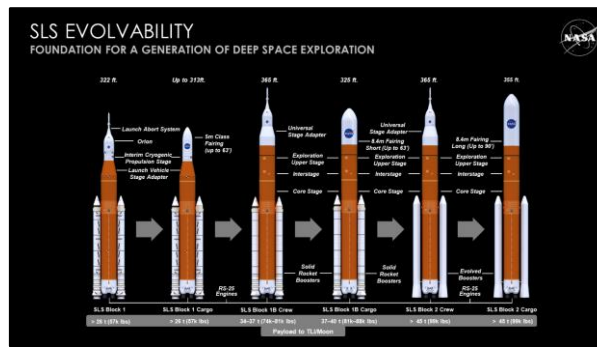




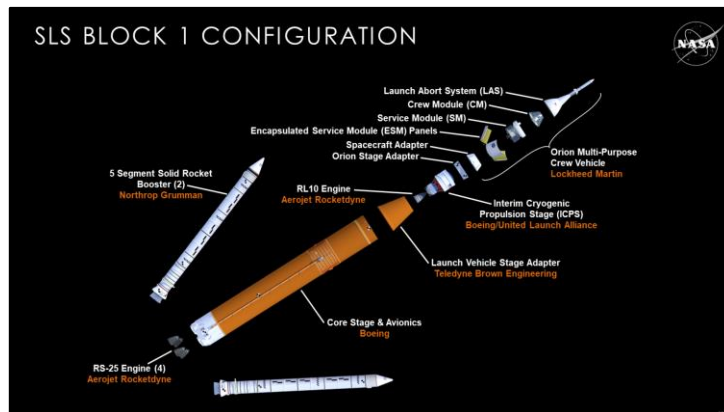
# **NASA'S SPACE LAUNCH SYSTEM: ARTEMIS 1 VEHICLE NEARS COMPLETION**

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SPACE LAUNCH SYSTEM PROGRAM  
AUGUST 19-22, 2019

- **Good morning!**
- **We want to update you on our progress.**
- **Every year seems to be more dramatic and more exciting than the last for SLS. 2018 and 2019 are no different.**
- **We have made significant progress while continuing to overcome some “first-article” manufacturing issues. I’ll talk about those subjects today.**
- **Note that the accomplishments and images here may be different than the images in the paper as submitted. We’ve added more recent accomplishments as they became available to give you the very latest information.**



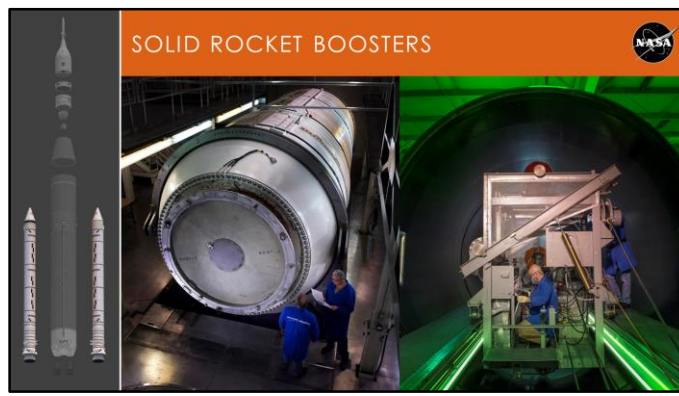
- Our government and commercial transportation fleet for the Moon and Mars is led by the Space Launch System, the most powerful, capable launch vehicle in the world. And it's also a capability designed to evolve as our goals become more challenging.
- We are building the first Block 1 crew vehicle now for our first mission – Artemis 1 – and work is under way on two more Block 1 vehicles for future missions.
- Artemis 1 will be a great early test of SLS, Orion and ground systems. , but it's just the beginning. We are also working on the Block 1B design that will become our workhorse for lunar missions beyond. The 1B will incorporate EUS, USA, and new production RS-25 engines.
- We're not a low Earth orbit rocket. We are designed as a human-rated deep space transportation system. Block 1 will have more than 26 metric tons (57,320 lb) of payload to TLI. Block 1B will have 34 to 40 metric tons (74,957 – 88,185 lb), depending on whether its crew or cargo configuration. Block 2 cargo will have more than 45 tons (99,208 lb). That is by far more capability than any existing rocket.
- These are not meaningless statistics. The benefits of heavy lift are obvious for something as challenging as space exploration. The ability to transport large payloads reduces payload complexity and operational complexity from the ground all the way to space. It saves time and money and increases our chances for mission success.



