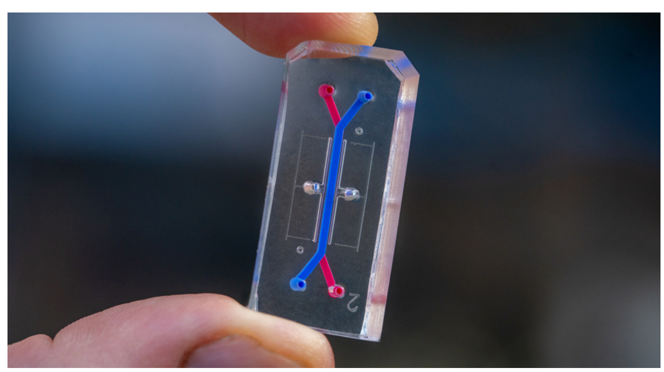
AVATAR is another important component of NASA's strategy to gain a holistic understanding of how the deep space environment affects humans. Scientists plan to use organ-on-a-chip technology during Artemis II, marking the first time these devices will be used beyond the Van Allen Belt.

Roughly the size of a USB thumb drive, the chips will measure how individual astronauts respond to deep space stressors, including extreme radiation and microgravity. The organ chips will contain cells developed from preflight blood donations provided by crew members to create miniature stand-ins, or "avatars," of their bone marrow. Bone marrow plays a vital role in the immune system and is particularly sensitive to radiation, which is why scientists selected it for this study.

A key goal for this research is to validate whether organ chips can serve as accurate tools for measuring and predicting human responses to stressors. To evaluate this, scientists will compare AVATAR data with space station findings, as well as with samples taken from the crew before and after flight.

AVATAR could inform measures to ensure crew health on future deep space missions, including personalizing medical kits to each astronaut. For citizens on

NASA astronaut Randy Bresnik prepares to collect a dry saliva sample aboard the International Space Station. The process, which helps scientists investigate how the immune system is affected by spaceflight, and will be part of the Artemis II mission. (NASA) ▲



An organ chip for conducting bone marrow experiments in space. (Emulate) ▲

Earth, it could lead to advancements in individualized treatments for diseases such as cancer.

AVATAR is a demonstration of the power of public-private partnerships. It's a collaboration between government agencies and commercial space companies: NASA, National Center for Advancing Translational Sciences within the National Institutes of Health, Biomedical Advanced Research and Development Authority, Space Tango, and Emulate.

Artemis II Standard Measures

The crew also will become the first astronauts in deep space to participate in the Spaceflight Standard Measures study, an investigation that's been collecting data from participating crew members aboard the space station and elsewhere since 2018. The study aims to collect a comprehensive snapshot of astronauts' bodies and minds by gathering a consistent set of core measurements of physiological response.

The crew will provide biological samples, including blood, urine, and saliva, for evaluating nutritional status, cardiovascular health, and immunological function starting about six months before their launch. The crew also will participate in tests and surveys evaluating balance, vestibular function, muscle performance, changes in their microbiome, as well as ocular and brain health. While in space, data gathering will include an assessment of motion-sickness symptoms. After landing, there will be additional tests of head, eye, and body movements, among other functional performance tasks. Data collection will continue for a month after their return.

All this information will be available for scientists interested in studying the effects of spaceflight via request to NASA's Life Sciences Data Archive at https://nlsp.nasa.gov/explore/page/home. The results from this work could lead to future interventions, technologies, and studies that help predict the adaptability of crews on a Mars mission.

Radiation Sensors Inside Orion

During the uncrewed Artemis I mission, Orion was blanketed in 5,600 passive and 34 active radiation sensors. The information they gathered assured researchers Orion's design can provide protection for crew members from hazardous radiation levels during lunar missions. That doesn't mean that scientists don't want more information, however.

Similar to Artemis I, six active radiation sensors, collectively called the hybrid electronic radiation assessors, will be deployed at various locations inside the Orion crew module. Crew also will wear dosimeters in their pockets. These sensors will provide warnings of hazardous radiation levels caused by space weather events made by the Sun. If necessary, this data will be used by mission control to drive decisions for the crew to build a shelter to protect from radiation exposure due to space weather.

Additionally, NASA has again partnered the German Space Agency DLR for an updated model of their M-42 sensor — an M-42 EXT — for Artemis II. The new version offers six times more resolution to distinguish between different types of energy compared to the Artemis I version. This will allow it to accurately measure the radiation exposure from heavy ions, which are thought to be particularly hazardous for radiation risk. Artemis II will carry four of the monitors, affixed at points around the cabin by the crew.

Collectively, sensor data will paint a full picture of radiation exposures inside Orion and provide context for interpreting the results of the ARCHeR, AVATAR, Artemis II Standard Measures, and Immune Biomarkers experiment.

Lunar Observations Campaign

The Artemis II crew will take advantage of their location to explore the Moon from above. As the first humans to see the lunar surface up close since 1972, they'll document their observations through photographs and audio recordings to inform scientists' understanding of the Moon and share their experience of being far from Earth. It's possible the crew could be the first humans to see certain areas of the Moon's far side, though this will depend on the time and date of launch, which will affect which areas of the Moon will be illuminated and therefore visible when the spacecraft flies by.

Spacecraft such as NASA's Lunar Reconnaissance Orbiter have been surveying and mapping the Moon for decades, but Artemis II provides a unique opportunity for humans to evaluate the lunar surface from above. Human eyes and brains are highly sensitive to subtle changes in color, texture, and other surface characteristics. Having the crew observe the lunar surface directly — equipped with questions that scientists didn't even know to ask during Apollo missions — could form the basis for future scientific investigations into the Moon's geological history, the lunar environment, or new impact sites.

It will also offer the first opportunity for an Artemis mission to integrate science flight control operations. From their console in the flight control room in mission control, a science officer will consult with a team of scientists with expertise in impact cratering, volcanism, tectonism, and lunar ice to provide real-time data analysis and guidance to the Artemis II crew in space. During the mission, the lunar science team will be located in mission control's Science Evaluation Room at NASA's Johnson Space Center in Houston.

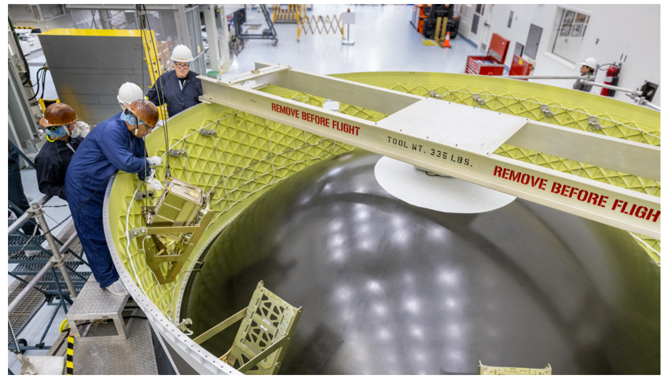
Lessons learned during Artemis II will pave the way for lunar science operations on future missions.

This image captured from a visualization simulates what the crew of Artemis II might see out the Orion windows on the day of their closest approach to the Moon. (NASA Goddard/Ernie Wright) ▲

CubeSats

Several additional experiments are hitching a ride to space aboard Artemis II in the form of CubeSats — shoe-box-sized technology demonstrations and scientific experiments. Though separate from the objectives of the Artemis II mission, they may enhance understanding of the space environment.

Four international space agencies will send CubeSats into space aboard the SLS (Space Launch System) rocket, each with their own objectives. All will be released from the Orion stage adapter on the SLS upper stage into a high Earth orbit, where they will conduct an orbital maneuver to reach their desired orbit.



Technicians install the Korea AeroSpace Administration, or KASA, K-Rad Cube within the Orion stage adapter inside the Multi-Payload Processing Facility at NASA's Kennedy Space Center in Florida on Sept. 2, 2025. The K-Rad Cube, about the size of a shoebox, is one of the CubeSats on Artemis II. (NASA) ▲

ATENEA

Argentina's Comisión Nacional de Actividades Espaciales will collect data on radiation doses across various shielding methods, measure the radiation spectrum around Earth, collect GPS data to help optimize future mission design, and validate a long-range communications link.

K-Rad Cube

The Korea Aerospace Administration will use a dosimeter made of material designed to mimic human tissue to measure space radiation and assess biological effects at various altitudes across the Van Allen Belts.

Space Weather CubeSat

The Saudi Space Agency will measure aspects of space weather, including radiation, solar X-rays, solar energetic particles, and magnetic fields at a range of distances from Earth.

TACHELES

The Germany Space Agency DLR will collect measurements on the effects of the space environment on electrical components to inform technologies for lunar vehicles.

Together, these research areas will inform plans for future missions within NASA's Artemis campaign. Through Artemis, NASA will send astronauts to explore the Moon for scientific discovery, economic benefits, and to build the foundation for the first crewed missions to Mars.

The official Artemis II mission crew insignia is projected on the exterior of the Vehicle Assembly Building at NASA's Kennedy Space Center in Florida on April 4, 2025. (NASA)

Exploration Ground Systems

Introduction

Exploration Ground Systems (EGS) provides the infrastructure behind America's return to the Moon and future voyages to Mars. Working alongside commercial partners, EGS is responsible for the integration, processing, launch, and recovery of the SLS (Space Launch System) rocket and Orion spacecraft, providing mission support and processing from start to splashdown. The EGS team operates out of NASA's Kennedy Space Center in Florida, where teams transform flight hardware into a fully integrated rocket that will carry humans deeper into space than ever before.

Unlike previous work focusing on a single rocket or spacecraft, such as the Saturn V or space shuttle, EGS is preparing the infrastructure to support several different spacecraft and rockets, including the SLS rocket and the Orion spacecraft for Artemis II. A key aspect of the program's approach to sustainability and affordability is to continue to modernize existing facilities, such as the Launch Control Center and the Vehicle Assembly Building (VAB), to support the next generation of spaceflight and deep space exploration.

Overview

EGS was established to develop and operate the systems and facilities necessary to process, assemble, transport, launch, and recover rockets and spacecraft. From the moment that flight hardware is handed over to EGS, NASA works with Amentum, the lead ground, launch, and recovery operations contractor, to perform prelaunch operations, including hardware acceptance, stacking, testing components, fueling, and launch support.

EGS doesn't stop at launch. Once Orion has successfully performed mission objectives and splashed down in the Pacific Ocean, NASA and U.S. Department of War recovery teams safely secure the capsule and crew onboard and return them to land. Orion is then transported back to Kennedy for postflight processing and analysis, paving the way for future missions. It's a full-circle system — launch to landing — with dedication to safety, innovation, and success.

Following the success of the uncrewed Artemis I test flight, EGS has continued to support crewed missions with upgrades to the Block 1 configuration of the SLS rocket for Artemis II and III. With the addition of a new liquid hydrogen tank (LH2) and emergency egress system, Launch Pad 39B is now ready for Artemis II. The new tank holds 1.25 million gallons of usable cryogenic propellant, making it the largest LH2 sphere in the world. Located on the crew access arm level of the mobile launcher, the emergency egress system provides a readily accessible escape path for the astronauts and ground crew in the unlikely event of an extremely hazardous situation.

Elements

Launch Complex 39

Launch Complex 39 consists of the VAB for final assembly and testing of the rocket and spacecraft; a crawlerway used by the crawler-transporter, which will carry the rocket on top of the mobile launcher between the VAB and the pad; the Launch Control Center, which contains the firing rooms for commanding the launch; various operational support buildings; and launch sub-complexes for separate launch pads, which include 39A and 39B, with Launch Pad 39B supporting SLS launches to send Orion on Artemis missions to the Moon.

Mobile launcher 1, atop the agency's crawler-transporter 2, moves from Launch Pad 39B, approaching to enter the Vehicle Assembly Building at NASA's Kennedy Space Center on Oct. 3, 2024. (NASA) ▲

Vehicle Assembly Building

The iconic VAB serves as the central hub of NASA's premier multi-user spaceport, capable of hosting several different kinds of rockets and spacecraft simultaneously. Whether the rockets and spacecraft are going into Earth orbit or deep space, the VAB has the infrastructure to prepare them for their missions.

In total, the VAB covers nearly 650,000 square feet and is 525 feet tall and 518 feet wide, making it one of the largest buildings in the world by volume. The VAB was constructed for the assembly of the Apollo Saturn V Moon rocket, the largest rocket ever built at the time. It is made up of 195,000 cubic feet of concrete, and its frame is constructed from 98,590 tons of steel. It stands on top of a support base of 4,225 steel pilings driven 164 feet into bedrock. The last structural beam was positioned in the VAB in 1965. The interior construction, including the extensible work platforms, was completed in 1966. The building is located 3.5 miles from Launch Pad 39A and 4.2 miles from Launch Pad 39B.

The tallest portions of the VAB are the four high bays, with two on the east side and two on the west side of the building. Each has a 456-foot-high door, enabling rockets to be stacked vertically and then rolled out to the launch pad. The high bay doors are the largest in the world and take about 45 minutes to open or close completely.

There are five primary overhead cranes inside the VAB, including two that can hold 325 tons. Operated from cabs near the VAB's ceiling, the cranes are precise enough to lower an object onto an egg without cracking it.

To prepare for the Artemis missions, NASA removed the shuttle-era work platforms in High Bay 3 and installed 10 levels of new work platforms, including 20 platform halves, to surround the SLS rocket and the Orion spacecraft for 360-degree access during processing. Several miles of Apollo- and shuttle-era abandoned copper and lead-shielded cabling were also removed to make room for the installation of state-of-the-art command, communication, and control systems needed to perform testing and verification prior to rollout to the launch pad.

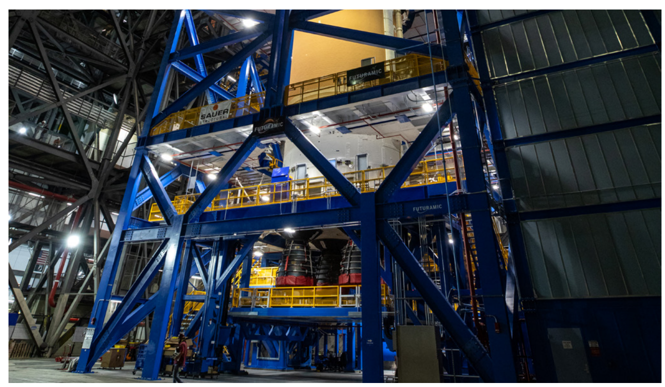
Platforms A to K

Each of the giant steel platforms measures about 38 feet long and 62 feet wide and weighs between 300,000 and 325,000 pounds. The platforms are attached to rail beams that provide structural support and contain the drive mechanisms to retract and extend them. Each platform rides on four Hillman roller systems, two located on each side — much like how a kitchen drawer glides in and out.

- **Platform A** (346 feet above the VAB floor) provides access to the Orion spacecraft's launch abort system for Orion lifting sling removal and installation of the closeout panels. Launch abort system antenna testing (antenna hat installation for testing) is also performed at this level.
- **Platform B** (311 feet above the VAB floor) provides access to the Orion service module umbilical and has emergency egress stairs from the Crew Access Arm White Room.
- **Platform C** (280 feet above the VAB floor) provides access to the Orion stage adapter and the interim cryogenic propulsion stage, or ICPS. Engineers use this level for operations to join the ICPS with the launch vehicle stage adapter (LVSA) and the ICPS umbilical. Platform C also makes it possible to open the LVSA upper-access doors for entry to the top of the ICPS.
- **Platform D** (264 feet above the VAB floor) makes it possible to open the LVSA lower-access doors for entry to the ICPS to perform flight battery and computer installation on the ICPS equipment shelf.
- **Platform E** (246 feet above the VAB floor) provides access to the core stage forward skirt umbilical. Engineers use an elevated access platform on this level for operations to join the LVSA and core stage. Entry into the core stage forward skirt is necessary to access components of the rocket's avionics for verification operations.
- **Platform F** (192 feet above the VAB floor) provides access to the core stage intertank section and the core stage intertank umbilical. Engineers use the multi-level ground support equipment access platform, referred to as F-1, on this level for access to the booster-forward assemblies and the core stage to booster-forward attach points. The upper level of F-1 is used for lifting sling removal during booster stacking to join the forward assembly.

- **Platform G** (166 feet above the VAB floor) provides access for booster segment stacking operations of the forward segment to the forward-center segment and booster systems tunnel cable routing and closeouts.
- **Platform H** (139 feet above the VAB floor) provides access to the booster segment for operations to join the forward-center segment to the center segment, as well as booster systems tunnel cable routing and closeouts.
- **Platform J** (112 feet above the VAB floor) provides access for operations to join the center booster segment to the aft-center segment, as well as booster systems tunnel cable routing and closeouts.
- **Platform K** (86 feet above the VAB floor) provides access for booster segment stacking operations of the aft-center segment to the booster aft assembly and booster systems tunnel cable routing and closeouts. Level K-1 is installed under the platform for access to the core stage and lower booster attach points.

Engineers and technicians with EGS stack the left-aft assembly for the Artemis II SLS solid rocket booster onto mobile launcher 1 inside the VAB. (NASA) ▲



Teams with EGS lower the 212-foot-tall SLS core stage into High Bay 2. (NASA) ▲

Vehicle Assembly Building

High Bay 2

High Bay 2 of the VAB was outfitted with new tooling to support Artemis II, enabling vertical integration of the SLS core stage. This upgrade allows engineers and technicians 360-degree access to the core stage, both internally and externally, during processing. The new core stage vertical integration center tool, designed and built by Futuramic Tool and Engineering, holds the core stage in vertical position, streamlining final production and integration activities. For Artemis II, this capability allowed the fully assembled SLS core stage to be suspended 225 feet in the air inside High Bay 2 for vertical work before being moved for final stacking, while solid rocket booster stacking continued in High Bay 3. This dual-bay approach doubles the usable assembly space within the VAB, supporting more efficient parallel processing for future Artemis missions.

Launch Pad 39B

NASA has upgraded Launch Pad 39B from its previous uses under Apollo and the Space Shuttle Program to support the SLS rocket and other potential users. The guiding principle behind the upgrades and modifications has been to make the area a "clean pad," which allows a variety of rockets to launch from the pad. The basics that all rockets need — such as electrical power, a water system, a flame trench, and a safe launch area — are in place. The other needs of individual rockets, including access for workers, can be met with the towers or other structures that deliver the rocket to the pad.

During refurbishment projects, teams replaced 1.3 million feet of copper cables with 300,000 feet of fiber-optic cable, installed new bypass lines and valves, removed the heritage liquid-oxygen vaporizer, installed a liquid hydrogen separator vaporizer, replaced the heritage environmental control system equipment, and replaced the fire-suppression piping around the entire pad complex. These vaporizers convert the liquid oxygen or hydrogen into gas, which then is fed back into the tank to pressurize it to begin the flow to the rocket.

NASA's SLS rocket and Orion spacecraft, standing atop the mobile launcher, arrives at Launch Pad 39B. (NASA) ▲

Launch Pad Systems and Elements

Sound Suppression System

The sound suppression system is used during liftoff to keep the rocket, mobile launcher, and the launch pad safe by dampening sound, vibrations, and extreme heat. The water tower for the ignition overpressure and sound suppression system holds roughly 400,000 gallons of water, or enough to fill 23 average swimming pools. At ignition and liftoff, this entire reservoir of water is dumped on the mobile launcher and inside the flame trench in less than 30 seconds. The peak flow rate is 1.1 million gallons per minute, enough to empty roughly two Olympic-sized swimming pools in one minute. The water tower was sandblasted and repainted so it can continue to withstand the corrosive salt air from the nearby Atlantic Ocean.

Flame Trench

The flame trench contains a flame deflector to safely divert the exhaust plume from the SLS rocket during launch. The refurbished flame trench is 450 feet long — the size of one-and-a-half football fields. The flame deflector experiences a peak temperature of 2,200 degrees Fahrenheit (1,204 degrees Celsius) during launch.

Prior to Artemis I, teams removed Apollo-era bricks from the flame trench and installed more than 96,000 heat-resistant bricks in three different sizes using bonding mortar and, where required, steel-plate anchors. In areas where significant temperature and pressure will occur, technicians fastened steel-plate anchors to the walls at intervals to reinforce the brick system.

The flame deflector is made up of 112 steel plates, 84 cladding plates on the main structure, and 28 fence plates that run along the side of the flame trench. All plates range in size and weight from 1,100 to 5,500 pounds. The deflector measures 57 feet wide, 43 feet high, and 70 feet long. The deflector's north side is slanted at about a 58-degree angle and will redirect the rocket's exhaust, pressure, and intense heat to the north at liftoff.

The flame trench and deflector are above ground level, and the two main structures on either side of the flame trench serve as the platform to support the mobile launcher and rocket. These structures are the catacombs on the east side and the Pad Terminal and Communication Room/Environmental Control System room on the west side of the flame trench, which is the area below the pad containing water lines and piping. As part of the refurbishment, teams also reinforced the roof of the catacomb to be able to support 25.5 million pounds.

Lightning Towers

To provide lightning protection for rockets as they are processed and launched from the pad, teams installed three 600-foot-tall masts with overhead wires used to transmit electrical energy around the pad's perimeter. The height of the towers is matched to the height of the mobile launcher and the SLS rocket when at the pad.

During wet dress rehearsal for Artemis I, the lightning protection system withstood the most powerful lightning strike ever recorded at Kennedy, successfully intercepting the strike and transferring the lightning's energy through catenary wires to the ground. There was no damage to the rocket or spacecraft despite the large electromagnetic field generated by the strike.

Steel plates make up the flame deflector inside the flame trench of pad 39B. (NASA) ▲

A lightning strike was recorded at Launch Complex 39B at NASA's Kennedy Space Center in Florida during the evening of April 2, 2022. (NASA) ▲

NASA's new 1.4-million-gallon liquid hydrogen sphere at pad 39B. (NASA)

Environmental Control Systems

While preparing for Artemis II, the environmental control system was upgraded. This system provides air supply, thermal control, and pressurization to the rocket and the Orion spacecraft during cryogenic propellant loading prior to launch. During propellant loading, the environmental control system purges specific compartments within Orion and SLS using gaseous nitrogen to maintain the proper environmental conditions. This process is critical, as the rocket and spacecraft must be in a safe and stable configuration and temperature when dealing with hazardous gasses.

Propellant Systems

Along the pad perimeter are storage spheres for liquid oxygen to the northwest and liquid hydrogen to the northeast. The liquid oxygen system holds more than 850,000 gallons of liquid oxygen, which is transferred to the SLS rocket during launch countdown via vacuum-jacketed lines from the sphere to the pad.

In preparation for Artemis II, EGS constructed the world's largest liquid hydrogen tank, a sphere 83 feet in diameter, with the capacity to hold more than 1.25 million gallons of liquid hydrogen. Along with the previous tank, which holds 850,000 gallons of liquid hydrogen, EGS will be able to accommodate the fuel requirements of SLS and carry out more back-to-back launch attempts.

The new tank is the first to use microsphere insulation, typically consisting of hollow glass bubbles, as a lightweight filler material instead of insulation, which reduces boiloff losses by 46%. Additionally, it is the first tank of its kind with a heat exchanger built into its interior, allowing teams to connect it to a cryogenic refrigeration unit and eliminate boiloff entirely.

Emergency egress system baskets, attached to the catenary system, rest at the pad terminus site. (NASA)

Emergency Egress System

Beginning with Artemis II, EGS developed an emergency egress system (EES) to provide exit from the launchpad. In the unlikely event of an emergency, the EES will safely deliver astronauts, operations teams, closeout crews, and pad fire/rescue personnel outside the Launch Pad 39B perimeter. Four baskets, each capable of carrying five personnel, will be staged and ready for boarding. Once crews are boarded, the baskets will release from the mobile launcher tower via a slide-wire system and travel roughly 1,700 feet of catenary steel wire to the landing location at the EES terminus located next to the launch pad perimeter. The evacuating crews will disembark the baskets once at a complete and controlled stop. At the pad terminus location, armored transport vehicles will be on standby, ready to take the evacuating crew to a safe haven through a crash-out gate outside of the pad perimeter, where triage and emergency responder teams will be waiting to receive them.

The EES baskets are very similar to suspended gondolas at ski lifts and are roughly the size of a mid-size SUV. Each basket contains a magnetic braking system, which operates to help control the acceleration and deceleration of the baskets in multiple weight and environmental conditions, ensuring a smooth and safe ride for any evacuating team members. In ideal conditions, each basket will take about 30 seconds to reach the pad terminus traveling roughly 50 mph.

One of the four emergency egress baskets on the mobile launcher as it is lowered to the terminus site. (NASA/Isaac Watson) ▲

Mobile Launcher

A close-up view of the Artemis I SLS (Space Launch System) rocket and Orion spacecraft atop the mobile launcher on Launch Pad 39B. (NASA) ▲

Weighing over 11 million pounds and standing 400 feet tall, the mobile launcher is the ground structure used to assemble, process, and launch the SLS rocket and Orion spacecraft from Launch Pad 39B for the first three Artemis missions.

The mobile launcher is designed to support the assembly, testing, checkout, and servicing of the rocket, as well as transfer it to the pad, and serves as the structural platform from which it will launch. During preparations for stacking the SLS, the crawler-transporter will pick up and move the mobile launcher into High Bay 3 in the VAB. The mobile launcher will sit on top of six support posts, called mount mechanisms, that will withstand the structural load of the mobile launcher and transfer it into the foundation of the VAB. Before SLS stacking operations begin, the crawler will roll out from under the mobile launcher and be relocated outside of the VAB.

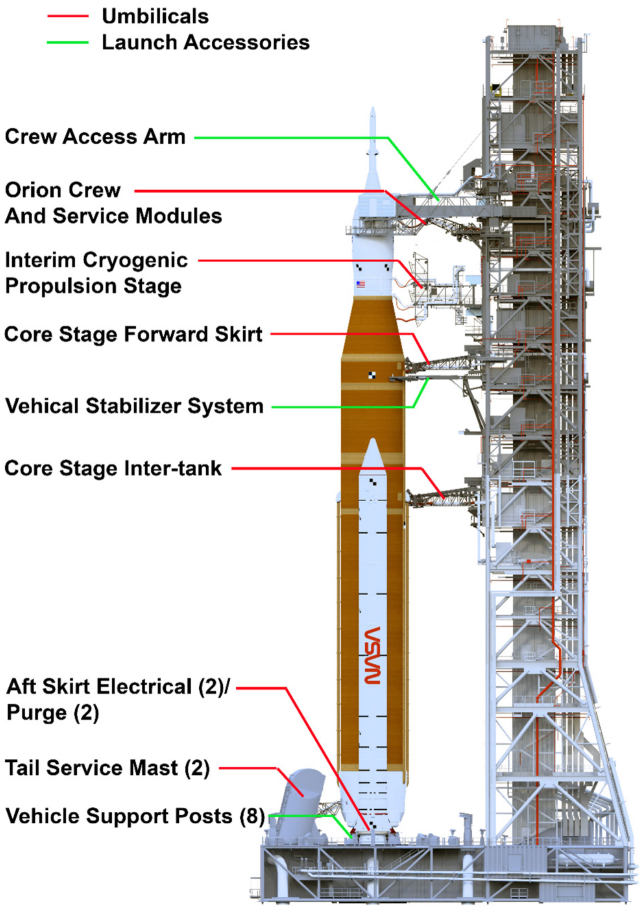
The mobile launcher for the Block 1 configuration of the SLS rocket consists of a two-story base, measuring 25 feet high, 165 feet long, and 135 feet wide, and a tower that is roughly 400 feet tall. The base serves as the platform for the rocket and contains many subsystem commodities, such as power, communication systems, facility systems, and hydraulics for purging — crucial for the rocket while on Earth. The tower is equipped with several connection lines, called umbilicals, as well as launch accessories that transfer and supply the commodity systems located in the launcher's base to the SLS and Orion systems, including power, communications, coolant, propellant, and stabilization prior to launch. The tower has a unique walkway for personnel and equipment to enter the crew module during launch preparations, as well as for astronauts to enter before launch called the crew access arm. There are tower floor levels every 20 feet for personnel to access the rocket ground support equipment.

The mobile launcher will roll out to the pad for launch on top of the crawler-transporter, carrying SLS and Orion. After the crawler-transporter makes the eight-hour trek to the pad just over four miles away, engineers will lower the mobile launcher onto the pad-mount mechanisms, and the crawler-transporter will relocate away from the launch pad, leaving the mobile launcher sitting on the pad and prepared for launch. During launch, each umbilical and launch accessory will release from its connection point, allowing the rocket and spacecraft to lift off safely.

Mobile Launch Contingency Capability

In accordance with launch safety requirements, all rockets must include a flight termination system, which is designed to safely allow the termination of a rocket in flight in the event of an emergency after liftoff. Teams with EGS have upgraded the ground systems at pad 39B to include capability for additional access to the rocket to allow for personnel to reach the flight termination systems components for testing. Three temporary access platforms allow engineers to reach locations on the upper left and right segments of the solid rocket boosters and core stage's intertank, bridging the gap between those points on the rocket and mobile launcher.

Umbilicals



Crew Access Arm

The crew access arm is located at the 274-foot level on the mobile launcher tower. The arm rotates from its retracted position and interfaces with the SLS rocket at the Orion crew hatch location to provide entry to and exit from the Orion crew module during operations in the VAB and at the launch pad. The access arm provides a clean and controlled work area for people and equipment entering the crew module, an egress path during an emergency, and access to servicing panels for the Orion crew module and service module. The access arm also provides entry and exit for astronauts. The arm retracts from the Orion spacecraft before launch.

Orion Service Module Umbilical

The Orion service module umbilical connects the mobile launcher tower to the Orion service module. The umbilical is located at the 280-foot level of the tower and, prior to launch, will transfer liquid coolant and air for the electronics and purge air and nitrogen gas for the environmental control system to support the spacecraft. The umbilical tilts back before launch.

Interim Cryogenic Propulsion Stage Umbilical

The ICPS umbilical is located at about the 240-foot level on the mobile launcher tower. This umbilical supplies fuel, oxidizer, purge air, gaseous nitrogen and helium, and electrical connections to the ICPS of the SLS rocket. The umbilical also provides hazardous gas leak detection and swings away before launch.

Vehicle Stabilizer System

The vehicle stabilizer system is located at the 200-foot level of the mobile launcher tower and provides a structural interface to the SLS core stage. The system helps reduce core stage motion during rollout to the launch pad, processing operations, high-wind events at the pad, and the launch countdown. The stabilizer drops down and away from the rocket at launch.

Core Stage Forward Skirt Umbilical

The core stage forward skirt umbilical is located at the 180-foot level on the mobile launcher tower, above the liquid oxygen tank. This umbilical will swing into position to connect to the core stage forward skirt of the SLS rocket and then swing away before launch. Its main purpose is to provide conditioned air and nitrogen gas to the SLS core stage forward skirt cavity.

Core Stage Intertank Umbilical

The core stage intertank umbilical is a swing arm umbilical that connects to the SLS core stage intertank. The intertank umbilical's main function is to vent gaseous hydrogen, which is boiloff from the extremely cold liquid hydrogen fuel, from the core stage. The arm also provides conditioned air, pressurized gases, and power and data connection to the core stage. This umbilical, located at the 140-foot level on the mobile launcher tower, swings away at launch.

Aft Skirt Electrical Umbilicals

Two aft skirt electrical umbilicals connect to the SLS rocket at the bottom outer edge of each booster and provide electrical power and data connections to the SLS rocket until it lifts off from the launch pad. The umbilicals act like a telephone line and carry a signal to another subsystem on the mobile launcher called the launch release system. This system distributes the launch signal to the rest of the launch accessories and the SLS boosters, and it initiates the launch-release command.

