

# Back to the Moon V



Infrastructure  
and Testing



Jim Rauf

# NASA Centers and Facilities

## **Ames Research Center**

IT, fundamental aeronautics, bio and space science technologies

## **Armstrong Flight Research Center**

Flight research

## **Glenn Research Center**

Aeropropulsion and communications technologies

## **Goddard Space Flight Center**

Earth, solar system, and universe observations, and space communications and navigation

## **Jet Propulsion Laboratory**

Robotic exploration of the solar system and Earth observations

## **Johnson Space Center**

Human space exploration

## ***Kennedy Space Center***

Prepare and launch missions around the Earth and beyond

## **Langley Research Center**

Aviation, space technology and Earth science

## ***Marshall Space Flight Center***

Space transportation and propulsion technologies

## ***Stennis Space Center***

Rocket propulsion testing and remote sensing technology

## **Goddard Institute for Space Studies**

Broad study of global climate change

## **Katherine Johnson Independent Verification and Validation Facility**

Safety and cost-effectiveness for mission-critical software

## ***Michoud Assembly Facility***

Manufacture and assembly of critical hardware for exploration vehicles

## **NASA Engineering and Safety Center**

Independent testing, analysis, and assessments of NASA's high-risk projects

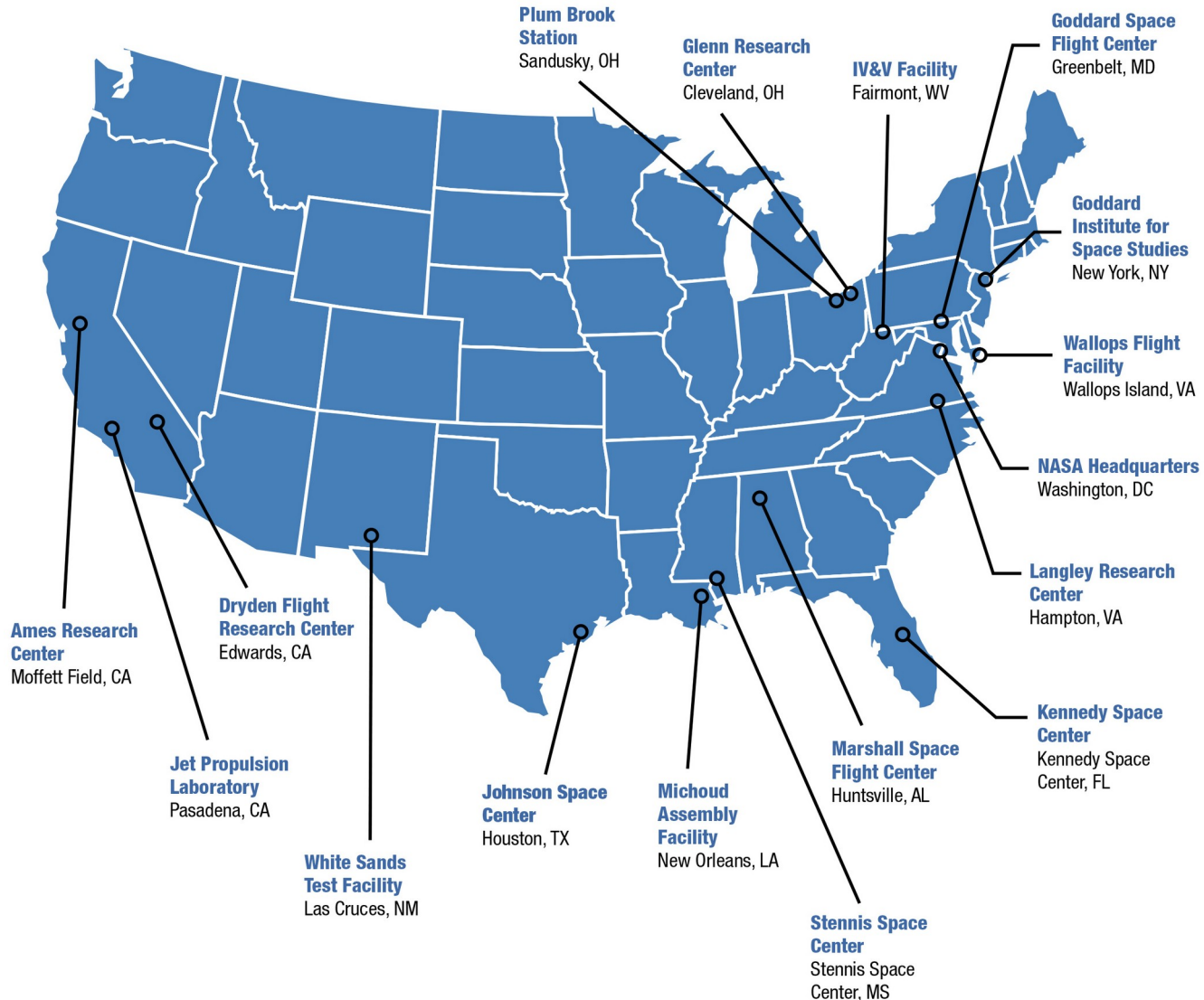
## **NASA Safety Center**

Development of personnel, processes, and tools needed for the safe and successful achievement of strategic goals

## **Wallops Flight Facility**

Suborbital Research Programs

# NASA Centers and Facilities



- Ames Research Center
- Armstrong Flight Research Center
- Glenn Research Center
- Goddard Space Flight Center
- Goddard Institute of Space Studies
- IV and V Facility
- Jet Propulsion Laboratory (JPL)
- Johnson Space Center
- Kennedy Space Center
- Langley Research Center
- Marshall Space Flight Center
- NASA HQ
- Stennis Space Center
- Wallops Flight Facility
- White Sands Test Facility
- Moffett Field, CA
- Edwards, CA
- Cleveland, OH
- Greenbelt, MD
- New York, NY
- Fairmont, WV
- Pasadena, CA
- Houston, TX
- FL
- Hampton, VA
- Huntsville, AL
- Washington, D.C.
- MS
- Wallops Island, VA
- Cruces, NM

## Apollo Infrastructure Vehicle Assembly Building (VAB)



The VAB is the largest single-story building in the world  
Its volume of 129,428,000 cu ft make it is the eighth-largest  
building in the world

- **Vehicle Assembly Building (VAB)**, standing 525 feet high
- **4 High Bays**
  - 2 on the East side and 2 on the West side
  - Total High Bay dimension: 442 ft L x 518 ft W x 525 ft H
  - Individually retractable doors (7 total) 456 ft high external opening
  - 2 High Bays open and lead to launch pads (East side)
  - 3 of 4 High Bays capable of handling Mobile Launch Platform (MLP) for vertical stacking/integration
- **Cranes**
  - 2 – 250-ton bridge cranes (E-W) with 460 ft hook height
  - 2 – 325-ton bridge cranes with 462.5 ft hook height
  - 1 – 175-ton bridge crane (length of transfer aisle) with 156 ft hook height
- **Communications**
  - Wireless Capability
  - Connectivity to the Launch Control Center (LCC)

