Thank you for this opportunity to talk the Artemis lunar exploration campaign. There's a lot going on right now, so let's get to it. Today we are talking about the backbone of deep space exploration, our current status, and our future plans.

Fifty years ago, we pioneered a path to the Moon, cutting through the fiction of science and showed us all what was possible.

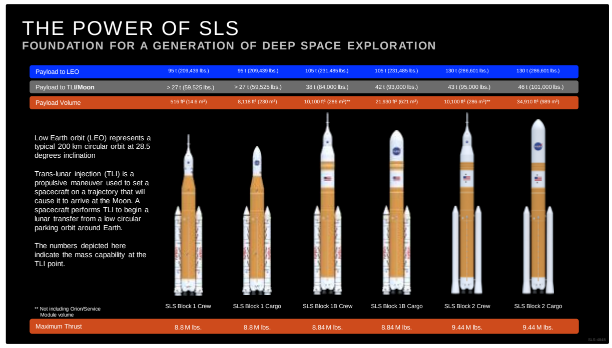
Today, the calling to explore is even greater – to go farther, we must be able to sustain missions of greater distance and duration.

We are again pushing the bounds of humanity.

At 06:47:44 UTC on November 16 – we took the first step to return humans to deep space and created a blueprint for a long-term human presence – expanding exploration throughout the solar system. Artemis I LAUNCHED!

OVERVIEW

- SLS Basics
- Payload Capability
- Test Program
- Artemis I Results
- Progress to Artemis II
- Progress to Artemis III and Beyond



This shows the SLS evolutionary path from greater capability than any existing launch vehicle, to unprecedented capability that changes how we explore.

FIRST 3 ARTEMIS MISSIONS WILL USE THE BLOCK 1 CONFIGURATION.

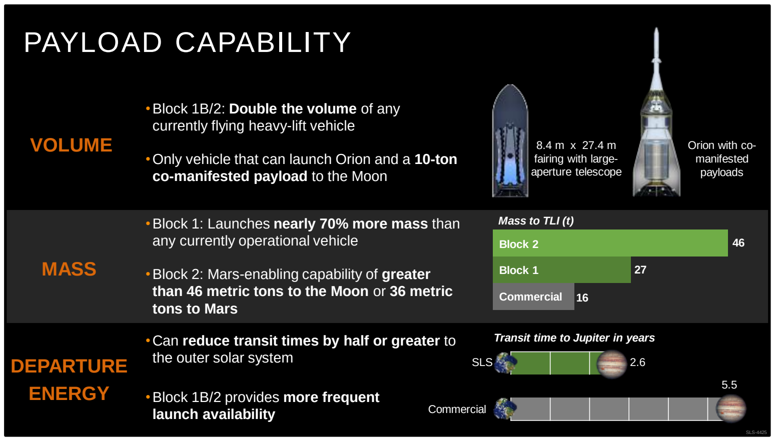
Along the way, SLS will retain many common elements rather than a completely new vehicle design:

- Orion/LAS remains the same
- The Universal Stage Adapter remains common to B1 and B2
- ICPS will evolve to EUS but will continue to use RL10 engines with EUS common to B1 and B2
- The Interstage remains common to B1 and B2
- The core stage remains common across all 6 variants, although it’s expected to undergo prudent weight reduction as we learn more about its performance
- All 6 variants will use the RS-25, while evolving from heritage SSMEs to new RS-25s designed to cost at least 30% less while increasing planned operational thrust
- All 6 variants will use the side boosters, evolving from today’s booster to a new booster wilth more powerful propellant, composite vs. steel motor casing, improved TVC, new insulation and other improvements.

SLS (SPACE LAUNCH SYSTEM)

Basic Statistics

- **Height:** 322-ft. including Orion spacecraft (Block 1)
- **Diameter:** Core stage - 27.6 ft.; Boosters - 12 ft.
- **Thrust:** 8.8 M lbs.
- **Weight:** 5.75 M lbs. at liftoff; 3.5 M lbs. unfueled with Orion
- **Upper Stage:** ICPS (Block 1); EUS (Block 1B/2)
- **Payload:** Orion spacecraft and more
- **Payload Capacity:** 59k lbs. to TLI in crewed Block 1 configuration
  - 84k lbs. to TLI in crewed Block 1B configuration
  - 95k lbs. to TLI in crewed Block 1 configuration



SLS more capable than commercial vehicles; a unique asset for space exploration

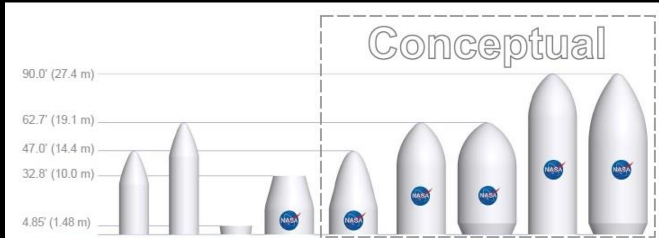
VOLUME - Twice the volume of any contemporary launch vehicle
Enables habitat modules, large-aperture telescopes, robust science package on robotic probes, etc.
Will talk more about this later in presentation.
Even the USA in B1B offers as much volume for payloads as industry-standard 5m fairings.

