NASA's Space Launch System: Exploration Mission-1 Hardware Nears Completion

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Fig. 1. Artist rendering of EM-1 launch from Kennedy Space Center.

The Space Launch System (SLS) Program completed several significant production milestones in 2018 for the launch vehicle's first mission (Fig. 1) and is poised for greater accomplishments in 2019. With manufacturing and hardware installation finished, Boeing completed the core stage forward join and shipped the liquid hydrogen tank structural test article to Marshall Space Flight Center for testing. The core stage aft join and LOX tank STA are expected to be completed in 2019 on the way to final stage integration. The four EM-1 engines are poised for stage integration in 2019. The Launch Vehicle Stage Adapter completed outfitting at Marshall and will be shipped to Kennedy Space Center in 2019. All solid rocket motor segments for the EM-1 boosters are cast, inspected and ready for shipment to KSC. The upper stage, the Interim Cryogenic Propulsion Stage (ICPS), and the Orion Stage Adapter (OSA), where 13 6U CubeSats will ride to deep space on EM-1, were completed and delivered to Exploration Ground Systems at KSC in 2017 and 2018, respectively. The Program continues to work toward first launch of the nation's new super heavy lift deep space capability in fiscal 2020. SLS is designed, engineered and tested to launch the most challenging exploration missions, minimizing risk and providing the greatest opportunity for mission success. This paper will discuss the technical and programmatic successes and challenges of the past year and look ahead to plans for 2019.

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I. Introduction

NASA is returning to the Moon, not to repeat the Apollo Program explorations, but to build on them, establishing a permanent presence in cislunar space, developing the technologies and the operational experience necessary for successful deep space exploration. NASA's current plans are based on Space Policy Directive 1, issued in 2017, which requires the agency to "*lead innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations."*

NASA's path for moving humanity into the solar system has four key aspects. The agency will build an infrastructure that will make deep space accessible to all humanity. NASA will develop incremental capabilities during human lunar expeditions that will inform future missions, deeper into the solar system. It will expand the near-Earth economy to establish a sustainable presence in deep space similar to the current low Earth orbit (LEO) economy. Finally, NASA will provide an initial "backbone" crew transportation system, which will be augmented with commercial transportation. Among the agency's strategic principles guiding this effort are fiscal realism, commercial partnerships, gradual capability buildup, architecture openness and resilience, global collaboration and leadership, technology pull and push, and continuity of human spaceflight.

This new effort will build on NASA's existing human exploration programs – International Space Station, commercial cargo and crew programs and long-standing collaborative partnerships with international space programs. NASA is developing the deep space transportation system required to support such a long-term vision with the Space Launch System (SLS), the Orion crew spacecraft, and the Exploration Ground Systems (EGS) at KSC necessary to integrate and launch SLS and Orion.

NASA has initiated plans for a Gateway outpost in lunar orbit as its initial foothold in deep space (Fig. 2). Gateway will be a human-tended outpost that will be supported by commercial and international partners. The Gateway will help advance lunar exploration and develop the technologies and operations necessary to continue exploration of the solar system.

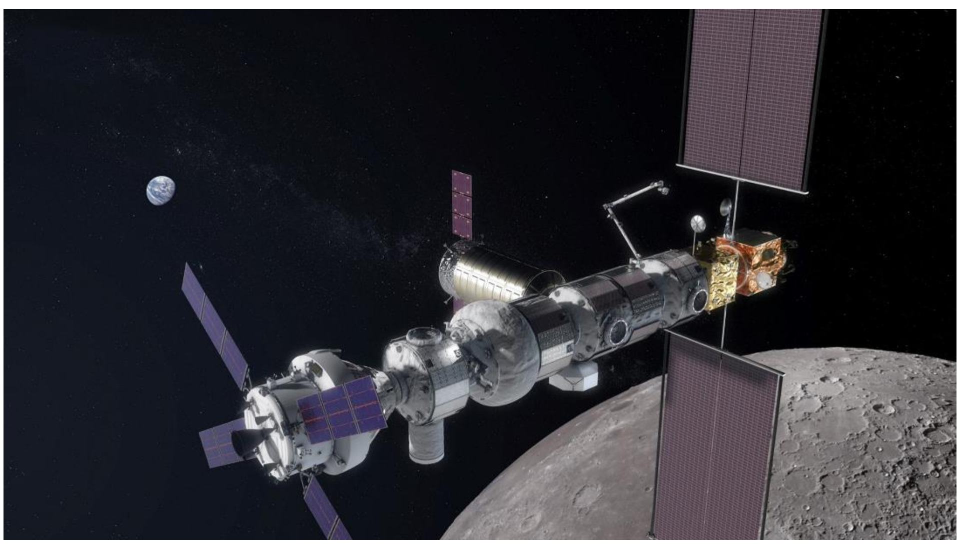

Fig. 2. Artist concept of the Gateway outpost at the Moon.