Aft Skirt Purge Umbilical

Two aft skirt purge umbilicals connect to the SLS rocket at the bottom outer edge of each booster. These remove potentially hazardous gases and maintain the required temperature range of components through a heated gaseous nitrogen purge to the cavity of each booster's aft skirt. Teams connect these umbilicals during stacking operations in the VAB, and they remain connected until released during liftoff.

Tail Service Mast Umbilicals

Two tail service mast umbilicals connect the zero-level deck on the mobile launcher to the SLS rocket core stage aft section. These umbilicals are about 33 feet tall and provide liquid oxygen and liquid hydrogen fluid lines, as well as electrical cable connections, to the SLS core stage engine section to support propellant handling during prelaunch operations. The umbilicals tilt back before launch to ensure that all hardware safely and reliably disconnects and retracts from the rocket during liftoff.

Vehicle Support Posts

Eight posts support the load of the solid rocket boosters, with four posts for each booster. The support posts, made of cast steel, are 5 feet tall and each weigh about 10,000 pounds. They are located on the deck of the mobile launcher and instrumented with strain gauges to measure loads during stacking, integration, rollout, and launch operations. The posts structurally support the SLS rocket through T-0 and liftoff.

Crawler-transporter 2 makes its way along the crawlerway to Launch Pad 39B. (NASA)

Crawler-Transporter

NASA has upgraded one of a pair of enormous machines, called crawler-transporters, to handle the SLS rocket and mobile launcher combination. NASA modified crawler-transporter 2 for Artemis from its previous purpose to move the space shuttle and Saturn V rocket. The redesigned crawler-transporter features upgraded roller bearings, a new assembly that can carry a greater load, and an improved lubrication system. The crawler's upgraded load-carrying capacity is 18 million pounds, 50% higher than the original design. The crawler does not interface with the rocket, enabling it to also carry other future rockets with no additional modifications needed.

Larger than the size of a baseball infield and powered by locomotive engines and large electrical power generators, the crawler weighs approximately 6.6 million pounds and is 131 feet long, 114 feet wide, and 20 to 26 feet tall when based on the position of the jacking equalization and leveling cylinders. The crawler was designed to travel 2 mph unloaded and 0.83 mph while carrying a rocket and spacecraft. Careful analysis determines what rate provides the smoothest ride. As of the spring 2025, crawler-transporter 2 has traveled 2,513 miles.

The crawler holds the Guinness World Record for the heaviest self-powered vehicle, a testament to its unique engineering and vital role in supporting Artemis II and future missions.

Able to raise and lower its sides and corners independently, the crawler is designed to roll underneath the mobile launcher while inside the VAB, pick it up, and steadily carry it 4.2 miles to Launch Pad 39B. The crawler has four reinforced pickup points on its surface that secure into place underneath the mobile launcher to carry it to the pad. Pinch blocks are located at three of the four pickup points to secure the load being carried. The crawler uses its hydraulic suspension to keep the platform level all the way to the top pad, which is built on a sloping pyramid, where it sets the platform in place.

Once the crawler makes the eight-hour trek to the pad with engineers and technicians aboard, the mobile launcher and SLS are lowered onto pad-mount mechanisms. After platforms are lowered and power transfers are complete, the crawler rolls back down the pad slope and parks just outside the pad perimeter gate. The crawler waits there until a few days prior to launch in case a rollback is required. Then, it rolls to a parking site for protection during launch.

Crawlerway

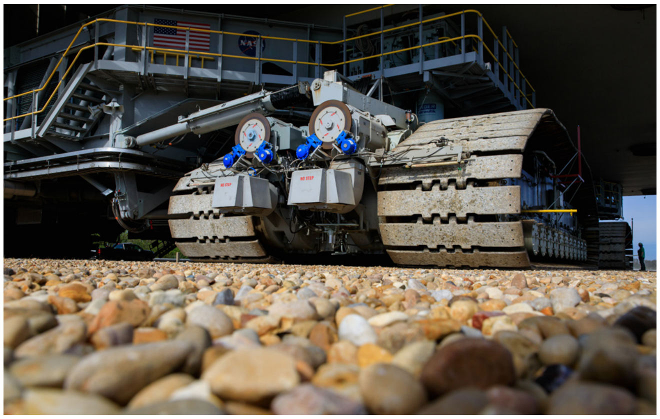
The crawlerway is the 4.2-mile path from the VAB to Launch Pad 39B that was constructed in 1964. From outside edge to outside edge, the crawlerway is 130 feet wide and has two 40-foot lanes with a 50-foot grass median strip in between. The top layer is comprised of river rock 4 inches (10 centimeters) thick on the straight sections and 8 inches (20 centimeters) thick on curves. Underneath it is at least 4 feet of crushed lime rock, which sits atop as much as 20 feet of hydraulically compressed fill. From the VAB to Pad 39B there is approximately 45,000 tons of rock.

For the Artemis II mission, the path from the VAB to Launch Pad 39B must be able to support at least 25.5 million pounds for the crawler, as well as the massive weight of the SLS rocket, Orion spacecraft, and mobile launcher.

Teams performed crawlerway conditioning to ensure that the crawlerway was strong enough to withstand the weight and provide stability for Artemis I and, now, in anticipation of heavier payloads on future missions.

Software

Spacecraft Command and Control System



A close-up of river rock on the crawlerway. (NASA) ▲

The computer software and hardware that operate, monitor, and coordinate the ground equipment for the launch of the SLS rocket and Orion spacecraft are called the spacecraft command and control system.

The SLS rocket and Orion spacecraft generate about 100 megabytes of data per second at liftoff, demanding a robust computer system that can process the volume and speed of this information and deliver it to the launch team and corresponding mission systems in real time. The system is the electronic hub where information traveling to and from the SLS core stage, the rocket's ICPS, Orion, ground systems, and the operators inside the firing room intersect. During loading and launch, the software processes up to 575,000 changes per second.

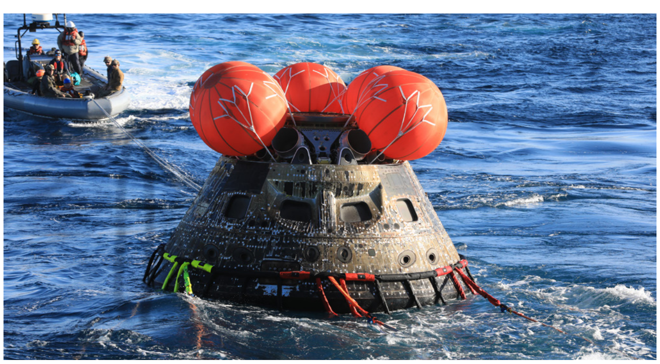
The spacecraft command and control system represents a suite of advanced software tailored to the unique needs of SLS and the Orion spacecraft. It is designed to take advantage of modern computers, servers, and information technology to provide a faster, safer, and more reliable network than systems previously developed to support the space shuttle. Engineers also designed it to be upgraded and adapted to support the rocket and spacecraft as they are flown in different configurations and advanced variants.

Recovery Operations

In addition to the hardware elements that are part of the ground systems supporting launch, the landing and recovery team, led by EGS, is responsible for safely recovering the Orion capsule, as well as the crew, after splashdown and returning them to land. The interagency landing and recovery team consists of personnel and assets from the U.S. Department of War, including Navy amphibious specialists and Air Force weather specialists, NASA's Sasquatch mapping team, and engineers and technicians from Kennedy and Johnson.

For Artemis II, the nominal recovery plan involves open-water extraction of the crew while Orion remains in the Pacific Ocean — a change from Artemis I's well deck recovery approach. Before the spacecraft splashes down, the recovery team will head out to sea in a Navy amphibious ship that has a well deck at the waterline to allow boats to dock inside the back of the ship. NASA's Sasquatch mapping team will track the locations of jettisoned hardware, such as the forward bay cover and parachutes, to support safe and efficient recovery operations.

Once the crew splashes down at the end of their mission, Navy divers and other team members in several inflatable boats will approach Orion and ensure it is safe for astronauts to exit the spacecraft. Divers will install an inflatable stabilization collar around the spacecraft and attach an inflatable platform, known as the "front porch," to assist with stabilizing Orion and helping recover the astronauts. Astronauts will exit the spacecraft one by one onto the front porch, where they will be individually lifted by helicopter and transported to the recovery ship. Once the astronauts are aboard the recovery ship, teams will secure Orion with a series of lines and slowly tow it inside the ship, just as they did with Artemis I.



NASA's Orion spacecraft for the Artemis I mission was successfully recovered inside the well deck of the USS Portland on Dec. 11, 2022, off the coast of Baja California. (NASA) ▲

Teams work to recover the Crew Module Test Article as they practice Artemis recovery operations during Underway Recovery Test-12 aboard USS Somerset off the coast of California on March 27, 2025. (NASA) ▲

Weather permitting, open-water personnel will work to recover Orion's forward bay cover and three main parachutes to the port side of the Navy ship, where a crane will lift them onto the ship's main deck. By recovering the jettisoned cover and parachutes, engineers can inspect the hardware and gather additional performance data. Teams will transport the spacecraft and other hardware on the ship from the landing site to a pier at U.S. Naval Base San Diego.

After technicians secure Orion and the other associated hardware in the recovery transportation fixture, they will move the hardware back to Kennedy.

The Artemis II SLS core stage and boosters inside High Bay 3 of the VAB. (NASA) ▲

Testing

Integrated Test and Checkout Tests to Prepare for Flight

The integrated test and checkout series starts after SLS and Orion are assembled in the VAB and continue at the launch pad, thoroughly testing all the systems, end to end, prior to launch.

Interface Verification Test

This test verifies functionality and interoperability of SLS and Orion element-to-element and element-to-ground interfaces.

Communications End-to-End Test

This test validates communications between the integrated rocket and spacecraft and the ground using a radio frequency antenna in the VAB, another near the pad that covers the first few seconds of launch, and a more powerful antenna that uses the Tracking and Data Relay Satellite System and Deep Space Network.

Launch Release System Signal Timing Test

The test verifies the end-to-end timing of the SLS booster ignition separation controller ARM/FIRE 1/FIRE 2 from the launch vehicle to ground systems.

Vehicle Assembly Building Program-Specific Engineering Test

This test performs element-level testing of SLS in the VAB.

Countdown Demonstration Test

This test will serve as a day-of-launch dress rehearsal and demonstrates the sequence of operations required to prepare for the Artemis II launch. It begins with crew suit-up in the Operations and Checkout Building and goes through terminal countdown, including flight crew insertion into Orion, crew module and launch abort system closure, white room closeout and securing, and terminal countdown to ~T-30 seconds.

Flight Safety System Test

This test occurs in three distinct parts:

- **Part I:** Booster ordnance connection and checkout.
- **Part II:** Flight termination system hardware installation and checkout.
- **Part III:** ICPS ordnance system checkout, ICPS firing line connection, booster ordnance circuit testing, safe and arm device testing and connections, and flight termination system end-to-end test.

Pad Program-Specific Engineering Tests

These procedures at the launch pad test radio frequency, as well as guidance, navigation, and control; they also perform final ordnance tests.

Wet Dress Rehearsal

This event will perform a full cryogenic propellent loading of SLS to demonstrate loading using the new liquid hydrogen (LH2) sphere at Launch Pad 39B, validating the updated LH2 procedures and ground systems upgrades for Artemis II. The test will also perform a terminal count run to at least T-30 seconds, including a terminal count recycle back to T-10 minutes, a three-minute “launch ready” hold demonstration between T-6 minutes and T-1 minute, 30 seconds, and a cutoff inside of the autonomous launch sequencer to validate safing procedures. Following the completion of the test, a nominal cryogenic propellent drain will be performed to demonstrate de-tanking and scrub turnaround procedures and timelines.

Integrated Systems Verification and Validation Testing

These are a series of ground demonstration tests that ensure the ground equipment is ready to support the Artemis II mission.

Launch Day Demonstration

Demonstrates activities required to get the crew to their spacecraft and rocket on launch day. The crew will practice putting on their Orion crew survival system spacesuits in crew quarters at Kennedy’s Operations and Checkout Building and depart in their fully electric fleet of crew transportation vehicles to the launch pad. Upon arrival at the pad, the crew will head onto the mobile launcher and proceed to the crew access arm used to board Orion on launch day.

Imagery Test

Engineers verify that all the high-speed imagery cameras at Launch Pad 39B function properly. High-speed cameras are used to monitor critical components and systems during launch countdown and liftoff.

A member of the Artemis II launch team monitors activities during the launch day demonstration for one of the Artemis II integrated ground systems tests from Firing Room 1 in the Launch Control Center. (NASA) ▲

Water Flow Tests

When the SLS solid rocket boosters ignite and the RS-25 engines start, the rocket produces thunderous noise (176 decibels), heat, and energy, generating nearly 9 million pounds of thrust. To ensure that the crew, SLS, Orion, and ground structures are protected, teams release 400,000 gallons of water onto the mobile launcher's deck, flame hole, and pad's flame detector. The water flow helps reduce and dampen damaging acoustic and thermal energy and high-pressure sound waves that could otherwise damage the mobile launcher, launch pad infrastructure and flame trench, and even the rocket.

During liftoff, 400,000 gallons of water will rush onto the pad to help protect NASA's SLS (Space Launch System) rocket, Orion spacecraft, mobile launcher, and launch pad from any over pressurization and extreme sound produced during ignition and liftoff. (NASA) ▲

Environmental Control System and Air Gaseous Nitrogen Test

While the mobile launcher is at the launch pad, engineers test the environmental control system to validate upgrades and demonstrate launch timeline procedure. This system provides air supply, thermal control, and pressurization to the SLS and Orion while at the launch pad and during cryogenic propellant loading.

Emergency Egress Demonstration

In the event of an emergency requiring evacuation during launch countdown, the astronauts and pad personnel will proceed to the emergency egress baskets. For this test, teams practice operating the emergency egress system during both daylight and at night. Teams train by leaving the crew access arm and heading to the terminus area down at the pad. They then test the baskets during separate occasions by using water-filled tanks filled to different levels to replicate the weight of the passengers.

Simulated flight crew members practice getting out of the emergency egress basket and into the emergency transport vehicle, which takes them to safety in the event of an unlikely emergency during launch countdown. (NASA) ▲

New Liquid Hydrogren Tank Flow Test

To minimize time between launch attempts, NASA built an additional liquid hydrogen sphere tank at the launch pad. During two separate flow tests, teams practice flowing of the super-cool liquid gasses. Once the SLS elements are transported to the pad, teams demonstrate fueling operations at the pad, allowing an opportunity to test the new tank with the mobile launcher and rocket prior to launch.

Firing Room Testing

Engineers, in addition, test all components in the firing room of the Launch Control Center. Teams utilize the audio loop used to communicate with astronauts inside Orion during the launch countdown, as well as a switch that would be used in the unlikely event that a pad abort is required.

Verify New Batteries Inside VAB High Bay 3

Teams also test out the new uninterruptable power supply for mobile launcher 2 whille it is positioned inside Kennedy's VAB for Artemis II rocket stacking operations. During this test, engineers turn off the power to the mobile launcher to verify that the new batteries do not negatively impact any systems aboard. These batteries provide power to the mobile launcher and allow teams the ability to safe all systems in the unlikely event the structure loses power while inside the VAB.

Underway Recovery Testing

NASA Artemis II crew members are assisted by U.S. Navy personnel as they exit a mock-up of the Orion spacecraft in the Pacific Ocean during Underway Recovery Test-11 on Feb. 25, 2024. (NASA)▲

The Landing and Recovery team, led by EGS, partnered with the Department of War to successfully complete three Underway Recovery Tests in preparation for Artemis II. These tests were conducted off the coast of San Diego and enabled teams to practice procedures for crew recovery in open water using the Crew Module Test Article, a full-scale Orion mock-up. The test article includes a functional bilge system and simulates astronaut presence to evaluate recovery hardware and procedures.

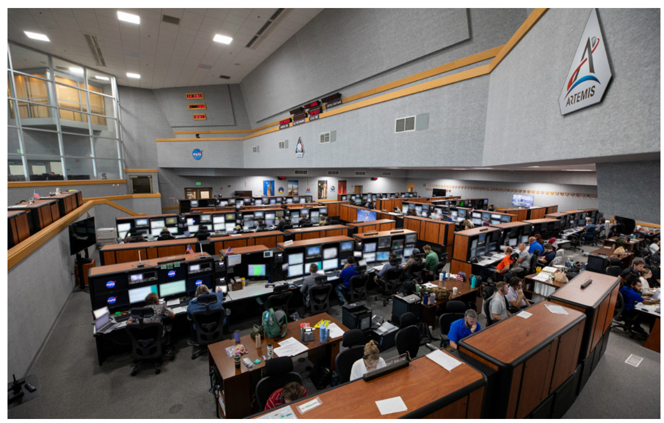
Drawing on lessons learned from the successful recovery of Orion after the splashdown of Artemis I and the addition of the Artemis II crew, recovery teams have modified their timelines and procedures to ensure astronauts will be safely delivered to the recovery ship less than two hours after splashing down.

While the primary focus is on the safe recovery of the crew and capsule, recovery teams also will attempt to recover the main parachutes if conditions permit. If recovered, these components are brought onto the recovery ship for inspection and data collection, supporting continued improvements to Orion's landing systems.

Validation Event Testing

NASA and the Department of War will conduct a Rescue Validation Event to demonstrate the ability of the War Department's rescue forces to render assistance to the Artemis crew in the event of an abort. The event will include two distinct demonstrations that will cover different abort scenarios, including response from fixed-wing strategic airlift aircraft and short-range rotary-wing aircraft to deploy rescue forces to render assistance to the crew.

Launch Simulations



Members of the Artemis launch team participate in the Artemis II Terminal Count Simulation #11 inside Firing Room 1. (NASA)▲

In preparation for Artemis II, teams in the Launch Control Center have been performing launch simulations that involve rehearsing all aspects of the launch countdown. Under the leadership of the Artemis launch director, Kennedy's team of engineers are seated at consoles inside Firing Room 1 and Firing Room 2 of the Launch Control Center for the simulations. The team uses software to replicate the commands and operations they will be giving and monitoring on launch day. Launch countdown simulations also include the participation of engineers and test directors from Johnson and NASA's Marshall Space Flight Center.

Simulations include training exercises that introduce fictional but realistic problems for engineers to identify and work through. They take teams from cryogenic loading — filling tanks in the SLS core stage with supercold liquid hydrogen and liquid oxygen — all the way through countdown and liftoff. These tests ensure that the Artemis II launch team is prepared for launch day.

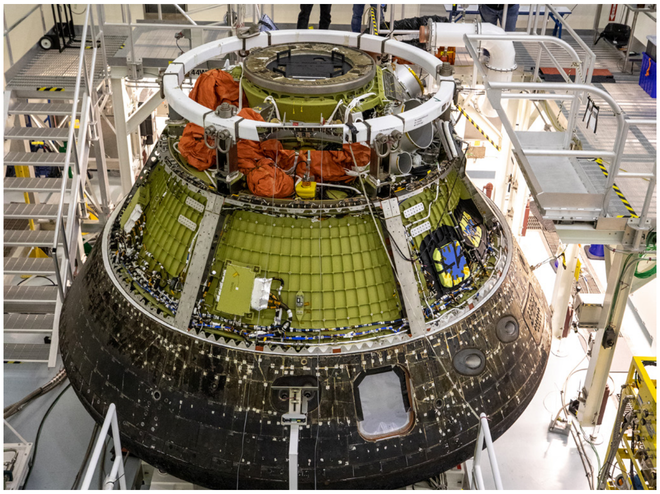
Management Roles and Facilities

Kennedy Space Center

Kennedy, home to the EGS Program, has transformed many facilities from their heritage shuttle or Saturn V and Apollo roles to support Artemis missions, focusing on the equipment, management, and operations required to safely process, assemble, transport, and launch the Orion spacecraft and SLS rocket.

Multi-Payload Processing Facility

A unique facility at Kennedy, the Multi-Payload Processing Facility (MPPF) is used to fuel the Orion spacecraft with hazardous propellants and other fluids the spacecraft will need for the journey around the Moon.



NASA's Artemis I Orion capsule is secured on a platform inside the Multi-Payload Processing Facility. (NASA) ▲

The spacecraft is moved out of the Operations and Checkout Building aboard a transport pallet and air-bearing system that sits atop a transporter. In the MPPF, Orion is moved into a service stand that provides 360-degree access, allowing engineers and technicians from EGS, Amentum, and other support organizations to fuel and service the spacecraft. Crane operators remove the transportation cover and use fuel lines and several fluid ground-support equipment panels to load the various gases and fluids into the crew and service modules.

When Orion returns to Earth after its mission, technicians will transport it to the MPPF, where they will use specialized equipment to remove unused hazardous propellants from its tanks during spacecraft postflight processing.

NASA's Artemis I Orion capsule is secured on a platform inside the Multi-Payload Processing Facility. (NASA) ▲

Launch Abort System Facility

After fueling in the MPPF, teams move the Orion spacecraft to the Launch Abort System Facility. The 50-foot-tall launch abort system is prepared horizontally inside the facility and then positioned on top of Orion for launch and ascent into orbit. The facility is taller than many processing facilities at Kennedy to allow clearance for vertical assembly of the Orion spacecraft with the launch abort system. The facility has cranes and other equipment needed to integrate the system during launch processing.

Booster Fabrication Facility

The Booster Fabrication Facility is a 45-acre site at Kennedy located near the VAB. Northrop Grumman, lead contractor for boosters, and NASA engineers use the facility to refurbish, manufacture, and assemble the aft skirt assembly and forward assembly for the twin solid rocket boosters on SLS.

The facility consists of seven buildings and includes facilities for the SLS Program's solid rocket booster processing and administrative offices. The buildings that most significantly contribute to booster hardware processing include the Manufacturing Building, Multi-Purpose Logistics Facility, and Aft Skirt Test Facility.

Rotation, Processing, and Surge Facility

The Rotation, Processing, and Surge Facility receives the booster segments for the SLS rocket and prepares them for integration with other hardware in the VAB prior to launch.

The facility is over 90 feet high, more than 190 feet long, and about 90 feet wide. The large open area, called the high bay, contains several work stands and platforms to provide access to hardware during processing. Two 200-ton cranes, one located at the east end of the building and the other at the west end, are positioned to lift the booster segments from a horizontal position to a vertical position. A crane control room provides access for two crane operators.

Railroad tracks lead to and continue through the facility to allow for transport and delivery of the large segments. During processing activities for the SLS rocket, the 10 booster segments will arrive at the Rotation, Processing, and Surge Facility by rail. Technicians will inspect the segments and rotate them to a vertical position for stacking operations.

The facility will also receive the booster aft skirt from the Booster Fabrication Facility. During processing, the aft segment is attached to the aft skirt and aft exit cone that covers the nozzle to compose the lower part, called the aft assembly. Teams will transport the two aft assemblies, six center segments, and the two forward segments to one of two smaller surge facilities that are part of the Rotation, Processing, and Surge Facility complex for storage until needed for stacking.

Launch Equipment Test Facility

The Launch Equipment Test Facility is a versatile test and development area used to test a wide variety of large-scale hardware and ground support equipment components.

Upgraded from its shuttle heritage to support Artemis missions, the Launch Equipment Test Facility provides a proving ground to safely assess machinery to support the launch of the SLS rocket. Equipment at the facility can recreate liftoff and operational conditions to evaluate component performance, and it can supply cryogenics, hydraulics, electrical systems, environmental control systems, and other commodities. Engineers build prototypes and test designs at the facility on machinery that duplicates sections of a launch pad, simulating pressures and forces experienced during launch to test in flight-like conditions.

Umbilicals being tested at the Launch Equipment Test Facility. (NASA)

Launch Equipment Test Facility Components

Vehicle Motion Simulator

The vehicle motion simulator emulates all the movements a rocket makes as it is rolled to the launch pad and, more importantly, through the first 30 milliseconds of flight. This process allows exact simulations of the forces and conditions under which umbilicals and other launch equipment must work to become qualified for use.

North and East Towers

There are two towers at the Launch Equipment Test Facility built to mirror the launch towers used for rockets. These simulation towers, while shorter than the structures seen at launch pads, are outfitted with the same features so that engineers can evaluate launch pad designs ahead of rolling out a rocket. The north tower is a 60-foot-tall structure, and the east tower stands 40 feet tall. Umbilical and access arms can be attached to the towers and used with the vehicle motion simulator to perform qualification testing.

Test Fixture

Engineers use the 600-ton test fixture for multi-purpose proof loading and to conduct experiments to ensure hardware and ground support components can meet engineering requirements.

Water Flow Test Loop

Teams verify fluid lines and components such as valves, pumps, and meters in a test apparatus that can run parts and lines through high-flow tests to confirm them for operation and other uses.

Cryogenic Systems

The Launch Equipment Test Facility is equipped with a cryogenic system for safely handling and using supercold chemicals and propellants commonly used with rockets. Liquid nitrogen and liquid hydrogen can be pumped to areas of the facility to accurately simulate launch operations with the vehicle motion simulator, towers, and other areas of the facility.

Control Room, Workshops, and High Bay

The Launch Equipment Test Facility is equipped with a full control room and the infrastructure to provide video and high-speed data to controllers, along with feeds for detecting hazardous gas leaks and other systems necessary to safely operate launch support equipment.

Launch Control Center

The Rocco A. Petrone Launch Control Center at Kennedy Space Center. (NASA)

The Rocco A. Petrone Launch Control Center contains several control rooms, known as firing rooms, from which countdown and launch operations are supervised and commanded. Once the rocket has cleared the launch tower, control switches from the Launch Control Center over to the Mission Control Center at Johnson. Many activities involved with preparing rockets, spacecraft, and payloads for space can be controlled by engineers sitting at computer terminals in the firing rooms.

Likewise, all activities at the launch pads can be run from a firing room. The Launch Control Center is also equipped with a suite of complex software linking launch team operators inside the main firing room to the SLS rocket and Orion spacecraft in processing areas such as the VAB and mobile launcher, as well as at Launch Complex 39B, and to controllers at the Space Force Eastern Range and personnel at other NASA control centers.

Young-Crippen Firing Room
Today's modernized firing rooms serve as the brain behind launch operations. EGS modified the Young-Crippen Firing Room, also known as Firing Room 1, for Artemis with the advanced computer and software systems that will allow greater situational awareness for launch controllers. Firing Room 1 will serve as the main firing room for Artemis II.

Firing Rooms 2 and 3
Firing Rooms 2 and 3 will also support Artemis. EGS upgraded Firing Room 2 to support software verification and validation testing, provide simulation support, and serve as the location for support launch team personnel for Artemis missions on launch day. Teams have repurposed Firing Room 3 for use as a software design and development environment for software required to operate and control ground and flight hardware.

Industry Partners

Amentum

Amentum provides comprehensive services to NASA's Artemis missions as a contractor for EGS, Orion, SLS, and other NASA programs. They provide key support to NASA human and robotic exploration missions, science programs, and aeronautics research at six facilities in mission-critical roles.

Amentum is the lead ground and launch operations contractor for EGS at Kennedy, supporting development and operations; spacecraft and launch vehicle systems engineering and integration; space vehicle and payload design, development, integration, testing, and operations; advanced propulsion system design, development, and testing; wind tunnel operations and maintenance; and advanced facility design, construction, and base operations and maintenance.

At Johnson, Amentum developed and qualified the Orion parachute recovery system and supports new spacesuit design. At Marshall, Amentum constructed and operates the Systems Integration Lab; supports design, coding, and testing of SLS flight software; and assists Marshall in the development of loads and environments for SLS and Human Landing System vehicles.

Amentum's Artemis support included wind-tunnel testing the SLS/Orion stack at NASA's Langley Research Center and NASA's Ames Research Center. Langley's Water Impact Test Facility was used by NASA and Amentum personnel to qualify the Orion crew capsule for splashdown at the end of Artemis missions.

Quick Facts

Mobile Launcher 1	
Total height above ground	~400 feet (~122 meters)
Two-story base	25 feet (7.7 meters) high × 165 feet (50.3 meters) long × 135 feet (41.1 meters) wide
Height off ground	22 feet (6.7 meters); “0” deck is 47 feet (14.3 meters) off ground
Height of six steel-mount mechanisms	22 feet (6.7 meters) (in VAB or on launch pad)
Height above the ground of mobile launcher deck when positioned on six steel mounts	47 feet (14.3 meters) (in VAB or on launch pad)
The booster aft skirt sits on vehicle support posts	Eight to support the rocket (four per booster) on the mobile launcher platform during transfer to the pad and at liftoff
Tower	40 feet (12.2 meters) square, about 345 feet (105.2 meters) tall
Tower floor levels	Every 20 feet (6.1 meters) for personal access to the rocket and ground support equipment
Approximate Mobile Launcher 1 weight	~11.3 million pounds (~5,125.6 tons)

Crawler-Transporter	
Height	Ranges from approximately 20 feet (6.1 meters) to 26 feet (1.8 meters) based on the position of the jacking, equalization, and leveling cylinders
Size overall	131 feet (40 meters) long × 114 feet (35 meters) wide. The mobile launcher contacts the crawler at four points, arranged in a 90-foot (27.4-meter) square (same as the base line on a professional baseball field)
Weight	Approximately 6.65 million pounds (or the weight of about 15 Statues of Liberty or 1,000 pickup trucks)
Speed	Loaded: 1 mph Unloaded: 2 mph

Crawler-Transporter	
Load capacity	Able to transport 18 million pounds (3,016.4 tons) (or the weight of more than 20 fully loaded 777 airplanes)
Hydraulic System	Reservoir capacity: 2,500 gallons (11,365 liters); steering: four pumps, 34.4 gallons (156.4 liters) per minute, or gpm/lpm, at 1,200 revolutions per minute (rpm) per pump; steering pressure: 5,000 pounds per square inch, or psi (34,474 kilopascal) maximum; jacking, equalization, and leveling, or JEL: eight pumps, 60 gpm (227 lpm) max, 15 to 20 gpm (56.8 to 75.7 lpm) nominal at 1,200 rpm per pump; JEL pressure: 3,000 psi (20,670 kilopascal) maximum

Electrical Systems	
DC (direct current) power system	16 locomotive traction motors at 375 horsepower (280 kilowatts, or kW); Diesel engines: Alco, 16 cylinders (two at 2,750 horsepower [2,051.5 kW] each, for DC); Generators (DC): four at 1,000 kW each
AC (alternating current) power system	Runs all onboard systems; diesel engines: power, 16 cylinders, two at 2,220 horsepower each, for AC power; generators (AC): two at 1,500 kW each
Capacity	Diesel fuel capacity is 5,000 gallons (18,927.1 liters)
Fuel consumption	1 gallon per 32 feet (10 meters) (approximately 165 gallons (750 liters) per mile); Drive system gear ratio: 168:1

NASA's SLS (Space Launch System) rocket carrying the Orion spacecraft launches on the Artemis I test flight on Nov. 16, 2022, from Launch Complex 39B at NASA's Kennedy Space Center in Florida. (NASA/Joel Kowsky) ▲

SLS

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 Orion spacecraft are critical capabilities, along with the agency's Exploration Ground Systems (EGS), advanced spacesuits and rovers, Gateway, and the commercial human landing systems that will enable human missions of increasing complexity in deep space.