# Apollo Infrastructure Transporter Crawler



Length 131 ft  
Width 114 ft  
Height 20-26 ft (variable)  
Weight ~5.5 million lbs  
Max speed loaded 1 mph (2 mph unloaded)  
Fuel consumption 150 gal/mile  
Price ~ \$14 million (1964)  
Manufacturer Marion Power Shovel Co.  
The two crawler-transporters were the largest self-powered land vehicles in the world

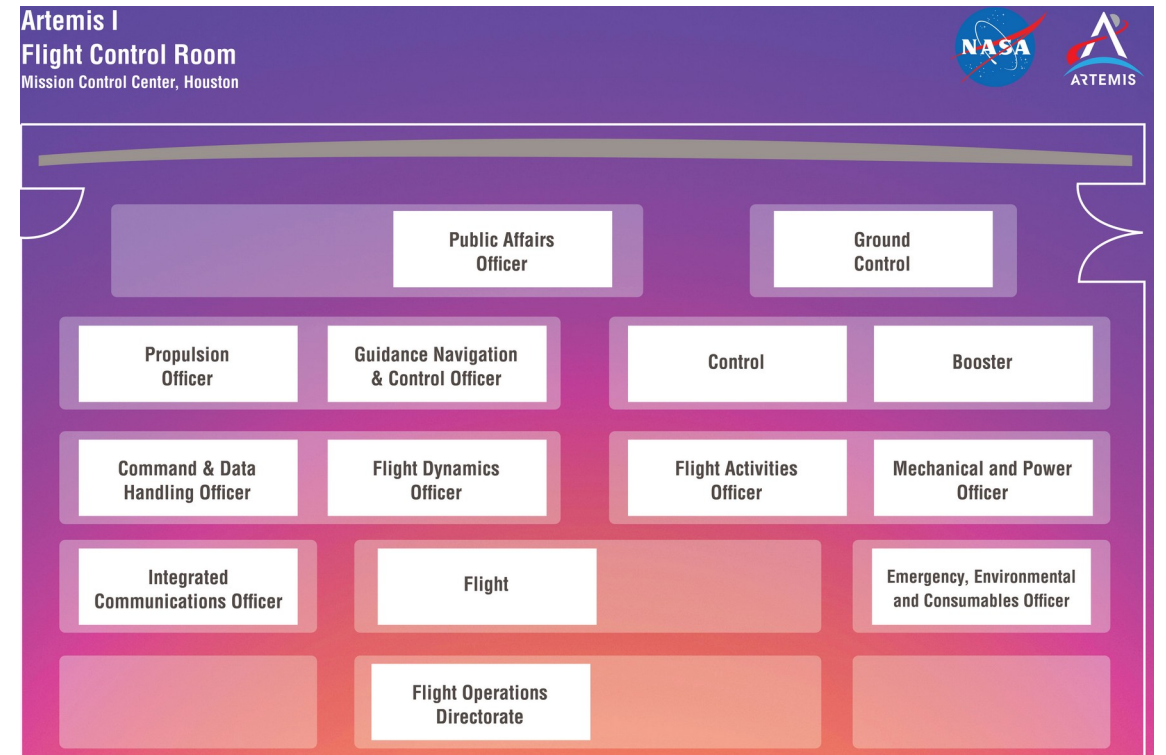
# Apollo Infrastructure Launch Pad



Foreground Launch Pad 39A

Background Launch Pad 39B

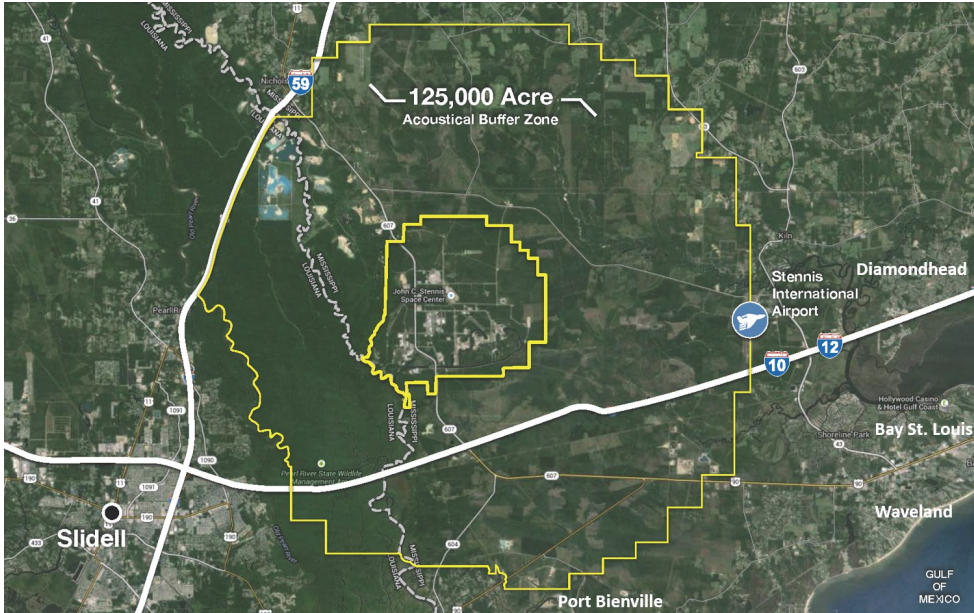
# Artemis Mission Control Johnson Space Center



# Apollo Infrastructure

# Mississippi Test Facility

# Stennis Space Center





# Apollo Infrastructure   Mississippi Test Facility   Stennis Space Center

- **High Pressure Industrial Water**

- 66,000,000 gallon reservoir
- Ten diesel-driven pumps with a total capacity of 330,000 gal/min
- Piping and foundation to expand to 13 pumps

- **High Pressure Gas Facility**

- Gaseous Nitrogen (GN<sub>2</sub>) 4,400 psig
- Gaseous Hydrogen (GH<sub>2</sub>) 3,000 psig
- Gaseous Helium (GHe) 4,000 psig
- High Purity Air (HPA) 3,000 psig

- **Cryogenic Propellant Systems**

- Storage, transfer and distribution of propellants
- Six 100,000 gal Liquid Oxygen (LOX) barges
- Three 240,000 gal Liquid Hydrogen (LH) barges

- **Emergency Power-Generating System**

- Four Cooper-Bessemer diesel engines each driving a 4160 volt, 1875 KVA generator used to provide emergency electrical power.