MASS - Initial capability > 27 metric tons (59,525 lb) to TLI; current U.S. launch vehicle maximum is 16-20 t [20 is generous] **
Evolved SLS will offer Mars-enabling capability of > 46 t (101,413 lb) to TLI

ENERGY - SLS offers reduced transit times to the outer solar system by half or greater (2-3 years for Europa instead of 7-8)
Heavy-lift reduces complexity and risk associated with payload design, ground infrastructure, and in-space operations
Provides the best opportunity for mission success

*Current U.S. launch vehicle maximum is ~16-20 t** (Falcon Heavy) to TLI
Block 1 = 23% greater mass than FH estimate
Block 1B = 38-42 t to TLI (crew or cargo) -- 50% more mass (40 t)
Block 2 = >55% more mass than FH

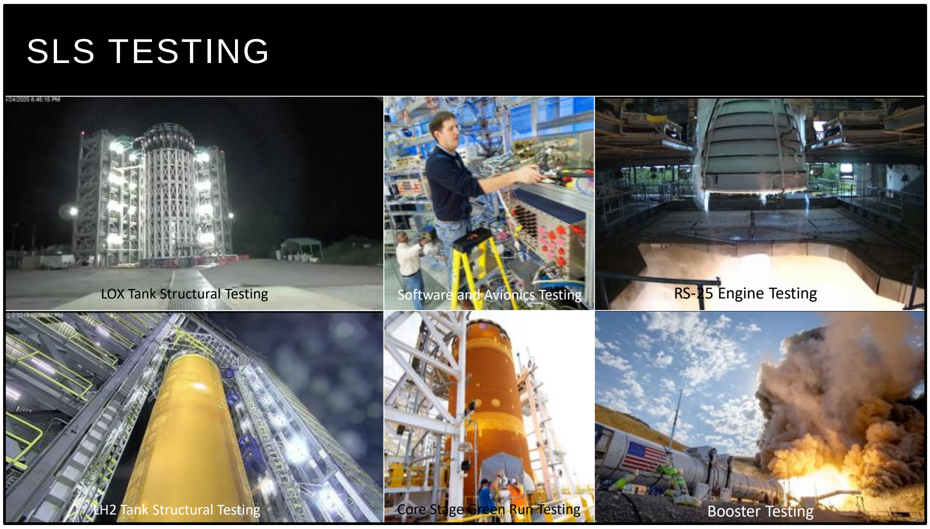
PAYLOAD CAPABILITY



Enclosure	5.1m PLF	5.1m PLF	OSA	8.4m USA	8.4m USA PLF	8.4m PLF, Short	10m PLF Short	8.4m PLF, Long	10m PLF Long
Payload Type	5m PPL	5m PPL	5m SPL	8.4m CPL	8.4m PPL	8.4m PPL	10m PPL	8.4m PPL	10m PPL
Length	47.0 ft	62.7 ft	4.85 ft	32.8 ft	47.2 ft	62.7 ft	62.7 ft	90 ft	90 ft
	14.3 m	19.1 m	1.48 m	10.0 m	14.4 m	19.1 m	19.1 m	27.4 m	27.4 m
Diameter	16.7 ft	16.7 ft	17.7 ft	27.6 ft	27.6 ft	27.6 ft	33.0 ft	27.6 ft	33.0 ft
	5.1 m	5.1 m	5.4 m	8.4 m	8.4 m	8.4 m	10.0 m	8.4 m	10.0 m
Internal Diameter	15.1 ft	15.1 ft	16.7 ft	24.6 ft	24.6 ft	24.6 ft	29.9 ft	24.6 ft	29.9 ft
	4.6 m	4.6 m	5.1 m	7.5 m	7.5 m	7.5 m	9.1 m	7.5 m	9.1 m
Available Volume	5,358 ft^3	8,118 ft^3	516 ft^3	10,100 ft^3	11,260 ft^3	21,930 ft^3	32,470 ft^3	34,910 ft^3	46,610 ft^3
	151.7 m^3	229.9 m^3	14.6 m^3	286.0 m^3	319 m^3	621 m^3	919 m^3	988 m^3	1,320 m^3
Potential Availability *(No Earlier Than)*	COTS	COTS	2020	2024	2025	2025	2029	2029	2029