***But first we have to build SLS. So having set the stage regarding the program, let's talk about our progress.***

***Let's take a look at the SLS configuration for our maiden Exploration Mission-1:***

- Visible are the major elements of the EM-1 vehicle – solid rocket boosters, core stage, {engine section, LH tank, intertank, LOX tank, forward skirt} LVSA and ICPS, OSA, and Orion/SM/LAS.
- Work is well underway on our initial Block 1 configuration, and we are overcoming challenges and making steady progress.
- As I will show you in upcoming slides, all major hardware for structural testing and for Artemis 1 has completed manufacturing, assembly and most outfitting. We've completed the ICPS, OSA and LVSA. The core stage is almost done, with the forward skirt, LOX tank, intertank, and LH tank joined. The engine section/boat tail is scheduled for integration in the August/September time.
- So let's shift gears from the vision to the hard stuff of making it happen. And we are making it happen.



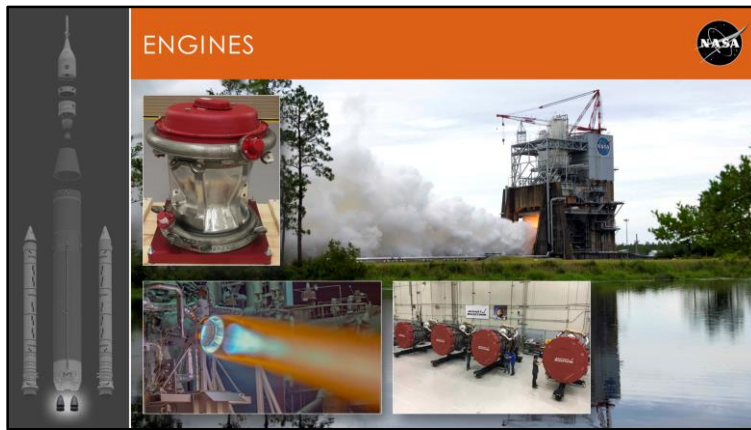
**LEFT IMAGE:** Technicians at Northrop Grumman in Promontory, Utah inspect a completed motor segment.

**RIGHT IMAGE:** Northrop Grumman technicians have applied insulation to the final booster motor segment for the second flight of SLS.

- The 10 booster motor segments for the first SLS mission are complete at Northrop Grumman facilities in Utah. Motor casting for 9 of 10 segments is complete for Artemis 2, with the final segment was cast in July. Avionics are qualified at the system level and will soon be tested with core stage avionics.
- At Kennedy, the Artemis 1 forward and aft skirts are being refurbished and outfitted for flight. TVC has been installed in the left-hand and right-hand aft skirts and teams recently completed a hot fire test on an aft skirt pathfinder in preparation for final assembly and checkout.
- Booster separation motors are complete on the left-hand and right-hand aft skirts.
- At Marshall, the avionics recently finished qualification testing and will be tested with vehicle avionics later this year.
- Hardware is in progress for the third SLS flight also.
- On the horizon – Flight Support Booster -1, which will qualify a new supplier for ammonium perchlorate and aluminum. Testing in spring of 2020.

#### **Booster facts:**

- Each 177 feet or 17 stories tall – taller than the Statue of Liberty
- Each is 12 feet in diameter.
- Each booster burns through 1,385,000 pounds of propellant in two minutes – that's an average of 5.5 tons of propellant every second.
- Each booster's thrust is greater than 14 four-engine Boeing 747s at full take-off power.
- During flight, the temperature of the motor chamber gases reach more than 5,000°F – hot enough to boil steel.