- **Waterway Transportation**

- 7-1/2 Miles of Canal System
- Connecting SSC Test Complexes to the Gulf of Mexico and Connected Waterways
- Allows Barge Transportation of Large Stages
- Used for Delivery of Propellants to the Large Test Stands

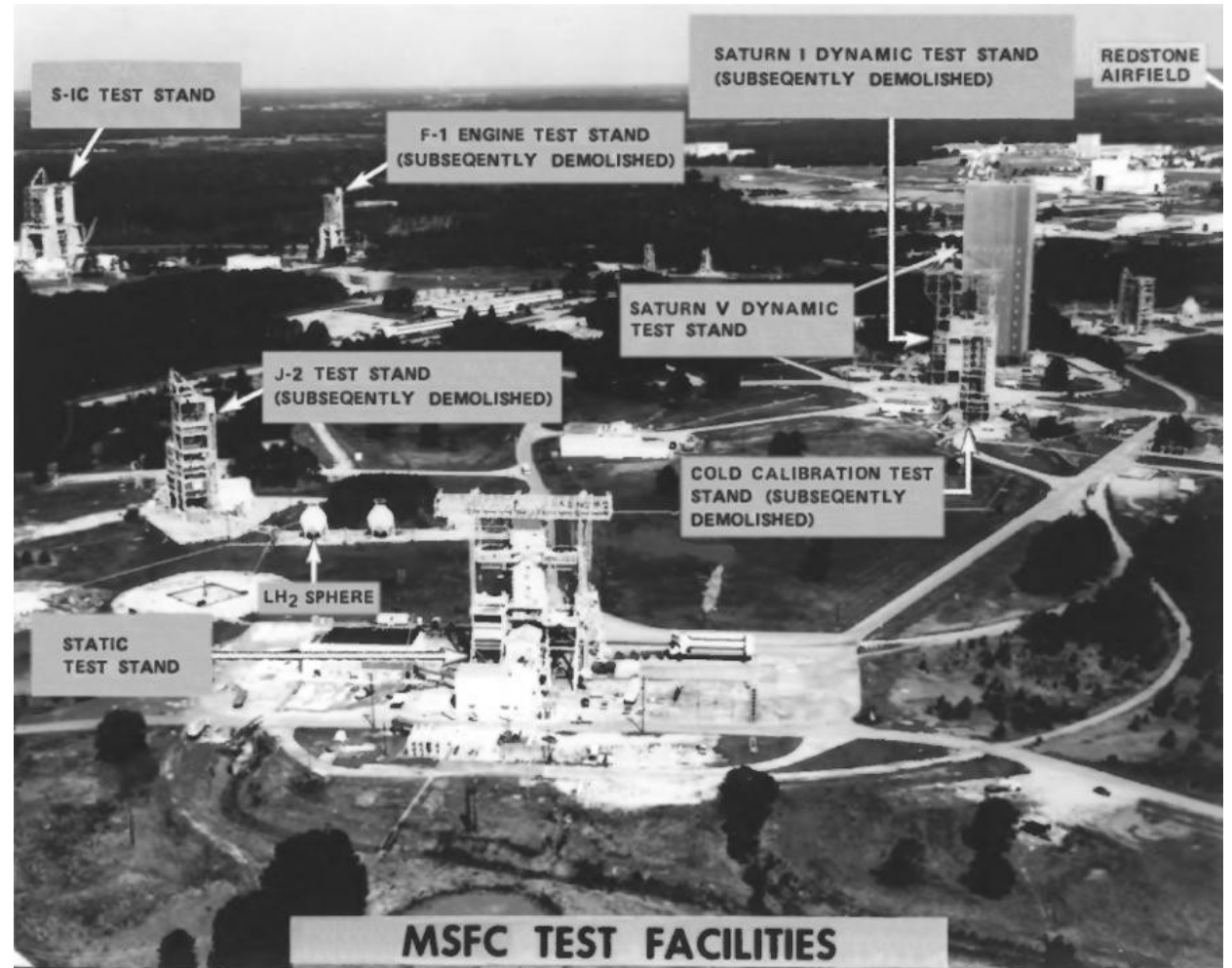
- **Manufacturing & Assembly**

- Over 800,000 square feet of industrial space is available
- Over 1100 acres of greenfield space is available (400 acres shovel ready)
- Allows co-location for manufacturing and assembly operations with test facilities

# Apollo Infrastructure Marshal Spaceflight Center(MSFC)



- **MSFC** provides concept and design for propulsion systems, space habitats, planetary landers
- It develops cutting-edge technology in support of scientific missions
- It manages activities at the **Michoud Assembly Facility** in New Orleans



# Michoud Assembly Facility New Orleans



- **NASA's** premiere site for manufacturing and assembly of large-scale space structures and systems
- Past programs included **Apollo's Saturn I, IB** and **S-1C** boosters and **Space Shuttle** external tank
- The government owned 829 acre facility has a 43 acre manufacturing space under one roof
- **Boeing** manufactures and assembles the **SLS** core stage
- **Lockheed Martin** manufactures **Orion** spacecraft's pressure vessel
- **Northrop Grumman** manufactures the launch abort system