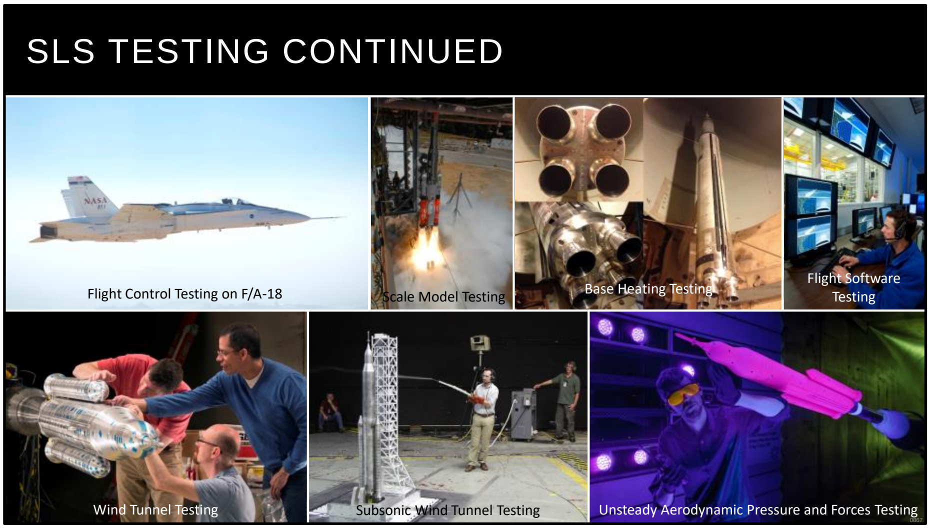
COTS: Commercial Off-the-Shelf CPL: Co-manifested Payload OSA: Orion Stage Adapter PPL: Primary Payload SPL: Secondary Payload PLF: Payload Fairing

Payload fairings for the cargo-only configuration are being studied and include 8.4-meter diameter fairings with volumes from 11,260 cubic feet (319 cubic meters) to 34,910 cubic feet (989 cubic meters). Even larger 10-meter diameter fairings with more than 32,000 cubic feet (909 cubic meters) are also under investigation.



From wind tunnel to flight hardware, testing is a big part of making SLS safe for astronauts.

- Before the vehicle flew, its components were structurally tested to ensure they can survive the extreme pressures and loads experienced in flight.
    - SLS structural qualification testing at Marshall complete, largest test campaign at MSFC since Space Shuttle. Five structural test articles underwent 199 separate test cases, and more than 421 gigabytes of data were collected to add to computer models used to design the rocket and optimize it in the future.
- Software is tested in a flight-like test environment, and then again on the flight hardware to ensure everything functions as needed to send crew to space.
- RS-25 engines adaptation hotfire series complete: 2015 – 2019 at Stennis to adapt the RS-25 to SLS performance and environment requirements and develop a modern engine controller and software. Tests also included new engine flight controller development and flight controller qualification as well as development parts for restart engine program. Total of 32 tests totaling nearly 15,000 seconds of hot-fire time.
- Eight-test Green Run series at Stennis ending with a simulated launch hot fire test will prove Core Stage 1 is ready for Artemis I.
- The 5-segment boosters for SLS underwent both hot and cold firings early in the program.



Clockwise from Top Left:

Top Left: MSFC Spacecraft and Vehicle Systems employees developed algorithms for SLS flight controls to improve performance to allow flight computer to re-=tune themselves to react to unknown scenarios in flight – a first NASA use in a launch vehicle of an Adaptive Augmenting Controller. Tested on an F/A-18 jet at **Dryden** Flight Research Center

Top Middle Left: Testing at **MSFC** of a 5 percent scale model with working engines and boosters to study how low- and high-frequency sound waves will affect the rocket on the launch pad. Instrumented w/ 200+ sensors

