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NASA's Space Launch System: An Evolving Capability for Exploration

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ABSTRACT:

Designed to meet the stringent requirements of human exploration missions into deep space and to Mars, NASA's Space Launch System (SLS) vehicle represents a unique new launch capability opening new opportunities for mission design.

NASA is working to identify new ways to use SLS to enable new missions or mission profiles. In its initial Block 1 configuration, capable of launching 70 metric tons (t) to low Earth orbit (LEO), SLS is capable of not only propelling the Orion crew vehicle into cislunar space, but also delivering small satellites to deep space destinations.

The evolved configurations of SLS, including both the 105 t Block 1B and the 130 t Block 2, offer opportunities for launching co-manifested payloads and a new class of secondary payloads with the Orion crew vehicle, and also offer the capability to carry 8.4- or 10-m payload fairings, larger than any contemporary launch vehicle, delivering unmatched mass-lift capability, payload volume, and C3.

1. PROGRAMMATIC BACKGROUND

Created to provide sufficient launch capability to enable human exploration missions beyond Earth orbit and ultimately to Mars, NASA's Space Launch System (SLS) rocket represents a new asset, not only for human spaceflight, but also for a variety of other payloads and missions with launch requirements beyond what is currently available. The initial configuration of the vehicle, on track for launch readiness in 2018, is designed to offer substantial launch capability in an expeditious timeframe and to support evolution into configurations offering greater

launch capability via an affordable and sustainable development path.



Figure 1. Artist's rendition of Space Launch System on its mobile launcher.

NASA is developing SLS in parallel with two other exploration systems development efforts – the Orion crew vehicle program and the Ground Systems Development and Operations (GSDO) program. Orion is a four-person spacecraft designed to carry astronauts on exploration missions into deep space. GSDO is converting the facilities at NASA's