# Michoud Assembly Facility New Orleans 1960s

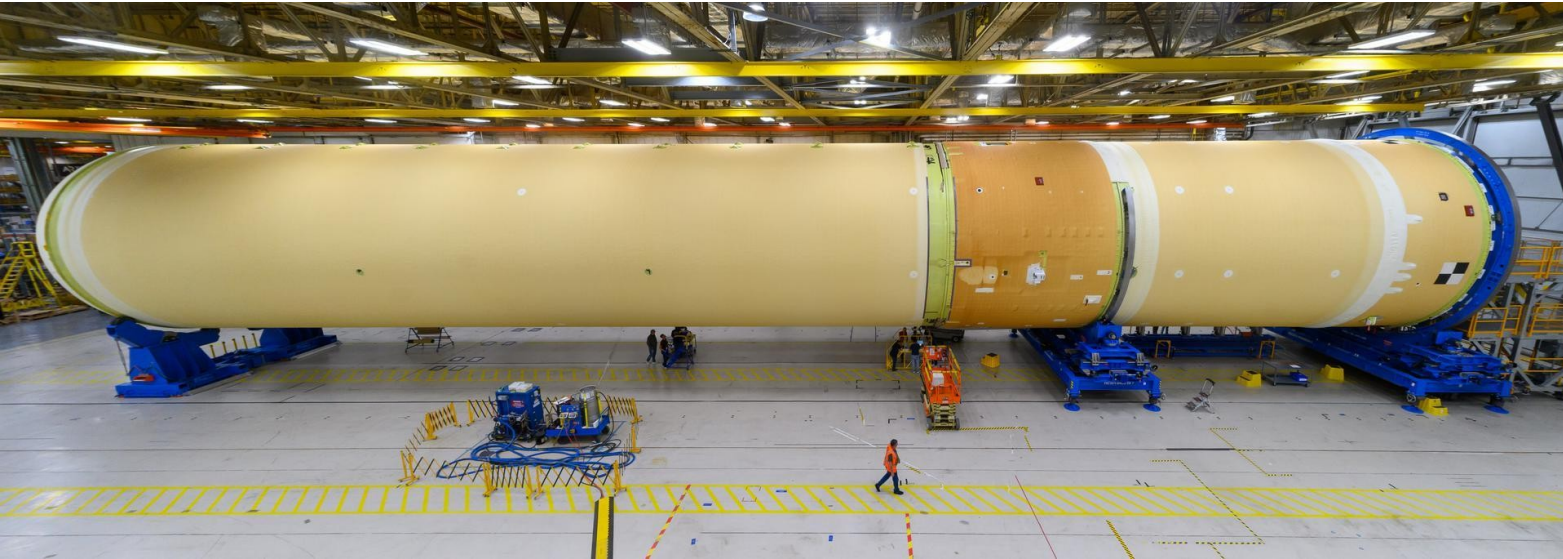


Chrysler Saturn I B



Boeing Saturn V S1- C

# SLS Core Stage Manufacturing



# SLS Core Stage Manufacturing



Liquid oxygen tank



Liquid hydrogen tank



Two fuel tank domes were recently finished for the SLS rocket. One is a qualification article and the other is the actual flight article for the first mission

# SLS Core Stage Manufacturing



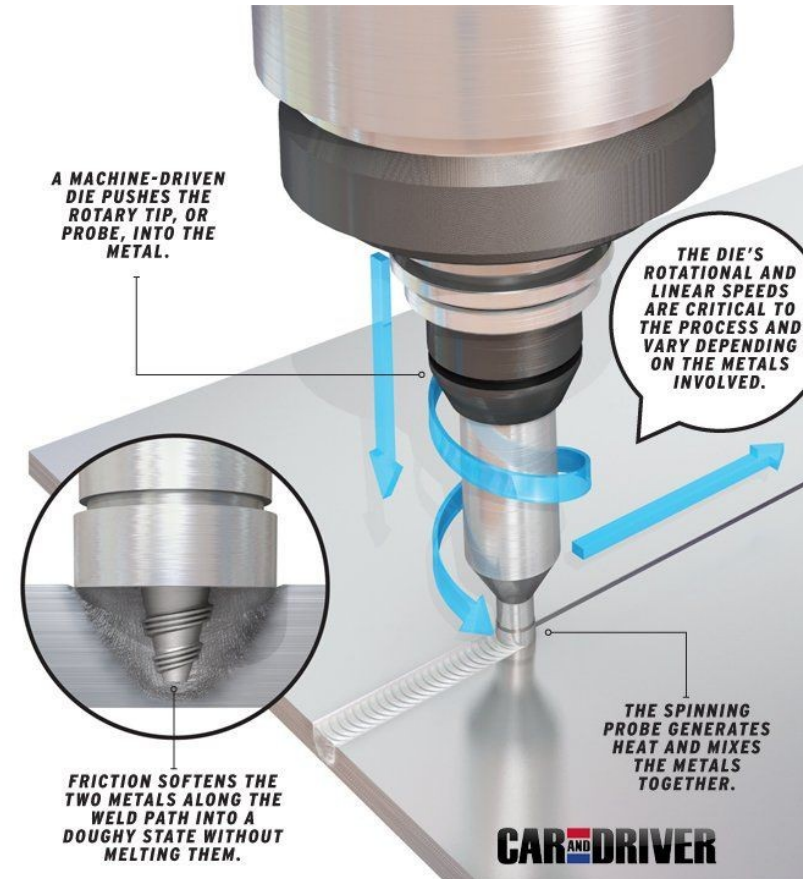
The Gore Weld Tool (foreground) and Circumferential Dome Weld Tool (background) used to fabricate dome segments for the SLS liquid hydrogen and oxygen core stage tanks via vertical *friction stir welding* operations



The Vertical Weld Center tool used to fabricate barrel segments for the SLS liquid hydrogen and oxygen core stage tanks via vertical *friction stir welding* operations To the right of the welder is the weld confidence barrel

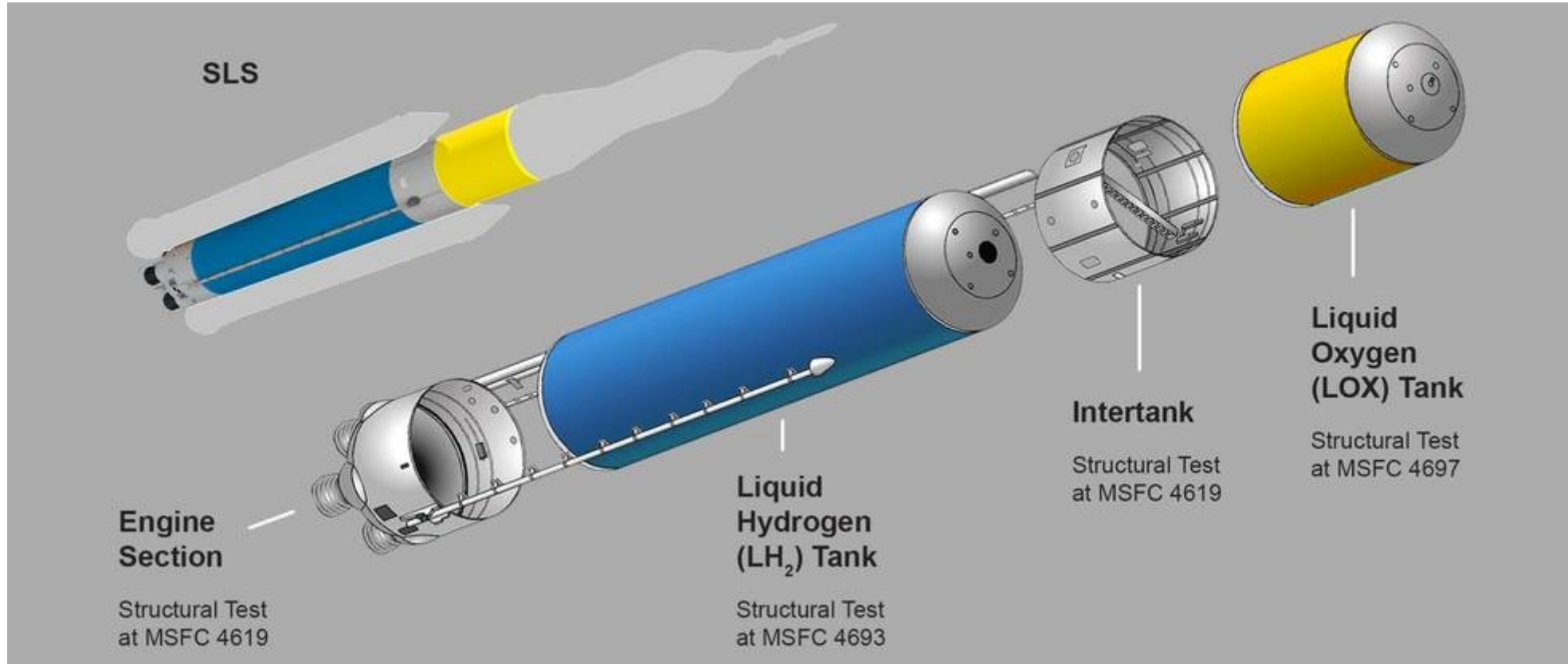
# SLS Core Stage Manufacturing Friction Stir Welding

