ASSEMBLING AND TESTING NASA'S SPACE LAUNCH SYSTEM FOR FIRST FLIGHT

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Figure 1: Artist's concept of SLS Block 1 on the Mobile Launcher for EM-1

ABSTRACT

NASA is planning its next step toward human expansion into the solar system. The Space Launch System (SLS) (Figure 1) is a critical enabling component of that expansion. SLS payloads for its early missions include the Orion crew vehicle and components for Gateway, a lunar outpost orbiting the Moon that will facilitate research, technology and partnerships for eventual Mars missions. All major core stage hardware for test and flight completed structural manufacturing in 2018. The major components for the first flight vehicle are complete or approaching completion of internal equipment installation. The core stage forward join operation is also complete. The 10 booster segments needed for first flight have been cast and are ready to ship to NASA's Kennedy Space Center (KSC) for mating and stacking. The four RS-25 core stage engines completed processing at NASA's Stennis Space Center (SSC) and are ready for core stage integration. The Orion Stage Adapter (OSA) joined the Interim Cryogenic Propulsion Stage (ICPS) at KSC to await the rest of SLS flight hardware. Production and preparation of hardware for the second mission is also underway. Looking ahead to a busy 2019, liquid oxygen (LOX) tank, liquid hydrogen (LH2) tank and intertank structural testing will take place. This paper will discuss the current and planned status of SLS development in context of NASA's overall exploration plans.

INTRODUCTION

NASA has a phased approach (Figure 2) to ensure our nation's leadership in space exploration, beginning in Earth orbit and expanding to Mars and beyond.[1] NASA is commercializing low-Earth orbit using private companies to transport supplies and scientific experiments to the International Space Station (ISS), and they will soon begin launching American astronauts to the ISS. ISS is our platform to better understand living and working in space for extended durations.

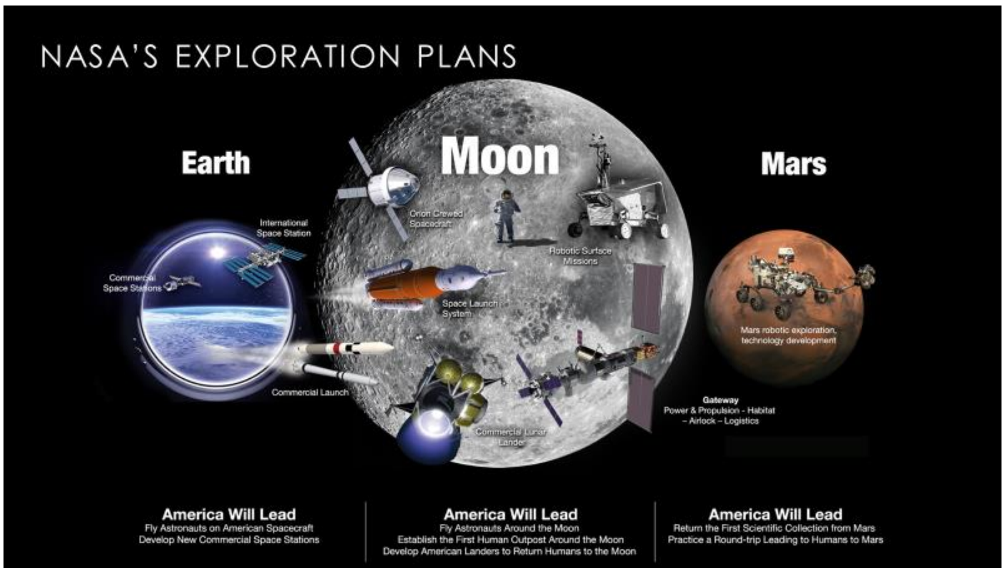

Figure 2: NASA's phased human exploration approach for deep space exploration

Concurrently, NASA is leading a sustainable return to the Moon with commercial and international partners to expand human presence in space and bring back new knowledge and opportunities. NASA will call on the strengths of both government and industry to establish a lunar orbiting outpost – the Gateway – near the Moon (Figure 3). A power and propulsion element, as well as habitation, airlock and logistics capabilities, will establish the core functionalities of the Gateway.[2]

Critical to human lunar return is the transportation infrastructure. Leading that return is SLS, the Orion crew vehicle, and Exploration Ground Systems (EGS) to process launch vehicles and spacecraft for deep space missions. 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 as a training and hardware maturation element, as well as operational element needed to send humans beyond low-Earth orbit.