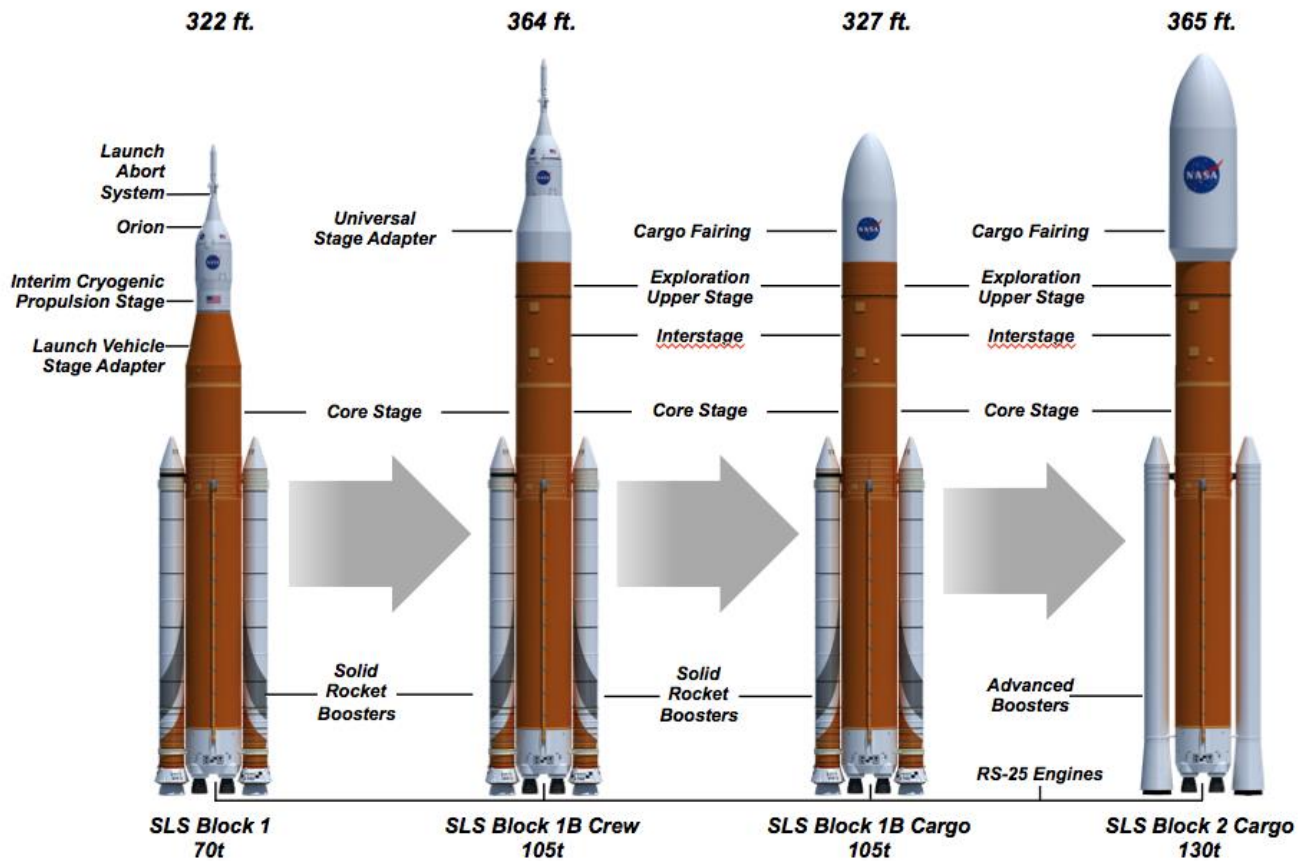


Figure 2. Evolutionary development path of Space Launch System

Kennedy Space Center (KSC) in Florida into a next-generation spaceport capable of supporting launches by multiple types of vehicles.

These capabilities are part of a larger NASA strategy of working with commercial partners that will support crew and cargo launches to the International Space Station, while the agency focuses its development efforts on an incremental approach to developing the systems necessary for human exploration beyond Earth orbit and eventually to Mars. SLS is being designed with performance margin and flexibility to support an evolvable human exploration approach. (Fig. 2)

Currently under construction, the initial configuration of the vehicle will have the capability to deliver a minimum of 70 t into low Earth orbit (LEO) and will be able to launch a crew aboard the Orion spacecraft on into cislunar space on its first flight, Exploration Mission-1 (EM-1) in 2018. The vehicle will evolve to a full capability of greater than 130 t to LEO and will

be able to support a stepping-stone approach to human exploration leading to the first footsteps on Mars.

2. VEHICLE OVERVIEW AND STATUS

The SLS initial Block 1 configuration stands 97 meters (m) tall, including the Orion crew vehicle. The vehicle's architecture reflects NASA's desire to meet the mandates for heavy-lift capability in the U.S. congressional NASA Authorization Act of 2010 in a manner that is safe, affordable, and sustainable. After input was received from industry and numerous concepts were reviewed, a shuttle-derived design was found to enable the safest, most-capable transportation system in the shortest amount of time for the anticipated near-term and long-range budgets.

The SLS operational scheme takes advantage of resources established for the Space Shuttle Program, including workforce, tooling, manufacturing

processes, supply chains, transportation logistics, launch infrastructure, and liquid oxygen and hydrogen (LOX/LH2) propellants and allows the initial configuration of the vehicle to be delivered with only one clean-sheet new development, the Core Stage. In October 2015, the SLS Program completed its Critical Design Review (CDR), the first time a NASA human-class launch vehicle has reached that milestone since the Shuttle Program almost 40 years ago.