Gateway and supporting NASA and industry transportation provide for a more long-term sustainable architecture than the lunar surface-direct, Apollo Program-style access of the 1960s. Gateway enables reusable lunar systems, long-term multiple mission capability, initial refueling capabilities necessary in the future, robotic and human lunar vehicle checkout, maintenance and operations, increased international and commercial opportunities, longer-duration surface missions, an in-space platform for long-duration science, interoperability standards/open architecture, and a testing ground for Mars exploration.

No other existing launch vehicle can carry as much mass or volume to the Moon as SLS, reducing payload complexity and mission risk. SLS is the only vehicle that can take Orion to the Moon – in addition to a major "co-manifested" payloads, including Gateway elements. And currently SLS is the only launch vehicle designed and tested from the start to carry NASA astronauts to deep space.

SLS is critical to the success of Gateway and NASA's entire cislunar architecture. Its first mission, Exploration Mission 1 (EM-1), will send an uncrewed Orion spacecraft into a near-lunar orbit to provide a rigorous, 25-plus-day checkout of new systems. The second flight, Exploration Mission-2 (EM-2), will follow a similar trajectory, this time with a human crew and free-return lunar trajectory. Following these precursor missions, EM-3 will send a crewed Orion and a U.S. utilization module and European Space Agency-provided module that will include a science airlock, among other capabilities, to the Moon to rendezvous and dock with a power and propulsion element for Gateway launched earlier by a commercial rocket. On future missions to the Gateway, SLS will transport Orion crews co-manifested with U.S. and international habitat modules for Gateway as shown in the notional manifest in Fig. 3

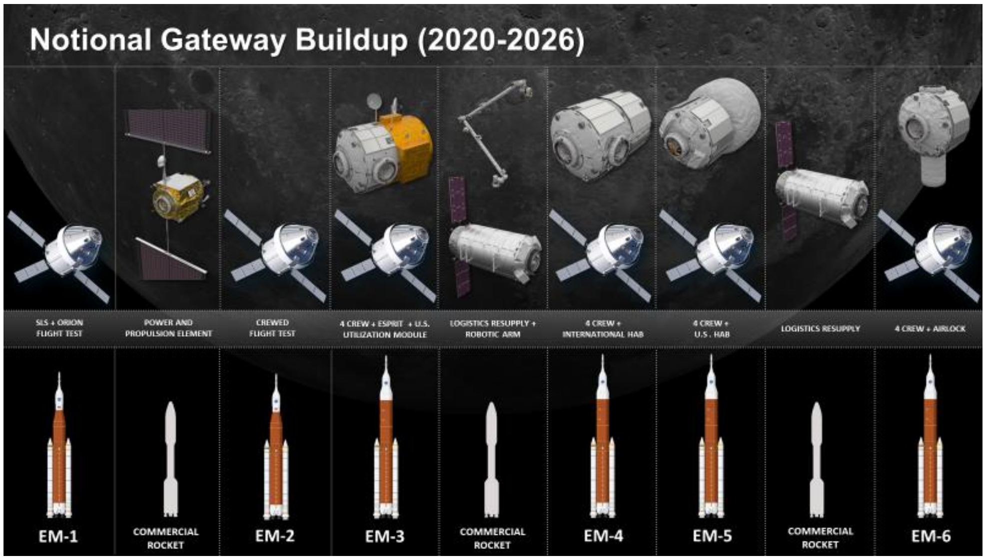

Fig. 3. Artist concept of the Gateway outpost at the Moon.

Additionally, the Gateway has the versatility to support robotic as well as human missions. It can send larger probes to the solar system's gas giants and their satellites, cutting years off of transit times and allowing more robust science packages to conduct greater science exploration. The following sections will discuss the SLS design, accomplishments to date and the challenges ahead for SLS on its way to the launch pad.

II. The SLS Design

The SLS design emerged from hundreds of configurations analyzed against a range of missions. In addition to mission capture, figures of merit also considered include safety, reliability and both design and architecture cost. The SLS architecture also leverages more than five decades of spaceflight knowledge, technologies, facilities and the nation's highly skilled technical workforce. SLS is not one vehicle but an evolutionary capability designed to evolve through block upgrades as exploration missions become more challenging. The SLS evolutionary path is shown in Figure 4.