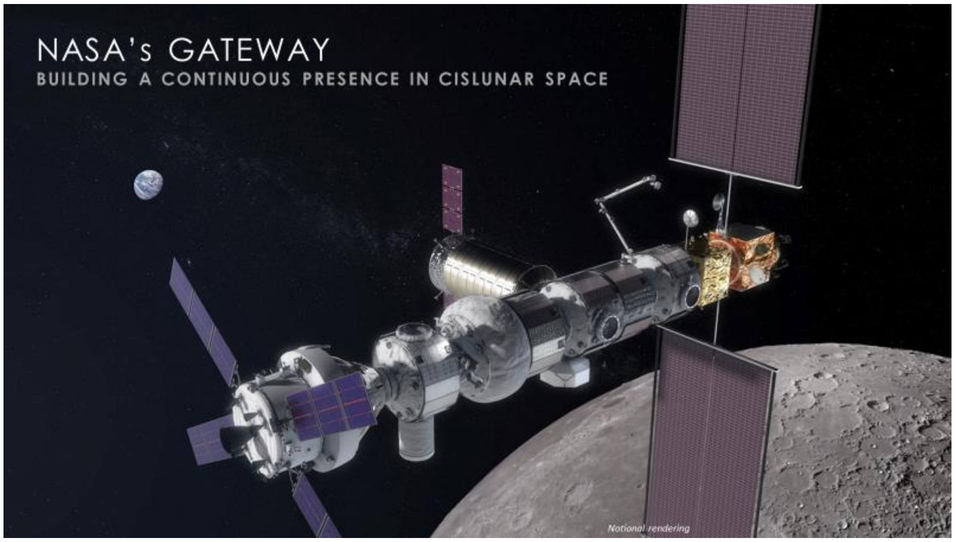

Figure 3: Artist's concept of Gateway outpost with visiting Orion crew vehicle

The benefits of heavy lift to complex missions in the challenging space environment are clear. The ability to transport large payloads reduces payload and operational complexity from the ground to space. It saves time and money and increases chances for mission success. SLS's mass and volume are significantly greater than any other current rocket, with the capability to launch 26 metric tons (t) to the Moon. It is the only rocket currently designed and tested to return humans to deep space, and it is the only rocket capable of sending both Orion and its crew, plus a 10 t co-manifested payload, such as a Gateway module, to the Moon. Moreover, the SLS design allows it to evolve, as budget constraints allow, to even more capable variants (Figure 4). The current Block 1 design can be enhanced to launch up to 40 t to the Moon in Block 1B configuration and ultimately more than 45 t in Block 2 configuration. Block 1B, anticipated to be the workhorse variant for the Moon, can launch twice the volume and 50 percent more mass than current rockets.