The SLS Core Stage, which stores the liquid oxygen (LOX) and liquid hydrogen (LH2) propellant for four Core Stage engines, will stand 61 m tall and will have a diameter of 8.4 m, sharing commonality with the space shuttle's external tank in order to enhance compatibility with equipment and facilities at Kennedy Space Center and elsewhere. At Michoud Assembly Facility (MAF), outside New Orleans, Louisiana, the last of six major welding manufacturing tools for the Core Stage, the world's largest space vehicle welding tool, the 52m-tall Vertical Assembly Center (VAC), has been installed and is being used by The Boeing Company, Core Stage prime contractor, to weld barrel sections, rings and domes together to form the propellant tanks for the stage. (Fig. 3)

The Core Stage will be powered by four RS-25 engines, which previously served as the Space Shuttle Main Engine (SSME), taking advantage of 30 years of U.S. experience with liquid oxygen and liquid hydrogen, as well as an existing U.S. national infrastructure that includes specialized manufacturing and launching facilities. These human-rated engines support the SLS goal of safety, with a record of 100 percent mission success for the engines over 135 flights. At the end of the Space Shuttle Program, 16 RS-25 flight engines and two development engines were transferred to the SLS Program and placed in inventory at NASA's Stennis Space Center, providing enough engines for the first four flights of SLS. (Fig. 4)

Modifications to Stennis Test Stand A-1 to support RS-25 testing were completed in 2014, and two test series have already been completed in preparation for flight certification of the SLS configuration of the engine, including a new engine controller unit. The testing includes propellant pressure and temperature inlet conditions that will both be higher



Figure 3. The core stage engine section weld confidence article at Michoud Assembly Facility.



Figure 4. Testing of an EM-2 flight RS-25 engine at Stennis Space Center in Mississippi.



Figure 5. Preparations are underway for the second booster qualification test in Utah.

with SLS than with the shuttle, as well as other SLS-specific performance requirements such as 109 percent thrust versus the shuttle's 104.5 percent thrust. Stennis Test Stand B-2 is being refitted for the

SLS “green run” – the test firing of the first Core Stage with four RS-25 engines beginning in 2017, which will be NASA’s largest engine ground firing since stage tests of the Saturn V in the 1960s.

The majority of the thrust for the first two minutes of flight will come from a pair of Solid Rocket Boosters, also of Space Shuttle Program heritage. The SLS is upgrading the boosters from the four-segment version flown on the shuttle to a more-powerful five-segment version. Each booster measures 54 m long and 3.7 m in diameter and is capable of generating up to 3.6 million pounds of thrust, the most powerful flight boosters in the world. Although largely similar to the SRBs used on the space shuttle, this upgraded five-segment SRB includes improvements such as a larger nozzle throat and an environmentally-benign insulation and liner material. In March 2015, the SLS configuration of the booster successfully underwent the first of two Qualification Motor tests, and the second test is scheduled for summer 2016. (Fig. 5)

In-space propulsion for the 70 t Block 1 version of SLS will be provided by the Interim Cryogenic Propulsion Stage (ICPS), a modified version of United Launch Alliance’s Delta Cryogenic Second Stage (DCSS) flown on more than 20 launches of the Delta IV Evolved Expendable Launch Vehicle (EELV). In order to support the currently planned initial test flight that would send Orion on a circumlunar trajectory, the LH2 tank of the SLS ICPS will be stretched 46 centimeters longer than the standard DCSS.

While the SLS Program is heavily focused on working toward first flight, efforts are already underway on the evolution of SLS beyond the 70 t Block 1. As early as the second launch of SLS, Exploration Mission-2, the vehicle will be augmented with a low-thrust dual-use Exploration Upper Stage (EUS), providing both ascent and in-space propulsion capabilities. This stage, which is working toward a preliminary design review in late 2016, will upgrade SLS to a performance of 105 t to LEO, and create a configuration that will serve as a workhorse for “Proving Ground” missions in cislunar space that will pave the way for further exploration. From there, additional upgrades, including enhancements to the RS-25 engines and upgraded boosters will ultimately evolve SLS to a configuration capable of delivering more than 130 metric tons to LEO, the capability identified as necessary for human missions to Mars.