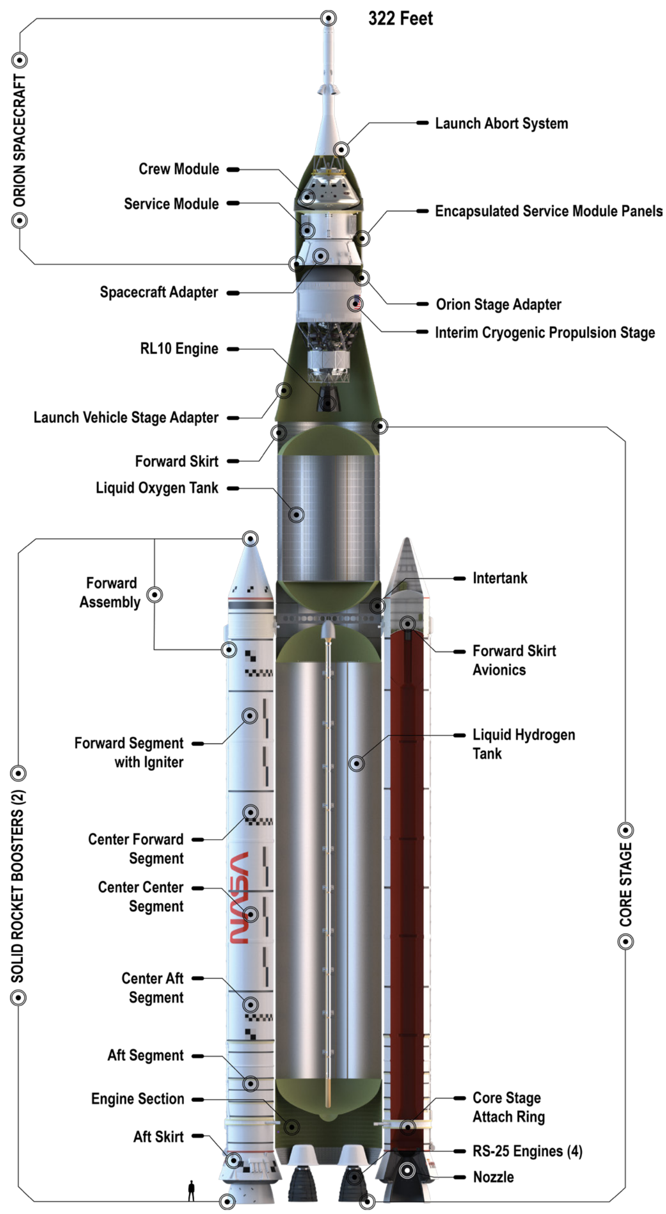
To make a new generation of crewed missions to the Moon possible, the SLS rocket uses proven propulsion systems consisting of space-shuttle-derived solid rocket boosters and liquid-fueled engines mated to a new central core stage.

The SLS rocket 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 connects the core stage to the interim cryogenic propulsion stage (ICPS). The adapter partially encloses the smaller-diameter stage. The Orion stage adapter, located on top of the ICPS, connects the Orion spacecraft to SLS and contains space for multiple CubeSat payloads from science and international communities.

The Artemis II core stage is seen here being lowered between the SLS solid rocket boosters in the Vehicle Assembly Building at NASA's Kennedy Space Center. (NASA) ▲

Technicians with NASA's Exploration Ground Systems complete installation of the America 250 emblem on the twin SLS (Space Launch System) solid rocket boosters for the Artemis II mission inside the Vehicle Assembly Building at NASA's Kennedy Space Center in Florida on Dec. 4, 2025. America 250 commemorates the 250th anniversary of the signing of the Declaration of Independence with NASA celebrating the "Spirit of Innovation" theme to inspire future generations. (NASA/Frank Michaux) ▲



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, interim cryogenic propulsion stage (ICPS), and Orion stage adapter. Orion is on top of the SLS. At lower left, a 6-foot person is shown for comparison. (NASA) ▲

Overview

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

The 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. It 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 the SLS, as well as the Orion crew spacecraft, which is managed at NASA's Johnson Space Center in Houston, and Exploration Ground Systems, managed at NASA's Kennedy Space Center.

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 virtually unchanged from the first flight, but they incorporate mission-specific changes, as well as lessons learned.

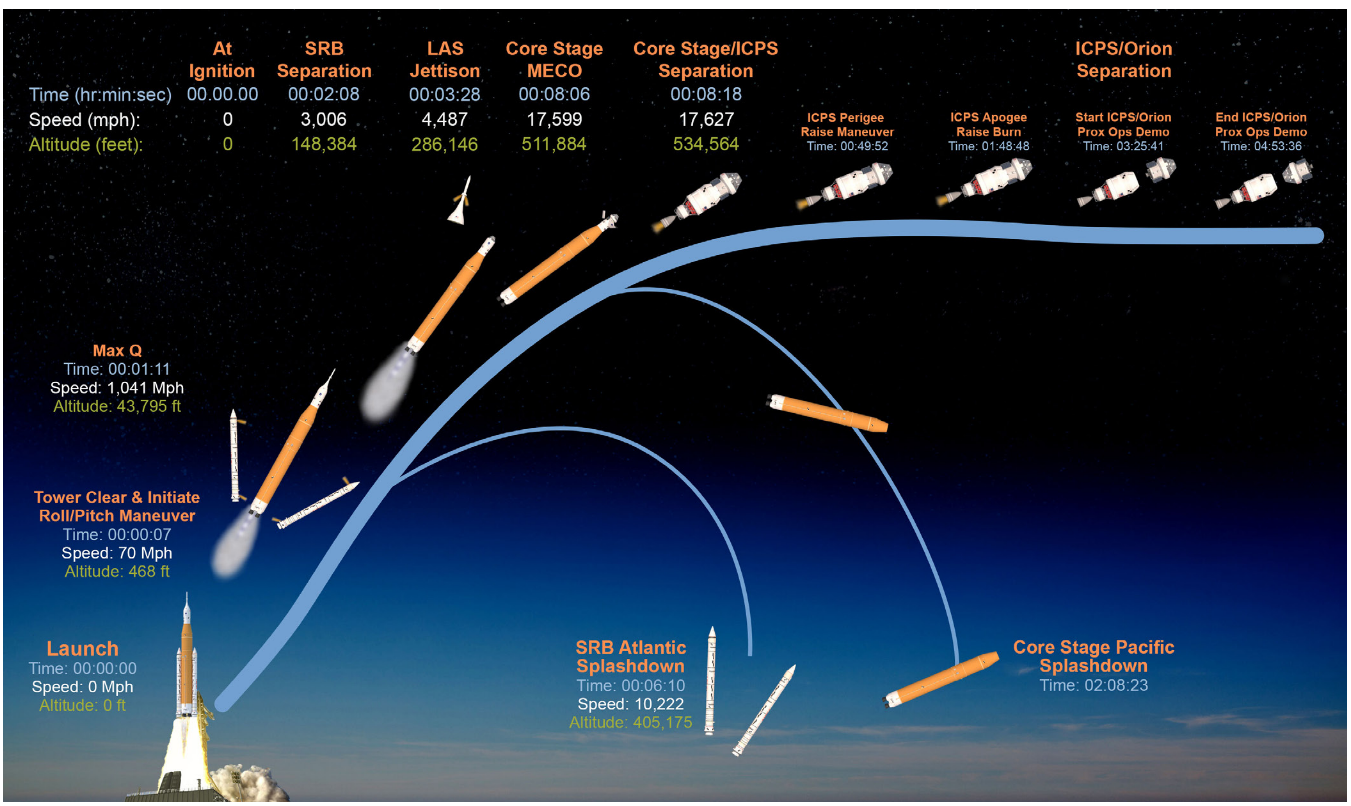
In particular, the Artemis II ICPS incorporates several changes reflecting its larger role in the mission. The ICPS will serve as a passive target for an Orion proximity operations demonstration, simulating docking maneuvers with other spacecraft for future Artemis missions, although the two spacecraft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



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

- 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.
- Prelaunch Integrated Test and Checkout tests reduced from 10 to seven. Three Artemis I prelaunch SLS tests were deleted from the Artemis II Integrated Test and Checkout series because their baseline objectives were met with the Artemis I tests and did not need to be repeated. Those were modal (vibration) tests, rollout testing with SLS on the mobile launcher, and umbilical release and retract test of propellent, power, and data connections.
- Wet dress rehearsal/tanking test added to prelaunch 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 Orion stage adapter.
- The mobile launcher at Kennedy has been modified to accommodate crew and emergency egress and will also provide access to critical SLS systems, including the range safety flight termination system; 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 Kennedy's Launch Complex 39B will enable a 24-hour turnaround between launch attempts.

Elements

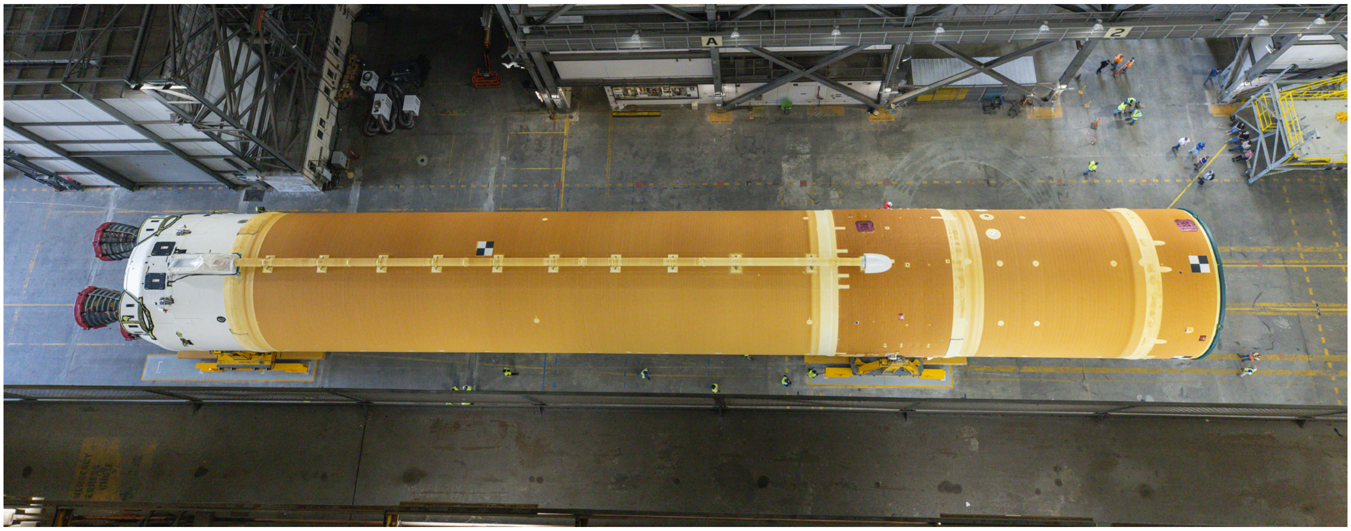
Core Stage

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 feet (64.6 meters) tall and 27.6 feet (8.41 meters) in diameter (excluding thermal protection system foam and flanges). Its fully fueled weight, excluding engines, is 2.4 million pounds (1,089 tons).

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. As its name suggests, it is the core of the rocket, supporting other stages, spacecraft, and payloads on top of 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 (over 17,600 mph) and more than 530,000 feet (161.5 kilometers) in altitude before it separates from the ICPS, Orion stage adapter, 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 had previous spaceflight experience.



The 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. (NASA)

Legacy Hardware

A key goal of the SLS design was to reuse space shuttle components, or to 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 p 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

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 measuring 27.6 feet (8.41 meters) in diameter and 22.5 feet (6.86 meters) 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 feet (8.41 meters) in diameter and 130 feet (39.6 meters) tall. It consists of five welded barrel sections, each 22 feet (6.7 meters) 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 gallons (2 million liters) of liquid hydrogen.

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

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 feet (8.41 meters) in diameter and 21.8 feet (6.64 meters) 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.

Liquid Oxygen Tank

The liquid oxygen tank is 27.6 feet (8.41 meters) in diameter and 51 feet (16 meters) tall. It consists of two 15.6-foot (4.75-meter) barrel sections made from isogrid aluminum panels and two domes. Liquid oxygen is fed to the engine section and engines through a pair of ducts that exit the intertank on opposite sides and run down the core stage. The liquid oxygen tank has a capacity of 196,000 gallons (741,941 liters). 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 after cleaning as it is prepared to move to another area for spray insulation at Michoud. (NASA) ▲

The Artemis II core stage forward skirt undergoes outfitting at Michoud. (NASA) ▲

Forward Skirt

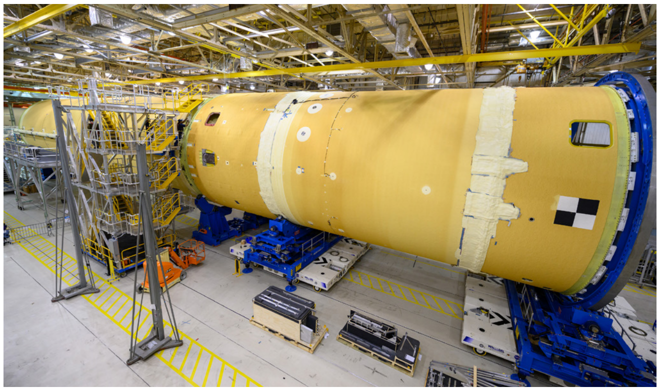
The forward skirt is located at the top of the core stage. It connects the core stage to the Integrated Spacecraft/Payload Element. The aluminum isogrid structure is 27.6 feet (8.41 meters) in diameter and 10.4 feet (3.17 meters) tall. It houses the majority of the vehicle's avionics and has connections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

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

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 movement and line/volume purges. To accomplish those functions, the main propulsion system has four subsystems:

- Liquid oxygen
- Liquid hydrogen
- Pressurization
- Ground-system-supplied pneumatics (prelaunch)



SLS team members connect the feed lines and other external components to the fully assembled core stage at Michoud. (NASA) ▲

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.

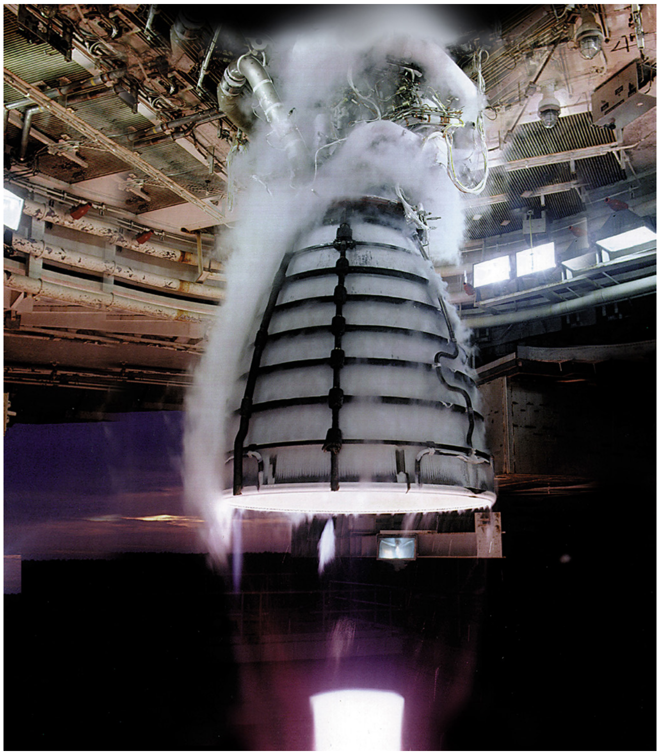
Engineers at Michoud insert 360 bolts to connect the forward assembly to the liquid hydrogen tank, making up the bulk of the core stage. (NASA) ▲

Artemis II Updates

Based on Artemis I lessons learned, the core stage power distribution control unit has been updated to better accommodate timing 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 meters) long were installed on intertank flanking booster attach points to reduce airflow-induced vibrations.

Due to the successful Artemis I test flight, extensive testing on the materials, and manufacturing of the core stage and its elements, proved the stage to be capable of performing its role on Artemis II.

RS-25 Engine



The RS-25 engines were upgraded with new controllers that were hot-fire tested prior to the Artemis I test flight. (NASA) ▲

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 and flew successfully on 135 space shuttle missions.

The RS-25s have accumulated more than 3,000 starts and 1 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 pounds (2,224 kilonewtons) of thrust. Each engine has an onboard computer that automatically controls start and shutdown, thrust ranging from 65 to 109%, propellant mixture ratio, and engine health. It was that power, efficiency, and reliability — as well as the knowledge and experience base — that led to the selection of the RS-25 for the SLS.

Each engine is roughly 14 feet (4.3 meters) tall, 8 feet (2 meters) in diameter, and weighs approximately 7,750 pounds (3.52 tons).

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 future missions.

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 space shuttle main engines throttled to 104.5%, or roughly 491,150 pounds (2,185 kilonewtons) of thrust. Each SLS engine operates at 109% thrust — approximately 512,300 pounds (2,279 kilonewtons) 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 pounds per square inch (48,263 kilopascals).

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. This is 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. The core stage size, as well as altitude and speed at main engine cutoff, 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, devices that use fluids for power to produce vehicle pitch 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 and 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 subjected to a hotter launch environment with their location closer to the SLS booster exhaust nozzles, compared to a location farther above the booster exhaust nozzles on the space shuttle. Operationally, prelaunch engine conditioning is different because of those environments, and the engine position profiles during ascent are different due to vehicle acceleration and trajectory profile.

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

- Engines start in series about six seconds prior to booster ignition
- Engines reach 100% of rated power level about one second before booster ignition
- Engines throttled to 109% 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
- At ~T+81 seconds, throttle back up to 109% rated power level
- At ~T+123 seconds, throttle down to 85% 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% 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% rated power level
- At ~T+483 seconds, main engine cutoff

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. This protocol was exercised for Artemis II to address engine test results.

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 their role on SLS.

Engine 2062 was test fired at NASA's Stennis Space Center before being assigned to Artemis II. (NASA) ▲

Solid Rocket Boosters

NASA's SLS boosters, manufactured by Northrop Grumman, are the largest and most powerful solid rocket boosters to fly. Two five-segment boosters support the entire weight of the SLS vehicle and Orion, including the 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 feet (53.9 meters) tall, 12 feet (3.7 meters) in diameter, and weighs 1.6 million pounds (726 tons) when filled with solid propellant.

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

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. (NASA) ▲

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 will use repurposed hardware from the Space Shuttle Program, including forward structures, metal cases, aft skirts, and thrust vector control elements.

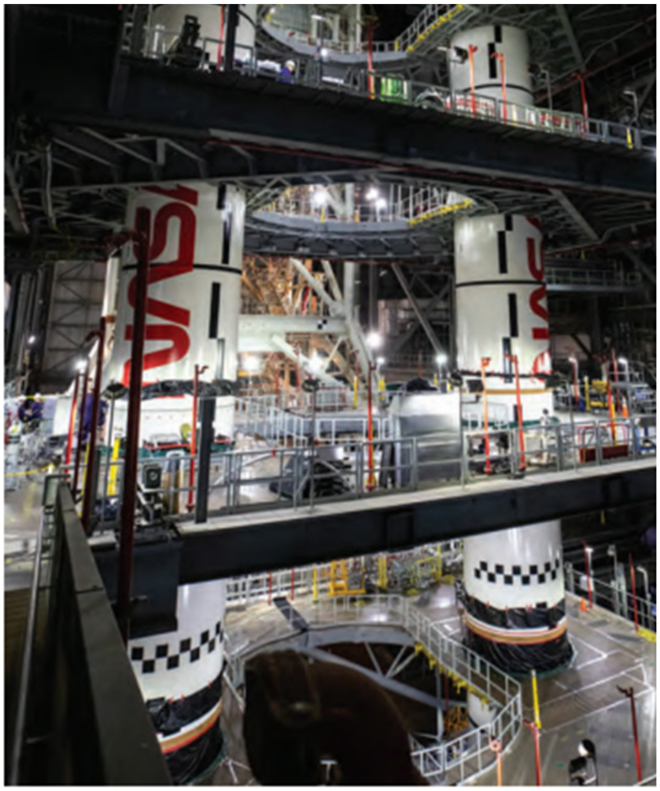
Design Features

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 than the shuttle lofted to low Earth orbit.

The larger SLS motor burns about three seconds longer and has more than 200,000 pounds (890 kilonewtons) 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 insulation and liner configuration
- New avionics and control systems
- Improved nondestructive evaluation processes
- Aft booster attach rings moved 20 feet (6 meters) 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, postlaunch 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 also were taken out. Deletion of the recovery systems translated into a reduction of approximately 20,000 pounds, which allows for an increase of 0.9 tons additional payload to translunar injection, the maneuver that sends Orion to the Moon.



The completed Artemis II boosters are shown stacked on the mobile launcher in the Vehicle Assembly Building before integration of the other SLS elements and Orion spacecraft. (NASA) ▲

Major Assemblies

Each SLS booster includes the following three major assemblies:

- Forward assembly
- Motor assembly
- Aft asssembly

Forward Assembly

The forward skirt assembly includes the nose cone, or frustum, with four solid fuel booster separation motors, 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.

The Artemis II crew and Northrop Grumman technicians with the Artemis II forward assemblies in the Booster Fabrication Facility at Kennedy. (NASA) ▲

Artemis II booster aft assemblies are pictured here on the mobile launcher in the Vehicle Assembly Building. (NASA) ▲

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
- Aft 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, or support braces, are also located on the forward segment.

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

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% of the steering for the SLS vehicle.

Booster Separation Motors

In addition to the booster motor, Northrop Grumman also produces the booster separation motors 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.

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 pounds (16,014 kilonewtons) thrust for roughly 25 seconds, ramping down to about 2.8 million pounds (12,455 kilonewtons) thrust as SLS passes through maximum dynamic pressure, and then ramping up to about 3.3 million pounds (14,679 kilonewtons) of thrust before beginning to tail off at about T+90 seconds.

Booster separation occurs at about two minutes into flight as the vehicle is traveling at 148,384 feet (45.2 kilometers) 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 booster separation motors 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 pounds (89 kilonewtons) of thrust for just under one second. The boosters splash down in the Atlantic Ocean approximately 5.5 minutes after launch.

Artemis II Updates

For Artemis II, the booster separation motors 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 booster separation motor 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 the design was updated. A single-layer insulation design was certified for flight on Artemis II and subsequent missions.

Interim Cryogenic Propulsion Stage

The 45-foot-(13.7-meter)-tall, 16.7-foot-(5.09-meter)-diameter interim cryogenic propulsion stage, or ICPS, is a modified Delta cryogenic second stage, a proven upper stage used on United Launch Alliance's (ULA's) 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 was 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 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 inches (46.7 centimeters), 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 pounds (110.1 kilonewtons) 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

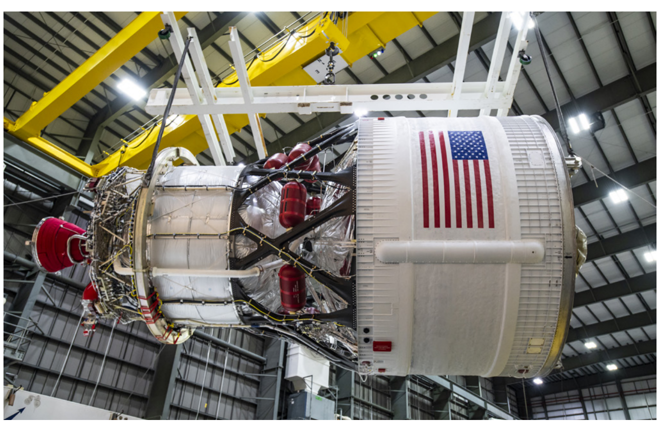
During Artemis II, Orion and ICPS will orbit Earth three times, with the ICPS firing once to maintain Orion's path, and then firing a second time to raise the spacecraft to a high Earth orbit. After the Orion spacecraft separates from the SLS upper stage, Artemis II astronauts will use targets added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

Artemis II Updates

Hardware improvements to the ICPS include a Teflon seal added to the liquid hydrogen and liquid oxygen umbilicals to make it safer to fill and drain the cryogenic propellant from the vehicle. 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 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 different conditions before and during flight. The addition of this avionics box is a key step in human-rating the ICPS for Artemis II. The emergency detection system will monitor critical systems during launch and alert Orion on the need to abort from the SLS rocket if an issue was predicted. The added communication bus protocol operator acts as an interface to send vehicle health updates to Orion.

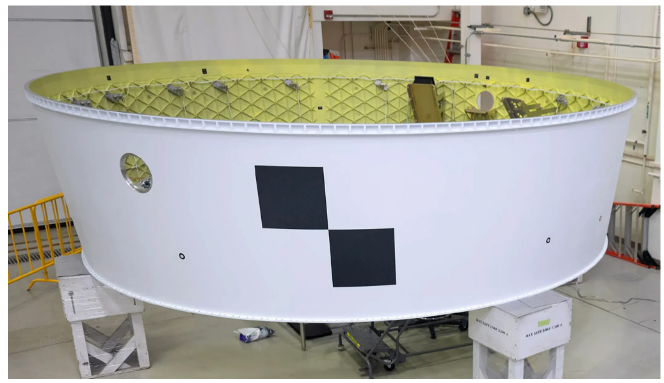
Prior to the successful Artemis I test flight, extensive testing on the materials and manufacture of the ICPS proved the element to be capable of performing its role on SLS.



The Artemis III ICPS is moved at United Launch Alliance's Delta Operations Center prior to stacking. (NASA) ▲

Orion Stage Adapter

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



The completed Orion stage adapter awaits delivery from NASA's Marshall Space Flight Center to Kennedy. The brackets to hold the dispensers for the CubeSat payloads and avionics unit are visible. (NASA) ▲

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, it 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.

Artemis II Updates

The Artemis II Orion stage adapter's brackets and dispensers have been updated to support five larger CubeSats rather than the 10 smaller from Orion supported during Artemis I. 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 preselected times.

Following secondary payload deployment, the adapter remains attached to the ICPS and enters an Earth atmospheric disposal trajectory.

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

Prior to the successful Artemis I test flight, extensive testing on the materials and manufacture of the adapter proved the element to be capable of performing its role on SLS.

The Orion stage adapter is the final element of SLS to be stacked before the Orion spacecraft is added. The Artemis I Orion stage adapter was covered to protect the mission's secondary payloads prior to the addition of the spacecraft. (NASA) ▲

Avionics and Software

The SLS core stage, engines, boosters, and 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 and 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.

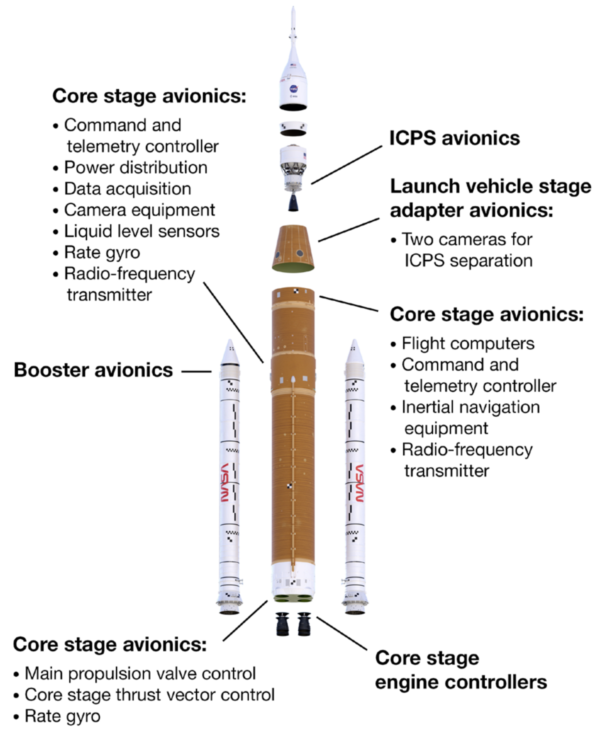
The SLS flight software provides the preflight and flight software functions necessary for on-pad prelaunch procedures, launch, and ascent of SLS up through ICPS separation. The software was developed at Marshall.

The flight control system, led by three redundant flight computers, monitors the rocket's condition, senses vehicle motion, generates navigation and control data, operates 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. (NASA) ▲

Testing

Core Stage Manufacturing, Test, and Checkout

The SLS core stage is manufactured at NASA's Michoud Assembly Facility, where the Saturn rocket stages used during the Apollo program 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.

A significant development campaign preceded and ran concurrently with the manufacturing of flight core stage components. Hundreds of metal "coupons," followed by test panels, were welded at Marshall to develop the friction-stir welding process used to manufacture the core stage components at Michoud. Full-size core stage barrel sections and tanks were welded, including production of full-size flight-like structural test articles for the engine section, liquid hydrogen tank, intertank, and liquid oxygen tank.

These were heavily instrumented with a range of sensors and installed in new test stands and fixtures at Marshall. They were subjected to flight loads created by hydraulic actuators applying millions of pounds of force to verify predicted performance and establish safety. The core stage structural tests, combined with testing of the SLS upper stage and adapters, made up the largest structural test campaign at Marshall since tests conducted for the Space Shuttle Program more than 30 years ago. During the test campaign, five structural test articles underwent 199 separate test cases, and more than 421 GB of data were collected to verify data from computer models used to design the rocket.

Likewise, avionics and flight software, the "brains" of SLS, were developed, tested, and virtually flown thousands of times at Marshall's Integrated Avionics and Software and Systems Integration laboratories before the flight hardware and software were installed in the core stage. In addition, core stage suppliers tested individual components before shipping to Michoud. Once at Michoud, Boeing tested the components and functions before installing them on the core stage. The completed stage underwent basic electrical and pneumatic testing before shipment to NASA's Stennis Space Center for the Green Run test campaign. "Green Run" describes the first operational test of a new component.

At Stennis, teams from Boeing, SLS, and Stennis used the Green Run test series of progressively more flight-like tests to activate stage systems, culminating in a hot fire of the engines that simulated launch and flight of the core stage.

Beginning in early 2020, the core stage was installed in the B-2 test stand, used previously to support Saturn and shuttle propulsion tests.

During the year it was subjected to a series of nine major Green Run tests:

- Modal (vibration).
- Core stage avionics power-on and checkout.
- Safing checks (how to shut down all core stage systems in case of an anomaly).
- Main propulsion system (stage propellant valves and ducts) and RS-25 leak checks and functional tests.
- Hydraulic and thrust vector control (engine steering) checkout.
- Simulated countdown.
- Countdown and wet dress rehearsal (full-stage operation, including flowing propellants to the engines for chilldown).
- Countdown and hot fire (limited duration test up to thrust vector control gimbal).
- Countdown and hot fire (full test of the stage including engines in flight-like operation). At the end of testing, the stage was inspected and refurbished before shipping to Kennedy aboard NASA's barge Pegasus.

RS-25 Engines Manufacturing, Test, and Checkout

Flight engines are processed by Aerojet Rocketdyne at Stennis. The company also supports engine integration into the core stage at Michoud, engine testing at Stennis, and vehicle integration and launch at Kennedy.

Because of differences in SLS requirements and operating environment, the SLS program conducted a series of "adaptation" firing tests from 2015 to 2019 at Stennis with a pair of existing ground test RS-25s. Testing also included running the engines at 113% thrust to demonstrate new production engines can run safely at 111% in case of a contingency.

The series also included Green Run testing of all 16 new engine controllers, as well as testing of new parts manufactured with new techniques aimed at restarting engine production. A total of 32 tests generated nearly 15,000 seconds of hot-fire time.