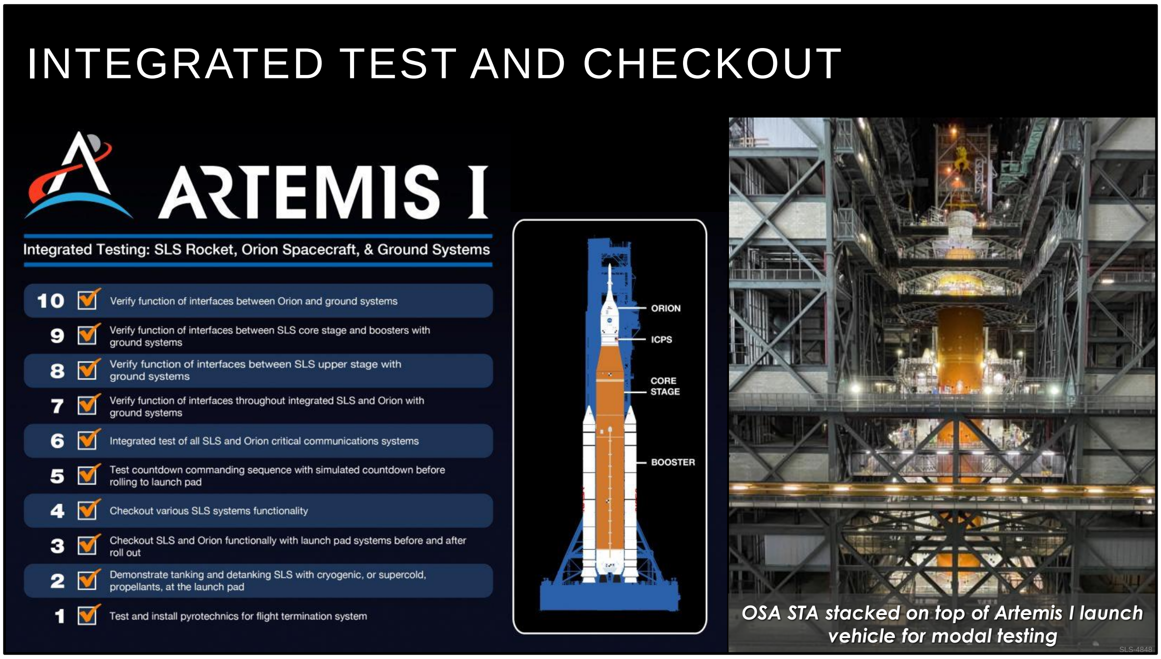
Top Middle Right: MSFC/CUBRC of Buffalo, NY, base heating w/ 2 percent, 6.5-foot-tall scale model

Top Right: MSFC developed and tested the flight software in-house running thousands of launches in various simulated launch conditions

Bottom Right: 1.3 percent 4.75-foot model, wind tunnel testing at **Ames** Research Center**,** trans sonic tests w/ pressure sensitive paint, engineer is from Langley Research Center

Bottom Middle: Liftoff transition testing of a 67.5-inch model of the SLS in a 14-by-22-foot subsonic wind tunnel at NASA's **Langley** Research Center in Virginia.

Bottom Left: Unsteady aerodynamic pressures and forces testing in **Langley** Research Center’s Transonic Dynamics Tunnel



OSA STA stacked on top of Artemis I launch vehicle for modal testing

Before we launched, we performed the Integrated Test and Checkout (ITCO) test series

The modal test series sought to understand the vehicle's natural frequencies to help ground computer models and improve the flight computers that will fly the rocket. The team placed hydraulic shakers at seven locations on the rocket and imparted forces. Additionally, a small hammer delivered calibrated taps near key parts of the navigation system to understand the dynamics local to those spots. A hammer on a dolly was also moved to different locations on the mobile launcher to impart further vibrations. In all, approximately 300 sensors attached to the rocket and mobile launcher detected, recorded, and transmitted the data to the engineers.

The test series was performed over multiple days, for 10 hours each day, during the overnight shift in the VAB when activity level in the building and surrounding areas is low. This quieter environment helped ensure a higher quality of data. The sensors remain on the vehicle and collected vibration data during rollout of the launch vehicle to Launch Pad 39B for WDR.

In addition to the modal tests, teams also completed a number of other tests, including the Interface Verification Test, the Communications End-to-End Test, the Umbilical Release and Retract Test, and the Countdown Sequence Test. They also uploaded the flight software that will fly the mission.

During one of the evaluations, which involved powering up the RS-25 engines, a problem was discovered with one of the engine controllers – the computers on the RS-25 engines. After analysis, the decision was made to remove and replace the engine controller – the first time this procedure has been done with SLS on the mobile launcher. The controller was sent to manufacturer Honeywell for further analysis, where the issue was tracked to a memory chip in the controller. Proper flight rationale has been developed, and the problem is not an issue for flight.