Early research has also been conducted into options for larger 8.4- and 10-m fairings, with which SLS will potentially offer payload volumes of 1,200 and 1,800 cubic meters, respectively. With a 10-m fairing, the vehicle will be able to offer payload volumes five times greater than currently available. In addition to those traditional classes of payload fairings, the Space Launch System offers additional unique payload capabilities, including launch of a co-manifested payload along with the Orion spacecraft or delivery of secondary payloads to lunar or planetary trajectories. A co-manifested payload, with a volume of up to 400 cubic meters, could be placed within the Universal Stage Adapter connecting the Exploration Upper Stage to the Orion stack, and could be used, among other purposes, to deliver multi-ton payloads to a destination alongside Orion, allowing, for example, deployment of Orion and a habitat with crew to cislunar space with a single launch.



Figure 6. Fairing options for evolved configurations of Space Launch System.

3. THE JOURNEY TO MARS

NASA’s Space Launch System and Orion spacecraft are designed to meet the requirements for a human mission to Mars, and the United States national space policy and international collaborative

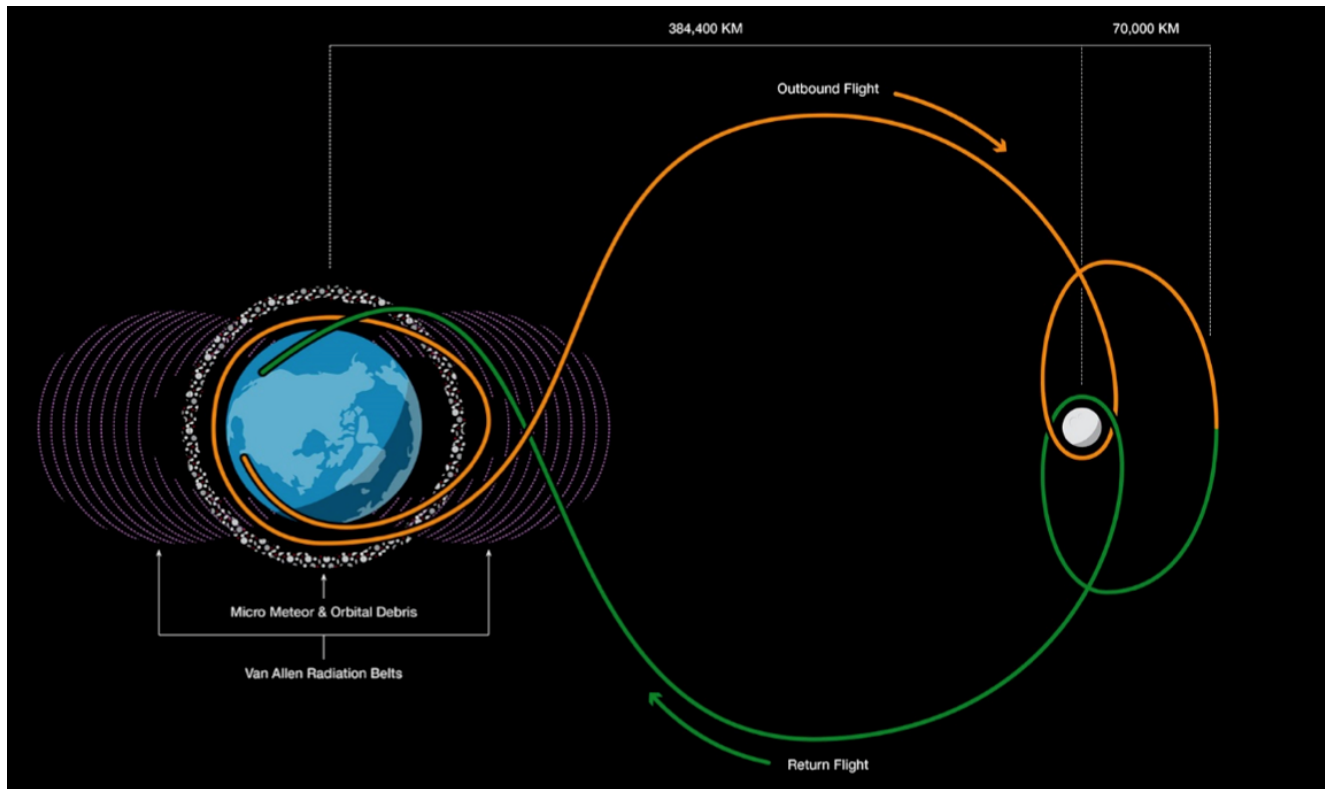


Figure 7. Distant Retrograde Orbit trajectory planned for Exploration Mission-1

planning are increasingly focused on Mars as the horizon goal for human space exploration.

On a high-level, the agency is outlining a “Journey to Mars,” which begins with biological, operational, and technological research at the International Space Station, precursor robotic science missions to the Red Planet, and Mars-focused technology development efforts, all of which are already ongoing. From there, the agency will move from being “Earth dependent” in its human spaceflight endeavors into a “proving ground” approach. There, new systems, beginning with SLS and Orion, will be tested and demonstrated on increasingly ambitious missions, beginning in the lunar vicinity and moving outward. These missions will be designed to validate new capabilities and gain operational experience that does not require the continuous resupply from Earth currently enjoyed on the International Space Station, and is focused toward being able to deal with contingency situations in deep space. From there, “Earth Independent” systems will be used to conduct missions to the Mars vicinity and ultimately the first human landings on the Martian surface.