- SLS uses “friction stir welding”
- Friction stir welding is one kind of solid-state joining that relies on a tool to combine two facing workpieces
- The tool is rotated and travels along the mating joint of the workpieces being welded, with the resulting friction generating the heat necessary to merge the two pieces
- The tool softens the two pieces of metal enough that mechanical intermixing occurs, forging the metal under the mechanical pressure
- The result is a stronger and more defect-free weld, than traditional methods of joining materials





# SLS Core Stage Testing at MSFC



# SLS Engine Section Structural Testing MSFC

## SPACE LAUNCH SYSTEM ENGINE SECTION Structure Testing of the World's Largest Rocket Stage

### WHAT'S THE OBJECTIVE?

- ✓ Validate models used for engine section design
- ✓ Verify the structural design will withstand predicted loads with margin
- ✓ Validate the core stage for both the SLS Block 1 and Block 1B rocket configurations

The engine section is attached to the structural test equipment at the top, called the "spider," which remains stable as **LOADS (INDICATED BY WHITE ARROWS)** are applied to the test assembly at the bottom and sides, simulating forces the SLS engine section will experience in flight.



### ENGINE SECTION

NASA's SLS core stage flight engine section is an attach point for **4 RS-25 ENGINES** and **2 SOLID ROCKET BOOSTERS** that produce a combined **8.8 MILLION** pounds of thrust.



**55 HYDRAULIC CYLINDERS** apply up to 4.5 million lbs vertical force and 900,000 lbs side force

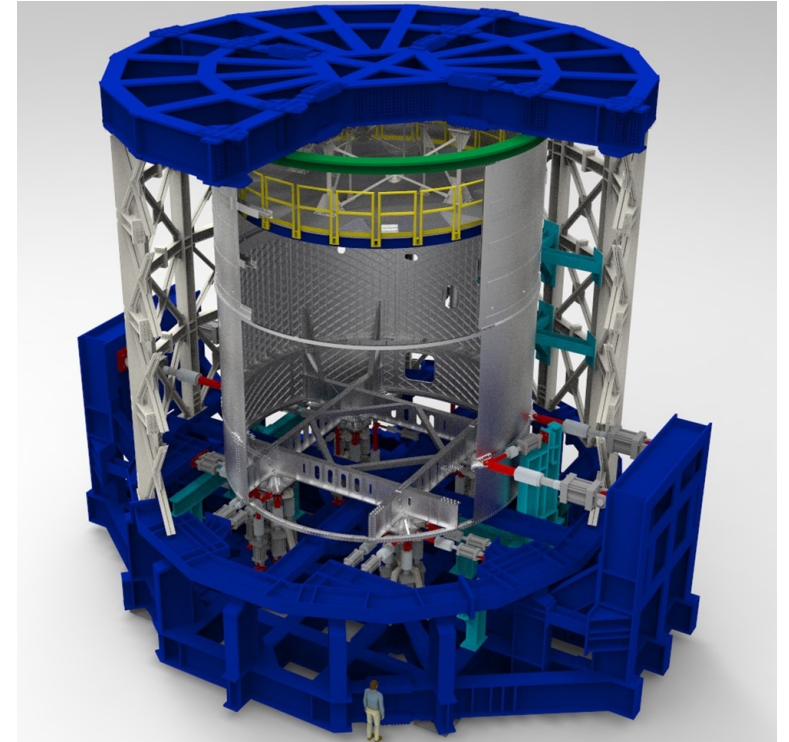
**59 TEST CASES** apply forces similar to launch loads to put the test article through its paces



The **ENGINE SECTION TEST ASSEMBLY** stands over **30 FT TALL** and weighs almost **70,000 LBS**

The **ENGINE SECTION STRUCTURAL TEST EQUIPMENT** stands about **50 FT TALL** and weighs approximately **1.5 MILLION LBS**

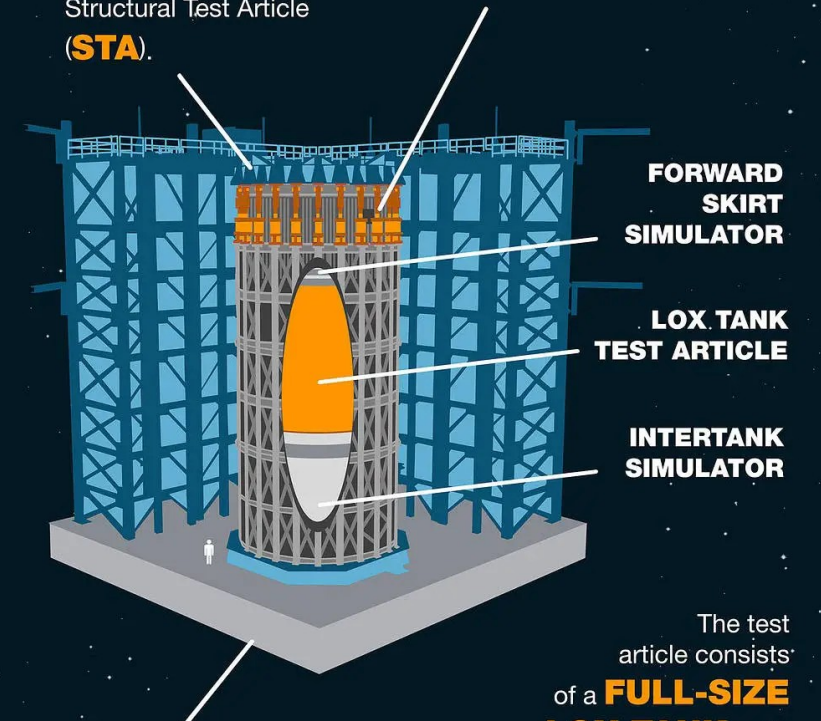
**3,200 SENSORS** measure forces, stress, temperature, pressure, sound, deflection and strain



## SLS Oxygen Tank Structural Testing MSFC

More than **1 MILLION LBS** of special test equipment will apply mechanical loads to the LOX Structural Test Article (**STA**).