ARTEMIS I – THE ULTIMATE TEST

- **Earth Orbital Insertion Actuals**
  - Orbital velocity: 25,579.86 ft./sec. (7,796.74 m/sec.)
  - Orbital parameters: 972.6 nautical miles (1,801 km) by 15.9 nautical miles (29.4 km)
- **Earth Orbital Insertion Pre-flight Predicted**
  - Orbital velocity: 25,586.44 ft./sec. (7,798.75 m/sec.)
  - Orbital parameters: 975 nautical miles (1,806 km) by 16 nautical miles (29.6 km)
- **Overall Vehicle Performance:** SLS performed its job with a high-degree of accuracy and precision

Artemis I was the ultimate test flight. Some data we can only collect in the flight environment.

ARTEMIS I – THE ULTIMATE TEST

- **Core Stage**
  - The SLS core stage's 999 sensors and 45 miles of cable executed all functions
  - Core stage experienced >3200º F fire raging at the surface of our cork base heat shield and ~1.3" away, the structure never knew it
- **RS-25 Engines**
  - Thrust and mixture ratio control valves were within 0.5 percent of pre-flight predicted values
  - Internal pressures and temperatures were within two sigma of pre-flight predicted values

ARTEMIS I – THE ULTIMATE TEST

- **Solid Rocket Boosters**
  - Burned out within 0.5 seconds of each
  - Peak thrust within 0.1 seconds of each other
  - Performed within one-quarter of a percent of each other during ascent
  - 50-psi separation signal, which is based on measurements during the tailoff pressure, was sent to each booster within 0.04 seconds of each other

ARTEMIS I – THE ULTIMATE TEST

- **Flight Software**
  - Nominal transition Ground Launch Sequencer (GLS) to Automated Launch Sequencer (ALS) transition
  - Excellent core stage LH2 and LOX closed-loop ullage control
- **Interim Cryogenic Propulsion Stage**
  - TLI Burn: 18 minutes, a record duration for the RL10

SLS is ready to support a crew on Artemis II. This lunar flyby mission will require the astronauts to check out, evaluate, and test the Orion spacecraft systems in the deep space environment.

And here's the crew:

Left to right: Mission Specialist 1 NASA's Christina Koch, Pilot Victor Glover (standing), Commander Reid Wiseman (sitting), and the Canadian Space Agency's Jeremy Hansen as Mission Specialist 2

Artemis II will be the first time we launch astronauts on SLS and Orion. They will even checkout how the vehicle handles and give it test drive in space.

Version Control
MAP DATE: MAR 2023

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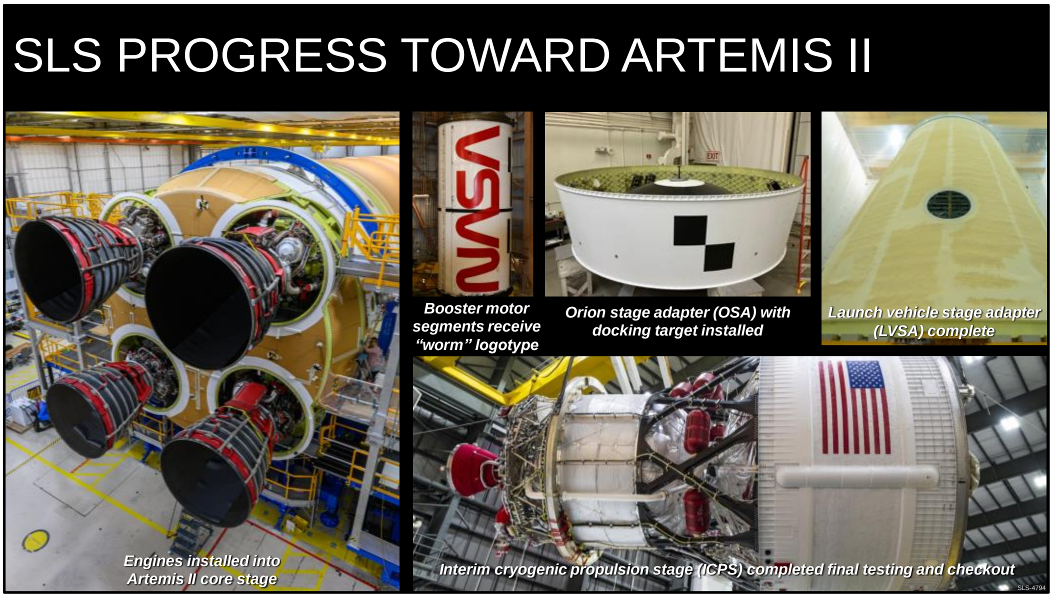
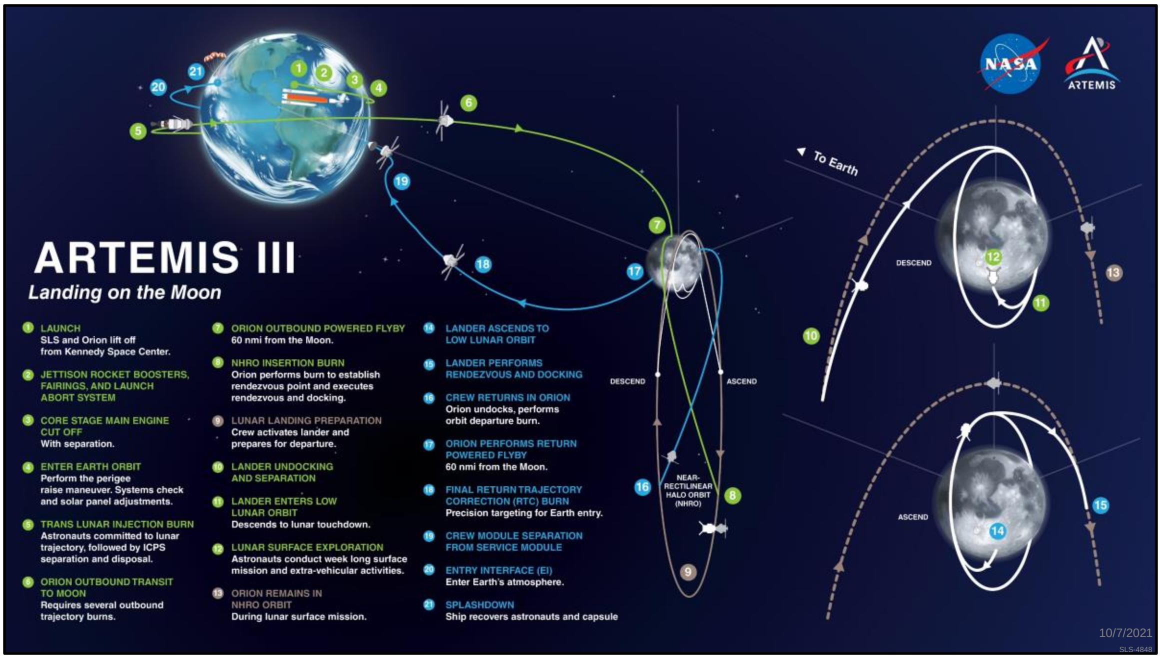