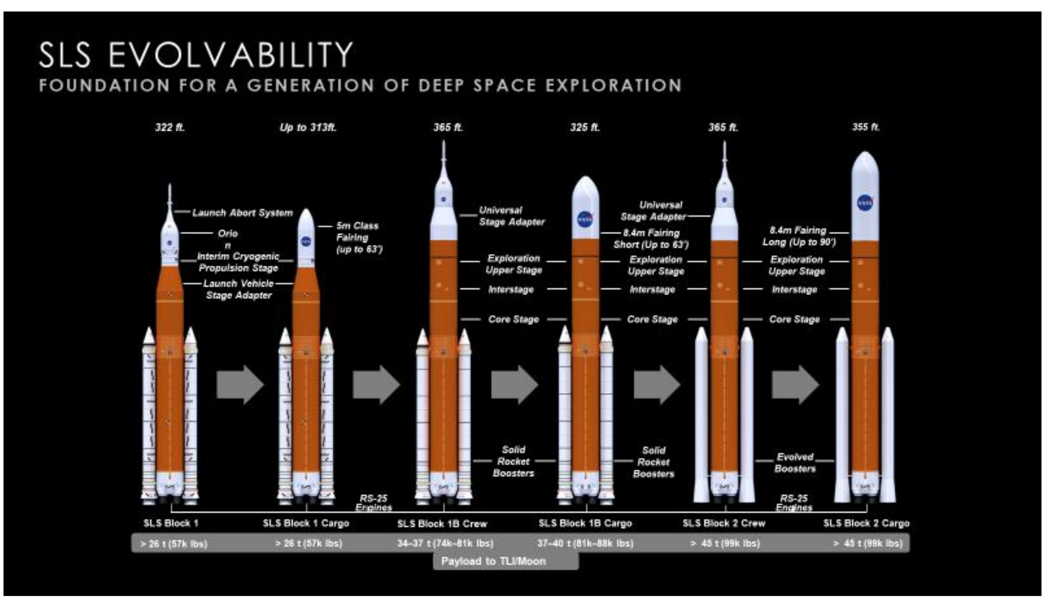

Figure 4: The SLS evolability path for crew and cargo versions.

SLS relies on powerful, proven propulsion elements from the Space Shuttle Program. The core stage will house four RS-25 engines, each providing more than 500,000 pounds (lbs) of vacuum thrust, powered by liquid oxygen (LOX) and liquid hydrogen (LH2). More than 75 percent of thrust for the first two minutes at launch will be provided by two five-segment solid rocket boosters (SRBs), each with approximately 3.6 million pounds of thrust. The core stage consists of five major sections – engine section, LH2 tank, intertank, LOX tank and forward skirt. Atop the core stage is a conical launch vehicle stage adapter (LVSA), which encloses the Interim Cryogenic Propulsion Stage (ICPS), and the Orion Stage Adapter (OSA) that connects the ICPS to the Orion crew vehicle (Figure 5).