Toward that end, NASA is currently maturing a capabilities-based framework focused on identifying and developing the systems needed for gaining ever-increasing operational experience in space, growing in duration from a few weeks to years in length, and moving from close proximity to Earth to Mars. The approach is consistent with the Global Exploration Roadmap, a Mars exploration partnership strategy developed by the International Space Exploration Coordination Group (ISECG), consisting of 14 space agencies, including NASA, from nations around the world. The Roadmap, which identifies Mars as “the driving goal of human exploration,” is a living document updated via an ongoing series of meetings between partner agencies and interested stakeholders.

SLS and the Orion crew vehicle represent the initial foundational capabilities needed to carry out a human exploration journey that leads to Mars, and NASA has outlined as first steps on that journey missions that will demonstrate those capabilities. In December 2014, the Orion crew vehicle performed Exploration Flight Test-1 (EFT-1), a launch of an

Orion test article on a Delta IV Heavy rocket that carried the spacecraft to an altitude of 5,800 kilometers, demonstrating its guidance, navigation, and control systems; thermal protection systems; and reentry systems.

The next steps will be the initial flights of SLS, which, under current plans, will send the Orion crew vehicle into cislunar space. The first of these test flights, Exploration Mission-1 (EM-1), would launch an uncrewed Orion, with the first European-built Service Module, using the Block 1 configuration of SLS into lunar Distant Retrograde Orbit (DRO). (Fig. 7) This trajectory would support NASA's plans for carrying out a robotic mission to move a large asteroid material sample into lunar DRO, and could lay the groundwork for future staging of deep-space missions in near-lunar space. The follow-up flight, Exploration Mission-2 (EM-2), will be a crewed demonstration of Orion, which will carry astronauts farther into space than ever before. The mission could fly on the Block 1B configuration of the vehicle, demonstrating the Exploration Upper Stage and potentially allowing for a comanifested payload in addition to the Orion crew vehicle.

Early habitat concepts are currently being matured, and as the initial capabilities of SLS and Orion have been developed and demonstrated, additional funding can be directed into the next human exploration capabilities, and international partnerships will provide opportunities for further expediting these next-step capabilities. SLS' substantial mass and volume lift capability enables numerous stepping-stone missions leading to human missions to Mars. With the development of a deep-space habitat, long-duration human missions in the Proving Ground of cislunar space become possible. With a habitat and in-space propulsion, missions into the Mars vicinity become possible. The moons of Mars offer potential as destinations enabled by SLS and Orion – allowing long-term Mars-vicinity operations prior to completion of the large-scale entry, descent, and landing systems needed for human Mars surface operations.