<u>Artemis II Progress: All elements of the second SLS Block 1 rocket for Artemis II, the first crewed lunar mission of the 21st century, are either complete and ready for stacking, or nearing completion.</u>

- The 10 complete solid rocket booster motor segments arrived at KSC fall 2023. At KSC, NASA's "worm" logotype has been painted on the booster segments, which will be stored in the Rotation, Processing & Surge Facility (RPSF) where the aft motor segment, nozzle and aft skirt are currently being mated to form the aft assemblies.
- The four Aerojet Rocketdyne, an L3Harris Technologies Company, RS-25 engines were installed into the core stage at NASA's Michoud Assembly Facility in New Orleans, Louisiana. The core stage completed Final Integrated Functional Testing at Michoud and is undergoing final outfitting ahead of its hardware acceptance review and delivery to KSC.
- The interim cryogenic propulsion stage (ICPS) completed final testing and checkout at United Launch Alliance (ULA) Delta Operations Center (DOC) at Cape Canaveral Space Force Station (CCSFS) and will be turned over to NASA's Exploration Ground Systems in preparation for Artemis II stacking operations later this year.
- At NASA's Marshall Space Flight Center (MSFC) in Alabama, the launch vehicle stage adapter (LVSA) is complete, and the Orion Stage Adapter (OSA) has completed all work before its shipment to KSC.
- Artemis II flight software has been approved for release and installation into the Artemis II core stage.

- Also realizing production improvements in building CS-II:
  - The Artemis II core stage production schedule currently is averaging 50% improvement in schedule over the Artemis I core stage
  - We have so far seen a 70% improvement in labor hours on the engine section and 33% improvement on the intertank.
  - To break that down further, for the engine section, the most complex section of the core stage, we have seen a significant improvement in manufacturing discrepancies, a 97% improvement in rework hours and an overall 70% improvement in baseline labor hours required



Artemis III will feature the first crewed landing on the Moon since Apollo 17. The mission will use an SLS Block 1 Crew to launch Orion and the crew to the Moon with an ultimate lunar orbit insertion in the near rectilinear halo orbit (NRHO), which will enable them to reach their landing site at the lunar south pole – an area of the Moon Apollo astronauts did not explore.