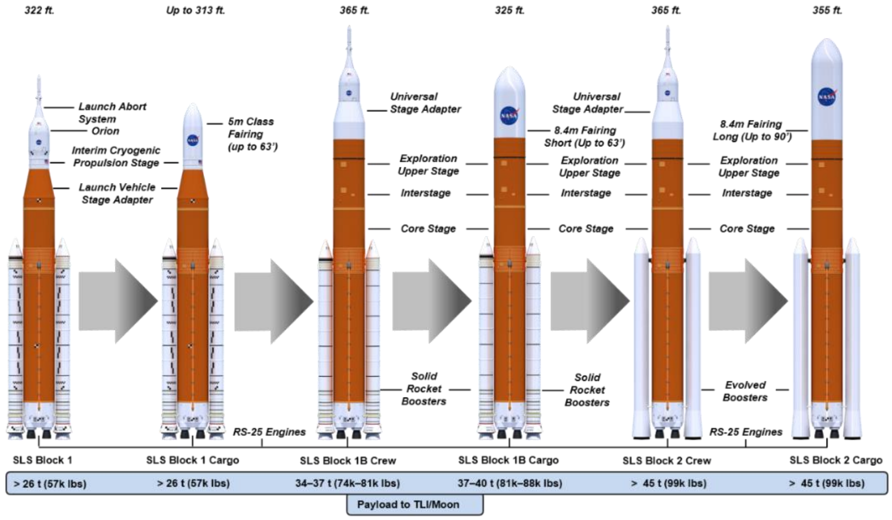

Fig. 4: The SLS vehicle evolution path illustrating the increasing mass and volume capability.

The initial Block 1 configuration will provide more than 26 metric tons (t) of payload mass to trans-lunar injection (TLI), more than any currently operational launch vehicle. In the Block 1B configuration, payload mass capability will grow to 34-40 t to TLI; the ultimate configuration, Block 2, will lift more than 45 t to TLI. Payload volume for the cargo configurations will increase from more than 150 cubic meters (m^3) to more than 900 m^3, with even larger payload shrouds under consideration. Unique to SLS, Block 1B and Block 2 crew configurations will deliver in a single mission the crewed Orion spacecraft plus large systems such as habitats needed for living and working in deep space as co-manifested payloads in a Universal Stage Adapter, which offers more volume for payloads than industry-standard 5 m-diameter fairings.

Critical to that evolutionary capability is propulsion. Propulsion is considered the most challenging part of any launch vehicle design. SLS is built around the most powerful and proven propulsion systems in the world, updated for performance and affordability. Main propulsion is provided by the space shuttle-heritage RS-25 engine and solid rocket booster. The program starts with 14 flown and two new engines from the shuttle program and a new five-segment solid-propellant motor design based on the shuttle's four-segment design. Initially, upper stage propulsion will be provided by a modified United Launch Alliance (ULA) Delta Cryogenic Second Stage (DCSS) commercial stage powered by an RL10 engine. Designs for the evolved Block 1B vehicle call for a new, more powerful upper stage powered by four RL10 engines.

NASA's plan to evolve SLS has been modified to support near-term human and robotic exploration plans. Congress directed NASA to build a second Mobile Launcher (ML) at KSC for SLS designed to support the Block 1B configuration. The second ML for Block 1B allows NASA to accelerate the SLS launch schedule for the first three missions using Block 1 rockets and the first ML while the ML for Block 1B is under construction. NASA will fly the Block 1 configuration for the first three SLS missions and then switch to Block 1B for later missions as described below:

- Exploration Mission-1 (EM-1) will be the first integrated test flight of SLS and the uncrewed Orion spacecraft, currently planned to launch in fiscal year 2020.
- Exploration Mission 2 (EM-2) will be the first crewed flight of SLS and Orion and will take humans farther into deep space than ever before, currently planned to launch in 2023.
- Additionally, under consideration for the second or third flight of SLS is Science Mission-1 (SM-1), launching the Europa Clipper robotic probe on a direct trajectory to investigate the habitability of Jupiter's icy moon Europa onboard an SLS Block 1 cargo vehicle.
- Engineers are also working on the first flight of the Block 1B vehicle, Exploration Mission-3 (EM-3), which will send astronauts in Orion to the Gateway and launch the U.S. utilization and ESPRIT Gateway modules as a co-manifested payload.

In this paper, the authors will also present details on progress to date on SLS manufacturing and testing, as well as related progress toward flight.