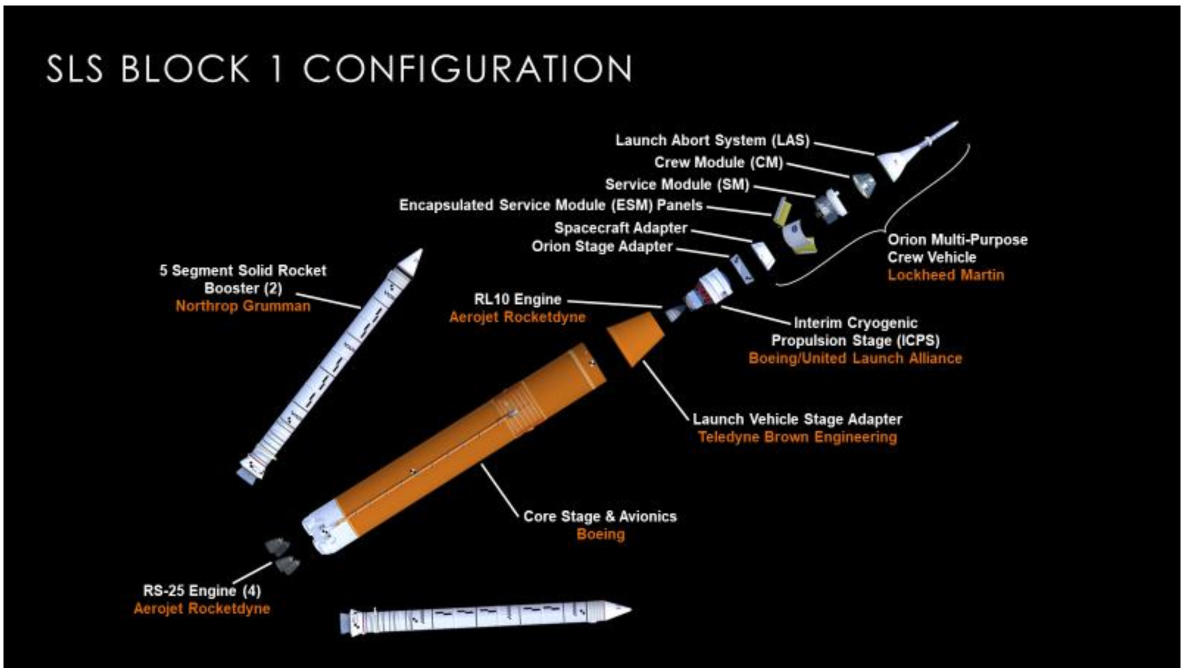

Figure 5: Expanded view of major SLS Block 1 and Orion elements and prime contractors

SLS PROGRESS

The SLS five-segment boosters are based on the shuttle four-segment boosters but employ more environmentally benign motor case insulation, new nozzle design and new avionics. Each booster burns about six tons of propellant every second for roughly the first two minutes of flight. Northrop Grumman, prime contractor for the SRBs, has completed manufacture and checkout of all 10 motor segments for the (Exploration Mission-1) EM-1 mission (Figure 6, left). The segments are awaiting shipment to KSC.[3] Both exhaust nozzles for EM-1 are completed at company facilities in Utah. At KSC, the EM-1 forward and aft skirts are being refurbished and outfitted for flight. Thrust vector Control (TVC) hardware has been installed in the left and right aft skirts. Teams completed a hotfire test on the TVC system in preparation for final assembly and checkout. Booster separation motors (BSMs) for both aft skirts are complete. At Marshall Space Flight Center (MSFC), booster avionics completed qualification testing and will be tested together with vehicle avionics later this year. Nine of 10 EM-2 motor segments have also been cast and hardware for the third SLS mission has begun processing.

The SLS Program began with 16 engines from the shuttle program, including two new engines -- enough to support the first four SLS missions -- while NASA and engine manufacturer

Aerojet Rocketdyne develop an expendable variant that will cost at least 30 percent less. The existing engines will operate at 109 percent of original rated thrust versus 104.5 percent used during shuttle launches. SLS has completed qualification of new Honeywell engine controllers and avionics for the current and future engines. The program has completed an “adaptation” test program to ensure the engines can operate under SLS requirements and environments, including the thrust profile required and the colder inlet temperatures as a result of being closer to the LH2 tank. The test series also included qualification of flight controllers and software as well as green run testing of new engines and early testing of new parts for future engines.[4] The test series included four hot fires up to 113 percent of rated thrust for up to 430 seconds, demonstrating a margin of safety for operating at 111 percent with future production engines (Figure 6, right). Following an early April hot fire test at NASA’s Stennis Space Center (SSC), the test program will stand down until next year when component testing for new engines resumes. As of that test, the program had completed 32 tests and nearly 15,000 seconds hot fire time. Processing is complete on the EM-1 engine flight set, and work is underway on processing EM-2 engines.

Figure 6: EM-1 SRB motor segment, left, and February 2019 RS-25 test firing, right

With propulsion consisting largely of heritage hardware, the most challenging aspect of SLS development has been the core stage, the only all-new design of the SLS Program. The challenges have been mainly first-time manufacturing issues that have been resolved. Core stage prime contractor Boeing has completed all major sections of the 212-foot EM-1 core stage and has started early manufacturing of the EM-2 core stage.

Forward join was completed in early 2019 at NASA’s Michoud Assembly Facility (MAF), where the forward skirt, LOX tank and intertank were bolted together (Figure 7, left)[5]. With outfitting of the complex engine section taking longer than planned, stage integration has been modified. The forward join will be rotated from vertical to horizontal on the factory floor and the LH2 tank bolted at the intertank interface. The majority of engine section installation work is complete, including more than 500 sensors, 18 miles of cable and numerous other critical systems for supporting the four RS-25 engines and delivering propellants. Technicians at MAF completed thermal protection system (TPS) application on the 130-foot-long LH2 tank in early 2019. Boeing has developed special tooling to install the engine section horizontally when it becomes ready, although several internal components must be mated in the vertical position prior to completing stage integration. (Figure 7, right).