The 14 previously flown engines do not require certification firing tests because they are flight-proven and certified to operate at 109% thrust. The Stennis test stand was also used to Green Run test the two new engines built from shuttle components.

Dedicated ground test RS-25 engines were fired at Stennis to qualify engines to specific SLS operating conditions. (NASA) ▲

Solid Rocket Boosters Manufacturing, Test, and Checkout

SLS boosters are manufactured by Northrop Grumman in Utah and at Kennedy. In Utah, motor segment cases are lined with insulation and then filled with solid propellant. Each segment undergoes a rigorous inspection process to confirm it is ready for flight. Motor segments are shipped by rail to Kennedy prior to flight.

Northrop Grumman builds the aft and forward skirt assemblies at several facilities near the launch site in Florida. Previously flown structures were refurbished at the Hangar AF complex at the Cape Canaveral Space Force Station, then moved to the Booster Fabrication Facility at Kennedy. There, Northrop Grumman installs avionics, thrust vector control systems, booster separation motors, and thermal protection. These systems are thoroughly tested at the Booster Fabrication Facility before delivery to the EGS program, along with the motor segments and aft exit cones delivered from Utah.

EGS then builds the overall aft assembly in the Rotation, Processing, and Surge Facility at Kennedy by attaching the aft motor segment to the aft skirt assembly and adding the lower core stage attach struts. That aft assembly is moved to the Vehicle Assembly Building and is the first element lowered onto the mobile launcher to begin rocket assembly.

The rest of the motor segments are then stacked and pinned on top of each other: center aft, center-center, center-forward, and the forward motor segment. A forward assembly, consisting of a forward skirt and nose cone, is attached to each booster. After booster stacking, the core stage is lowered between the boosters. Each booster is mated to the SLS core stage by braces on the forward and aft booster segments. On the mobile launcher, the booster aft skirts carry the entire load, or weight, of the SLS and Orion stack.

The SLS five-segment solid rocket motor is the result of experience of the shuttle booster motor as well as extensive post-shuttle development. Northrop Grumman conducted numerous tests on subscale motors to evaluate specific components or materials such as the motor-case insulation and nozzle materials and configuration. The company also conducted a series of full-scale development motor tests and qualification motor tests.

Three development motor tests in 2009, 2010, and 2011 were used to evaluate the five-segment design and various other design changes. The Development Motor-1 test was the first to evaluate thrust, roll control, acoustics, and motor vibrations using 650 data channels. The Development Motor-2 test motor was chilled to 40 degrees Fahrenheit (4.4 degrees Celsius) to verify performance of 53 test objectives using more than 760 data channels. Development Motor-3 was the most heavily instrumented motor to date, with more than 970 sensors collecting data for 37 test objectives after the motor was heated to 90 degrees Fahrenheit (32.2 degrees Celsius).

Subsequently, Northrop Grumman conducted two full-scale qualification motor tests at its Utah test facilities in 2015 and 2016. Test motors were again heated to 90 degrees Fahrenheit (32.2 degrees Celsius) and cooled to 40 degrees Fahrenheit (4.4 degrees Celsius), respectively. Engineers collected additional data on motor upgrades such as the new insulation and booster case liner, redesigned exhaust nozzle, and more to support more than 100 test objectives. This is how solid rocket motor designs are determined to be ready for flight. Once these ground tests are complete, the manufacturing process is carefully controlled to ensure the flight boosters will perform as well as the ground test articles.

Integrated Spacecraft/ Payload Element Manufacturing, Test, and Checkout

The ICPS is manufactured by ULA. Its RL10 engine is manufactured by Aerojet Rocketdyne in its West Palm Beach, Florida, facility.

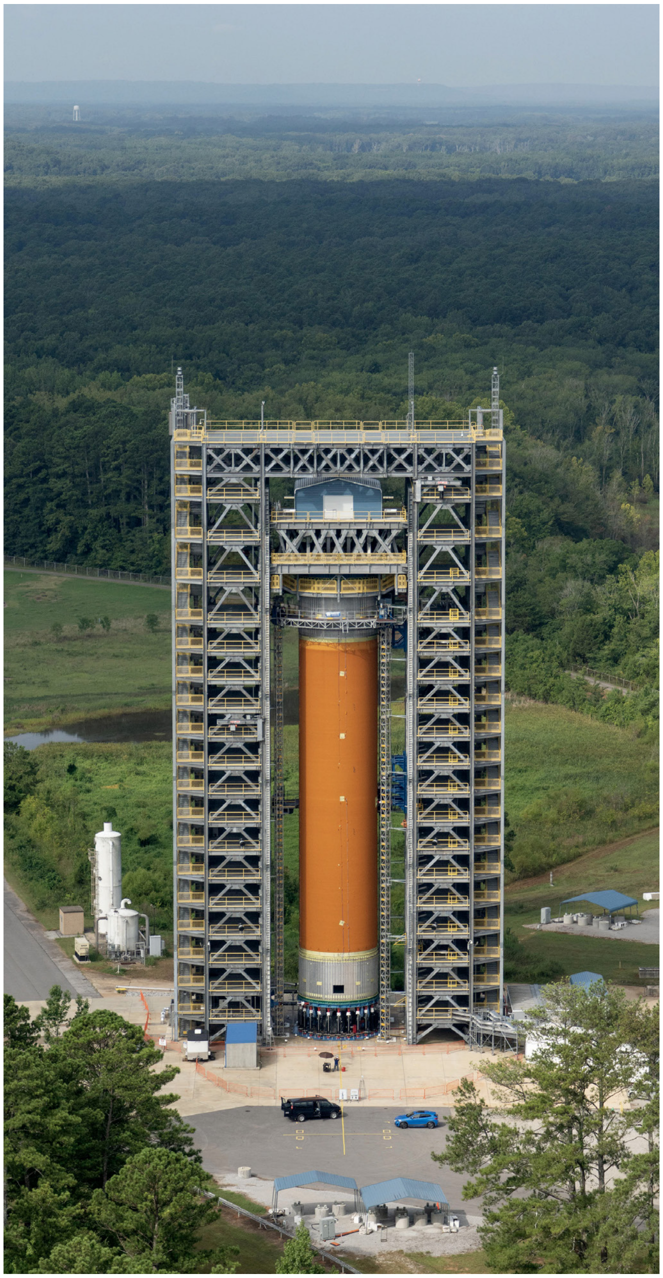
Teledyne Brown Engineering manufactures the launch vehicle stage adapter using self-reacting friction-stir welding tools at the Advanced Weld Facility at Marshall. The adapter consists of two cones and two ring sections. Technicians first vertically weld panels to make the bottom cone. Then they weld panels to make the upper cone. Finally, a circumferential weld joins the two cones. Welded rings go on the top and bottom of the cone.

The first launch vehicle stage adapter manufactured at Marshall's Advanced Weld Facility was used as a test article, along with the ICPS, Orion stage adapter, and a core stage simulator for a series of structural tests conducted at Marshall. Engineers subjected the stack of test articles to loads up to 40% greater than they will experience during ascent and flight. The results of this Integrated Structural Test were used to validate computer models simulating how the Integrated Spacecraft/ Payload Element will behave in flight.

The Integrated Structural Test series at Marshall was the beginning of the largest structural testing campaign since the Space Shuttle Program. The test qualified the launch vehicle stage adapter, ICPS, Orion stage adapter, and joint assembly that separates the ICPS and Orion from SLS. The integrated stack, which included an Orion simulator, was subjected to forces up to 40% higher than anticipated flight loads. Approximately 50 test cases collected about 1,900 channels of data, including temperature, deflection, bend, compression, and other factors.

A crane is seen here lowering the launch vehicle stage adapter onto the SLS core stage in the Vehicle Assembly Building at Kennedy. (NASA) ▲

Management Roles and Facilities



NASA's SLS 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. (NASA) ▲

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. Marshall also develops and tests the flight software.

The program office is supported by Resident Management Offices at NASA field centers and industry partner sites. The offices conduct engine testing, are responsible for integration and launch, and coordinate SLS technical and operations expertise with the EGS program.

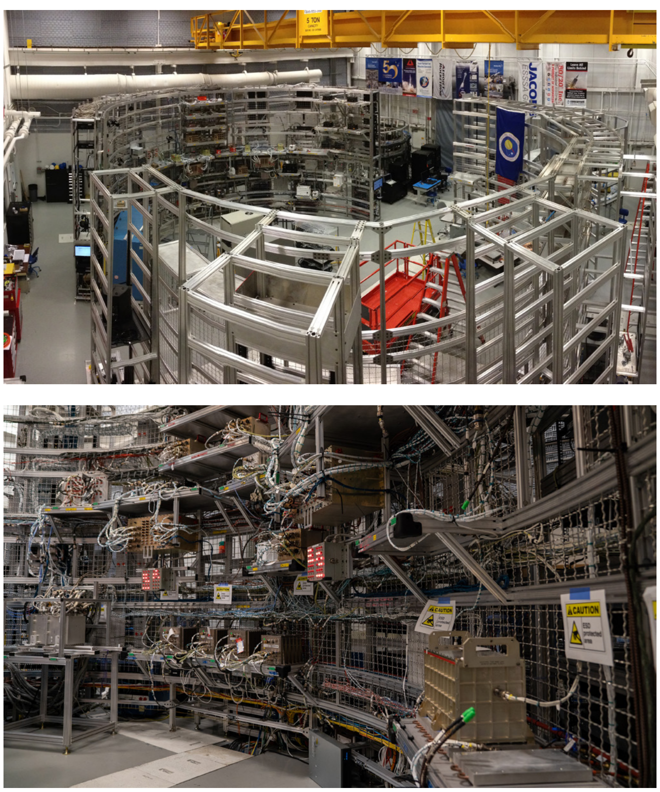
Unique Test Facilities

Several Marshall facilities support SLS. Building 4693 is a tower open structure built to perform structural testing on a liquid hydrogen tank test article. Measuring 221 feet (67.3 meters) 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. Standing 90 feet (27.4 meters) tall, the stand used 24 hydraulic pistons and more than 2,700 sensors to conduct 32 structural loads tests on the liquid 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 feet (18 meters) tall, and the intertank tower measures 62 feet (19 meters) 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 a 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.



Supporting Launch Operations

The SLS Engineering Support Center, located in the Huntsville Operations Support Center at Marshall, allows engineers specializing in the engines, boosters, core stage, avionics, and the upper stage to monitor the rocket's propulsion and other systems during the countdown and flight. The teams in the SLS Engineering Support Center leading up to and during launch analyze and monitor temperatures, pressures, flow rates, stresses, and other types of telemetry from the rocket. Teams there 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 SLS Engineering Support Center also supports the Launch Control Center at 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 SLS Engineering Support Center 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 facility is staffed by a team from the SLS program, Marshall engineering teams, and SLS contractors.

The Systems Integration Laboratory/Systems Integration Test Facility at Marshall is a full-scale mock-up of flight-like avionics systems for the solid rocket boosters and core stage. Here, engineers can test hardware and software integration prior to manufacture and flight. (NASA) ◀

The Natural Environments Branch at 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 Kennedy since Apollo. 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 to minimize stress on the vehicle to ensure a safe flight.

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

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

Marshall's SLS Engineering Support Center is networked to Kennedy, NASA's Johnson Space Center, and contractor locations nationwide to provide engineering support for SLS testing and launch operations. (NASA) ▲

Michoud Assembly Facility

For more than half a century, NASA's Michoud Assembly Facility in New Orleans has been America's rocket factory, the 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. Marshall manages Michoud, while commercial firms and NASA contractors use several areas of the facility. 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

Michoud is managed by Marshall and is one of the largest manufacturing facilities in the world, with 43 acres under one roof. (NASA) ▲

The Artemis II core stage liquid hydrogen tank is readied for its next production phase at Michoud. (NASA) ▲

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

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

At Michoud, six major multifunction assembly/welding tools developed for SLS have resulted in a greater than 80% reduction in tooling from shuttle external tank production. This reduced tooling also minimizes hardware handling, reducing complex hardware — lifting operations by more than 70%. 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
- 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 tons)
- 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 feet (51.8 meters) tall and 78 feet (24 meters) wide and is one of the world's largest welding tools

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

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 Stennis' 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%.

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, Stennis completed testing of all 16 RS-25 main engines that will help launch the first four SLS missions. In June 2025, NASA began hot-fire testing the RS-25 rocket engines slated to help power future Artemis missions, successfully testing the first two new production engines at Stennis.

Technicians at Stennis prepare an RS-25 engine at the Fred Haise Test Stand. (NASA) ▲

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

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

Stennis test stands are linked by a 7.5-mile (12-kilometer) canal system used for transporting rocket stages and liquid propellants. Support facilities for 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-gallon (250-million-liter) reservoir.

More than 32,500 5/32-inch holes drilled in the B-2 test stand flame deflector direct more than 240,000 gallons (908,000 liters) of water a minute to cool the engine exhaust during a test. Another 92,000 gallons (348,000 liters) 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.

Industry Partners

Over the course of NASA's SLS Program, more than 2,400 companies from 48 states have contributed to designing, developing, manufacturing, testing, and supporting SLS, the rocket that returns NASA's human spaceflight program to the Moon. Several prime contractors head up the manufacturing, test, and assembly of the major elements of SLS, and also are supported by hundreds of smaller suppliers across the United States.

L3Harris Technologies

L3Harris Technologies is the prime contractor for the four powerful RS-25 engines used to help propel SLS missions. The four liquid hydrogen/liquid-oxygen-fed RS-25 engines produce more than 2 million pounds (8,896 kilonewtons) 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.

Industry partner L3 Harris, headquartered in Melbourne, Florida, supplies RS-25 engines for the SLS core stage and RL10 engines for the ICPS. (NASA) ▲

Assembly and testing occur at the company's facility located at Stennis. In addition to the RS-25 engines, the company also provides propulsion that will be used for Artemis missions.

L3Harris Technologies in West Palm Beach, Florida, designs, manufactures, and tests the RL10 engine that propels the ICPS. 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 tanks 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.

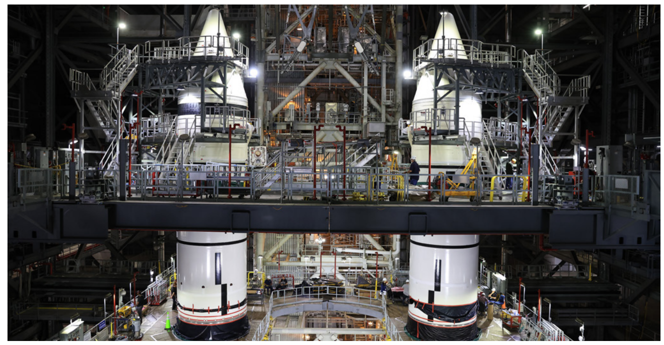
Boeing

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

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 are underway, including the exploration upper stage, a more powerful in-space stage for NASA's Block 1B and 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.

Northrop Grumman



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. (NASA) ▲

Northrop Grumman is the prime contractor for the design, development, testing, and production of the twin solid rocket boosters that provide more than 75% 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% more propellant, making 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 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.

Teledyne Brown Engineering

Teledyne Brown Engineering, based in Huntsville, Alabama, has provided 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.

The launch vehicle stage adapter is manufactured using the friction-stir welding tools in the Advanced Weld Facility at Marshall. It is the largest piece of the current SLS configuration built there. In addition to the Artemis II adapter, Teledyne Brown delivered the adapter's 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, which has a pneumatically activated frangible joint that separates it and the core stage from the ICPS, Orion stage adapter, and Orion spacecraft during flight. (NASA) ▲

United Launch Alliance

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

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. Launch operations are located at Cape Canaveral Space Station in Florida and Vandenberg Space Force Base in California.

United Launch Alliance supplies the ICPS, which is based on the Delta cryogenic second stage, for the SLS Block 1 rocket. (NASA) ▲

SLS Block 1 by the Numbers

SLS Vehicle	
Vehicle design	Evolvable super heavy lift
Height	322.4 feet (98.27 meters)
Weight	5.74 million pounds (2,604 metric tons) fueled 3.5 million pounds (1,588 tons) unfueled
Main propulsion	Four RS-25 liquid propellant engines and two five-segment solid rocket boosters
Maximum thrust	8.8 million pounds (39,144 kilonewtons)
Launch thrust	8.27 million pounds (36,787 kilonewtons)
Maximum speed	22,670 mph (36,484 kilometers/hour) at ICPS translunar injection (TLI) main engine cutoff (MECO)
Single-launch payload to low Earth orbit	209,439 pounds (95 tons)
Payload to TLI	> 59,525 pounds (27 tons)
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

Core Stage	
Contractor	Boeing
Height	212 feet (64.6 meters) from forward skirt to engine exhaust exit plane
Diameter	27.6 feet (8.41 meters)
Weight (without engines)	2.4 million pounds (1,089 tons) fueled; 188,000 pounds (85.3 tons) unfueled
Capacities	537,000 gallons (2 million liters), 317,000 pounds (143.8 tons) liquid hydrogen fuel; 196,000 gallons
Maximum thrust	Approximately 2 million pounds (8,896 kilonewtons)
Burn time	480 seconds
Artemis II completion date	July 2024 (shipped to launch site)

RS-25 Engines	
Contractor	L3Harris Technologies
Height	14 feet (4.3 meters)
Diameter	8 feet (2.4 meters)
Weight (each)	7,750 pounds (3.52 tons)
Propellants	Liquid hydrogen, liquid oxygen
Thrust	418,000 pounds (1,859 kilonewtons) at launch; 512,300 pounds (2,279 kilonewtons), maximum at 109% power level
Burn time	480 seconds
Artemis II completion date	December 2019

Solid Rocket Boosters	
Contractor	Northrop Grumman
Height	177 feet (53.9 meters)
Diameter	12 feet (3.7 meters)
Weight (each)	1.6 million pounds (726 tons) loaded; 219,000 pounds (99.3 tons) empty
Solid rocket motor	Five propellant segments
Propellants	Polybutadiene acrylonitrile
Thrust	3.3 million pounds (14,679 kilonewtons) each at launch; 3.6 million pounds (16,014 kilonewtons) each maximum
Burn time	~126 seconds
Artemis II completion date	Motor segments, July 2019; forward and aft assemblies, July 2024

Interim Cryogenic Propulsion Stage (Upper Stage)	
Contractor	Boeing/United Launch Alliance
Designation	Interim Cryogenic Propulsion Stage (modified Delta cryogenic second stage)
Height	45 feet (14 meters)
Diameter	16.7 feet (5.09 meters)
Weight	72,197 pounds (32.748 tons) fueled; 8,200 pounds (3.719 tons) unfueled
Engine	L3Harris Technologies RL10B-2, RL10C-2 (Artemis II/III)
Propellants	Liquid hydrogen/liquid oxygen
Maximum thrust	24,750 pounds (110.1 kilonewtons)
Reaction Control System	Hydrazine
Artemis II completion date	October 2023

Launch Vehicle Stage Adapter	
Contractor	Teledyne Brown Engineering
Height	27.5 feet (8.38 meters)
Diameter	27.5 feet (8.38 meters) bottom; 16.5 feet (5.03 meters) top
Weight	10,000 pounds (4.5 tons)
Artemis II completion date	June 2024

Orion Stage Adapter	
Contractor	NASA’s Marshall Space Flight Center
Height	5 feet (1.5 meters)
Diameter	18 feet (5.5 meters)
Weight	1,800 pounds (0.82 tons)
Available volume for payloads	516 $feet^3$ (14.6 $meters^3$)
Artemis II completion date	August 2024

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 inches (36.6 centimeters) x 9.4 inches (23.9 centimeters) x 8.8 inches (22.4 centimeters), not to exceed 57.3 pounds (26 kilograms).

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

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

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

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

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

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. 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 multipurpose 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.

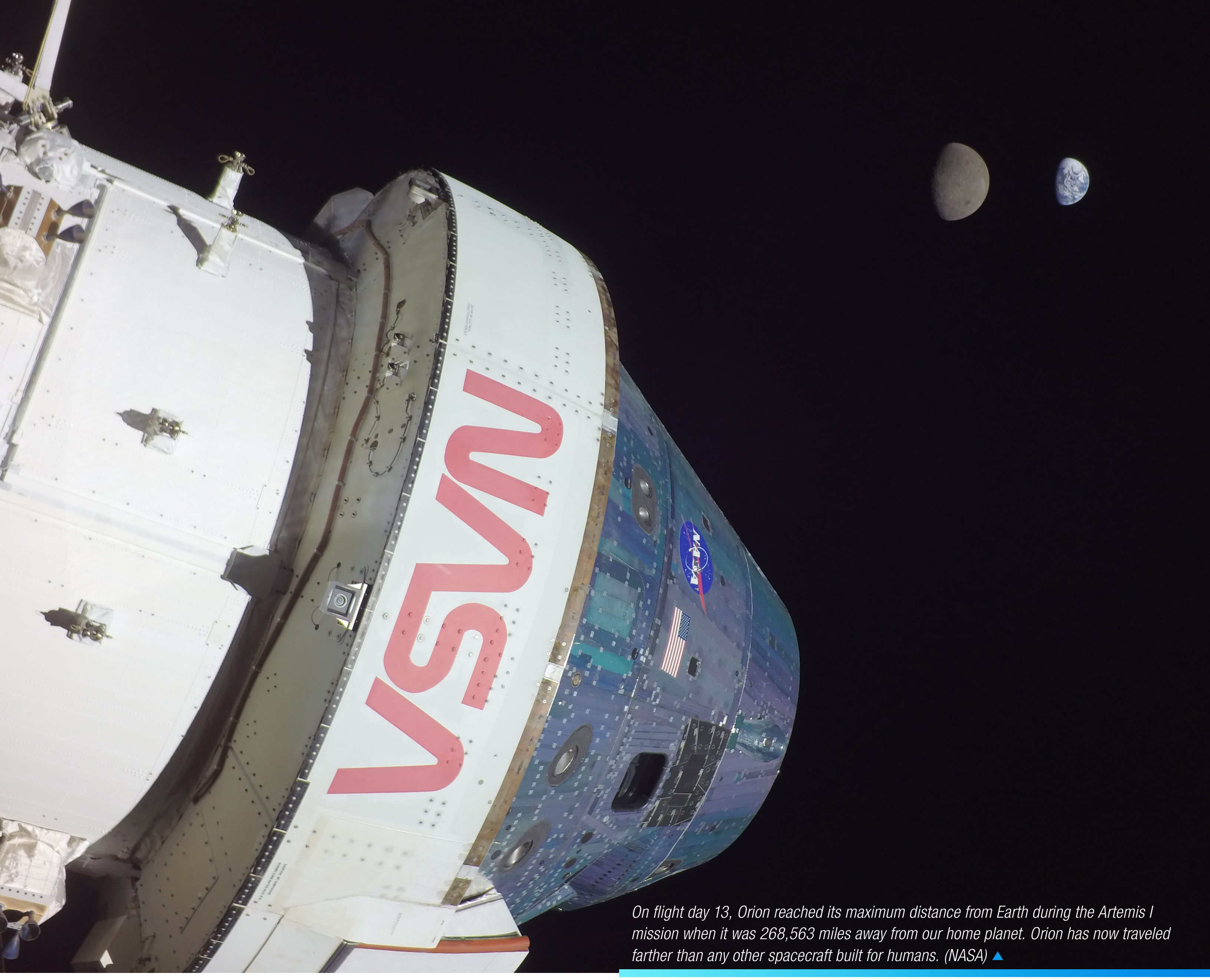
Pathfinders mimicking shape, size, weight, center of gravity, and handling interfaces provided realistic practice handling, lifting, and transport operations using newly designed ground support equipment at Michoud, Stennis, and Kennedy before teams worked with the Artemis I core stage. Ground support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

NASA's Pegasus barge 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 Michoud, where they were manufactured, to Kennedy. Pegasus also transported the Artemis I and II launch vehicle stage adapters from Marshall to Kennedy.

Pegasus was designed and built in 1999 to transport space shuttle external tanks from Michoud to Kennedy. It replaced the Poseidon and Orion barges that were used to carry Saturn rocket stages and hardware for the Apollo and Space Shuttle programs. Pegasus was modified in 2014 to carry the longer SLS core stage. A 115-foot (35-meter) section was removed and replaced with a 165-foot (50-meter) section capable of carrying more weight and lengthening Pegasus from 260 feet (79 meters) to 310 feet (94 meters). 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 Kennedy prior to stacking in the Vehicle Assembly Building.

» For more details about the SLS role in Artemis missions, including illustrations, photos, tables, additional infographics, and downloadable versions, go to: https://www.nasa.gov/humans-in-space/space-launch-system/



On flight day 13, Orion reached its maximum distance from Earth during the Artemis I mission when it was 268,563 miles away from our home planet. Orion has now traveled farther than any other spacecraft built for humans. (NASA) ▲

Orion

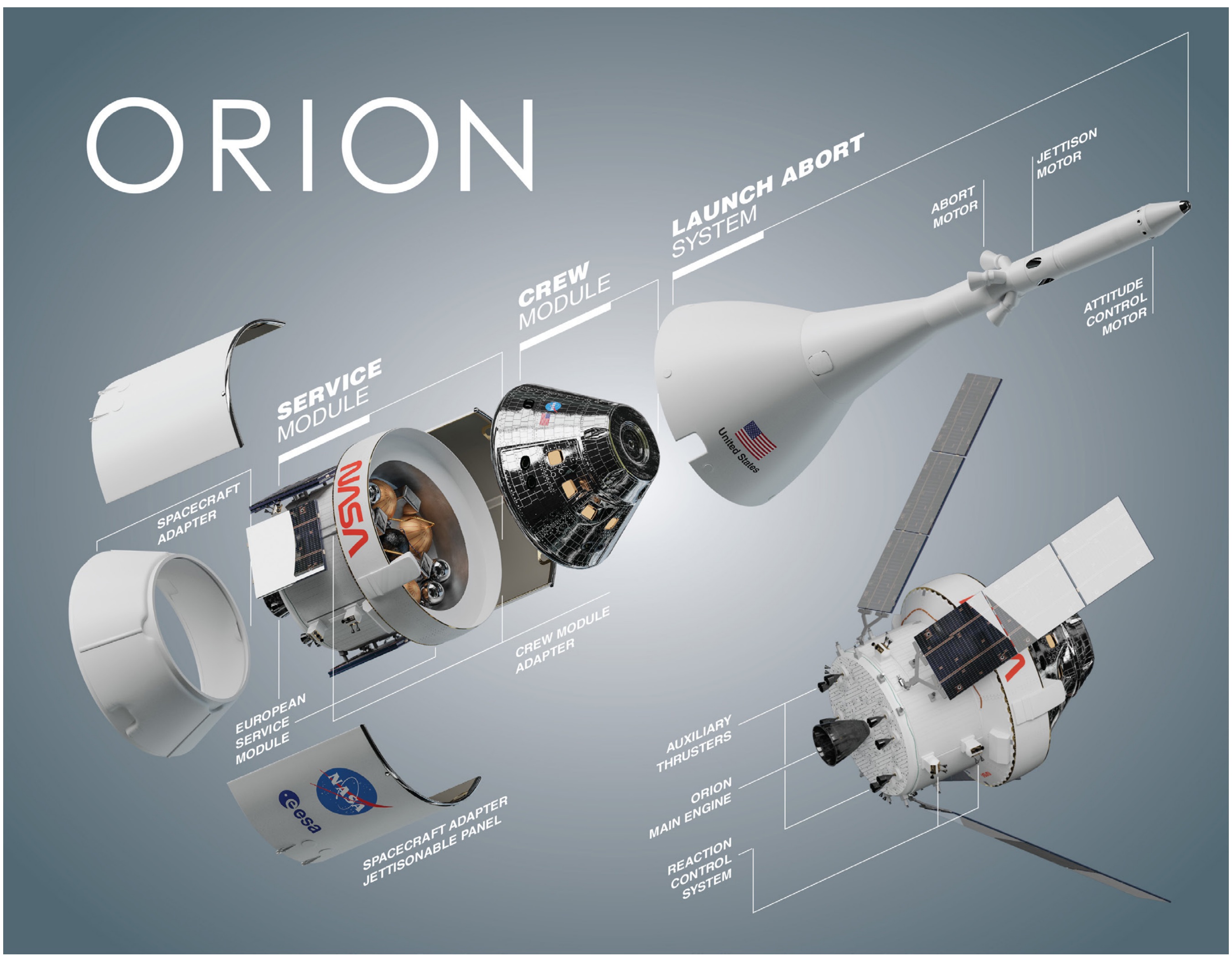
Introduction

Orion will serve as the exploration spacecraft that will carry and sustain the crew on Artemis missions to the Moon and return them safely to Earth. Orion is comprised of three main elements and supporting subsystems. The main elements are 1) the crew module, where astronauts live and work; 2) the service module, which provides power, propulsion, and critical supplies; and 3) the launch abort system, or LAS, which can pull the spacecraft and crew to safety in the event of an emergency during launch or ascent to orbit. Drawing from more than 50 years of spaceflight research and development, the Orion spacecraft is built to take astronauts farther than they've ever gone before, and a key part of eventually sending humans to Mars.

A full Moon is in view from Launch Complex 39B at NASA's Kennedy Space Center in Florida on June 14, 2022. The Artemis I SLS (Space Launch System) and Orion spacecraft, atop the mobile launcher, are being prepared for a wet dress rehearsal to practice timelines and procedures for launch. (NASA/Ben Smegelsky) ▲

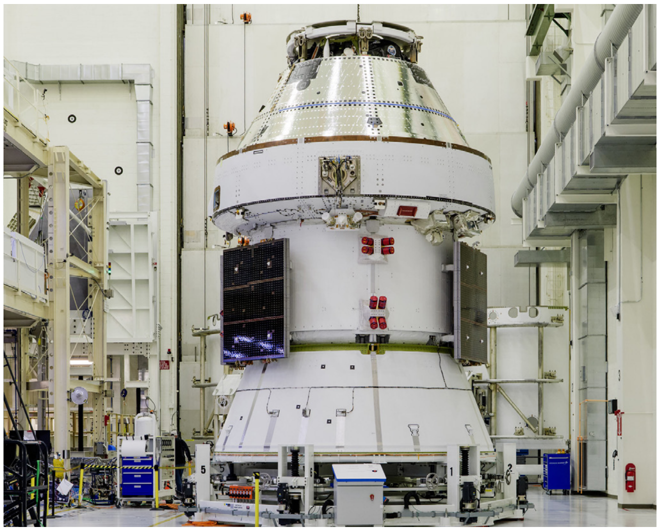
Overview

The Orion spacecraft, built by lead contractor Lockheed Martin for NASA, is specifically designed to carry astronauts on deep space exploration missions farther than ever before and requires an array of features to keep the spacecraft and its crew safe. On deep space missions, both distance and duration dictate the capabilities and advanced technologies needed. No other spacecraft has the technology to endure the extremes of deep space, such as advanced environmental and life support, navigation, communications, radiation shielding, and the world's largest heat shield to protect astronauts and return them safely home.



Artemis II builds on the uncrewed Artemis I test flight by demonstrating a broad range of Orion capabilities needed on deep space missions to explore the Moon and, eventually, Mars. This mission will prove Orion's critical life support systems are ready to sustain astronauts on the longer-duration missions ahead and allow the crew to practice operations essential to the success of Artemis III and beyond.