About **9 MILLION LBS** of combined force can be applied to the STA via **34 ACTUATORS**, designed to simulate stresses the SLS LOX tank will encounter in flight.



The diagram shows a cross-section of the LOX tank test article (a yellow and white cylindrical structure) mounted within a large, blue, cage-like test stand. The stand is supported by a reinforced concrete floor. Labels point to the 'FORWARD SKIRT SIMULATOR' at the top, the 'LOX TANK TEST ARTICLE' in the center, and the 'INTERTANK SIMULATOR' at the bottom. A small human figure is shown at the base of the stand for scale.

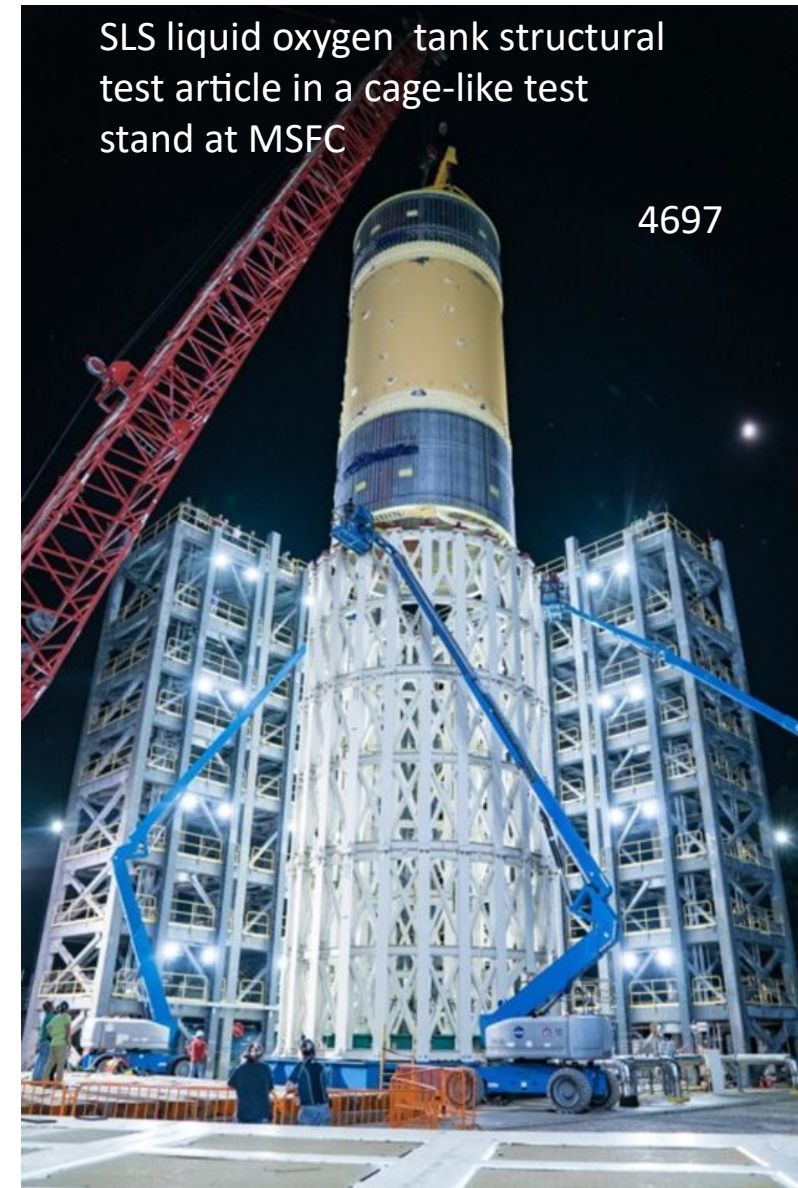
**FORWARD SKIRT SIMULATOR**

**LOX TANK TEST ARTICLE**

**INTERTANK SIMULATOR**

The test article consists of a **FULL-SIZE LOX TANK**, with intertank and forward skirt **SIMULATORS**.

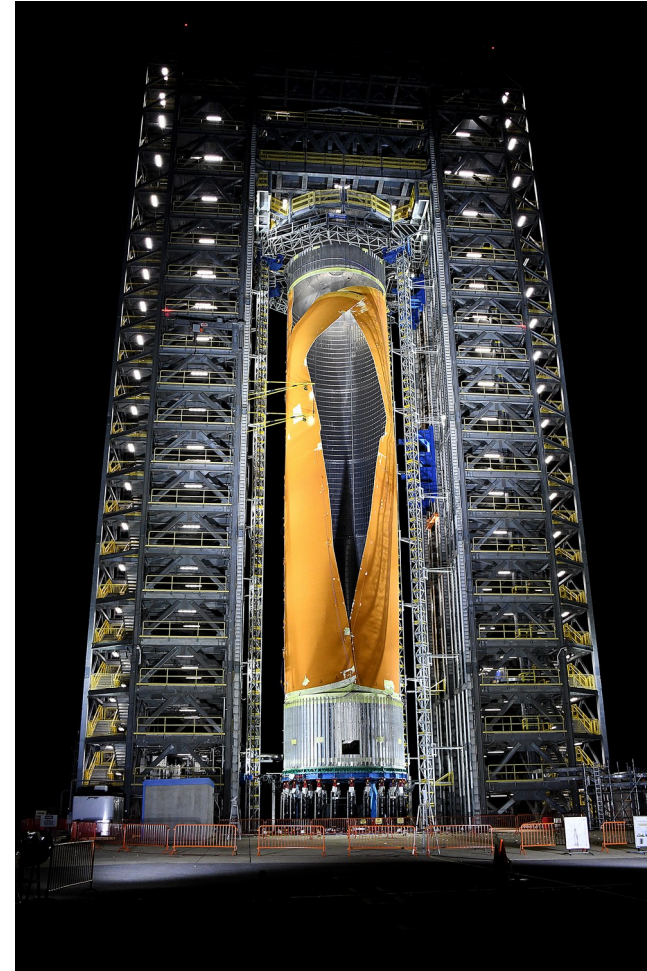
The new test stand has a **REINFORCED CONCRETE FLOOR** with over **1600 ANCHORS**.