Version Control
MAP DATE: OCT 2021

POC
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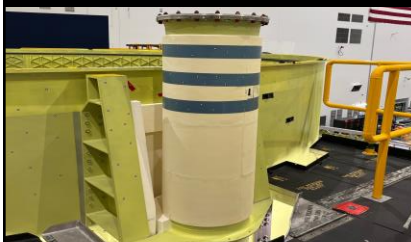
SLS PROGRESS TOWARD ARTEMIS III


Engine section at NASA Kennedy


Booster segments complete


RS-25 flight set processed

Core stage forward skirt complete


ICPS Delta Operations Center processing


LVSA Frangible Joint Assembly


Liquid oxygen tank manufactured


Liquid hydrogen tank moves to Spray-on Foam Insulation Facility

SLS-4874

<u>Artemis III Progress: The SLS Program has hardware complete or in work for every element of the Artemis III mission, the first lunar landing since 1972. The mission is currently scheduled for September 2026.</u>

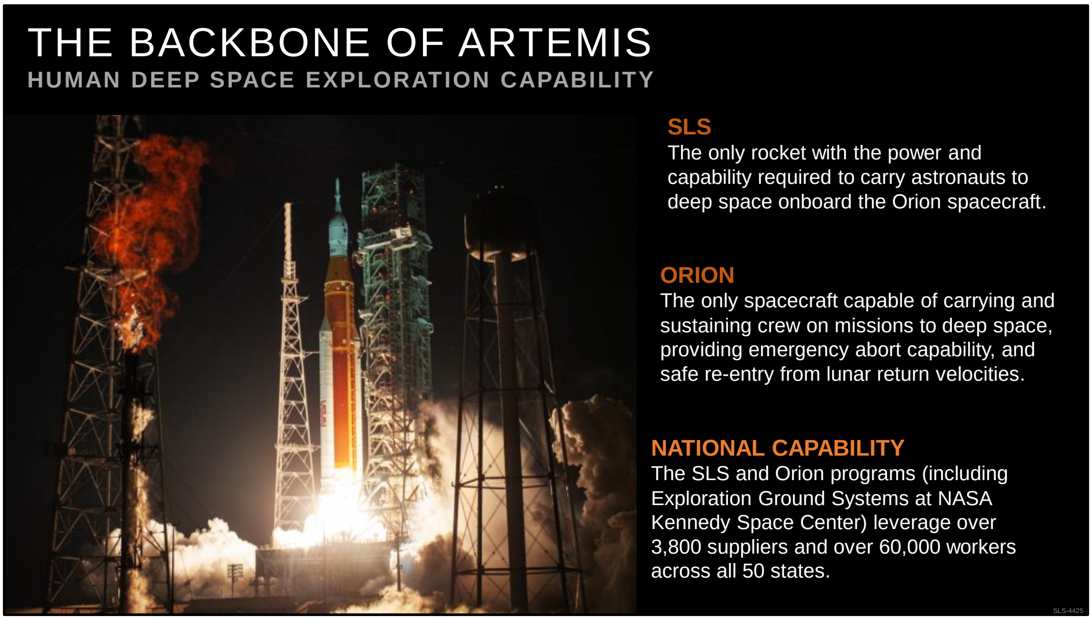
- In Utah, Northrop Grumman has completed all 10 motor segments. Work at KSC on the forward and aft assemblies is in progress at the Booster Fabrication Facility (BFF), with all 16 booster separation motors (BSMs) completed.
- The four RS-25 engines are complete at NASA's Stennis Space Center in Bay St. Louis, Mississippi.
- At Michoud, the core stage's liquid hydrogen (LH2) tank, liquid oxygen (LOX) tank, forward skirt, and intertank are structurally complete. Forward skirt integration and engine section outfitting is ongoing.
- MSFC received the OSA diaphragm in 2023. The LVSA is in the final phase of integration.
- The ICPS is undergoing additional processing at CCSFS in the ULA DOC Test Cell near KSC.

ARTEMIS IV AND BEYOND

Exploration upper stage LOX dome wield confidence article
Engine section in progress
LH2 tank in progress
Intertank in progress
RL10 engines complete
Interstage structural test article aft L-ring on Ingersoll Machine
Universal stage adapter development test article in test stand at NASA Marshall SLS-4794

Artemis IV and Beyond: The Artemis IV flight is scheduled for 2028, and will use the first SLS Block 1B rocket featuring the more powerful exploration upper stage (EUS) and a universal stage adapter (USA) carrying a large co-manifested payload. The EUS, interstage, and USA will replace the LVSA, OSA, and ICPS from Block 1. Artemis IV's first co-manifested payload will be the International Habitation (iHab) Gateway module.