The crew will complete an array of objectives to test Orion's systems over the course of the mission, including a proximity operations demonstration to asses Orion's handling qualities; performance of the life support systems, including while wearing Orion crew survival system spacesuits, and during exercise and sleep periods; communication and navigation systems; demonstrating Earth departure and return operations; practicing emergency procedures; and testing the radiation shelter, among other activities.



The four solar array wings for the Artemis II Orion spacecraft are installed inside the Operations and Checkout Building at NASA's Kennedy Space Center in Florida on March 7, 2025. (NASA) ▲

Future Missions

Artemis II will be the first flight with astronauts aboard Orion. The spacecraft is equipped with advanced environmental control and life support systems, designed to be highly reliable while taking up minimal mass and volume. Additional crew systems include advanced displays and control panels, a compact toilet, exercise equipment to help prevent muscle and bone atrophy, and spacesuits capable of keeping the astronauts safe for six days in the event of cabin depressurization, supporting a multi-day return from the Moon. Deep space missions require highly reliable systems, because astronauts at the Moon will not have the benefit of frequent resupply shipments to bring spare parts from Earth, like those to the International Space Station. Distance and duration for these flights have shaped the design of Orion's compact systems, not only to maximize available space for crew comfort, but also to accommodate the volume needed to carry consumables such as food and water for the entirety of a mission lasting days, weeks, or even months. Missions beyond Artemis II will also include a rendezvous and docking system for docking to a human landing system, which would take astronauts to the surface of the Moon or to another spacecraft.

Artemis II crew members, shown inside the Neil Armstrong Operations and Checkout Building at NASA's Kennedy Space Center in Florida, check out their Orion crew module on Aug. 8, 2023. (NASA) ▲

Elements

Crew Module

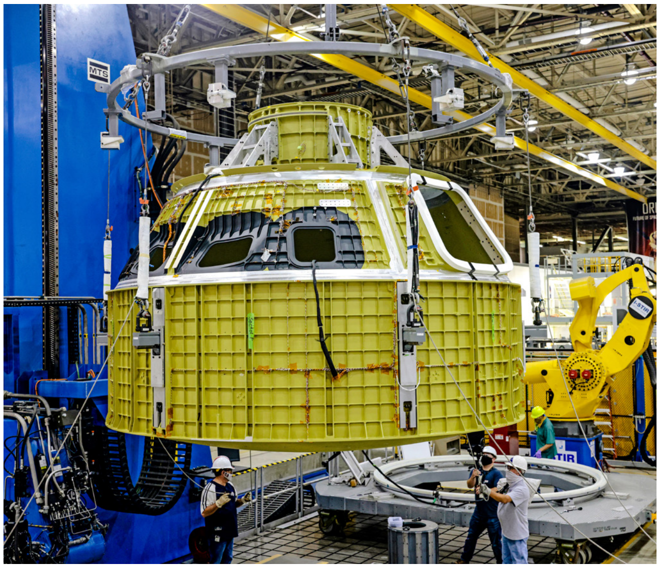
The crew module is the pressurized part of the Orion spacecraft, sometimes referred to as the capsule, where crew members will live and work on their journey to the Moon and back to Earth. It is the only portion of Orion that returns to Earth at the end of the mission. The crew module can accommodate four crew members on missions for up to 21 days without docking with another spacecraft, and provides a safe habitat through launch, in-orbit operations, landing, and recovery. Orion's cabin has a habitable volume of 330 cubic feet, giving the crew about as much living space as two minivans.

Pressure Vessel

The underlying structure of Orion's crew module is called the pressure vessel. The pressure vessel consists of seven large aluminum alloy pieces that are joined together using friction-stir welding to produce a strong, yet lightweight, airtight capsule. The seven major structural pieces include the barrel, the tunnel, the forward and aft bulkheads, and three cone panels. Orion's original designs required 33 welds to create the pressure vessel. Engineers refined the design to reduce the number of welds to seven on Artemis I and missions beyond, saving 700 pounds of mass on the spacecraft.

Backshell

The backshell, which covers Orion's pressure vessel on the sides of the crew module, is made up of 1,300 thermal protection system tiles. These tiles are made of a silica fiber material similar to the tiles used for more than 30 years on the space shuttle, and they incorporate a stronger coating called "toughened uni-piece fibrous insulation," which was used toward the end of the Space Shuttle Program. The tiles protect the spacecraft from in-space micrometeoroid debris, as well as extreme temperature variances ranging from the -350-degree Fahrenheit (-212-degree Celsius) coldness of space to the 5,000-degree (2,760-degree Celsius) heat when entering Earth's atmosphere at lunar-return velocities. Spacecraft returning from the Moon re-enter Earth's atmosphere faster and hotter than spacecraft from low Earth orbit.



At NASA's Michoud Assembly Facility in New Orleans, Orion's newly completed pressure vessel for the Artemis III mission is lifted out of the welding tool on Aug. 27, 2021. (NASA/Michael DeMocker) ▲

Orion's backshell tiles can be seen in close-up images of NASA's Orion spacecraft, which were taken by solar-array-mounted cameras on Dec. 5, 2022 — the 20th day of the Artemis I mission. (NASA) ▲

Forward Bay Cover

The Artemis I Orion crew module, also known as the Orion Environmental Test Article, prepares for testing with installation of the forward bay cover. The crew module returned to NASA's Neil Armstrong Test Facility in Sandusky, Ohio, in January 2024 and completed an 11-month test campaign necessary for the safety and success of Artemis II. (NASA/Jordan Salkin) ▲

On Orion's crew module, the forward bay cover protects the top portion of the capsule, as well as the parachutes, during launch, orbital flight, and re-entry. It is covered with the same thermal protection tiles as the backshell. After the spacecraft re-enters Earth's atmosphere, the forward bay cover is jettisoned at an altitude of approximately 23,000 feet to allow for the parachutes to deploy. The parachute system includes a series of 11 parachutes that are deployed in a sequence to slow down the crew module from about 325 mph to 20 mph or less, providing a safe speed for splashdown into the ocean.

Heat Shield

Teams install the heat shield on the Artemis II Orion spacecraft inside the high bay of the Neil A. Armstrong Operations and Checkout Building at NASA's Kennedy Space Center in Florida on June 22, 2023. (NASA/Cory Huston) ▲

The bottom of the Orion capsule is covered by the world's largest ablative heat shield, measuring 16.5 feet in diameter. The heat shield sheds intense heat away from the crew module as Orion returns to Earth, traveling about 25,000 mph and enduring temperatures about half as hot as the surface of the Sun at nearly 5,000 degrees Fahrenheit (2,760 degrees Celsius). The outer surface of the heat shield is made of 186 billets, or blocks, of an ablative material called Avcoat, a reformulated version of the material used on the Apollo capsules. The Avcoat is bonded to a titanium skeleton and composite skin that gives the shield its shape and provides structural support for the crew module during descent and splashdown. During descent, the Avcoat ablates, or burns off, in a controlled fashion, transferring heat away from Orion.

The Avcoat is first made into large blocks at NASA's Michoud Assembly Facility in New Orleans and then shipped to NASA's Kennedy Space Center in Florida. There, it is machined into 186 unique shapes before applied onto the heat shield. Engineers look for voids in the bond lines and measure the steps and gaps between the blocks. The gaps are filled with an adhesive material and then reassessed. After the thermal protection system has been applied and inspected, engineers and technicians put the heat shield through a thermal cycle test. This testing ensures that the thermal protection blocks are properly bonded and will perform as expected when exposed to temperature extremes during the mission. The heat shield is then given a coat of white epoxy paint. Aluminized tape is applied after the painted surface dries to dissipate electrical surface charges and maintain acceptable temperatures. Once all testing has been completed, the heat shield is bolted to the crew module.

Propulsion System

The crew module has a propulsion system comprised of 12 small engines, called reaction control system thrusters. These are provided by Aerojet Rocketdyne and provide full control of crew module translation and rotation. When the crew module separates from the service module for re-entry into Earth's atmosphere, the 12 thrusters control the spacecraft's return by firing bursts of propellant in varying sequences.

Interior and Crew Systems

Backbone Assembly
Inside the crew module, the floor structure is called the backbone assembly. This is where the crew seats are attached and where the crew stowage lockers are located. It consists of a nine-piece bolted structure of crisscrossing beams. The backbone, made of aluminum, also provides additional structural support for the crew module.

The Artemis II crew, NASA astronauts Reid Wiseman, Victor Glover, and Christina Koch, and CSA (Canadian Space Agency) astronaut Jeremy Hansen, complete Post Insertion and Deorbit Preparation training at NASA Johnson Space Center's Space Vehicle Mockup Facility in Houston. (NASA/Mark Sowa) ▲

Crew Seats
The Orion crew module includes four crew seats. Viewed from the side-hatch opening, the crew seats for the commander and pilot are located to the left of the side capsule, facing the display and control units placed at an arm's length away. The two other seats for the mission specialists are located on right side of the capsule. When configured for launch and re-entry, the astronauts will be lying on their backs, their knees bent at a 90-degree angle, with their feet resting on foot pans.

The seats are designed to accommodate anyone from the 1st to the 99th percentile of body anthropometries — from a 4-foot-10-inch, 94-pound female to a 6-foot-5-inch, 243-pound male. They can be adjusted in multiple ways to fit the astronauts more comfortably. This includes adjusting the seat pans, foot plate, head and arm rests of the seats, and adjusting hand-controller mounts to make sure that astronauts of any height or weight can reach all the controls while in their pressurized suits. Once in space, the foot pans on the pilot and commander seats can be removed and stowed, allowing the crew more open space in the cabin.

The crew seats have features to help secure crew members during flight phases of the mission. A five-point harness — or seatbelt — restraint, a concave headrest, shoulder and hip bolsters, and a peg in the foot pan that locks into the crew boots to minimize the movement of the crew member's body.

The seats also include a crew impact attenuation system that helps protect the Orion crew from excessive g-load during landing. This mechanism attaches to each crew seat and Orion's backbone structure and helps absorb shock when Orion splashes into the ocean after returning to Earth. It decreases the impact energy the astronauts will feel and limits the load by allowing the seat to slide on guard rails. Each seat has 6 inches of room to slide; however, the crew impact attenuation system will not slide back and forth during the regular vibrations of spaceflight. It only engages on landing.

Artemis II crew during "Day in the Life" training in an Orion medium-fidelity mock-up on May 2, 2024. (NASA/Robert Markowitz) ▲

Displays and Controls

The Orion display and control equipment is the crew interface to Orion's systems. The displays and controls consist of three display units, seven switch interface panels, two rotational hand controllers, two translational hand controllers, and two cursor-control devices. The switch panels and hand controllers' hardware communicate through serial interfaces to the power and data units, and then via the onboard data network to either flight control modules or the display units for processing. The display units use a variety of display formats to provide data to the crew for awareness and action when necessary.

The Orion displays and controls are designed for an intensive amount of crew interaction, both in nominal and off-nominal scenarios. Electronic procedures have been developed for Orion that allow direct interaction with the display formats, reducing workload on the crew. The electronic procedures efficiently step the crew through planned tasks and reduce crew workload by highlighting various telemetry on a display format or queuing up commands. Additionally, the electronic procedures have built-in links to the caution and warning system aboard, which alert the crew when faults and anomalies occur. The electronic procedures link provides the ability for the crew to bring up the urgent actions the crew needs to take to address any caution and warning conditions.

Display Units

NASA astronauts Victor Glover and Christina Koch train in an Orion flight simulator at NASA's Johnson Space Center in Houston. (NASA/Helen Arase) ▲

NASA astronauts Reid Wiseman and Victor Glover train during an entry simulation in the Orion mission simulator. (NASA/Robert Markowitz) ▲

The Orion crew module uses three display units, or DUs, to convey all display and control information to the crew members. These three units are set into the switch panel stationed directly in front of commander and the pilot seats, with the commander positioned about eye level with the left-most unit (DU1), and the pilot stationed in front of the right-most unit (DU3). The middle unit (DU2) acts as a shared display screen that can be reached and operated by both the commander and pilot.

The display units can be controlled by the edge keys and twizzle knob located on the frames surrounding each of the three screens. The pilot and commander can also use the cursor control devices to control the DUs and select options being displayed.

The devices are located on the left side of each of their seats and allow for easy access — even when gravitational forces are acting against the astronauts.

The display units are the main point of interface between the crew and the spacecraft. Through this system, the crew can receive vehicle status updates, command new operations or edit information, and interact with the spacecraft systems, making the display units one of the most crucial systems on Orion.

Next to Orion's displays, the spacecraft also has a series of switches, toggles, and dials on the switch interface panel. Along with switches the crew will use during normal mission operations, there is also a backup set of switches they can use to fly Orion if issues arise with the display or hand controller.

Hand Controllers

Crew members will use two different controllers, called rotational and translational hand controllers, to steer the spacecraft.

The rotational hand controller allows the pilot and commander to rotate the spacecraft using their right hand to control. This controller directs Orion's attitude, allowing the crew to control the orientation of Orion's nose, to pitch up or down, or roll right or left.

The translational hand controller, located on the right or left side of the display screens, allows the spacecraft to move from one point to another. It enables the crew to move the spacecraft forward and backward, pushing the translational hand controller inwards and outwards. Similarly, the controller can also be pushed up or down and left or right to move in the directed orientation.

Orion Crew Survival System Suits

At several points during Artemis missions, astronauts will wear a bright orange spacesuit called the Orion Crew Survival System suit, which is designed to protect them on their journey.

Improvements have been made from head to toe to the suit previously worn on the space shuttle and, now, for Orion.

The Artemis II crew stands in the white room on the crew access arm of the mobile launcher at Launch Pad 39B as part of an integrated ground systems test at NASA's Kennedy Space Center in Florida on Sept. 20, 2023. (NASA/Frank Michaux)

Elements have been reengineered to improve safety and range-of-motion for astronauts. Instead of the small, medium, and large sizes from the shuttle era, they are custom fit for each crew member.

The suits can keep astronauts safe for up to six days if Orion were to lose cabin pressure during its journey, with interfaces that supply air and remove carbon dioxide. They also are equipped with a suite of survival gear in the event astronauts must exit Orion after splashdown, in the ocean, before recovery personnel arrive. The color is an easily recognizable beacon in ocean waters.

The outer layer is fire resistant, and a stronger zipper allows astronauts to quickly put the suit on. Improved thermal management helps to keep them cool and dry. A lighter, stronger helmet improves comfort and communication, and the gloves are more durable and touch-screen compatible. Better-fitting boots also provide protection in the event of fire and help astronauts move more swiftly.

Astronauts will wear the suit on launch day, in emergency situations, during high-risk parts of missions near the Moon, and for the high-speed return to Earth. Its design and engineering enhancements provide an additional layer of protection for astronauts and ensure they return home safely from deep space missions.

Environmental Control and Life Support Systems

On Orion, environmental control and life support systems make the crew module a habitable, safe place for astronauts, and is key to survival as they travel to the Moon. The key components of the systems include atmosphere revitalization, pressure control, crew water supply, and crew waste management. For Orion, these systems must be mass and volume efficient, as well as dependable. Orion provides an environmental control and life support system that balances between the constraints of launch mass, volume, system fault tolerance, and reliability of resources to sustain astronauts and keep them safe.

Atmosphere revitalization is the highest priority on deep space missions. Systems must not only provide oxygen and remove carbon dioxide from the atmosphere, but also prevent gases like ammonia and acetone, which humans emit in small quantities, from accumulating. They must also provide adequate ventilation for the crew and filter particles and microbes.

Orion has a new carbon dioxide and humidity-removal system that is regenerable, a key for saving mass and volume on deep space vehicles. The system, when exposed to the cabin air, absorbs carbon dioxide and humidity. When exposed to the vacuum of space, the carbon dioxide and humidity are vented overboard, and the system regenerates back to a clean state to return to cleaning the cabin air. On other human spacecraft such as the space shuttle, a method using expendable chemicals was used to remove carbon dioxide. For perspective, these chemicals took up the volume of nearly 143 basketballs. Orion's system takes up the space of only 16 basketballs and saves more than 100 pounds.

Orion uses high-pressure oxygen and nitrogen tanks to provide the pressure control for the crew environment. Using these tanks simplifies the system to provide for greater reliability on Moon missions. The pressure control system can be manually operated by the crew, if required, in a severe situation.

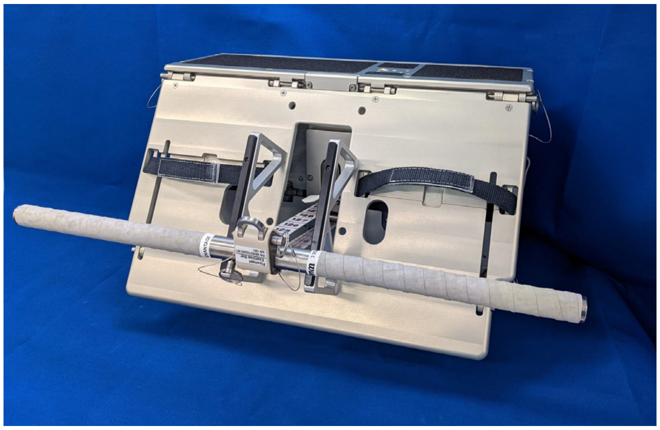
A water supply system stores and distributes potable water to the crew for drinking, food preparation, and medical and hygiene needs. Environmental monitoring maintains the spacecraft's temperature, humidity, and pressure, and detects when the spacecraft's enclosed environment is compromised, causing it to become unsafe.

Flywheel Exercise Device

Exercise is an essential requirement for crewed spaceflight missions. Without consistent exercise routines, microgravity environments can cause a noticeable reduction in muscle mass and bone density. Artemis crews will exercise inside Orion using the flywheel exercise device, a device that uses a flywheel, a series of pulleys, and a torque limiter encased in a frame the size of an extra-large shoe box, which functions like a rowing machine.

The crew will use a strap placed between their feet, attached to either a bar or a harness, to interact with the device. Pulling on the strap allows the crew to perform aerobic, resistive, and rowing exercises. The crew member straps their feet against the footplate of the device, which is held at a slight angle from the front of the frame. Using the bar, the crew can perform exercises such as bicep curls, bent-over rows, and deadlifts for resistance training, as well as rowing ergometry for aerobic training. With the harness, the crew can also perform exercises such as squats and calf raises.

The footplate, bar, and harness are stowed during launch and return to Earth. The flywheel is located directly below the Orion's side hatch and above the hygiene bay, and can be multipurposed as a step into and out of the vehicle.



The Artemis II crew will exercise on Orion using a flywheel, a simple cable-based device for aerobic exercises like rowing and resistance workouts like squats and deadlifts. (NASA) ▲

With three main resistance-level options and other adjustments, the loading or resistance of the flywheel can be tailored to the crew member's strength and adjusted for specific exercises. The options include "low," "medium," and "high" gears, which are toggled using the gear selector. The exact load of each exercise is determined by the energy put into the flywheel system by the user, similar to a yo-yo. When moved, the gear selector shifts a lever arm that engages specific pulleys that either increase or decrease the amount of resistance in the traction of the device. The highest expected load of the flywheel is 400 to 500 pounds.

For the Artemis II mission, the crew will use the flywheel every day of the mission except launch and landing days. Each astronaut will spend approximately 30 minutes a day performing exercises, allowing an additional 15 to 30 minutes before and after each session to allow for prep time, data collection, and cooldown. Part of this process for Artemis II includes attaching accelerometers to the flywheel and its mounting point on the Orion vehicle to verify the interacting forces between the exercise device and the surrounding structures. This data, amongst other observations such as video of exercise sessions, will be used to further develop the flywheel in preparation for future Artemis missions.

Potable Water Dispenser

Orion's potable water dispenser gives the crew easy access to water inside the crew module during their missions to the Moon. The potable water dispenser will be used to rehydrate food and drink packages and can also be used for medical emergencies.

Orion's European Service Module will carry four water tanks, each containing about 125 pounds of water. These tanks contain bellows, which pressurize the water by a regulated nitrogen source. Each of the four tanks is connected to a water manifold, which has two water lines that lead to the crew module. The two lines each have a manually operated valve at the crew end and a quick disconnect. This allows the crew to turn the water on and off at any given time.

The water that dispenses from the potable water dispenser is used for rehydrating freeze-dried food or powdered drinks. The water is analyzed to be within a crew-tolerable range for medical use, but isn't necessarily dispensed at a controlled temperature, meaning it cannot be set to hot or cold like a home faucet.

When the crew is ready to dispense water, they will attach an external potable filter assembly to one of the two quick disconnects. The assembly includes a filter to remove impurities from the water and a small needle assembly, which is used to puncture the crew's food or drink bag packages.

Daily tables will be generated for the crew that will inform them how long they need to open the isolation valve for a specified volume of water, which is based on cabin pressure, temperature, and water-tank pressure. Once the crew knows their desired time, they will set up a timer or watch a clock, open the manual valve, and then close the valve once the desired time has elapsed. The crew can then disconnect their food or drink package and, if they need to warm it further, the crew can insert it in the food warmer.

Artemis II crew member Jeremy Hansen and backup crew member Andre Douglas receive training on Orion's potable water dispenser in the Space Vehicle Mockup Facility at NASA's Johnson Space Center in Houston. (NASA) ▲

An Orion food warmer used for crew training in the Space Vehicle Mockup Facility at NASA's Johnson Space Center. (NASA) ▲

Food Warmer

The Artemis II crew has designated mealtimes to follow throughout their mission. To assist the crew during mealtimes, the Orion spacecraft is equipped with a custom-made food warmer system similar to the International Space Station's suitcase-style food warmer. The crew will use it to heat up rehydratable and thermostabilized food and drink packages.

During Artemis II, each crew member will receive three meals per day, with one shared 60-minute mealtime each day. The food warmer will be used during these mealtimes. Prior to launch, the Orion food warmer will be stowed in the spacecraft's stowage lockers. Once in orbit, it will be unstowed by the crew and stuck to the walls or acoustic blankets with Velcro.

To power the food warmer on, crew members will plug the warmer into the power utility panel with the food warmer power cable. When not in use, the food warmer will be turned off to conserve power and stowed near the potable water dispenser to save space inside the cabin. The mission control team will be in constant communication with the Artemis II crew regarding power limitations for the food warmer, allowing the crew to prepare in advance of any restrictions. The mission control team will enable the crew to identify when power is limited, off, or when the food warmer can be used outside of designated mealtimes.

Universal Waste Management System

Orion's crew module has a new space toilet, called the Universal Waste Management System, that makes the essential task of going to the bathroom easier for both women and men and reduces the ever-important mass and volume calculation of the system launching into deep space.

Astronauts on Mercury, Gemini, and Apollo did not have toilets. They urinated into diapers and bags and brought their solid waste, mixed with bactericide, back home in bags. Skylab was the first American spacecraft with a toilet, followed by the space shuttle. The space shuttle toilet was a full size larger (about 12.3 cubic feet) and a massive system, using several separate motors and fans for operations.

Orion's toilet works in a similar way, using air flow to pull fluid and solid waste away from the body and into the proper containers, but is improved for the needed mass and volume constraints of deep spaceflight in Orion and is more accommodating to female astronauts. Based on their input, the shape of the seat for solid waste and design of the funnel for urine has been changed, and they can be used simultaneously.

The Universal Waste Management System is self-contained and compact, about 5 cubic feet in volume, and thus approximately 60% smaller and lighter than the space shuttle toilet, as well as easier to use and more comfortable. A new automatic air-flow feature helps with odor control, fewer control interfaces simplify crew operations, and a more ergonomic design requires less cleanup and maintenance time for its corrosion-resistant, durable parts.

treated urine, which prevents the generation of ammonia from the breakdown of the urine, is stored in a special tank and then vented overboard each day by the crew, much like on the space shuttle. Solid waste is collected in fecal canisters, which the crew replaces every few days, and can be stored in Orion up to 21 days. The canisters have filtered caps to control odor and gas buildup generated within.

Artemis II astronaut Christina Koch receives training on the Orion Universal Waste Management System at NASA's Johnson Space Center. (NASA) ▲

Sleeping Bags

Astronauts inside Orion will sleep in lightweight, wall-attached sleeping bags. The bags are secured to attach points on the crew module's walls or ceiling and will function like four stretched hammocks across the cabin. For Artemis II, a full eight hours of sleep is built into the crew's schedule, with the four astronauts sleeping at the same time in their secured sleeping bags to ensure they are well-rested for the mission.

Artemis II crew sleeping bag configurations are tested in the Orion spacecraft medium-fidelity mock-up at NASA's Johnson Space Center in Houston, as well as used for astronaut training and systems familiarization. (NASA) ▲

Artemis II crew member Victor Glover receives training on the Orion medical kit at NASA's Johnson Space Center. (NASA/Helen Arase Vargas) ▲

Medical Kit

The Orion medical kit aboard the Orion crew module is a unique collection of hardware and items designed to provide comprehensive medical care to the astronauts during their mission. The system has four main components: the Orion prime medical kit, the Orion secondary medical kit, the Orion medical accessory kits, and the seat-accessible medical items.

The overall design of the system is adaptable and caters to the specific health needs of the crew. Varying from routine to emergent care, the system can address 128 identified medical conditions and has 139 medical resources at the crew's disposal. It was influenced by the medical kits provided by the Apollo, Space Shuttle, and International Space Station programs.

The majority of the hardware will be placed in storage lockers within Orion, with a subset accessible to the crew in their seats for easier access while suited. The system is equipped with a wide range of medical resources, including medications (e.g., anti-inflammatory, antibiotics, space motion sickness, sleep, and allergic-reaction medications), therapeutics (e.g., wound, urinary, and dental care), diagnostics (e.g., vital sign, electrocardiogram, and oximetry devices), and even basic life support and limited trauma care.

The prime medical kit contains most of the medications flown for communal use, and has items bundled inside for emergency access, such as the in-suit pill delivery tool for administering medication to a pressurized, suited crew member through the helmet's drink port. The secondary medical kit treats clinical cases such as urinary retention, wounds, physical injuries, limited dental care, medical device diagnostics, and medical oxygen delivery hardware.

The Orion medical accessory kit contains a crew member's personal medications and other personal items, such as prescription eyewear or custom earplugs. One of these kits is flown for each crew member in selection with their flight surgeon's recommendations. These are also stowed in lockers during launch and landing. The seat-accessible medical items, containing mostly medications, are in a small container that is required to be in reach of a restrained crew member prelaunch, after ascent, and postlanding. These are stored in an astronaut's suit-leg pocket.

During the mission, a space-to-ground support plan is detailed with audio/video connection capabilities for videoconferencing, with a flight surgeon available for medical discussions or guidance — similar to "tele-visits" on Earth. The crew is trained on operating the available equipment, built by subject-matter experts, to prioritize safety on missions to the Moon.

Stowage Lockers

Most of the equipment the crew will need during their mission, such as food, clothing, medical kits, emergency equipment, sleeping bags, tools, cameras, computers, and science payloads, are stored in 12 lockers located under the crew seats. These lockers can hold up to 1,050 pounds of cargo.

The crew stowage lockers are mounted onto the backbone assembly, and the locker doors provide the floor on which the crew will walk when entering and exiting the spacecraft. Inside the lockers, equipment is organized into stowage bags or foam cushions. The stowage bags are sized to fit the unique shapes of the lockers, including curved edges around the barrel wall. The bags allow equipment to be organized to support specific mission tasks or prioritize access to certain items, such as emergency equipment.

Orion will use up to 34 custom-sized stowage bags inside the lockers to carry all the equipment needed on the mission. Foam cushions will be used when items need additional protection against the vibration loads of launch, or for large items that do not fit inside the stowage bags. This ensures that the hardware is protected against damage

Engineers conduct testing in a representative Orion vehicle at NASA's Johnson Space Center to evaluate procedures that will be used to protect astronauts during radiation events in space. (NASA) ▲

inside the metal locker. Combined, these stowage accommodations will provide about 54 cubic feet of cargo space for the flight, which is equivalent to a compact SUV, or about 38 carry-on suitcases.

Radiation Shelter

One of the many challenges astronauts face during journeys to deep space is radiation. Earth's magnetosphere partially shields space station astronauts from radiation from the Sun (e.g., solar particle radiation and galactic cosmic rays); however, when astronauts travel into deep space, they will no longer have that protection.

In the case of a radiation contingency such as a solar particle event, NASA developed a system to repurpose resources aboard Orion to put enough low-mass materials, such as stowage bags, between the astronauts and the radiation source to protect the crew without increasing the total mass of the spacecraft during their mission.

Orion is equipped with a radiation-sensing instrument integrated into the vehicle called the hybrid electronic radiation assessor, which provides a warning if crew members need to take shelter in the case of a radiation event. They will have up to one hour to prepare the shelter.

During a radiation event, the crew will open two large storage bays located beneath their seats in the central part of the crew module and remove all the stowage bags in the bays. They will then strategically position the stowage bags so that the mass of the bags creates a barrier between the bays and the less-shielded parts of the crew module. For example, the bottom of Orion, where the heat shield and service module are attached, will provide more shielding than other areas, and stowage bags can be used for the parts of the spacecraft's interior with less shielding. This method protects the crew by shielding localized radiation points using existing stowage and does not add mass to the crew module itself.

Two astronauts will get into each storage bay. The crew will bring necessary food, water, medical supplies, air lines, and computers inside with them, since they may need to stay inside the storage bays for up to 24 hours. Once the danger has passed, they can leave the shelter, restow their gear, and continue their mission.

The Orion crew module is equipped with other systems to help the crew monitor radiation levels. Five ESA (European Space Agency) active dosimeter detectors will be mounted around Orion at optimal locations, ranging from least- to most-protected areas from radiation. The detectors will assess radiation levels in the surrounding deep space environment, collecting data that will help the crew maintain radiation awareness.

Hatches

The Orion spacecraft has three hatches: the crew module side hatch, the launch abort system (LAS) hatch, and docking hatch. The crew module hatch and LAS hatch enable safe crew entry and exit during nominal and emergency operations. The docking hatch enables crew transfer to other spacecraft, such as the human landing system planned for future crewed missions, and provides an additional crew exit path after landing. The ground crew closes the crew module and LAS hatch during prelaunch procedures after the flight crew is inside the spacecraft.

Crew Module Side Hatch

Astronaut and Artemis II Pilot Victor Glover maneuvers the latch handle on an Orion test side hatch during performance evaluations at the Lockheed Martin Space campus in Littleton, Colorado. (Lockheed Martin) ▲

The side hatch is the primary entry and exit point for the crew. It features two complex hinges, a mechanical latch train operated by a gearbox and handle, manual handles, and a counterbalance system to assist with opening. It is built to withstand space and re-entry conditions, with thermal protection system panels and a window for visibility.

On the launch pad, the side hatch is closed first. The hatch has a pressurized counterbalance system that resists closure and must be vented in order to close. Initially held in an "auto lock" position, the hatch is manually pushed slightly open to release the lock before counterbalance venting, allowing it to close slowly. It is then latched externally and verified via ground systems. The counterbalance is repressurized to ensure the hatch can open in emergencies or after landing. Seal and cabin pressure leak checks follow using hatch interfaces. These steps — venting, closing, latching, repressing, and leak checks — take about an hour. Finally, exposed valves and fittings on the hatch are covered with thermal protection system panels for flight.

In the case of an emergency on the launch pad, the side hatch can be opened using a pyrotechnic system activated by the ground crew via lanyard, or the flight crew by removing a safety pin and hitting a paddle. The flight crew can unstrap, vent the cabin, and activate the pyros to initiate exit. The counterbalance helps push the hatch open, followed by the LAS hatch.