**Basics:** 4 RS-25 engines vs 3 for shuttle, 109% thrust vs 104.5%, new controller and software and nozzle insulation, more than 500,000 lbs thrust each, more than 1 million seconds total ground and flight time. Program starts with 14 flown engines and 2 new serial number engines built from spares.

**MAIN IMAGE:** April 4, 2019 RS-25 #2062 hotfire test, completing 4 years of RS-25 testing.

**COUNTERCLOCKWISE FROM TOP LEFT:** HIP bonded Main Combustion Chamber for test program, RL10 upper stage engine in testing, Artemis 1 RS-25 flight set at Michoud Assembly Facility ready for integration.

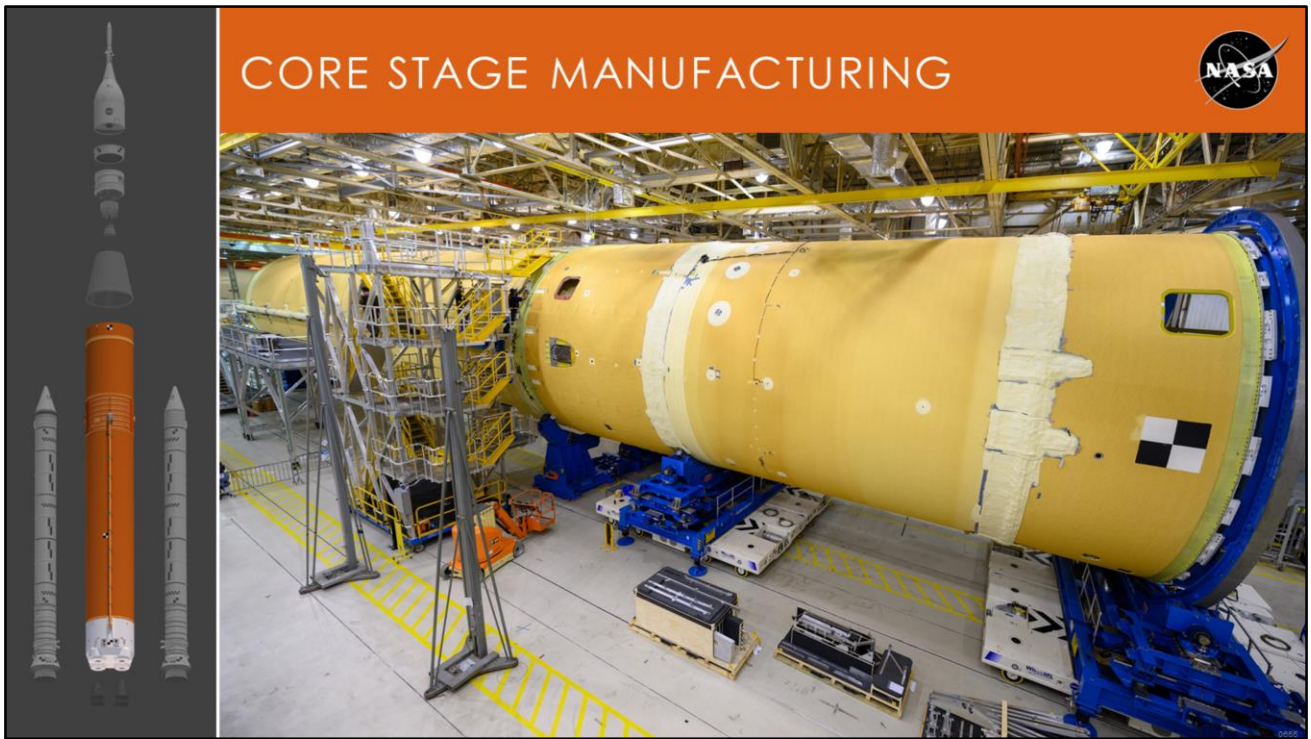
#### **RS-25 TEST SERIES ACCOMPLISHMENTS:**

- Development engine hotfire series clears all 16 former space shuttle main engines and their new engine controllers for SLS. (Only 2 flight engines green run hotfired.)
- Program has been hot-fire testing the RS-25 engines since 2015 to ensure the engines can perform under the different SLS pre-launch conditions, higher heating environment, and flight thrust profiles, and also to qualify the new Artemis 1 controllers. 32 tests and more than 14,000/nearly 15,000 seconds hot fire time when we take a break from testing after our 4/4/19 test for test stand mods.