- The five barrel sections of the Artemis IV core stage LH2 tank are complete, and the engine section is being manufactured.
- Three of four RS-25 engines for Artemis IV have completed processing with the fourth to be completed in spring 2024.
- Aerojet Rocketdyne is making progress on manufacturing the first six RS-25 "restart" engines that will begin flying on Artemis V. These new engines will cost 30% less to manufacture and will operate at 111% thrust vs. 109% for the current RS-25 engine.
  - The first production engine began assembly Nov. 2, 2023. Aerojet Rocketdyne is under contract to produce 24 new RS-25 engines for Artemis V and beyond.
  - The second and final certification series of 12 RS-25 hot fire tests to support restart engine certification began in October 2023 with nine completed by mid-March, 2024.
  - The first new-production RS-25 flight engine is planned for acceptance hot firing in fall 2024.
- Seven Artemis IV booster motor segments have been cast with propellant, with the eighth scheduled to be cast in April 2024. Aft skirt structures refurbishment is complete. Northrop Grumman is fabricating nozzles.
- The boosters team and prime contractor Northrop Grumman are working to design, develop, and test next-generation boosters after shuttle-era case hardware is expended. These composite-case boosters, being developed under the Booster Obsolescence and Life Extension (BOLE) contract modification, will



Built by America - for America – in the public eye – for a new generation of space explorers. This is <u>America's rocket</u>.

SLS is the **<u>only</u> exploration-class vehicle capable of sending humans to deep space** along with the large systems necessary to live and work in deep space.

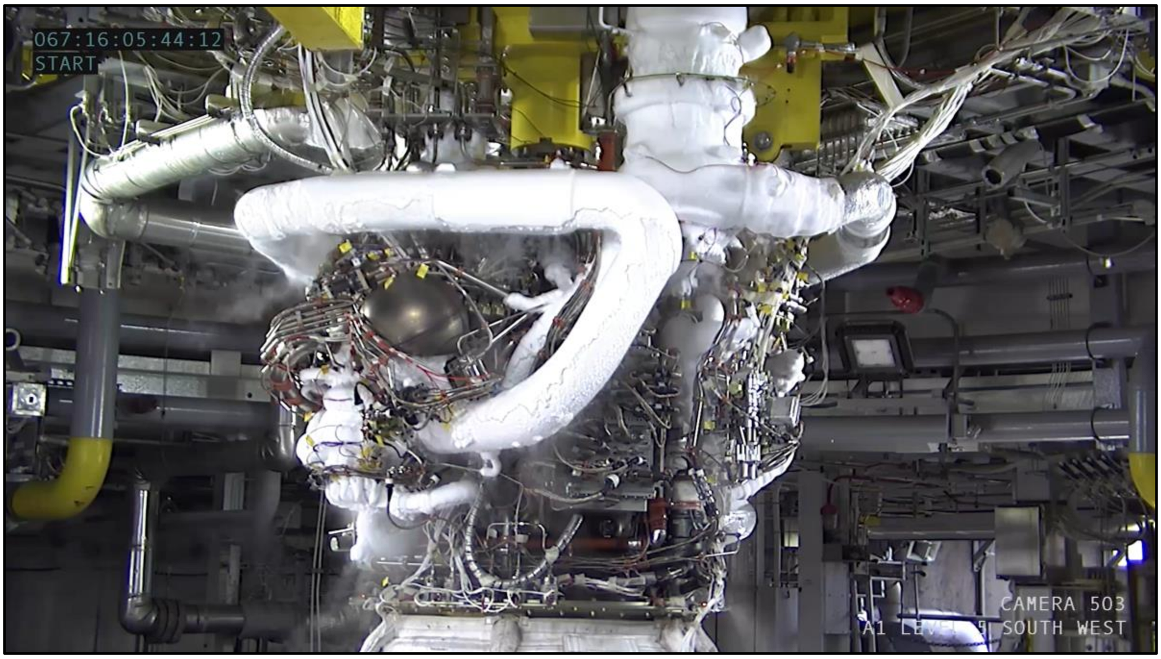
SLS has the **power and capacity to lift large and complex payloads, reducing the number of launches needed to put hardware into space.**

SLS stands at 322' tall, weighing in at 5.75 million pounds and boasting 8.8m lbs of thrust.

Orion is the only spacecraft capable of sustaining human life in deep space

Exploration Ground Systems – provide the technology, skill and equipment to launch SLS and recover Orion.

With all that power and capability, SLS is the only rocket capable of fulfilling the missions of the Artemis program



VIDEO (NO AUDIO): RS-25 Engine Testing at Stennis

Here’s how you can keep an eye on us… our social media platforms. We’re putting new pictures and stories out every day.