After landing, the recovery team removes the access panels, services the counterbalance, and assists with the crew's exit from the side hatch. External pyros can also be used during recovery if rapid access is needed. If the side hatch is inaccessible, the docking hatch can be opened by the recovery team for crew exit. The crew may also open the docking hatch from the inside and deploy their own ladder. The counterbalance can be vented again to allow the side hatch to be reclosed after recovery.

Launch Abort System Hatch

The LAS hatch covers the side hatch until the LAS is jettisoned during flight. It shares similar structural and hinge configurations but uses a pneumatic latch train, where gas pressure drives the latches. Like the side hatch, it includes a window and manual handles.

After the side hatch is closed, the closeout crew manually pushes the LAS hatch shut, working against a permanently pressurized gas strut. Unlike the side hatch, which closes as the counterbalance is vented, the LAS hatch requires about 100 pounds of force per person to close. It is held open by an auto-lock mechanism that must be manually released.

Once shut, the closeout crew holds the LAS hatch in place while another team pneumatically latches it with ground equipment. A closeout panel is then installed to cover exposed components. This process takes about 30 minutes and differs from the side hatch, mainly in the manual force required and the use of a gas strut instead of a vented counterbalance.

In an emergency, the LAS hatch can be opened by the ground crew using a handle that instantly disengages the latches.

Before launch, the flight crew has minimal interaction with the hatches. Once suited, leak-checked, and strapped in, they remain seated while the ground crew handles all hatch operations, including closing, checking for leaks, and securing panels. In the event of a scrub, the crew may initiate their exit through the side hatch themselves, with the ground crew first opening the LAS hatch.

At 12:40 p.m. EST on Dec. 11, 2022, NASA's Orion spacecraft for the Artemis I mission splashed down in the Pacific Ocean after a 25.5-day mission to the Moon. (NASA) ▲

Parachutes

Also contained within the crew module are systems that support Orion's safe return to Earth. Orion's parachute system is designed to ensure a safe landing for astronauts in the crew module returning from deep space to Earth at speeds exceeding 25,000 mph, as well as during abort scenarios. While Earth's atmosphere will initially slow the spacecraft down to 325 mph, the parachutes slow Orion to a safe speed of 20 mph or less for landing in the Pacific Ocean.

The parachute system includes 11 parachutes made of 36,000 square feet of parachute canopy material and is attached to the top of the spacecraft with more than 13 miles of Kevlar lines. Parachute deployment begins at about five miles in altitude, with three forward bay cover parachutes used in conjunction with pyrotechnic linear thrusters to ensure separation of the forward bay cover. This protects Orion and its parachutes during the heat of re-entry. The forward bay cover parachutes are packed using a hydraulic press with forces as high as 3,000 pounds.

Two drogue parachutes are deployed to slow and stabilize the crew module during descent and establish proper conditions for the main parachute deployment to follow. The drogues are deployed by cannon-like mortars from the crew module forward bay at 100 feet per second (68 mph). The drogues are packed using a hydraulic press with forces as high as 10,000 pounds.

Three pilot parachutes will lift and deploy the main parachutes from the crew module forward bay. They are mortar-deployed from the crew module forward bay at 112 feet per second (76 mph). The pilots are packed using a hydraulic press for convenience, but are much lower density and can be “hand packed” if required.

The three main parachutes then slow the crew module to a speed that ensures astronaut safety during landing. Each of Orion’s main parachutes weighs 270 pounds and is packed densely to fit in the top part of the spacecraft. Once fully inflated, the three mains would cover almost an entire football field. The mains are packed using a hydraulic press, with forces as high as 50,000 pounds. They are autoclaved with a vacuum applied to the parachute at 190 degrees Fahrenheit (88 degrees Celsius) for 48 hours to help “set” the packing and remove atmospheric moisture.

Embedded in several parachutes are pyrotechnic riser cutters, which use fuses set to ignite at specific times and push blades through bulletproof materials, severing the lines at precise moments and allowing the parachutes to unfurl to complete the deployment sequence. Within 10 minutes of descent through Earth’s atmosphere, everything must deploy and assemble itself in a precise sequence to slow Orion and its crew for a safe splashdown in the ocean. The parachute system also is designed to keep the crew safe in several scenarios, such as mortar failures that could prevent a single parachute from deploying, launch aborts, or other conditions that produce loads close to the maximum material capability.

Crew Module Uprighting System

When Orion splashes down in the Pacific Ocean off the coast of San Diego, it will stabilize in one of two positions: the top of the capsule pointed up, or top pointed down. The crew module uprighting system deploys a series of five bright orange helium-filled bags on the top of the capsule to flip Orion right side up in the event it stabilizes upside down.

The five bags that make up the crew module uprighting system are packed in hard containers and installed on top of the capsule inside the structural gussets between the parachutes and other equipment. The bags are inflated with helium gas that is stored in pressure vessels located close by the bags. Each bag has an independent inflation system. The system initiates after landing and opens a valve for helium to flow into the uprighting bags. As the gas fills the bags, they deploy from their containers and inflate to their full volume.

The crew module uprighting system will deploy regardless of the landing position of the capsule. It takes less than four minutes for the system to upright the capsule, and the system will keep Orion upright and stable after splashdown in the ocean and for at least 24 hours, if necessary. The capsule must be upright for crew module communication systems to operate correctly and to help protect the health of the crew members inside on future missions from health impacts due to extended time hanging upside down in seat harnesses.

NASA's Orion spacecraft for the Artemis I mission splashed down in the Pacific Ocean after a 25.5-day mission to the Moon. (NASA) ▲

European Service Module

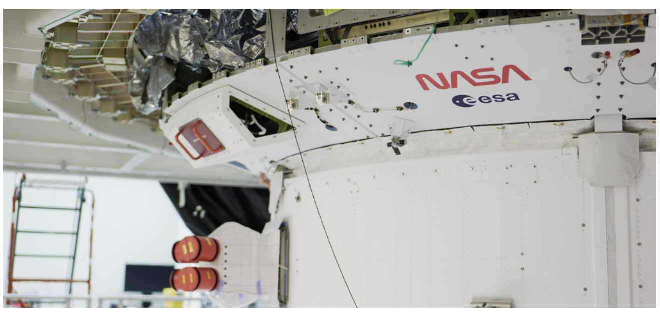
Orion's European Service Module is provided by ESA (European Space Agency) and built by lead contractor Airbus. It is the powerhouse that fuels and propels the Orion spacecraft in space. The service module is located below the crew module and is designed for long-duration missions to deep space destinations. It provides critical functions for Orion, including propulsion, thermal control, and electrical power generated by the solar arrays. It also provides commodities necessary for life support, including consumables for the astronauts such as water, oxygen, and nitrogen.

The European Service Module for NASA's Artemis II mission is lifted by crane and moved along the center aisle of the high bay inside the Neil A. Armstrong Operations and Checkout Building at NASA's Kennedy Space Center in Florida on May 22, 2023. (NASA/Amanda Stevenson) ▲

The service module is cylindrical, unpressurized, and about 13 feet high, including the main engine and tanks for gas and propellant. The service module's structure is covered with Kevlar to absorb shocks from micrometeorites and debris impacts.

During launch, the service module fits into a 17-foot-diameter housing surrounded by three fairing panels, which protect it from the harsh environmental elements of launch, such as heat, wind, and acoustic vibrations. Once Orion is above the atmosphere, the fairing panels surrounding the service module are jettisoned, and its four solar arrays unfurl. After the spacecraft separates from the upper stage of the SLS rocket, the service module propels Orion on its mission and helps it return to Earth, detaching before the crew module enters Earth's atmosphere.

Crew Module Adapter



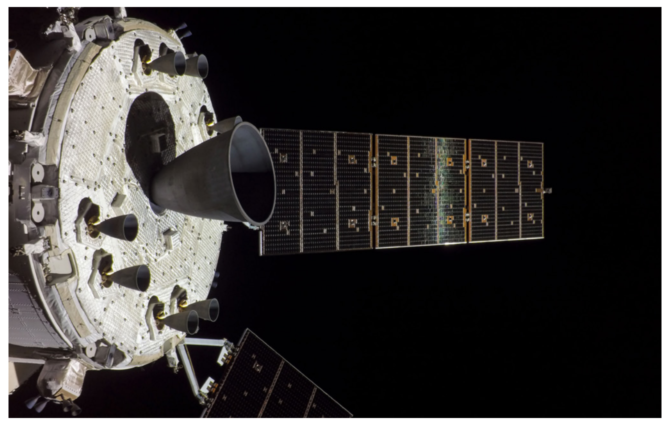
Teams adhered the agency's iconic "worm" logo and ESA (European Space Agency) insignia on the Artemis II Orion spacecraft's crew module adapter inside the Neil A. Armstrong Operations and Checkout Building at NASA's Kennedy Space Center in Florida. (NASA/Rad Sinyak) ▲

During launch, the service module is held in place between the Orion crew module adapter — which connects the service module to the spacecraft's crew module — and the spacecraft adapter, which attaches to the Orion stage adapter to connect Orion and its service module to the SLS rocket. The crew module adapter houses electronic equipment for communications, power, and control, and it includes an umbilical connector that bridges the electrical, data, and fluid systems between the modules.

Consumable Storage

The consumable storage system of the service module provides potable water, nitrogen, and oxygen to the crew module. Potable water is provided by the water delivery system and stored in four tanks with metal bellows, covering the usable water needs of the crew for the duration of the mission. Oxygen and nitrogen are provided by the gas delivery system and stored in four tanks.

Propulsion



The engines on Orion's service module are prominently featured in this image from flight day 22 of Artemis I. The largest is the orbital maneuvering system engine, surrounded by eight smaller auxiliary thrusters. (NASA) ▲

The farther into space a spacecraft ventures, the more capable its propulsion systems need to be to maintain its course with precision and ensure its return home. In addition to its function as the main propulsion system for Orion, the service module is responsible for orbital maneuvering and position control. It's equipped with a total of 33 engines: one main engine, eight auxiliary engines, and 24 reaction control thrusters.

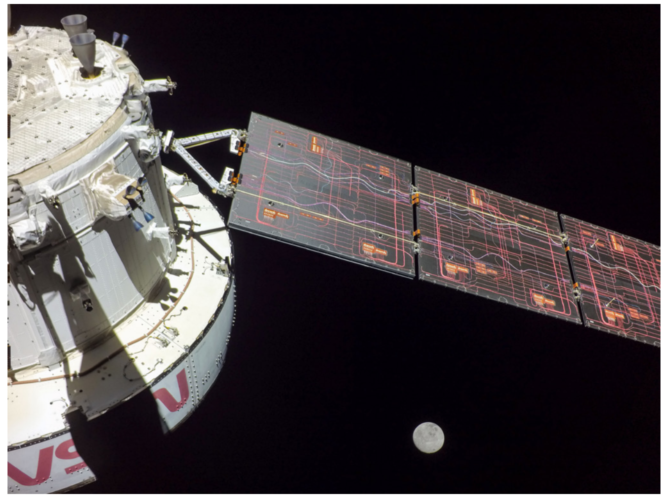
The main engine is an orbital maneuvering system engine previously flown on space shuttle missions, provided by NASA and made by Aerojet Rocketdyne. The auxiliary engines are R4D-11 engines, also made by Aerojet Rocketdyne and provided by NASA. The reaction control thrusters are provided by ESA and are the same model as those used on the Automated Transfer Vehicles built by ESA that carried cargo and resupply goods from Earth to the International Space Station between 2008 and 2015.

The main engine will provide major in-space maneuvering capabilities throughout the mission, including performing the translunar injection burn needed to put Orion on a path toward the Moon. The eight auxiliary engines are also used for translational maneuvers, essentially backing up the main engine. The 24 reaction control thrusters are used to steer and control Orion in orbit, but usually only 12 are used, and the other 12 serve mostly as backup. The propulsion system can also be used during some late phases of the launch for potential abort scenarios.

Artemis II Orbital Maneuvering System Engine Flight History		
Flight	Date	Orbiter
STS-101	05/19/2000	Atlantis
STS-106	09/08/2000	Atlantis
STS-98	02/07/2001	Atlantis
STS-104	07/12/2001	Atlantis
STS-110	04/08/2002	Atlantis
STS-112	10/07/2002	Atlantis

Power

The service module's electrical power system provides power for the Orion spacecraft, manages the power generated by the four solar array wings of the service module, and charges the main batteries on the crew module. Each solar array wing consists of three panel sections, and each panel is approximately 6.5 by 6.5 feet (2 by 2 meters). The total length of each wing is nearly 23 feet (7 meters). There are a total of 15,000 gallium arsenide cells on the four arrays used to convert light into electricity, and the arrays can turn on two axes to remain aligned with the Sun for maximum power.



On flight day 16, a camera mounted on one of Orion's solar arrays snapped this image of our Moon as the spacecraft prepared to exit distant retrograde orbit during Artemis I. (NASA) ▲

A power control and distribution unit provides the power interface between the service module and the crew module adapter, distributes electrical power to service module's electrical equipment, and protects the power lines.

Thermal Control

The service module's thermal control system includes radiators and heat exchangers to keep the equipment and astronauts at a comfortable temperature. The thermal control system includes an active portion, which transfers the heat of the entire spacecraft to the service module's radiators, and a passive portion, which protects the service module from internal and external thermal environments.

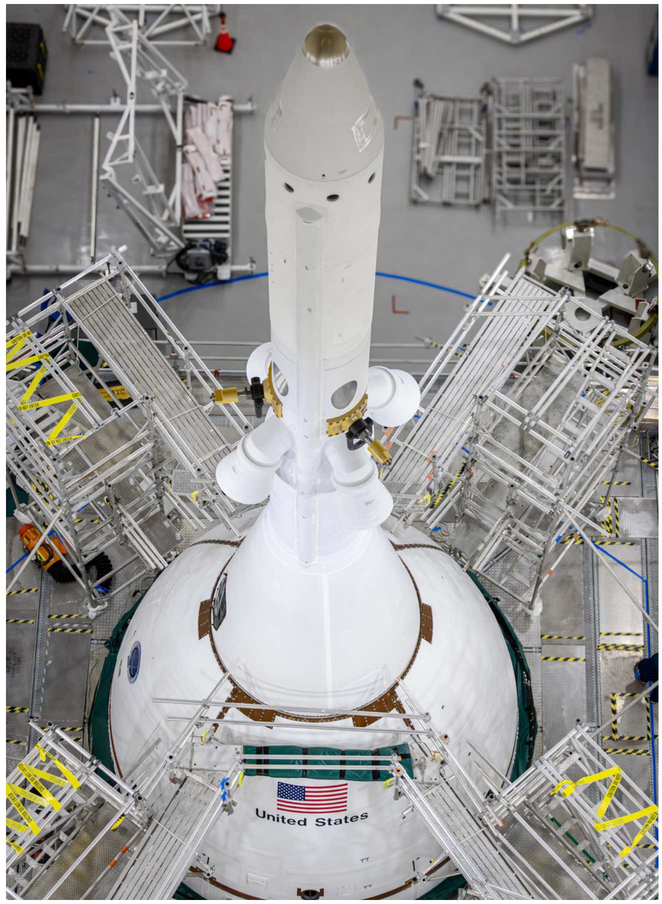
Avionics

Computers control the aspects of the service module. The module's avionics manage the powered equipment of the service module and the data-exchange services, which are based on instructions received from Orion's flight computers in the crew module. Nearly seven miles of cables send commands and receive information from sensors.

Launch Abort System

Orion's launch abort system, or LAS, is designed to carry the crew to safety in the event of an emergency during launch or ascent atop NASA's SLS rocket. It can activate within milliseconds to pull the spacecraft away from the rocket and position the module for a safe landing.

The LAS is divided into two parts: the fairing assembly and the launch abort tower. The fairing assembly is a shell of ogive panels surrounding the crew module. The panels are comprised of a lightweight composite material that protect the crew module from the heat, wind, and acoustics of launch, ascent, and abort environments. The launch abort tower sits on top of the crew module and includes the system's three motors. The three solid rocket motors work together to propel Orion's crew module to safety in an emergency: the abort motor pulls the crew module away from the rocket; the attitude control motor steers and orients the capsule; then the jettison motor ignites to separate the LAS from the crew module prior to parachute deployment.



Teams with NASA's Exploration Ground Systems attached the fourth and final ogive fairing for the LAS of the Orion spacecraft for Artemis II. The fully installed fairings were photographed inside the LAS Facility high bay at NASA's Kennedy Space Center in Florida on Sept. 17, 2025. (NASA) ▲

The LAS is specifically built for deep space missions and to ride on a high-powered rocket. The system offers the highest thrust and acceleration escape system ever tested, generating 400,000 pounds of thrust. In the event of an abort during ascent to orbit, the LAS can outrun the SLS rocket, which generates 8.8 million pounds of thrust.

The LAS is designed with its motors above the Orion crew module, which pulls the capsule away from the rocket, rather than push it away with motors at the base, as some other escape systems are built to do. The puller-style system with the tower above the spacecraft also is the first of its kind capable of controlling the spacecraft's orientation after separating from the rocket.

The LAS design is ideal for deep space missions because it minimizes the mass that aborts in an emergency by leaving the service module behind. It also avoids carrying thousands of pounds of unwanted mass to deep space by fully jettisoning the entire LAS once it is no longer needed.

On Artemis II, all of the LAS motors will be active. The abort and attitude control motors were not active on Artemis I because there were no astronauts inside the spacecraft on that mission. The jettison motor still fired once Orion reached orbit to enable the spacecraft to continue on the remainder of its journey. The full abort system has been thoroughly tested and certified for flights with astronauts beginning with Artemis II.

Abort Motor

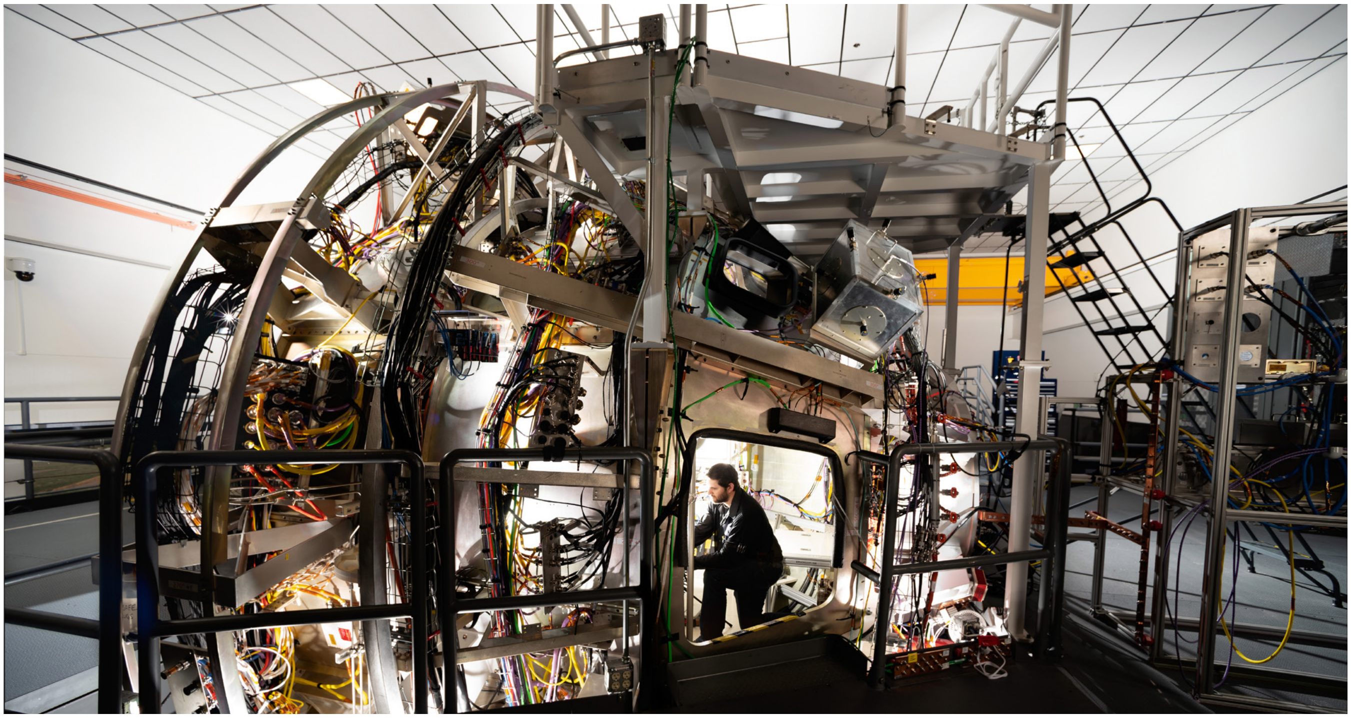
The 17-foot-long, 3-foot-diameter abort motor, built by Northrop Grumman, has a manifold with four exhaust nozzles that provides thrust to quickly pull the crew module to safety if problems develop during launch. The high-impulse motor is designed to burn most of the propellant within the first three seconds, and it burns three times faster than a typical motor of this size to immediately deliver the thrust necessary to pull the crew module to safety. If needed during a launch emergency, the crew module would accelerate from zero to 400 to 500 mph in just two seconds.

Attitude Control Motor

The attitude control motor, also built by Northrop Grumman, consists of a solid propellant gas generator and eight equally spaced valves capable of providing 7,000 pounds of thrust in any direction. The unique valve control system enables each valve to open and close, directing the flow of gas. The motor operates to keep the crew module on a controlled flight path after it is pulled away from the rocket by the abort motor, and then it reorients the module for parachute deployment and landing.

Jettison Motor

The jettison motor was built by Aerojet Rocketdyne and is the only LAS motor that fires on every mission. During a normal launch, once SLS successfully clears most of the atmosphere and the LAS is no longer needed, the jettison motor fires to separate the LAS from the spacecraft. From this point, abort scenarios are handled by the engines in the service module. In a pad-abort or launch-abort scenario with crew, the jettison motor ignites to separate the LAS from Orion after the abort motor is used and the attitude control motor has reoriented the spacecraft — and prior to parachute deployment and landing.



Engineers run flight simulations in the Orion Integrated Test Laboratory located at Lockheed Martin's Waterton facility near Littleton, Colorado. (Lockheed Martin) ▲

Avionics and Software

The Orion primary flight computers have over 750,000 lines of code that operate all the spacecraft systems, including power, communications, guidance, navigation, control, thermal management, instrumentation, and propulsion. For Artemis II, the software supports both automated and manual operations as needed. The automated system can operate through loss of communication and scenarios where the system is affected by radiation.

The crew can take over manual operation of the spacecraft at any time. The Artemis II mission has several planned checkout events of manual operations, including a manual piloting demonstration with the upper stage after separation. In addition, the software has a robust command and telemetry system that provides NASA's Mission Control Center with the insight and ability to handle unforeseen circumstances and adjust software operations.

In the event of a complete failure of all flight computers, Orion has a backup flight computer with independently developed software that will take over control. This capability covers all orbital and descent phases of flight and ensures spacecraft and crew safety until the primary system is recovered. For critical events like re-entry and orbit-changing burns, the backup system can fully complete the activity independent of the primary system.

Software, in additional computers, handle various other tasks such as video processing and optical navigation. All software has been extensively tested in multiple laboratories and in nominal and off-nominal conditions to ensure that all the various subsystems are working together to execute the planned mission.

Engineers at Lockheed Martin's Waterton facility monitor flight simulations. (Lockheed Martin) ▲

The Orion spacecraft houses a number of state-of-the-art avionics units to handle data generated by the systems onboard, control the various functions of the spacecraft, carry out commands sent from the Mission Control Center or the crew, and return systems telemetry for insight into systems status.

The avionics and other electronics used in Orion are almost entirely driven by software and commercial processor technologies that have been strengthened to endure extreme radiation and temperature fluctuations. Orion's updated avionics also can handle the severe acoustic and vibration environments associated with launch, orbit, entry into Earth's atmosphere, and a saltwater landing.

Orion's avionics system consists of the following subsystems:

- Command and data handling
- Guidance, navigation, control, and propulsion
- Communications and tracking
- Power
- Instrumentation
- Displays and controls

Command and Data Handling

Vehicle Management Computers

The brains of the Orion spacecraft consist of two vehicle management computers that deliver more computing power to the Orion spacecraft than any previous spacecraft designed for humans.

Each of the vehicle management computers is made up of two flight computer modules (FCMs) that oversee flight control and other software; a communication control module that allows commands and data to flow between Orion and mission control; and a display control module for the crew displays.

The FCMs provide a high-integrity platform to house software applications and have sufficient processing power to perform command and control of Orion. Each of the four FCMs is internally redundant and continually checks all operations to ensure that they match. If the FCMs ever detect a difference between them due to a hardware failure or a radiation upset, the different FCM "fails silent" by stopping all outputs so that a potentially corrupted FCM doesn't issue critical commands to the spacecraft. The FCM then resets itself, listens to the other FCMs to relearn where the spacecraft is and what is happening, and then rejoins the other FCMs in controlling the spacecraft — all within 22 seconds.

Having four FCMs on the spacecraft allows the flight software to continue firing thrusters and flying as Orion transitions through the radiation environment of the Van Allen Belts.

Backup Flight Software

The four redundant FCMs greatly improve system reliability, yet Orion includes another measure of backup capability with the addition of a completely different computer capable of running different code, if necessary. This capability is called the backup flight software.

In the unlikely event that something goes wrong with the primary flight computers on Orion, a dissimilar processing platform with dissimilar flight software is hosted on a system called the vision processing unit. This distinct computer and software provide a backup function to the redundant FCMs during critical phases of flight, with a focus on crew survival and return functions in the scenario something renders all the FCMs ineffective. The vision processing unit also provides a place to store data during times when Orion can't communicate with the ground.

Power and Data Units

Eight power and data units connect the flight computers and the software to the rest of Orion. These units, each of which has two cards with two redundant channels on each card, control the power to every component on the spacecraft, and they control effectors such as valves, thrusters, and heaters. All sensor data, such as temperature and pressure, is routed through the power and data units as well. The units also communicate with the SLS as it launches Orion on its trajectory to the Moon.

Onboard Data Network

Orion's triple-redundant data network allows the FCMs to communicate with all of the other avionic components on the spacecraft. It uses a networking technology called time-triggered gigabit ethernet that is capable of moving data 1,000 times faster than systems used on the space shuttle and space station. This networking technology allows NASA engineers to categorize different types of data and prioritize how it should travel through the onboard network. Time-critical data relating to vital systems like navigation and life support, called time-triggered data, has guaranteed bandwidth and message timing to ensure it is always delivered exactly on time. Data critical for delivery but not timing, such as file transfers, is called rate-constrained data. This is sent immediately, whenever time-triggered data is not present. Data used for non-critical tasks, such as crew videoconferencing, is delivered over the remaining bandwidth. This technology means that critical data and non-essential data, for the first time, can travel safely over a single network aboard a spacecraft. This network is built upon a reliable commercial data bus that has been hardened for resiliency against space radiation and was proven on Orion's Exploration Flight Test-1 and Artemis I missions. The data system communicates with all components, including the service module, through radiation-hardened network switches.

Guidance, Navigation, Control, and Propulsion

The Guidance, Navigation, Control, and Propulsion system is responsible for always knowing where the spacecraft is and where it is going, and it controls the propulsion system to keep Orion pointed in the proper direction and on the correct trajectory.

Guidance, Navigation, Control, and Propulsion Flight Software

At the center of this system is the guidance, navigation, control, and propulsion flight software that runs on the vehicle management computers. This software receives inputs from navigation sensors and pilot controls and commands the appropriate effectors on the crew module, service module, and LAS to accomplish mission objectives.

The Orion guidance, navigation, control, and propulsion software operates across a variety of mission phases, including prelaunch, ascent, Earth orbit, transit to and from the Moon, entry, and various abort scenarios, as well as loiter, rendezvous, and docking for future missions. The software must operate in both manual and automated modes and must be able to handle commands from the ground and the crew. The software must also run complex guidance and navigation algorithms while controlling highly dynamic configurations during re-entry, ascent aborts, and orbital maneuvers.

Onboard Navigation System

The onboard navigation system for Orion is composed of a number of redundant sensors for measuring Orion's position in space and attitude, which refers to the direction the spacecraft is pointing. Like most systems on the spacecraft, there are usually at least two of each sensor to increase reliability of the overall system. Several different types of sensors are needed, as the spacecraft operates in the atmosphere during ascent and re-entry, in low Earth orbit, and near the Moon. These include the following:

Orion Inertial Measurement Units

Each unit contains three devices, called gyros, that measure spacecraft body rotation rates, and three accelerometers to measure spacecraft body accelerations. This inertial data is used by the vehicle management computers for onboard navigation to compute spacecraft position, velocity, and attitude.

GPS Receivers

The GPS receivers on Orion are similar to ground-based receivers, except that these are capable of operating at the very high velocities of spaceflight. The GPS sensor system provides position and velocity updates during low Earth orbit operations, ascent, and re-entry. GPS-based altitude values are the primary triggers for entry events. Outside the range of GPS in deep space, Orion will rely on NASA's Deep Space Network to determine the spacecraft's location using sensitive measurements of communication signals that pass between Orion and large tracking satellite dishes on the ground.

Barometric Altimeter Assembly

By sensing the atmospheric air pressure outside the spacecraft during ascent and re-entry, these assemblies can measure Orion's altitude. They provide a backup altitude value for parachute and other deployments during entry.

Star Trackers

The star tracker operates like a camera, but is much more sensitive and takes pictures only of stars. By comparing the pictures to a known star catalog, the sensor determines spacecraft attitude during orbital operations.

A Jena-Optronik technician in Jena, Germany, works on a star tracker, a sensitive camera that will take pictures of the star field around the Orion spacecraft. By comparing the pictures to its built-in map of stars, the star tracker can determine which way Orion is oriented. (Lockheed Martin) ▲

Optical Navigation Camera

The optical navigation camera takes images of the Moon and Earth. By looking at the size and position of these objects in the picture, the camera can determine Orion's range and bearing relative to that object. The optical navigation camera is part of the Orion emergency return system to autonomously operate the spacecraft in the event of lost communication with Earth.

On the second day of the 25.5-day Artemis I mission, Orion used its optical navigation camera to snap black-and-white photos of planet Earth. (NASA) ▲

Sun Sensors

The Sun sensors are located on the service module and are used to determine the direction of the Sun during emergency safe mode. Knowing where the Sun is ensures that Orion can point its solar arrays in the right direction to keep power flowing to the spacecraft.

Communications and Tracking

Orion uses a high-speed communications system, employing four phased-array antennas on the crew module and two phased-array antennas on the service module. Phased-array antennas allow signals to be controlled and directed without requiring any physical movement of the antenna. These will be used for video, data, and voice communications with the spacecraft, along with command uplink and telemetry downlink to ground stations, NASA's Tracking and Data Relay Satellite systems, and NASA's Deep Space Network after leaving Earth's orbit.

On Artemis II, the primary audio system aboard will enable the crew to speak with each other and with the Mission Control Center while they are wearing spacesuits, as well during the in-orbit mission phase during shirtsleeve operations. An emergency communication system will allow two-way voice communications during the mission if the primary communications system fails. Search-and-rescue radios and satellite phones will be available after landing for communication with the recovery team.

On Artemis II, the primary audio system onboard will enable the crew to speak with each other and with mission control while they are wearing spacesuits, as well during the in-orbit mission phase during shirtsleeve operations. (NASA) ▲

Power

The Orion power system is capable of generating and supplying all of the power that is required for its in-orbit operations. The four solar arrays, which are located on the service module, generate about 11 kilowatts of power. Power is transferred between the solar arrays and batteries and to the end systems via the power and data units.