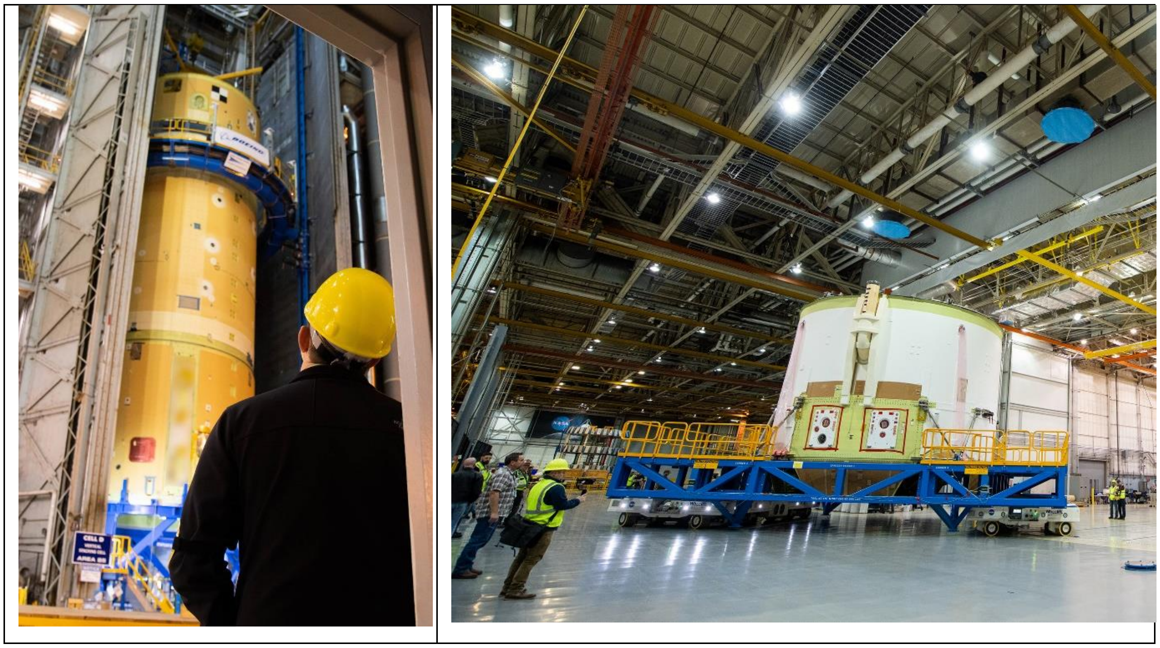

Figure 7: EM-1 core stage forward join, left, and engine section, right

A series of flight software tests was completed in 2018 as part of intertank functional testing. In addition, forward skirt testing was completed in summer 2018, including demonstration of avionics system harnesses – the first major core stage component ready for flight.[6]

In parallel with flight article manufacturing, core stage structural testing made progress at MSFC. The engine section structural test article (STA) completed its test series in 2018. Intertank STA testing began in 2018 and completed initial testing in 2019, with ultimate and limit load testing beginning in early 2019 (Figure 8, right). The LH2 STA arrived at MSFC in early 2019 and was scheduled to begin testing in summer 2019 (Figure 8, left)[7]. The final test article, the LOX STA, is scheduled to ship to MSFC from MAF in summer 2019. In related progress, core stage ground support equipment (GSE) testing was conducted in 2018, and the core stage Pathfinder simulator completed "first movement" operations in early 2019. It is scheduled to be barged on Pegasus to SSC in 2019 to rehearse stage green run moves. Additionally, the B-2 test stand at SSC continues to prepare for the stage.