#### **OTHER PROGRESS:**

- AR has completed acceptance hotfire tests of the 4 RL10C-3 flight engines in support of the first SLS Block 1B missions.
- Received AR's proposal for 18-follow-on new RS-25 engines. The new engine will be an affordable, expendable variant of the RS-25 that costs at least 33 percent less and operates at 111% (521,000 lb) thrust. It incorporates new materials and new manufacturing processes, as well as new technology like 3D printing. The latest test series beginning in 2018 includes a 3D printed pogo accumulator and a hot isostatic pressure (HIP) bonded main combustion chamber.





**MAIN IMAGE:** 4/5 of the core stage joined at MAF.

Core stage flight hardware is well underway for the Artemis 1 rocket. The top half of the Core Stage, known as the “forward join” is complete, and has been joined with the liquid hydrogen tank. The forward join consists of three parts: the forward skirt, liquid oxygen tank and intertank. It makes up 66 feet of the 212-foot-tall core stage.

To expedite delivery, we have increased the number of technicians, created new parallel work processes where possible, begun prepackaging tools for the next shift and co-located SLS Program staff with the contractor to accelerate decision-making and problem resolution.

We plan to complete the core stage in December and ship it to Stennis Space Center for green run.

**Other:**

- Last core stage avionics hardware component has been installed.
- SITF-Q completed software testing as part of intertank functional tests in 2018, and forward skirt testing was completed summer 2018 to demonstrate avionics system harnesses – first major core stage component ready for flight.
- Ground support equipment has completed testing.
- B-2 test stand at Stennis Space Center continuing to get ready for core stage green run.



**While flight stage work continues at MAF, MSFC is engaged in its largest test program since the Shuttle.**

**LEFT IMAGE:** The nearly 70 feet long LOX tank structural test article is loaded into test stand 4697 at MSFC in July. The test program is pending. The test article includes intertank and forward skirt simulators on top and bottom. A totally of 34 actuators capable of generating a combined force of more than seven million pounds will be attached. More than 2500 channels of data will collect tank performance. As part of the test the tank will be filled with about 193,000 gallons of liquid nitrogen for one test and 197,000 gallons of water for other test cases. The four-month campaign includes about 24 load cases.

**RIGHT IMAGE:** Workers at NASA's Marshall Space Flight Center loaded the SLS liquid hydrogen tank test article into test stand 4693 at MSFC Jan. 14, 2019. The liquid hydrogen tank is part of the rocket's core stage that is more than 200 feet tall with a diameter of 27.6 feet, and stores cryogenic liquid hydrogen and liquid oxygen that will feed the vehicle's RS-25 engines. The liquid hydrogen tank test article is structurally identical to the flight version of the tank that will comprise two-thirds of the core stage and hold 537,000 gallons of LH2 liquid hydrogen at minus 423 degrees Fahrenheit. Testing is planned for June through September. The STA consists of a full-size hydrogen tank, with intertank and engine section simulators on the top and bottom of the tank. Thirty-eight hydraulically-actuated load lines will compress and stretch the tank vertically with up to 3 million pounds force, push and pull the tank laterally with up to 340,000 pounds force, and apply specified forces in key locations. Approximately 40 tests will be performed during a roughly 4-month test campaign. A variety of instruments will collect nearly 4,000 measurements on the test article including strain, deflection, temperature, pressure, sound, and video. Additional instrumentation will record test stand movement and fluid supply line temperature and pressure.