Orion's four main batteries are located on the crew module and use small-cell packaging technology to ensure crew safety while providing 120 volts of power to the many systems on the spacecraft. The batteries are fully charged before launch so that the spacecraft can operate until the solar arrays can be deployed once in orbit. The batteries also operate the spacecraft when the solar arrays cannot be pointed at the Sun, or when Orion is in the shadow of Earth or the Moon. The solar arrays are jettisoned with the service module right before entering Earth's atmosphere, so the batteries also provide all the power needed to keep the astronauts safe for return to Earth and up to 24 hours after splashdown.

Instrumentation

Accomplishing flight test objectives requires a dedicated instrumentation system that will measure the dynamic response of all Orion subsystem performance during critical phases of the Artemis missions.

The developmental flight instrumentation data system measures unique subsystem performance, such as spacecraft temperature and vibration, during all phases of the mission. The system is required to measure the response of newly designed components and structures to verify and validate engineering models that will be used to predict their future performance.

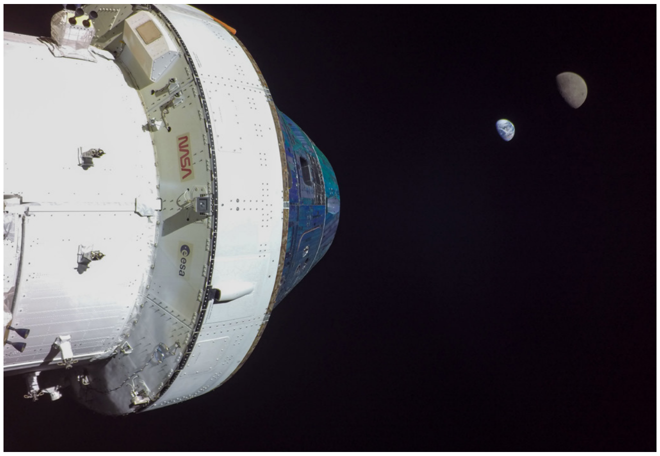
The architecture of the developmental flight instrumentation system is robust and relies on proven hardware and software to deliver high reliability. The central components are data acquisition units that have two interfaces: one for the sensor interface and one for the control interface. The sensor interface communicates with the temperature, strain, accelerometers, and acoustic sensors. The control interface communicates with the power, control, recording, telemetry, and time-sync hardware. The sensors can be changed between flights to allow engineers to adjust based on what was learned on a previous flight.

Testing

The Orion Program conducted rigorous testing of the spacecraft, from element-level testing with test articles for the crew module, service module, LAS, parachute system, and other supporting systems — including both flight tests and ground tests — to integrated testing of the full spacecraft that flew on Artemis I.

Artemis I

Artemis I was the first integrated test flight of the Orion spacecraft, SLS rocket, and upgraded Exploration Ground Systems at Kennedy. The flight thoroughly tested Orion's integrated systems — including its structures, power, propulsion, navigation, communication, and thermal protection, such as its heat shield — in the harsh environment of deep space before being validated to fly crew on Artemis II. The mission allowed the team to evaluate the critical systems, subsystems, and procedures through all mission phases: countdown, liftoff and ascent, beyond the far side of the Moon, through the high-heat and high-speed return to Earth, and recovery after splashdown.



On flight day 13, Orion reached its maximum distance from Earth during the Artemis I mission when it was 268,563 miles away from our home planet. Orion has now traveled farther than any other spacecraft built for humans. (NASA) ▲

The SLS rocket launched an uncrewed Orion spacecraft on a 25.5-day mission around the Moon on Nov. 16, 2022. Over the course of the mission, Orion completed two lunar flybys, coming within 80 miles of the Moon's surface, and entered a distant retrograde orbit. At its farthest point, Orion traveled nearly 270,000 miles from Earth — farther than any spacecraft designed for humans has ever flown.

Orion exceeded performance expectations, allowing the mission team and flight controllers to accomplish 161 test objectives, including 20 added mid-flight, to fully demonstrate every aspect of the spacecraft. Mission data shows the European-built service module generated about 20% more power than initially expected, and the spacecraft consumed about 25% less power than predicted. All the spacecraft's dynamic separation events, involving 375 total pyrotechnic devices, were completed without issue.

Upon re-entry, Orion performed a skip-entry technique enabling the spacecraft to splash down accurately and consistently at the selected landing site. The spacecraft endured re-entry temperatures near 5,000 degrees Fahrenheit (2,760 degrees Celsius) and slowed from nearly 25,000 mph to just 16 mph before a parachute-assisted splashdown within 2.4 miles of the target site in the Pacific Ocean on Dec. 11, 2022. Covering more than 1.4 million miles, Orion's flight on Artemis I demonstrated the spacecraft's deep space capabilities and performance in lunar orbit, paving the way for crew to fly on Artemis II.

Exploration Flight Test-1

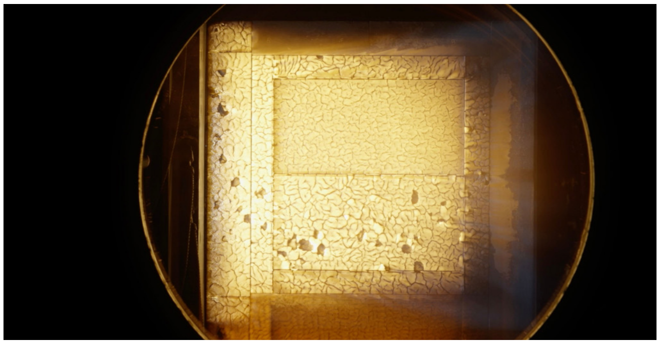
Orion's first uncrewed test flight, known as Exploration Flight Test-1, or EFT-1, demonstrated and validated the Orion crew module's systems critical to crew safety, such as heat shield performance, separation events, avionics and software performance, attitude control and guidance, parachute deployment, and recovery operations.

The United Launch Alliance Delta IV Heavy rocket with NASA's Orion spacecraft mounted atop lifts off on Exploration Flight Test-1 from Cape Canaveral Air Force Station's Space Launch Complex 37 at 7:05 a.m. EST on Dec. 5, 2014, in Florida. (NASA) ▲

The EFT-1 test flight launched a high-fidelity crew module and mock service module on a United Launch Alliance Delta IV Heavy rocket from Space Launch Complex 37 at Cape Canaveral Air Force Station in Florida on Dec. 5, 2014. During the nearly four-and-a-half-hour test flight, Orion orbited Earth twice, reaching an altitude of approximately 3,600 miles — about 15 times farther into space than the International Space Station — before returning to Earth. At the end of the flight, Orion landed in the Pacific Ocean and was recovered by NASA and the U.S. Navy.

Sending Orion to such a high altitude allowed the spacecraft to return to Earth at speeds near 20,000 mph. Returning at this speed, as fast as any spacecraft built for humans had endured since the Apollo program, exposed the heat shield to temperatures close to 4,000 degrees Fahrenheit (2,204 degrees Celsius), 80% of what the crew module would endure returning from the vicinity of the Moon. The EFT-1 test collected data to help NASA lower risks to the astronauts who will fly on Orion beginning with Artemis II. This first flight also gave NASA the chance to continue refining its production and coordination processes, and Orion's teams gained important experience and training in preparation for launching Orion on its first integrated flight with the SLS rocket on Artemis I.

Heat Shield Testing



A test block of Avcoat undergoes heat-pulse testing inside an arc jet test chamber at NASA's Ames Research Center in California. The test article, configured with both permeable (upper) and non-permeable (lower) Avcoat sections for comparison, helped to confirm understanding of the root cause of the loss of charred Avcoat material that engineers saw on the Orion spacecraft after the Artemis I test flight beyond the Moon. (NASA) ▲

Artemis I Findings

After Orion's return to Earth at the end of the Artemis I mission, unexpected char loss was observed across the spacecraft's heat shield. Soon after NASA engineers made this discovery, the agency began an extensive investigation process that included a multi-disciplinary team of experts in thermal protection systems, aerothermodynamics, thermal testing and analysis, stress analysis, materials test and analysis, and many other related technical areas. NASA's Engineering and Safety Center was also engaged to provide technical expertise, including nondestructive evaluation, thermal and structural analysis, fault-tree analysis, and other testing support.

The Artemis I heat shield was heavily instrumented for flight with pressure sensors, strain gauges, and thermocouples at varying ablative material depths. Data from these instruments augmented analysis of physical samples, allowing the team to validate computer models, create environmental reconstructions, provide internal temperature profiles, and give insight into the timing of the char loss.

Approximately 200 Avcoat samples were removed from the Artemis I heat shield at NASA's Marshall Space Flight Center in Alabama for analysis and inspection. The team performed nondestructive evaluation to "see" inside the heat shield.

Extensive analysis, including 121 tests at unique facilities across the country, determined the heat shield on Artemis I did not allow for enough of the gases generated inside a material called Avcoat to escape, which caused some of the material to crack and break off. Avcoat is designed to wear away as it heats up. This key material in the thermal protection system guards Orion and its crew from the nearly 5,000 degrees Fahrenheit (2,760 degrees Celsius) of temperatures that are generated when Orion returns from the Moon through Earth's atmosphere. Although a crew was not inside Orion during Artemis I, data shows the temperature inside Orion remained comfortable and safe had a crew been aboard.

In the spring of 2024, NASA stood up an independent review team to conduct an extensive review of the agency's investigation process, findings, and results. The review occurred over a three-month period to assess the heat shield's postflight condition, entry environment data, ablator thermal response, and NASA's investigation progress. The review team agreed with NASA's findings on the technical cause of the physical behavior of the heat shield.

Engineers studied both the material phenomenon and the environment the materials interact with during entry. By changing the material or the environment, they can predict how the spacecraft will respond. Extensive data from the investigation has given engineers confidence that the heat shield for Artemis II can be used to safely fly the mission's crew around the Moon and back. NASA modified the Artemis II trajectory by shortening how far Orion can fly when it enters Earth's atmosphere and splashes down in the Pacific Ocean. This will limit how long Orion spends in the temperature range in which the Artemis I heat shield phenomenon occurred.

Knowing that permeability of Avcoat is a key parameter to avoid or minimize char loss, NASA has the right information to assure crew safety and improve the performance of future Artemis heat shields. Engineers already are assembling and integrating the Orion spacecraft for Artemis III based on lessons learned from Artemis I and implementing enhancements to how heat shields for crewed returns from lunar-landing missions are manufactured to achieve uniformity and consistent permeability.

Exploration Flight Test-1 Findings

Following EFT-1, the Orion heat shield was redesigned from a single-piece system to individual blocks of material. Before the time-saving block system was used, a fiberglass-phenolic honeycomb structure was bonded to the structure's skin. Then, each of the 320,000 tiny honeycomb cells were individually filled with Avcoat by hand, inspected by X-ray, cured in a large oven, and robotically machined to meet precise thickness requirements.

The new design introduced several considerations that prompted further testing for risk reduction. Engineers performed more than 30 tests across the United States on the new design to investigate the effects of the block structure that could disrupt the smooth airflow and cause localized heating spots. Understanding both effects confirmed that the heat shield will thermally protect the astronauts during entry into Earth's atmosphere.

Teams tested the Avcoat material at the Arc Jet Complex at NASA's Ames Research Center in Silicon Valley and the Atmospheric Reentry Materials and Structures Evaluation Facility at NASA's Johnson Space Center in Houston. Teams also performed thermal testing at Johnson's Radiant Heat Test Facility. During these tests, the Avcoat surface reached temperatures of over 3,000 degrees Fahrenheit (1,649 degrees Celsius). Heat-shield testing also took place at NASA's Langley Research Center in Hampton, Virginia, with a 6-inch Orion heat shield model in the 20-inch Mach 6 wind tunnel. The model was machined to represent small-scale features, including the patterns expected as the heat shield ablated during a return to Earth.

Artemis I Orion Environmental Test Article Campaign

Following the Artemis I mission, Orion's crew module — now known as the Orion Environmental Test Article — returned to NASA's Neil Armstrong Test Facility in Sandusky, Ohio, in January 2024 and completed an 11-month test campaign. The campaign was necessary to ensure Orion is ready to protect the crew if an emergency occurs during Artemis II's launch.

Engineers and technicians from NASA and Lockheed Martin subjected the test article to the extreme conditions Orion may experience in a launch-abort scenario. Experts conducted tests that simulated the noise levels of an abort during launch, in addition to the electromagnetic effects of lightning strikes. The test campaign also jettisoned the test article's docking module and parachute covers, as well as the crew module uprighting system, which consists of five airbags on top of the spacecraft that inflate upon splashdown.

After completing testing at Armstrong Test Facility, the Environmental Test Article was shipped to Kennedy, where the team performed final functional testing of Orion's propulsion, environmental control, and life support systems inside the center's Multi-Payload Processing Facility.

Data from the testing matched engineers' prediction models, and Orion operated as expected after being subjected to nominal and launch-abort acoustic levels. This critical testing helped to ensure that the Artemis II spacecraft can fly crew safely and successfully.

The Orion crew module, also known as the Orion Environmental Test Article, returned to NASA's Neil Armstrong Test Facility in Sandusky, Ohio, in January 2024 and completed an 11-month test campaign necessary for the safety and success of Artemis II. (NASA/Jordan Salkin) ▲

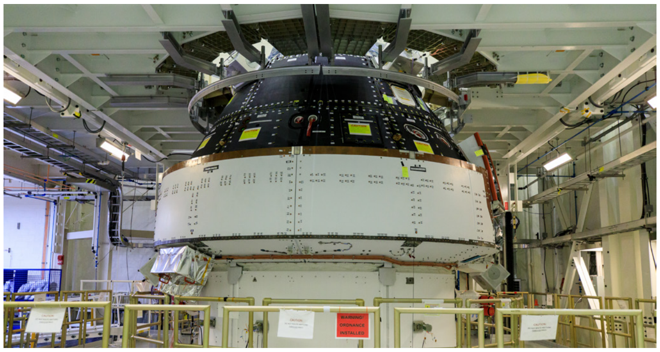
Acceptance Testing

At Kennedy, the Artemis II Orion crew and service modules underwent functional and performance testing in the high bay of the Neil A. Armstrong Operations and Checkout Building to ensure quality assurance before ground processing and integration with the SLS rocket in the Vehicle Assembly Building.

Proof Pressure Testing

To ensure that the Artemis II spacecraft could withstand the rigors of spaceflight, engineers completed a series of tests on the pressure vessel. In a test stand inside the proof pressure cell, technicians attached hundreds of strain gauges to the interior and exterior surfaces of the structure. The strain gauges measured the strength of the welds as the vessel was pressurized at incremental steps over two days to reach the maximum pressure expected during flight. The tests confirmed that the weld points could endure the extreme forces encountered during launch, in space, entry into Earth's atmosphere, and landing phases on Artemis missions.

Crew Module and Service Module Functional and Performance Testing



The Orion spacecraft for NASA's Artemis II mission is photographed inside the Final Assembly and System Testing cell at the Neil A. Armstrong Operations and Checkout Building at NASA's Kennedy Space Center in Florida on March 15, 2024. (NASA/Isaac Watson) ▲

The Artemis II Orion crew module underwent initial power-on events. This included the first time the vehicle management computers and the power and data units were installed on the crew module, loaded with flight software, and tested. These tests verified the health and status of Orion's core computers and power and data units; they also ensured that the systems were able to communicate precisely with one another to accurately route power and commands throughout the spacecraft.

The Artemis II Orion service module also separately underwent initial power-on tests. The tests allowed technicians to check that all cables were properly connected, and data was transferred at the speeds required by the spacecraft and to accommodate power distribution across the module.

After initial power-on, the Orion crew module and service module underwent separate functional testing, which ensured that each of the module's systems could power on and function as designed. Engineers completed functional testing, and then teams conducted separate performance testing of the crew module and service module. This testing verified that each module's systems not only powered on, but functioned within the correct parameters. Performance testing also took place after the two modules were joined. For Artemis II, this included additional testing to demonstrate that the life support systems not flown on Artemis I could function and perform as expected.

Environmental Testing

Environmental testing simulates environments the spacecraft will experience through launch, travel in deep space, and recovery. It also evaluates the spacecraft's structure and systems in those conditions. Before joining the crew module and service module for the Artemis II mission at Kennedy, engineers conducted acoustic and thermal-cycle testing for each module separately in the high bay of the Operations and Checkout Building.

Direct Field Acoustic Testing

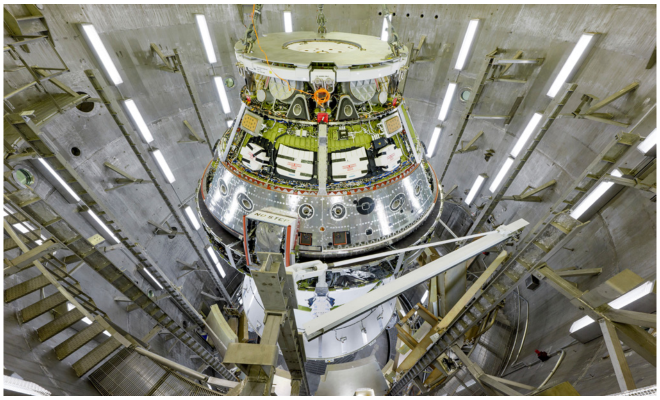
The European Service Module for the Artemis II mission is photographed inside the Neil A. Armstrong Operations and Checkout Building at NASA's Kennedy Space Center in Florida. The service module successfully completed a round of acoustic tests to ensure it can withstand the speed and vibration it will experience during launch and throughout the mission. (NASA/Amanda Stevenson) ▲

During this testing, the crew or service module was surrounded with speakers and exposed to maximum acoustic levels that Orion will encounter during the mission. Engineers secured the module inside a test cell and then attached microphones, strain gauges, and accelerometers. The module was blasted with extreme vibrations and acoustic levels up to 141 decibels — as loud as a jet engine during takeoff — to ensure that the spacecraft and its systems could withstand the noise expected during launch.

Module Thermal Cycle Testing

Inside a specially constructed thermal cycle chamber, teams rapidly cycled the crew or service module between hot and cold temperatures over several days to thermally stress the hardware and ensure the workmanship of its hardware and subsystem operations. The cycle of temperatures for the initial thermal test ranged from 29 to 129 degrees Fahrenheit (-1.6 to 54 degrees Celsius) during 105 hours of testing.

Altitude Chamber Testing



The Artemis II Orion spacecraft is lifted from the Final Assembly and System Testing, or FAST, cell and placed in the west altitude chamber inside the Operations and Checkout Building at NASA'S Kennedy Space Center in Florida on June 28, 2024. (NASA/Rad Sinyak) ▲

After engineers at Kennedy completed testing on the Artemis II crew and service modules individually, they were moved to the Final Assembly and System Testing cell, where they were integrated and put through their final system tests prior to two rounds of rigorous, simulated in-space environmental testing inside the west altitude chamber in the Operations and Checkout Building high bay.

To prepare, the west altitude chamber was upgraded to test the spacecraft in a vacuum environment that simulates an altitude of up to 250,000 feet. These upgrades reactivated altitude chamber testing capabilities for the Orion spacecraft at Kennedy. Previous vacuum testing on the Orion spacecraft for Artemis I took place at NASA's Glenn Research Center in Cleveland. Teams also installed a 30-ton crane in the Operations and Checkout Building to lift and lower the Orion crew and service module stack into the chamber, lift and lower the chamber's lid, and move the spacecraft across the high bay.

Originally used to test environmental and life support systems on the lunar and command modules during the Apollo program, the interior of the two altitude chambers in the Operations and Checkout Building measure 33 feet in diameter and 44 feet high and were designed to simulate the vacuum equivalent of up to 200,000 feet — a deep space environment. Both chambers were rated for astronaut crews to operate flight systems during tests.

Integrated Spacecraft Electromagnetic Interference/Compatibility Testing

During the first round of altitude chamber testing in April 2024, the team checked out Orion's electromagnetic interference and compatibility, as well as verified that systems performed as they would during the mission. All electronic components have an electromagnetic field that can affect other electronics nearby. This testing ensured that the spacecraft's electronics worked properly when operated at the same time, as well as when bombarded by external sources. The test campaign confirmed that the spacecraft's systems performed as designed.

Integrated Spacecraft Vacuum Chamber Testing

In July 2024, the Artemis II spacecraft was returned to the altitude chamber for another round of testing, simulating deep space conditions.

In early November 2024, teams returned the Artemis II spacecraft to the altitude chamber for a second round of vacuum testing, which was focused on checking out environmental control and life support system components.

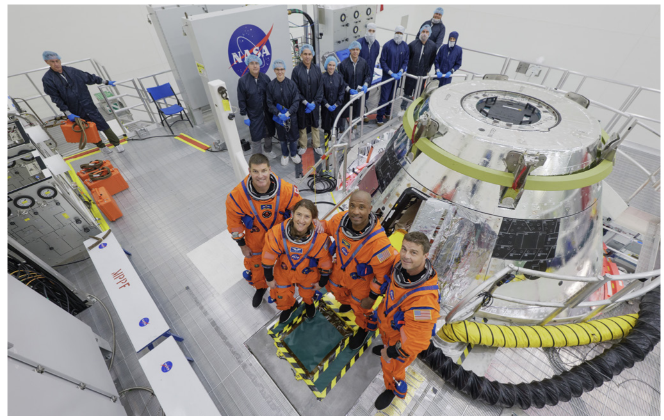
Following altitude chamber testing, Orion was returned to the Final Assembly and System Testing cell for a final round of testing and assembly that included end-to-end performance verification of the spacecraft's subsystems, checking for leaks in the spacecraft's propulsion systems, installing its solar array wings, performing spacecraft closeouts, and pressurizing a subset of its tanks in preparation for flight prior to rolling to the Multi-Payload Processing Facility. There, Orion received servicing and crew equipment interface testing before being integrated with the rocket.

Flight Servicing and Integrated Testing

After the Orion crew and service module stack completes testing and assembly in the Operations and Checkout Building, the spacecraft is handed over to the Exploration Ground Systems team to be serviced for flight, integrated with its launch abort system, stacked on top of the SLS rocket in the Vehicle Assebly Building, and undergo final integrated testing before launch.

Multi-Payload Processing Facility

Inside the Multi-Payload Processing Facility, the spacecraft is fueled with hazardous propellants and other fluids it will need for the journey around the Moon, and undergoes various testing:



The Artemis II crew don their Orion Crew Survival System suits for a multi-day crew module training beginning July 31, 2025, in the Multi-Payload Processing Facility at the agency's Kennedy Space Center in Florida. (NASA/Rad Sinyak) ▲

Crew Module/Service Module Propulsion Servicing

Once inside the Multi-Payload Processing Facility, teams begin with service module propellant servicing, filling the service module's tanks with monomethylhydrazine propellant, an oxidizer known as mixed oxides of nitrogen, or (MON)-3, and helium for pressurization. The teams then service the crew module propulsion system with hydrazine and helium for pressurization.

Crew Module/Service Module Oxygen Servicing

Teams fill the crew module and service module oxygen tanks the crew will use to breathe. Oxygen tanks in the service module are used from launch up until the crew module separates from the service module for re-entry into Earth's atmosphere. The crew module oxygen tanks are then used from separation until splashdown.

Crew Module/Service Module Ammonia Boiler Servicing and Test

Teams fill the crew module ammonia boiler tanks, then perform a functional test of the ammonia boiler to ensure it will function properly during ascent and entry. The ammonia boiler cools the vehicle during ascent and entry.

Crew Suited and Crew Equipment Interface Testing

After the Artemis II spacecraft was serviced with its necessary commodities, the Artemis II crew entered their spacecraft for a multi-day training event in July 2025. The crew boarded Orion for a suited crew test and crew equipment interface test, performing launch day and simulated orbital activities inside the spacecraft.

Inside Orion, to replicate launch preparations, the crew performed communications checkouts and suit-leak checks. For the first time, the crew was connected to the spacecraft and its communications and life control systems, and all umbilicals were connected while the spacecraft operated on full power.

Teams simulated several different ground and flight conditions to give the crew more experience managing them in real time. Some of the activities practiced scenarios where the crew was challenged to address potential issues while in space, such as leaks and failure of the air revitalization system fan, which is needed to provide oxygen and remove carbon dioxide from the cabin.

The test provides astronauts the ability to train on the actual hardware they will use during flight, allowing them and support teams the opportunity to familiarize themselves with the equipment in configurations very close to what will be experienced during flight. It also allows teams to verify compatibility between the equipment and systems with flight controller procedures so they can make any final adjustments ahead of launch.

Launch Abort System Facility

Teams with NASA's Exploration Ground Systems attached the fourth and final ogive fairing for the launch abort system of the Orion spacecraft for the Artemis II mission. The fully installed fairings were photographed inside the Launch Abort System Facility high bay at NASA's Kennedy Space Center in Florida on Sept. 17, 2025. (NASA/Frank Michaux) ▲

After fueling is completed in Kennedy's Multi-Payload Processing Facility, the spacecraft is transferred to the center's Launch Abort System Facility, where the launch abort system, or LAS, is integrated with the crew and service modules. Once the LAS tower and ogives are integrated with the spacecraft, various testing takes place:

LAS and Crew Module Tandem Hatch Testing

After installation of the LAS ogives, the team performs functional testing of the LAS hatch in tandem with the crew module hatch to ensure that both hatches will open properly in an emergency egress situation.

LAS Communications System Testing

The team conducts communications testing of the LAS S-band antennas to verify that they can be used to transmit vehicle data from the crew module during launch and ascent.

Vehicle Purge Leak Test

Purge-leak testing identifies and verifies leakage areas of the LAS, as well as crew and service modules, to ensure that purge operations will be able to keep the vehicle protected from the outside environment during transportation and while the spacecraft is out on the pad.

Vehicle Assembly Building

After the LAS is fully integrated and Launch Abort System Facility operations are complete, the full Orion stack leaves the building and moves to the VAB for stacking on top of the SLS rocket. Once integrated with the SLS, Orion undergoes further servicing, testing, and closeout operations:

Potable Water System Servicing
Once Orion is integrated with the rocket inside the VAB, the four potable water tanks in the service module are flushed and filled. This is done as close as possible to rollout to the launch pad.

Nitrogen System Servicing
Orion's service module nitrogen tank is filled. This is performed after the potable water system servicing, as the nitrogen is used for pressurizing the water tanks and providing pressure control for the crew module.

Countdown Demonstration Test, or CDDT
Teams will conduct a launch day demonstration with the Artemis II crew to test launch countdown procedures and make any final necessary adjustments ahead of launch. While SLS and Orion are in the VAB, the Artemis II crew will depart their crew quarters after suiting up at the Operations and Checkout Building and drive to the VAB, where they will enter Orion like they would on launch day and practice getting strapped in.

Final Closeouts Before Rollout
The team closes out all of Orion's service panels and performs final stowage operations before the entire SLS stack rolls out to Pad 39B.

NASA's Artemis II Orion spacecraft, with its launch abort system, is stacked on the agency's SLS (Space Launch System) rocket in High Bay 3 of the vehicle Assembly Building at NASA's Kennedy Space Center in FLorida on Oct. 20, 2025. (NASA/Kim Shiflett) ▲

CSA (Canadian Space Agency) astronaut Jeremy Hansen, right, and NASA astronauts Victor Glover and Christina Koch exit the elevator at the 275-foot level of the mobile launcher as they walk toward the crew access arm and prepare to board their Orion spacecraft during the Artemis II countdown demonstration test on Dec. 20, 2025. (NASA/Joel Kowsky) ▲

Launch Abort System Testing

Testing for Orion's launch abort system included two major flight tests and hot-fire testing for the individual motors.

Pad Abort-1

NASA's Pad Abort-1 test was Orion's first major flight test and the first fully integrated test of the LAS. The agency successfully launched a test version of the crew module and its launch abort stack on May 6, 2010, at the U.S. Army's White Sands Missile Range near Las Cruces, New Mexico. The flight test demonstrated the capability of the LAS to propel the crew module to a safe distance during a ground-initiated abort on the launch pad.

The test lasted about 2.5 minutes from launch, until the test version of the crew module touched down about a mile north of the launch pad. The crew module reached a speed of approximately 445 mph in the first three seconds, with a maximum velocity of 539 mph in its upward trajectory to about 1.2 miles at its highest point. The parachutes guided the crew module to touchdown at 16.2 mph.

Ascent Abort-2

NASA conducted the second major flight test for the launch abort system, known as Ascent Abort-2, on July 2, 2019, to test the Orion LAS during ascent, which is when the spacecraft is expected to experience the greatest aerodynamic stress. Combined with subsystem qualification tests and the successful Pad Abort-1 test, this test certified the LAS to fly on Artemis missions with astronauts aboard.

A fully functional launch abort system with a test version of Orion attached soars upward on NASA's Ascent Abort-2 flight test atop a Northrop-Grumman-provided booster on July 2, 2019, after launching from Launch Pad 46 at Cape Canaveral Air Force Station in Florida. (NASA) ▲

During the test, which lasted approximately three minutes, a booster provided by Northrop Grumman launched from Space Launch Complex 46 at Cape Canaveral Air Force Station in Florida. It carried a fully functional LAS and a test version of Orion to an altitude of nearly 6 miles at over 1,000 mph. At that point, the LAS' powerful reverse-flow abort motor fired 400,000 pounds of thrust, propelling the Orion test article a safe distance away from the rocket to splash down in the Atlantic Ocean. For cost-saving purposes, the test article was not equipped with parachutes, nor was the test capsule recovered from the ocean.

Motor Testing

Engineers have completed final qualification testing for each of the LAS motors — the attitude control motor, jettison motor, and abort motor. These tests looked at the maximum high- and low-temperature conditions that a motor might see during a launch in Florida to provide data on how the motor reacts under stressful hot or cold conditions.

European Service Module Propulsion Testing

On Feb. 21, 2017, engineers successfully installed ESA's European Service Module propulsion qualification module at NASA's White Sands Test Facility in New Mexico, which was delivered by Airbus — ESA's prime contractor for the service module. (NASA/Rad Sinyak) ▲

Engineers used a replica of the service module's propulsion subsystem, called the propulsion qualification module, for testing at NASA's White Sands Test Facility. The data from these tests helped certify the service module propulsion system for Artemis I, II, and missions beyond. The propulsion qualification module was designed to verify the performance of the service module engines, propellant feed systems, and various other propulsion operations during expected and unexpected conditions. Testing of the module ensured that all engines and thrusters fired safely and accurately to prove that they would be reliable in getting the spacecraft where it needs to go during deep space exploration missions.

The propulsion qualification module was equipped with a total of 21 engines: one U.S. space shuttle orbital maneuvering system engine, eight auxiliary thrusters, and 12 smaller reaction control system thrusters produced by Airbus in Germany. The service module that will fly on Artemis missions has 33 engines in total, with double the amount of reaction control system thrusters included in the propulsion qualification module. The full module was a roughly 15-foot cube made of stainless steel that provided the full components for testing the thrusters, fuel lines, and firing of Orion's engines.

Teams from NASA and ESA completed 48 hot-fire tests and three discrete pressurization tests conducted in two phases at White Sands. These firing tests focused on the interaction between the engines and the propulsion subsystem, as well as the performance of the pressurization control assembly. Engineers conducted five additional hot-fire tests with the auxiliary engines on the propulsion qualification module, as well as tests on the pressure control assembly valves that involved chilling the valves and performing multiple cycles to recreate anomalies.