## SLS Hydrogen Tank Structural Testing MSFC



The SLS liquid hydrogen tank structural test article in a cage-like test stand at MSFC



[https://duckduckgo.com/?q=sls+hydrogen+tank+test&t=ffab&iax=videos&ia=videos&iai=https%3A%2F%2Fwww.youtube.com%2Fwatch%3Fv%3DoUvjZ9E\\_L\\_8](https://duckduckgo.com/?q=sls+hydrogen+tank+test&t=ffab&iax=videos&ia=videos&iai=https%3A%2F%2Fwww.youtube.com%2Fwatch%3Fv%3DoUvjZ9E_L_8)

# SLS Core Stage Transport

## ROLLIN' ON THE RIVER: NASA'S BARGE PEGASUS

Pegasus was modified to transport the **LARGEST ROCKET STAGE IN THE WORLD**—the Space Launch System (SLS) Core Stage. The barge's first trips will ferry Core Stage test articles.

The SLS Core Stage measures **212' LONG & 27.6' DIAMETER**

**BARGE PEGASUS**  
310' LONG & 50' WIDE

**AFT (REAR)** **FORE (FRONT)**

**MARSHALL**  
**MICHOUD**

**FOUR TEST ARTICLES** are being transported to NASA's Marshall Space Flight Center for a series of critical structural tests that simulate the forces experienced during flight

**CORE STAGE TEST ARTICLES**

- 1 **ENGINE SECTION (MINUS ENGINES)**
- 2 **LIQUID HYDROGEN (LH2) TANK**
- 3 **LIQUID OXYGEN (LOX) TANK**
- 4 **INTERTANK**

From NASA's Michoud Assembly Facility—America's rocket factory in New Orleans—to Marshall Space Flight Center in Huntsville, Alabama, Pegasus travels **710 MILES BY RIVER**

Pegasus is a self-sustaining vessel except for propulsion, which comes via **2 TUGBOATS (ONE PUSHES AND ONE PULLS)**



# SLS Core Stage Transport Pegasus Barge

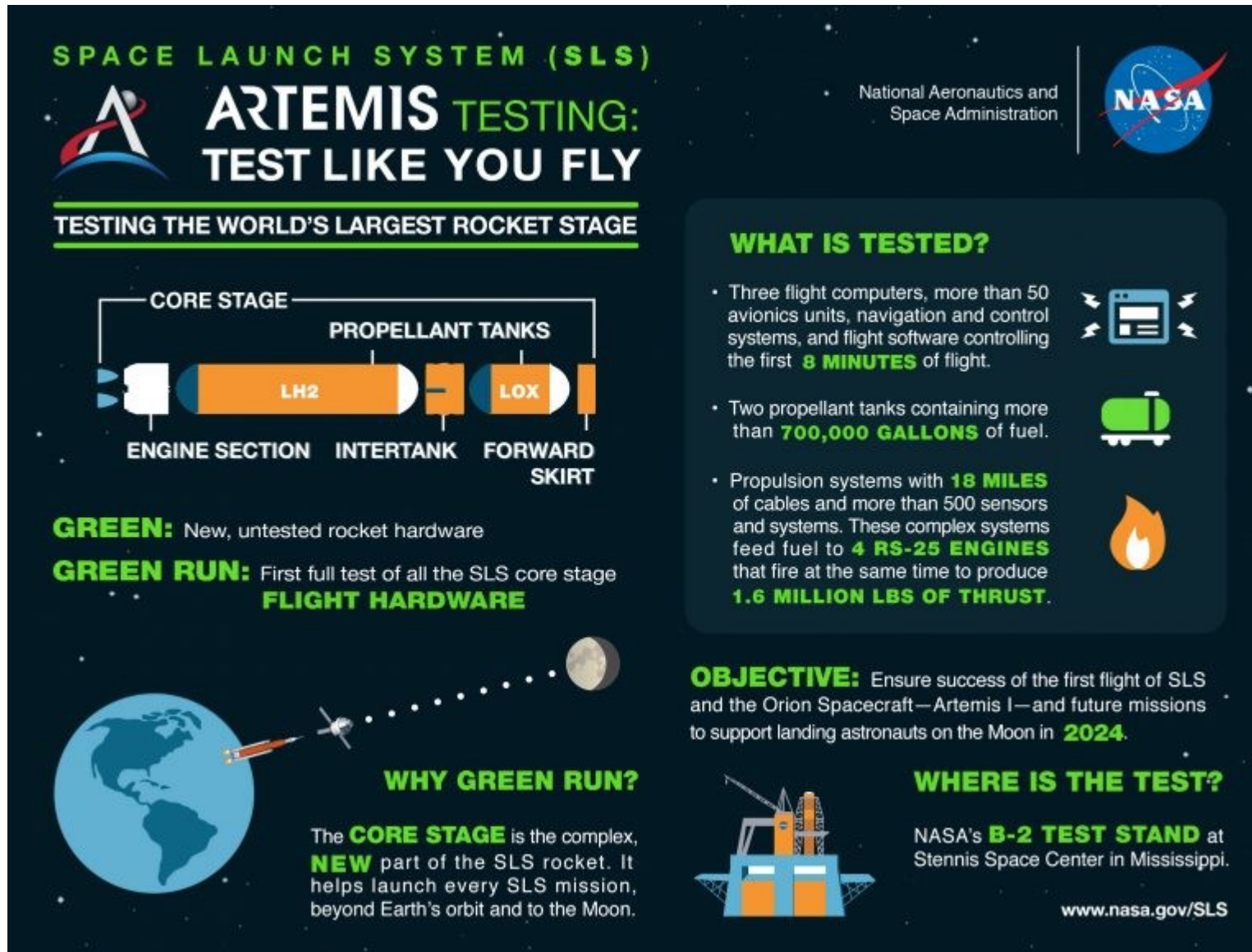


# Stennis Space Center SLS Core Stage Testing



An aerial photo shows all three NASA Stennis Space Center (SSC) test complexes - the E Test Complex (foreground), the three A Test Complex stands (middle) and the B Test Complex (back).

# SLS Core Stage Green Run Test



The infographic is set against a dark blue space background with stars. At the top left is the Artemis logo, a stylized 'A' with a red swoosh and a blue swoosh. To its right is the text 'SPACE LAUNCH SYSTEM (SLS)' in green, 'ARTEMIS TESTING: TEST LIKE YOU FLY' in white and green, and 'TESTING THE WORLD'S LARGEST ROCKET STAGE' in white. In the top right corner is the NASA logo and the text 'National Aeronautics and Space Administration'. The central part features a diagram of the core stage with labels: 'CORE STAGE' (bracketed), 'ENGINE SECTION', 'PROPPELLANT TANKS' (bracketed), 'LH2', 'INTERTANK', 'LOX', and 'FORWARD SKIRT'. Below this are three green text blocks: 'GREEN: New, untested rocket hardware', 'GREEN RUN: First full test of all the SLS core stage FLIGHT HARDWARE', and 'WHY GREEN RUN?' with a paragraph explaining the core stage's role. To the right is a 'WHAT IS TESTED?' section with three bullet points and icons: a computer monitor for avionics, a fuel tank for propellant, and a flame for engines. Below that is an 'OBJECTIVE' section and a 'WHERE IS THE TEST?' section with an illustration of the B-2 test stand. At the bottom right is the website 'www.nasa.gov/SLS'. At the bottom left is an illustration of the Earth and the Moon with a rocket trajectory.