#### **OTHER TEST STATUS:**

- Engine section structural testing was completed in early 2018. Intertank testing began summer 2018 and is nearing completion
- The SLS Core Stage will be the tallest rocket stage ever flown. When completed, the Core Stage will be 212 feet tall (64.6 m) and 27.6 ft. (8.4 m) in diameter.
- The core stage will weigh 2.3 million pounds when fueled
- The liquid hydrogen tank measures more than 130 feet tall, comprises almost two-thirds of the core stage and holds 537,000 gallons of liquid hydrogen cooled to minus 423 degrees Fahrenheit.
- The Core Stage is being built by prime contractor Boeing at Michoud Assembly Facility outside New Orleans, LA, using state-of-the-art manufacturing tools, including the world's largest friction-stir welding tool, the Vertical Assembly Center.



**Touching on several other accomplishments:**

**TOP LEFT:** The core stage pathfinder article arrives in May at Stennis Space Center for tests. It's the same size, shape and weight as the core stage and was built to practice moves with the flight core stage at MAF, SSC and KSC. It's 212 feet long 27.6 feet in diameter and weighs 228,000 pounds. It validates ground support equipment and helps train operators.

**TOP RIGHT:** Work continued this year to finish integrating components with the Launch Vehicle Stage Adapter, which connects the core stage with the interim cryogenic propulsion stage. This shows the frangible joint assembly, designed to break apart allowing the hardware elements to separate in flight. The LVSA is due to ship to KSC in early 2020.

**BOTTOM RIGHT:** Researchers at NASA's Plum Brook Station in Ohio conducted development tests on a proposed design of acoustic panels for the SLS Universal Stage Adapter. Acoustic data will be used to ensure future payloads aboard Block 1B, are protected from the high levels of noise and vibration experienced during launch.

**LOWER LEFT:** The former Shuttle Engineering Support Center has been renovated as the SLS Engineering Support Center at MSFC. More than 160 SLS engineering experts with reachback to other NASA centers and contractors to analyze any problems. Shuttle data stream was about one megabit per second. The new center will have 25 times that. The new center will have up to 156 voice loops vs. 20 loops in Shuttle.

**OTHER:**

- Integrated Structural Test of upper stage successfully completed in May 2017 at MSFC. Consisted of test articles of ICPS, LVSA, OSA and FJA
- ICPS and OSA finished and shipped to EGS in 2017 and 2018
- ICPS will remain in Space Station Processing Facility until needed for stacking
- OSA will remain in SSPF until payloads are integrated, then it will be stacked



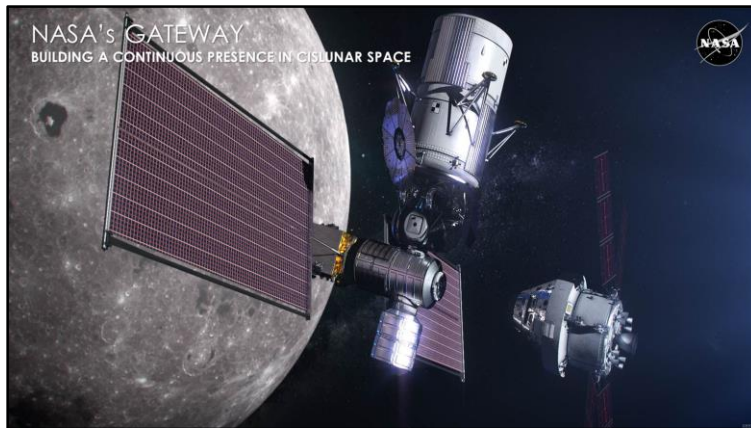


**LEFT IMAGE: Full moon photographed by Apollo 11 trans-Earth return, 10,000 miles away.**

**I generally stick to technical progress and steer clear of policy and budget, but I'll make an exception here as this is affecting technical and schedule.**