Above the core stage are the ICPS and adapters. The ICPS, built by Boeing and United Launch Alliance (ULA), is a Delta Cryogenic Second Stage that has been modified by lengthening the LH2 tank, adding hydrazine bottles for attitude control and minor avionics changes. It is powered by one Aerojet Rocketdyne RL10B-2 engine with 24,750 pounds of thrust. It provides the trans-lunar injection (TLI) burn for Orion during the EM-1 mission. The ICPS and OSA were shipped to KSC in 2017 and 2018 and stored in the Space Station Processing Facility (SSPF) until needed for vehicle integration. The LVSA at this writing is undergoing final processing at MSFC and expected to ship to KSC in 2019. The Integrated Structural Test (IST) of all those components was completed in 2017 at MSFC.

Figure 8: LH2 STA at MSFC, left, and Intertank STA, right, underway at MSFC

The historic support center once used to support Saturn and space shuttle missions was updated in 2018 to support SLS. The SLS Engineering Support Center (SESC) participated in a connectivity test in August 2018[8] (Figure 9). The test verified voice communications among 13 locations, including the Launch Control Center (LCC) at KSC and the Mission Control Center (MCC) at JohnsonSpace Center (JSC) and the U.S. Air Force Patrick Air Force Base and Cape Canaveral Air Force Station, as well as several NASA contractor sites. While the data stream in the shuttle era was no greater than one megabit per second, the SESC will receive more than 25 times that amount of data. Voice, imagery and data used to monitor the engines, boosters, core stage, avionics and the upper stage have been upgraded to provide technical expertise to launch and mission controllers at KSC and JSC.. While support centers in the shuttle era could link about 20 groups – or “voice loops” – the SESC will be able to connect up to 156 groups. More than 160 engineers will be monitoring real-time data from the rocket during pre-launch and flight operations in the SESC.

Figure 9: Upgraded equipment at the SLS Engineering Support Center at MSFC

THE 2024 CHALLENGE

While SLS continues to make progress in manufacturing, assembly and testing, NASA's overall exploration effort has seen dramatic change. In April 2019, the Administration challenged NASA to get American astronauts to the Moon in the next five years with a landing on the lunar South Pole. Key to that success will be an un-crewed SLS first launch in 2020 and the first SLS crewed launch to the lunar vicinity by 2022. NASA has been directed to "use all means necessary" to ensure mission success.[9]

NASA continues to implement the President's Space Policy Directive – 1 to "lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system."

At the time this paper was in preparation, the agency was working the details of how to meet an accelerated human return to the Moon, including the resources needed to do it. NASA is establishing a new Moon to Mars Mission Directorate to lead lunar exploration development activities.

In announcing the accelerated program, NASA also reaffirmed the importance of SLS after a study of commercial alternatives. While some commercial options could meet the task, none was capable of achieving NASA's goals to orbit around the Moon within NASA's timeline or budget. The agency is evaluating multiple options to accelerate work across SLS, Orion and EGS to conduct the first launch in 2020.

SUMMARY AND CONCLUSIONS

SLS has made significant progress in the past year. For the first SLS flight vehicle, the Program is in final testing, outfitting and assembly for flight. Structural components for second and third flights are also in production.

The core stage forward join is complete. The LH2 tank will be mated later this year followed by the engine section. The first flight set of RS-25 engines is ready for installation. The solid rocket motor segments and other hardware for the first SRB flight set is ready for shipment to KSC. The ICPS, OSA and LVSA are complete. Structural testing is complete on the engine section and intertank with testing underway on the LH2 tank test article and soon to begin on the LOX tank test article. The SLS/NASA industry team is laser-focused on delivering this unprecedented capability for its first flight as soon as possible for America. As with any large, complex space vehicle, SLS has experienced manufacturing challenges with the first production article. SLS is working to shorten its development schedule without sacrificing safety or quality in the drive toward a 2020 first launch and unmatched deep space exploration capability for the future.

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