Teams successfully conducted a 12-minute propulsion test fire to simulate an abort-to-orbit scenario in which the spacecraft's service module puts Orion in a safe orbit if a problem were to arise after the LAS had been jettisoned. The test, which was the longest-ever continuous burn conducted on an orbital maneuvering system engine at White Sands, used the module to fire the system's engine, eight auxiliary thrusters, and six reaction control system thrusters.

Structural Testing

NASA's Orion structural test article in its "full stack" launch configuration at Lockheed Martin Space in 2018. (Lockheed Martin) ▲

Testing with Orion's "structural twin" at Lockheed Martin's facility in Colorado validated Orion's structure and enabled engineers to push the structure past design standards, simulating the harsh environments that will physically affect the Orion spacecraft. NASA and Lockheed Martin built the structural test article to be identical to Orion's main structural elements: the crew module, service module, and LAS. It did not include the non-structural items such as the spacecraft computers, propulsion, and seats for these tests.

A series of 21 tests used six different configurations — from a single element to the full stack — and various combinations in between to simulate the different flight conditions Orion undergoes during a mission. During some test phases — including launch, return to Earth, parachute deployment, and water landing — engineers pushed expected pressures, mechanical loads, vibration, and shock conditions up to 40% beyond the most severe conditions anticipated during the mission, analyzing data to confirm that the spacecraft structures could withstand the extreme environments of space. These tests helped to verify Orion's design and structural durability for Artemis missions to the Moon.

Pressure Testing

Pushing and pulling with pressure that equates to 140% of the maximum expected loads during missions ensure that the spacecraft structures can withstand intense loads at launch and re-entry.

Modal Testing

During modal testing, dynamic loads of pressure were applied to the spacecraft structures. With more than 20,000 parts making up Orion's service module alone, modal tests evaluate how the spacecraft components hold up to vibration, especially at connection points.

Stiffness Testing

Stiffness testing applied pressure steadily and continuously to the spacecraft's structures. This tests how the structures would respond to the static loads that the spacecraft will experience on missions.

Acoustic Testing

Acoustic testing blasted the structures with sound waves that simulated the vibrating rumble of launch, reaching more than 160 decibels.

Pyrotechnic Shock Testing

Shock tests recreated the powerful pyrotechnic blasts needed for separation events during flight, such as the LAS separating from the crew module after a successful launch.

Jettison Testing

Jettison tests mimicked deployment mechanisms required to jettison the forward bay cover and ensure that components can endure the shock levels expected during flight.

The Orion Aerosciences team has performed more than 30 tests across the United States in support of the program, investigating the heating of the spacecraft during re-entry into Earth's atmosphere. (NASA/David C. Bowman) ▲

Lightning Testing

Lightning tests evaluated potential flight hardware damage that could occur if the rocket and spacecraft are exposed to a lightning strike prior to launch.

Aerodynamic, Aerothermal, and Aeroacoustics Testing

Engineers used wind-tunnel testing and simulations to understand Orion's flight behavior in Earth's atmosphere and develop the aerodynamic, aerothermal, and aeroacoustics databases for Orion. The databases help verify the performance, controllability, thermal protection system, structure, and safety during all phases of atmospheric flight, including for launch aborts, by allowing accurate flight simulations and informing the design of the spacecraft.

Defining the crew module aerodynamics, both static and dynamic, help to ensure stable and controllable flight from entry into Earth's atmosphere to parachute deployment and descent.

Similarly, defining the aerodynamics for the LAS help to ensure successful launch aborts during ascent, from the launch pad to orbit. Defining the aerothermal environments for the crew module and LAS ensures that the thermal protection systems will protect the crew from heat during atmospheric entry, ascent, and ascent aborts. Characterizing the aeroacoustics was also important in designing and testing the Orion and LAS structures for the vibrations and loads they will experience during ascent and re-entry.

Teams completed more than 120 tests as part of developing the aerodynamic, aerothermal, and aeroacoustic databases for Orion. Teams conducted tests in 25 different wind tunnels and at four ballistic ranges, two shock tunnels, and three research laboratories across the United States at NASA facilities in Virginia, California, and Ohio; Department of War facilities in Tennessee, Maryland, and Florida; and universities such as the University of Buffalo in New York. The tests have covered speeds from 38 mph to about 15,000 mph.

Parachute Testing

NASA completes the final test to qualify Orion's parachute system for flights with astronauts, checking off an important milestone on the path to send humans on missions to the Moon and beyond on Sept. 12, 2018. (U.S. Army) ▲

NASA has fully qualified the parachute system for flights with crew through an extensive series of 17 developmental tests and eight qualification tests at the U.S. Army's Yuma Proving Ground in Arizona.

During the development series, engineers tested different types of failure scenarios and extreme descent conditions to refine Orion's parachute design and ensure that the parachutes will work in a variety of circumstances.

During the qualification testing, engineers evaluated the performance of the parachute system during normal landing sequences, as well as for several failure scenarios and a variety of potential aerodynamic conditions to ensure that astronauts can return safely from deep space missions.

While airdrop testing was a vital and very visible component to the development of Orion's parachutes, ground testing and analysis were equally important to its success. Airdrop testing cannot physically reach all possible spaceflight deployment conditions, but its data helped generate computer models of parachute performance, allowing the team to evaluate the parachutes in altitude and airspeed regimes that could not be thoroughly drop-tested. Repeated simulation of the parachutes with varied parameters, called the Monte Carlo method, allowed the team to estimate the bounds of what parachute loads and performance should be expected throughout the life of the program. Ground testing of material capabilities, coupled with the parachute simulations, determined how much structural margin exists in the system. This combination of ground tests, airdrop tests, and analysis qualified the system for Artemis flights with astronauts.

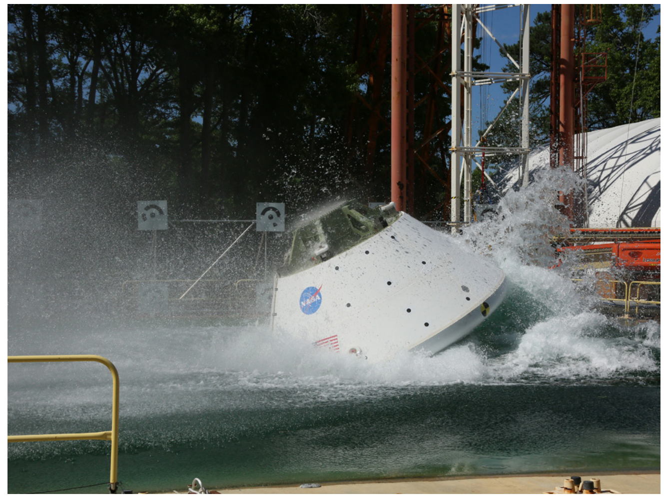
Crew Module Uprighting System Testing

Engineers tested the crew module uprighting system as part of Orion's first flight test and implemented a series of design changes to improve its performance. During EFT-1, three of the system's five bags did not properly inflate. The spacecraft landed and remained upright in the water; however, had the capsule landed upside down, the two functioning crew module uprighting system bags would likely not have been able to fully upright the capsule. Design improvements included thickening the inner bladder of each bag to make it more durable, changing how the bags are packed, developing a hard enclosure for the packed bags, and improving manufacturing processes for better control and consistency. During the Artemis I mission, all five uprighting system bags deployed after Orion's splashdown in the Pacific Ocean, demonstrating the successful implementation of the post-EFT-1 changes to the uprighting bags.

Several full-scale uprighting tests have been performed with a mock-up of the Orion crew capsule, demonstrating that the system would still be able to perform as intended if any one of the five uprighting bags were to fail. This included seven tests in the calm water of the Neutral Buoyancy Laboratory at NASA's Johnson Space Center in Houston. The Johnson crew module uprighting system and Neutral Buoyancy Laboratory teams also successfully completed two tests off the coast of Galveston, Texas, in cooperation the U.S. Coast Guard Cutter Cypress, Air Force personnel, and Texas A&M University at Galveston. Teams completed an additional four tests in the Atlantic Ocean, off the coast of Atlantic Beach, North Carolina, in cooperation with the U.S. Coast Guard Station Fort Macon and the U.S. Coast Guard Cutter Maple. These tests demonstrated performance in a natural wave environment and were instrumental in the certification of the crew module uprighting system.

The Orion crew module uprighting system and Neutral Buoyancy Laboratory team completed two successful sea tests off the coast of Galveston, Texas, from Dec. 1 to 3, 2018. (NASA) ▲

Water Impact Testing



The Orion Ground Test Article completes its first swing water impact test at NASA's Langley Research Center in Virginia on June 8, 2016. (NASA/David C. Bowman) ▲

Teams conducted water-impact testing at NASA's Langley Research Center in Hampton, Virginia, at the center's Hydro Impact Basin at the Landing and Impact Research Facility. The tests provided high-fidelity data of the forces that the Orion spacecraft structure and its astronaut crew would experience during landing, helping to protect the crew and informing future designs. Water-impact testing evaluates how the spacecraft may behave in parachute-assisted landings in different wind conditions and wave heights.

Engineers used three different test versions of Orion, as the spacecraft's design was refined over the course of the test series. The final series of drop tests used the test article previously used for structural testing at Lockheed Martin's facility in Colorado, which was based on the final design for the configuration that will fly on Artemis II. Teams used data from the drop tests, as well as from the Artemis I mission, in final computer modeling for loads and structures prior to Artemis II.

Avionics and Software Testing

The Orion program uses a network of integrated test labs designed to reduce cost and schedule risk by providing an early opportunity in the development phase of the program to perform systems-level avionics and software testing for Orion in a realistic environment.

Engineers used Lockheed Martin's state-of-the-art facility in Houston, called the Exploration Development Laboratory, for this testing, including avionics system testing, to reduce risk prior to the Pad Abort-1 test and EFT-1. Initial testing of systems also included the guidance, navigation, and control elements, as well as automated rendezvous and docking and crew interfaces. Engineers also used the facility to perform early development, integration, and dry-run testing of Orion avionics hardware and software and associated internal and external crew module interfaces using flight-representative software and an appropriate suite of ground support tools, systems, and software.

Lockheed Martin's Orion Integrated Test Lab, located near Denver, runs full mission scenarios, from prelaunch to landing, or specific phases of flight. The lab uses a full-size Orion mock-up with a fully integrated set of Orion's crew and service module hardware: avionics; power; wiring; and guidance, navigation, and control. The lab's systems connect to the Mission Control Center, which allows for real-time monitoring and commanding of the spacecraft in Houston to simulate the Artemis II mission.

Tests performed in the Integrated Test Lab are essential for identifying software problems and validating proper functionality and performance of the spacecraft avionics system. An Integrated Test Lab configuration is the highest-fidelity test platform that Orion avionics hardware and software would experience prior to actual testing regimens on the assembled spacecraft, providing as close to a "test like you fly" environment as can be assembled within a lab setting.

Flight Control Team Training

During flight day 6 of the 25.5-day Artemis I mission, Lead Flight Director Rick LaBrode monitors the progress of the outbound powered flyby in the White Flight Control Room at NASA's Johnson Space Center in Houston. (NASA/Robert Markowitz) ▲

The flight control team is completing training for the Artemis II mission and will continue up to launch. As software, hardware, and operations plans are finalized, they refine and practice the procedures they will use on the ground to monitor, command, and control Orion. Flight controllers in mission control prepare by simulating various parts of Orion's journey, from launch through its outbound transit to the Moon, including the translunar injection burn that sends the spacecraft out of Earth orbit and toward the Moon. The Mission Control Center also simulates Orion's lunar flyby and trans-Earth return through entry, descent, landing, and recovery, including the final trajectory corrections and burns Orion will need to execute to enter the atmosphere and splash down in the Pacific Ocean.

The agency began conducting a host of integrated simulations with the crew, launch, and flight control teams in the months before the mission. The crew trains and participates in simulations from the Orion Mission Simulator, a full-task mission trainer at Johnson. The high-fidelity vehicle simulator incorporates real flight software and extensive malfunction capabilities, allowing teams to train on nominal flight activities and complex malfunction scenarios, including emergency events.

Simulations and testing also have included joint operations between industry partners and NASA's flight operations team, with NASA doing real-time monitoring and commanding of the simulated version of Orion at the Integrated Test Lab in Denver from the Mission Control Center in Houston. Testing and training have also been done with a medium-fidelity mock-up to validate spatial requirements, as well as with a low-fidelity Orion mock-up at the Exploration Development Lab in Houston.

In addition, testing has been performed with the actual Orion spacecraft while it is at NASA's Kennedy Space Center.

Engineers also tested the Orion communications system to ensure that the spacecraft and mission control could communicate and send data through NASA's satellite networks in space and on the ground. Mission control verified that these communication systems work with Orion during tests of different Artemis II scenarios, from launch to landing.

Management Roles and Facilities

Armstrong Flight Research Center

For the Artemis II mission, NASA's Armstrong Flight Research Center in Edwards, California, has provided system engineering and integration expertise to assist with an Orion heat shield spectrometer system that will provide valuable data used to enhance astronaut safety.

Armstrong has also supported Orion's flight testing in preparation for Artemis I and beyond. Armstrong was the developmental flight instrumentation lead for Ascent Abort-2 and supported flight test development and system integration, ground operations definition, planning, and personnel. The center also provided component testing.

The team led test vehicle integration and developmental flight instrumentation for the Pad Abort-1 flight test and was the integrated product team lead for construction of the flight's launch site. Armstrong also led the Ikhana remotely piloted aircraft that was used to capture live video during the Orion entry and landing for EFT-1. The center supported Orion's Capsule Parachute Assembly System during parachute qualification testing.

Goddard Space Flight Center

NASA's Goddard Space Flight Center in Greenbelt, Maryland, supports Orion communication and navigation operations through NASA's Near Space Network, including a constellation of Tracking and Data Relay Satellites and associated ground stations. The center also provides tracking and navigation support with its Flight Dynamics Facility.

Goddard supports the NASA Communications Network, which carries command and telemetry data and provides mission-critical voice loops between ground stations, mission control centers, and other ground segments. The Goddard team supports NASA's Search and Rescue Office, which provides the responsive location services for Orion crew recovery.

Goddard also manages the Orion Artemis II Optical Communications System. The system is a laser communications terminal that will fly aboard Orion on Artemis II to demonstrate laser communications capabilities required for future exploration missions.

Jet Propulsion Laboratory

The Jet Propulsion Laboratory (JPL) in Southern California supports Orion communication and navigation operations through the Deep Space Network, handling communications beyond low Earth orbit with three equidistant facilities around the world. JPL supports Orion systems engineering and integration and provides independent validation of Orion's thermal protection system and parachutes, as well as advanced spacecraft environmental monitoring.

Johnson Space Center

NASA's Orion program is managed at NASA's Johnson Space Center in Houston, where engineers oversee the design, development, and testing of the spacecraft manufacturing taking place across the country and in Europe. Johnson is also home to the nation's astronaut corps and the iconic Christopher C. Kraft Mission Control Center.

Mission Control Center

Since 1965, NASA's MCC has been the helm of America's human spaceflight and is the primary facility where flight controllers command and control NASA's human spacecraft missions. The MCC is the facility from which flight operations personnel remotely monitor and operate the Orion spacecraft and receive data from Orion and the SLS rocket during Artemis missions.

The MCC is composed of several flight control rooms (FCRs), including FCR-1; FCR-2; and the Red, White, and Blue FCRs. Johnson upgraded the White FCR from its shuttle legacy configuration into a modern mission control configuration to serve as the mission control for flights of NASA's Orion spacecraft.

The MCC also houses the Orion Mission Evaluation Room, which provides Orion program engineering expertise to the flight control team during all phases of the mission, from prelaunch countdown to recovery, and provides Orion program engineering support to the Mission Management Team, as well as during any technical discussions regarding vehicle performance.

White Sands Test Facility

NASA's White Sands Test Facility in Las Cruces, New Mexico, is a component of Johnson that tests and evaluates potentially hazardous materials, spaceflight components, and rocket propulsion systems for NASA centers, other government agencies, and commercial industry. This work includes testing Orion's service module, the powerhouse of the spacecraft that provides in-space propulsion, power, and other astronaut life-support systems, including consumables like water, oxygen, and nitrogen.

Kennedy Space Center

Neil A. Armstrong Operations and Checkout Building

When the Artemis II Orion spacecraft arrived at Kennedy following initial manufacturing at Michoud Assembly Facility in New Orleans, it was placed in the Operations and Checkout building.

The Operations and Checkout Building contains a large room, called a high bay, that operates as a high-tech factory, where the spacecraft is assembled and readied for Artemis II. The high bay includes unique tooling stations, test fixtures, chambers, and clean rooms for the buildup and testing of the spacecraft.

The facility is capable of processing multiple spacecraft in different phases of production. Orion spacecraft for EFT-1 and Artemis I and II have been completed in the Operations and Checkout Building, with the assembly of spacecraft for future Artemis missions well underway.

Marshall Space Flight Center

More than 1,500 parts for the Orion spacecraft, including clips, sleeves, and rod ends used for unique connections, have been fabricated in the machine shop at NASA's Marshall Space Flight Center in Huntsville, Alabama. Marshall assists Orion's European Service Module Integration Office by providing Orion isolation valve refurbishment and Orion gas valve seat material testing, as well as support for Orion's service module propulsion systems with subsystem-level hot-fire test operations, along with data review.

Marshall has also contributed to Orion heat shield work for the EFT-1 and Artemis I flights. The center led physical machining efforts for EFT-1 to remove the heat shield's charred outer surface, permitting researchers to study the material. Post Artemis I, the Marshall team removed approximately 200 Avcoat samples for analysis and inspection, allowing engineers to perform nondestructive evaluation to "see" inside the heat shield at the facility.

Other contributions include support related to space and terrestrial environments, including radiation, plasma, sea states, atmosphere, and winds; and plume and aerothermodynamic analysis and consultation.

Integration of the LAS and transition-to-production operations is managed by Marshall with Lockheed Martin as the lead contractor. Marshall also provides fabrication, production, and assembly support to NASA teams across the Orion program. This effort includes the integration of Orion and the SLS rocket.

Michoud Assembly Facility

Michoud Assembly Facility in New Orleans is a component of Marshall where manufacturing and assembly of some of the largest parts of the Orion spacecraft, including Orion's pressure vessel, take place.

The work done at Michoud includes the production and welding of the Orion crew module pressure vessel structure, production of the crew module adapter structure, production of heat shield block material and composite panels, production of service module fairings, and assembly and integration of LAS structural components.

Langley Research Center

Landing and Impact Research Facility

Engineers performed water impact testing on Orion at the Hydro Impact Basin at NASA Langley's Landing and Impact Research Facility in Hampton, Virginia. The water basin is 115 feet long, 90 feet wide, and 20 feet deep. The basin is located at the west end of the gantry, which is a 240-foot-high, 400-foot-long, 265-foot-wide A-frame steel structure. The gantry provides the ability to control the orientation of the test article while imparting a vertical and horizontal impact velocity, which is required for human-rating spacecraft.

Glenn Research Center

NASA's Glenn Research Center in Cleveland serves as the lead for ESA/Airbus integration and management. It also leads in spacecraft mechanisms, pyrotechnics, and structures. Furthermore, the center is a co-lead for the crew and service module and spacecraft adapter. It also provides support for spacecraft integration; test and verification; avionics, power, and wiring subsystems; and software and guidance, navigation, and control.

Neil A. Armstrong Test Facility

NASA's Neil A. Armstrong Test Facility, formerly known as Plum Brook Station, is a remote test facility near Sandusky, Ohio, that is home to four world-class test facilities that perform complex and innovative ground tests for the international space community. Engineers conducted major tests for the Orion spacecraft at the facility's Space Environments Complex, which houses the world's largest and most capable space environment simulation facilities. These include the Space Simulation Chamber, which simulates the thermal and vacuum conditions of space and provides an environment to test electromagnetic interference; the Reverberant Test Facility, a 100,000-cubic-foot reverberant acoustic chamber; and the Mechanical Vibration Facility, a vibration table capable of testing an entire spacecraft in all three axes

Ames Research Center

Ames has contributed to a variety of testing and development activities for the Orion spacecraft. Engineers at Ames helped develop and test materials for Orion's heat shield and cone-shaped back shell using Ames' Arc Jet Complex under various heating and pressure environments selected to simulate flight conditions. Using Ames' Unitary Plan Wind Tunnel, teams also tested models of Orion at supersonic air speeds. Additionally, researchers at Ames used supercomputing capabilities to predict and better understand how different abort scenarios — from the launchpad to the edge of space — will affect vibration levels on the spacecraft.

Industry and International Partners

Lockheed Martin

Lockheed Martin is the lead contractor for the design, development testing, and production of the Orion spacecraft for NASA's Artemis missions. As lead contractor for Orion, Lockheed Martin manufactures the spacecraft's crew module, LAS, and crew module adapter. The company also integrates Orion's service module into a completed spacecraft. Lockheed Martin's Orion Program Office is based in Houston, where teams conduct Orion engineering and design. The team performs the majority of the Orion engineering work in Denver, manufactures the crew module pressure vessel and thermal protection materials at Michoud, and completes final assembly of the spacecraft in the Operations and Checkout Building at Kennedy and at Lockheed Martin's Spacecraft, Test, Assembly and Resource Center nearby in Florida.

Northrop Grumman

Northrop Grumman produces the launch abort motor and the attitude control motor for the Orion spacecraft's LAS under an agreement with Lockheed Martin. The abort motor is manufactured at the company's facilities in Magna, Promontory, and Clearfield, Utah, and the attitude control motor is produced at the company's facility in Elkton, Maryland.

Aerojet Rocketdyne

Aerojet Rocketdyne provides eight auxiliary engines and 12 reaction control thrusters for the Orion crew module, as well as the jettison motor for the LAS, under contract to Lockheed Martin. The company also manufactures the high-pressure helium tanks that inflate Orion's flotation system for water-based landings. Orion's auxiliary engines and reaction control thrusters are produced at Aerojet Rocketdyne's facility in Redmond, Washington. The jettison motor is a combined effort of the company's facilities in Orange, Virginia, and Huntsville, Alabama.

ESA (European Space Agency) and Airbus

Orion's European Service Module is provided by ESA and built by main contractor Airbus. Workers across 10 European countries and the United States supply components for the service module, including Germany, Italy, Switzerland, France, Belgium, Sweden, Denmark, Norway, Spain, and the Netherlands. The final product is assembled at Airbus facilities in Bremen, Germany, before being shipped to NASA.

Quick Facts

Orion Summary	
Gross Liftoff Mass	78,000 pounds (35,380 kilograms)
Trans-Lunar Insertion Mass	58,500 pounds (26,535 kilograms)
Post Trans-Lunar Insertion Mass	57,000 pounds (25,854 kilograms)
Usable Propellant	19,000 pounds (8,618 kilograms)
Crew Module + Service Module Stack Height	26 feet (7.9 meters)
Full Stack (Launch Abort System + Crew Module + Service Module) Height	67 feet (20.4 meters)

Launch Abort System	
Height	50 feet (15.2 meters) from LAS tip to LAS/service module interface, with ogive panels
Diameter	3 feet (1 meter) at tower 17 feet (5.2 meters) at base
Mass at Liftoff	17,000 pounds (7,711 kilograms)
Total Propellant Mass	5,700 pounds (2,585 kilograms)
Abort Motor	7,600 pounds mass (3,447 kilograms) 4,700 pounds propellant mass (2,131 kilograms) 400,000 pounds thrust (1,779 kilonewtons)
Attitude Control Motor	1,700 pounds mass (771 kilograms) 650 pounds (295 kilograms) propellant mass 7,000 pounds thrust (31 kilonewtons)
Jettison Motor	900 pounds mass (408 kilograms) 350 pounds propellant mass (204 kilograms) 40,000 pounds thrust (178 kilonewtons)

Crew Module	
Height	11 feet (3.4 meters)
Diameter	16.5 feet (5 meters)
Habitable Volume	330 feet^3 (9.3 meters^3)
Pressurized Volume	690.6 feet^3 (19.6 meters^3)
Lunar Return Payload Mass	220 pounds (99.8 kilograms)
Reaction Control System	12 thrusters 160 pounds thrust (0.7 kilonewtons) each
Mass at Liftoff	22,900 pounds (10,387 kilograms)
Nominal Landed Mass	20,500 pounds (9,299 kilograms)

Service Module	
Height	15.7 feet (4.8 meters)
Diameter	16.5 feet (5 meters)
Solar Wings	4 solar arrays 15,000 solar cells 62 feet (18.9 meters) when deployed 11 kilowatts regenerable power
Engines	24 reaction control system thrusters 50 pounds (0.2 kilonewtons) of thrust each 8 auxiliary engines 110 pounds (0.5 kilonewtons) of thrust each 1 orbital maneuvering system 6,000 pounds (26.7 kilonewtons) of thrust
Mass at Liftoff	34,300 pounds (15,558 kilograms)
Spacecraft Adapter Mass	2,800 pounds (1,270 kilograms)
Jettison Fairings Mass	1,000 pounds (454 kilograms)

Near Space Network antennas at NASA's White Sands Complex in Las Cruces, New Mexico. These antennas will be a key part in getting Orion's data to mission control during launch, low Earth orbit, re-entry, and splashdown. (NASA) ▲

Space Communications and Navigation Services

Artemis missions will rely on NASA's Near Space Network and Deep Space Network for comprehensive communications and navigation services. The networks, overseen by the agency's SCaN (Space Communications and Navigation) Program, will use worldwide network infrastructure and relay satellites to provide seamless communications and tracking support as Orion launches, orbits Earth, journeys to the Moon, and returns home.

NASA's Near Space Network

The Near Space Network, managed by NASA's Goddard Spaceflight Center in Greenbelt, Maryland, provides a suite of communications and navigation services through government and commercial network infrastructure. Using the Tracking and Data Relay Satellite fleet in geosynchronous orbit and a global network of Earth-based antennas, the Near Space Network will provide services for launch and Earth orbit, as well as during Orion's re-entry and splashdown on Earth.

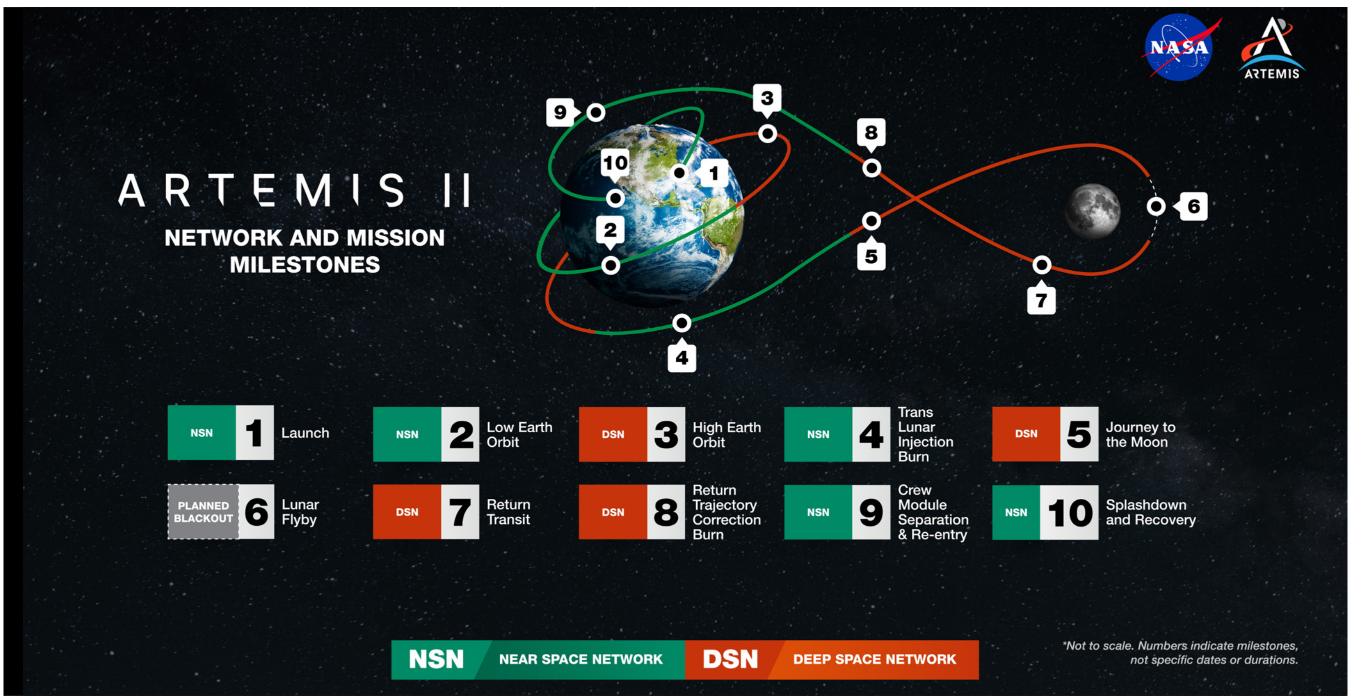
NASA's Deep Space Network

NASA's Deep Space Network, managed by NASA's Jet Propulsion Laboratory in Southern California, will handle communications beyond low Earth orbit. The Deep Space Network consists of three equally distant facilities — approximately 120 degrees apart in longitude — around the world. These sites are near Barstow, California; Madrid, Spain; and Canberra, Australia.

The strategic placement of these sites permits constant communication with spacecraft as Earth rotates, allowing one site to immediately pick up the spacecraft's signal as it exits another's line of sight.

Multiple space- and Earth-based assets will communicate with and track the SLS (Space Launch System) rocket's upper stage and the Orion spacecraft. The networks will work collectively to enable critical data exchanges between mission controllers on Earth and Orion. This includes all videos, images, voice communications, and science data.

An antenna at the Goldstone Deep Space Communications Complex near Barstow, California. (NASA) ▲



The Artemis II mission will use SCaN's networks to exchange vital data with mission controllers on Earth. This includes astronaut communications, mission health and safety information, images, video, and more. (NASA/David Ryan) ▲

Navigation

The Near Space Network and Deep Space Network will also work together to support navigation for Orion through a technique called three-way Doppler tracking. With one or more ground stations from each network in contact with Orion simultaneously, NASA can calculate Orion's location relative to the ground stations. Navigation, or tracking, services will enable the flight controllers to precisely calculate where Orion is along its trajectory, adjust its flight path if needed, and provide the coordinates for Orion's successful re-entry and splashdown.

The SCaN Now tool displays real-time data in the Mission Control Center at NASA's Jet Propulsion Laboratory during the Artemis I launch. (NASA) ▲

Demonstrating New Capabilities

NASA will demonstrate an advanced communications capability during the mission: laser communications. Laser communications use infrared light, rather than radio waves, to transmit data. Infrared light's shorter wavelengths allow spacecraft to pack significantly more data into each transmission, translating to more discoveries. During the spacecraft's journey, the Orion Artemis II Optical Communications System will demonstrate the benefits of laser communications by transmitting pre-recorded 4K ultra-high-definition video from the lunar vicinity, along with flight procedures, images, science data, and voice communications to two optical ground stations on Earth. While Artemis' primary communications support are the Near Space Network and Deep Space Network, demonstrating laser communications will inform capabilities for future exploration missions.

The Orion Artemis II Optical Communications System at NASA's Kennedy Space Center undergoes testing prior to integration into the Orion capsule. The system will demonstrate the benefits laser communications can have for lunar human spaceflight. (NASA/Isaac Watson) ▲