- In a National Space Council meeting in Huntsville on March 26, Vice President Mike Pence gave NASA the historic challenge “use all means necessary” to return American astronauts to the Moon within the next five years, accelerating NASA’s plans by four years. Our goal is a landing on the lunar South Pole.
- Teams across the agency are looking at how to do that. From an SLS perspective, we delivered a report to NASA Headquarters on doing an SLS flight readiness firing at KSC versus a stage green run at Stennis Space Center. We concluded it was possible with additional risk. In July, the Administrator decided we will go forward with green run. We continue to look at ways to be more efficient with our time.
- NASA also announced it completed an analysis to assess flying Orion around the Moon on schedule. The review reaffirmed NASA’s commitment to launch SLS with Orion on Artemis 1 in 2020. While some commercial options could meet the task, none was capable of achieving NASA’s goals to orbit around the Moon within our timeline or budget.
- We are looking at other ways to accelerate core stage production and testing and the resources needed to make that happen. One of those ways is classifying Artemis 1 as a “test flight”, which has fewer requirements.
- NASA is continuing to work with OMB and the National Space Council, on the

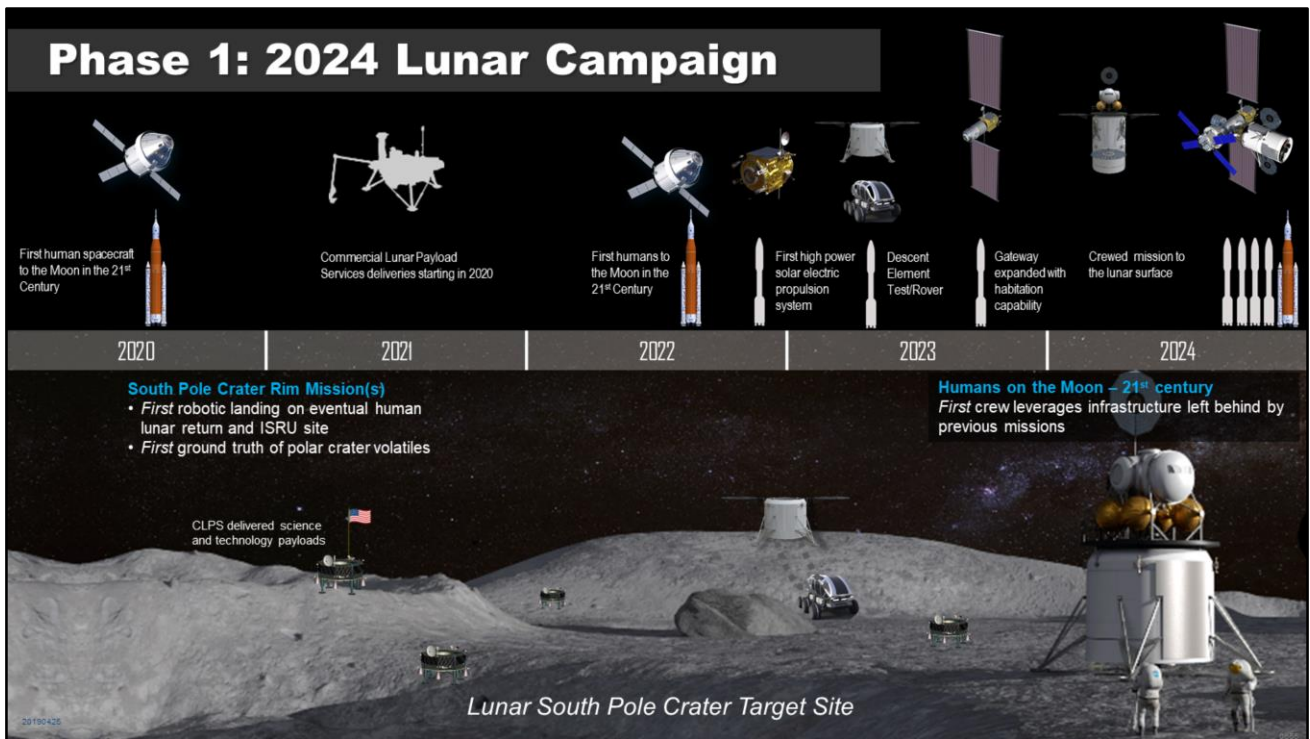
- resources required to land American astronauts on the Moon by 2024.
- We continue to work toward a late 2020 first launch and look for ways to accelerate our work, so we can launch the first crewed mission in 2022.