**SPACE LAUNCH SYSTEM (SLS)**

**ARTEMIS TESTING: TEST LIKE YOU FLY**

**TESTING THE WORLD'S LARGEST ROCKET STAGE**

**WHAT IS TESTED?**

- Three flight computers, more than 50 avionics units, navigation and control systems, and flight software controlling the first **8 MINUTES** of flight.
- Two propellant tanks containing more than **700,000 GALLONS** of fuel.
- Propulsion systems with **18 MILES** of cables and more than 500 sensors and systems. These complex systems feed fuel to **4 RS-25 ENGINES** that fire at the same time to produce **1.6 MILLION LBS OF THRUST**.

**OBJECTIVE:** Ensure success of the first flight of SLS and the Orion Spacecraft—Artemis I—and future missions to support landing astronauts on the Moon in **2024**.

**WHERE IS THE TEST?**

NASA's **B-2 TEST STAND** at Stennis Space Center in Mississippi.

[www.nasa.gov/SLS](http://www.nasa.gov/SLS)

**GREEN:** New, untested rocket hardware

**GREEN RUN:** First full test of all the SLS core stage **FLIGHT HARDWARE**

**WHY GREEN RUN?**

The **CORE STAGE** is the complex, **NEW** part of the SLS rocket. It helps launch every SLS mission, beyond Earth's orbit and to the Moon.



# Stennis Space Center B2 Test Stand SLS Green Run Testing




**SLS Core Stage** is removed from **Pegasus** barge and installed in the B-2 position at the B Test Stand at the Stennis Space Center (SSC) in Mississippi



The **Green Run** test for SLS Core Stage

# SLS Core Stage Green Run Test




SPACE LAUNCH SYSTEM

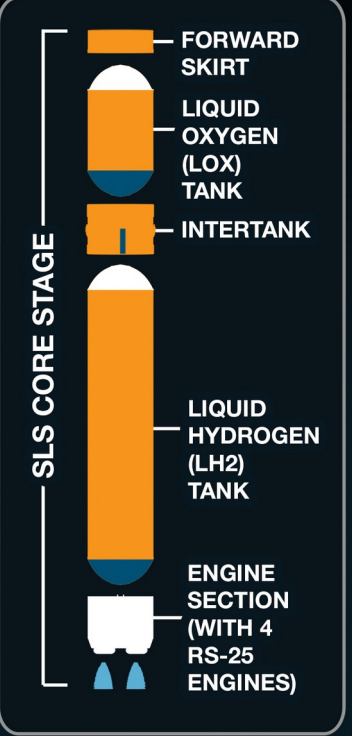
## ARTEMIS TESTING: GREEN RUN CHECKLIST

**TESTING THE WORLD'S LARGEST ROCKET STAGE**

A total of eight Green Run tests minimize risk to the **ARTEMIS I** core stage and ensure the flight hardware satisfies design objectives and validates design models:

- TEST 1** Apply forces simulating launch to the unpowered, suspended core stage. ✓
- TEST 2** Turn on and check out core stage avionics. ✓
- TEST 3** Simulate potential issues to test systems that shut down other systems if there's a problem. ✓
- TEST 4** Test main propulsion system components that connect to the engines. ✓
- TEST 5** Test thrust vector controls and check out all the related hydraulic systems. ✓
- TEST 6** Simulate launch countdown to validate timeline and sequence of events. ✓
- TEST 7** Load and drain more than 700,000 gallons of cryogenic propellants. ✓
- TEST 8** Fire all four RS-25 engines for up to 8 minutes.

National Aeronautics and Space Administration 



FORWARD SKIRT  
LIQUID OXYGEN (LOX) TANK  
INTERTANK  
LIQUID HYDROGEN (LH2) TANK  
ENGINE SECTION (WITH 4 RS-25 ENGINES)


SLS CORE STAGE

### #ARTEMIS




<https://youtu.be/-uiayTfW9TQ>

# SLS, Orion and Ground Systems Test

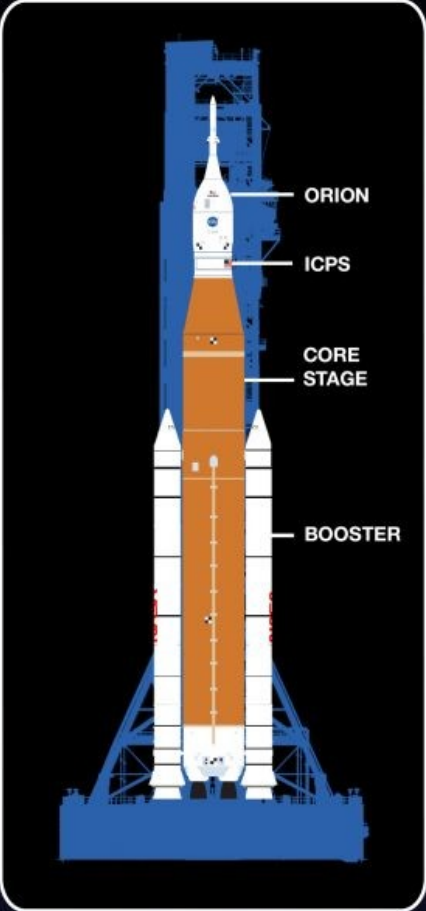


# ARTEMIS I

National Aeronautics and Space Administration 

## Integrated Testing: SLS Rocket, Orion Spacecraft, & Ground Systems

- Verify function of interfaces between Orion and ground systems
- Verify function of interfaces between SLS core stage and boosters with ground systems
- Verify function of interfaces between SLS upper stage with ground systems
- Verify function of interfaces throughout integrated SLS and Orion with ground systems
- Integrated test of all SLS and Orion critical communications systems
- Test countdown commanding sequence with simulated countdown before rolling to launch pad
- Checkout various SLS systems functionality
- Checkout SLS and Orion functionally with launch pad systems before and after roll out
- Demonstrate tanking and detanking SLS with cryogenic, or supercold, propellants, at the launch pad
- Test and install pyrotechnics for flight termination system



# Space Exploration Company Launch Sites and Facilities

- Cape Canaveral FL- Space Force Station\*
- Kennedy Space Center FL – NASA\*
- Vandenberg CA- Space Force Base\*
- SpaceX Rocket Development and Test Facility, McGregor, Texas
- SpaceX high-altitude test facility - New Mexico
- SpaceX Starbase - TX
- Floating launch platforms

\*U.S. Government facility



Next Session

Artemis I Mission