- SLS' first major job will be transporting crew and cargo to the Moon with the goal of assembling a new crew-tended Gateway spaceport in orbit around the Moon and landing the first woman and the next man on the lunar surface.
- A power and propulsion element, as well as habitation, airlock and logistics capabilities, will establish the core functionalities of the Gateway.
- NASA is looking at commercial and SLS co-manifested payload options to launch the individual Gateway components, and assemble them in space.
- The Gateway can operate from a variety of lunar orbits and be moved when the crew is not present.
- The Gateway can contribute to lunar surface activities and have application to farther destinations in the solar system, including Mars. It serves both as training and hardware maturation element as well as operational element needed to send humans beyond low-Earth orbit.
- NASA is discussing components that International Space Station partners could potentially provide to the Gateway.
- NASA and its partners will use the Gateway for deep-space operations including missions to and on the Moon with decreasing reliance on Earth. Using lunar orbit, the agency will develop its exploration systems and gain the experience necessary to extend human presence farther into the solar system than ever before.

**PROGRESS:** NASA selected Northrop Grumman to build a pressurized hab module derived from their Cygnus cargo craft. NASA selected Maxar Technologies to develop and demonstrate a 50 kw solar electric propulsion spacecraft called the Gateway Power and Propulsion Element module. Also, under the NextSTEP program, in coming months, NASA will do ground test inside 5 full-size habitat prototypes from 5 US companies. None will advance to flight. They will be used to evaluate design standards, common interfaces, requirements for a future habitation module, and reduce risk for flight systems. Effort began in 2015 with concept studies – Lockheed Martin, Northrop

Grumman, Boeing, Sierra Nevada, Bigelow Aerospace. NanoRacks has proposed a concept study with plan to develop full-scale prototypes.



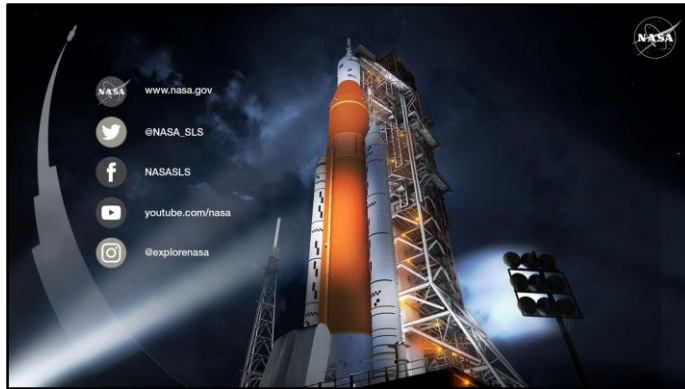
### Overview of the agency's revised plans for deep space exploration based on recent administration guidance:

- This is a simplified view of a notional manifest through 2024, showing SLS and commercial transportation required to implement our plan. NASA will call on the strengths of both government and commercial industry to establish the Gateway as an assembly point for a landing mission by 2024.
- The Artemis program incorporates the commercially provided support missions, delivering hardware and supplies to the Moon, as well as the SLS/Orion/Exploration Ground Systems programs' missions.
- NASA is charged with landing American astronauts on the Moon in the next five years with a landing on the lunar South Pole.
- Artemis 1: First flight test of SLS and Orion spacecraft as an integrated system
- Artemis 2: First flight of crew to the Moon aboard SLS and Orion
- Artemis 3: First crew to the lunar surface (via a human landing system from the Gateway in lunar orbit.
- As a result of Artemis, NASA will also establish a sustainable human presence on the Moon by 2028.





Here's a short video of a sample of our progress.



- As always, there are many ways to follow developments with SLS and NASA exploration.
- Reserve your seats for my presentation next year, when we hope we will be getting close to launch.
- Thanks for your time. I'd be happy to answer questions.