4. SCIENCE UTILIZATION

While the vehicle was designed around the goal of enabling human exploration of the solar system, the capabilities of the Space Launch System to fulfill that charter will also provide game-changing benefits for a range of promising space science missions. Three

major interrelated areas have been identified in which SLS offers unique benefits that make possible new missions or mission profiles – mass-lift capability, payload volume capacity, and departure energy.

These areas offer the potential for numerous benefits:

- Less-complex payload design and miniaturization needed to fit in fairings, leading to increased design simplicity.
- Less folding/deployment complexity, leading to increased mission reliability and confidence.
- High-energy orbit and shorter trip times, leading to less expensive mission operations and reduced exposure to the space environment.
- Increased lift capacity and payload margin, resulting in less risk.

The SLS team has participated in technical interchange meetings with members of the science community to further a dialogue on the vehicle's benefits for future missions and to better define how it could enable them. Taking advantage of the mass and volume capacity that SLS offers will allow spacecraft designers and mission planners to change fundamental assumptions about spacecraft and mission design.

SLS' characteristic energy (C3) offers reduced mission transit time, thereby reducing power requirements as well as the amount of time that scientific instruments are exposed to space. While commercial launchers will continue to serve as the workhorse for many of NASA's science missions, those spacecraft often have to make multiple gravity-assist maneuvers around inner planets before reaching the velocity needed to reach the outer planets. These maneuvers increase mission times by years and increase risk to onboard instruments because of the extended time in the space environment and the range of conditions to which they require exposure.

SLS utilization is currently being considered for NASA's proposed Europa Multiple Flyby Mission, which would provide an unprecedented look at the icy Jovian moon, believed to hold a subsurface ocean with more than twice the quantity of water on Earth, and investigate its potential habitability.

While launch on an Atlas V 551 EELV-baseline vehicle could require a Venus-Earth-Earth

gravitational assist trajectory requiring 7.5 years, launch on SLS would enable a direct transit to the Jovian system in less than three years, providing for earlier science return and reduced operational costs, among other benefits.

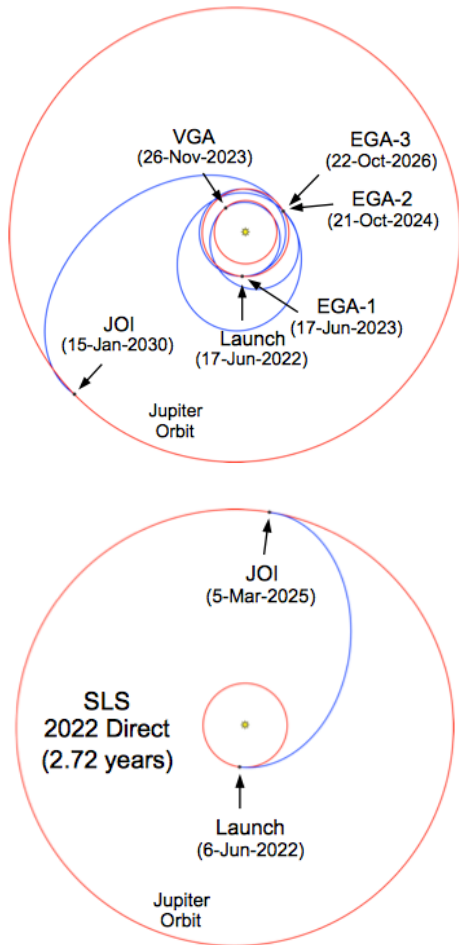


Figure 8. Gravitational-assist trajectory to Europa enabled by current EELVs (top) versus direct trajectory enabled by SLS (bottom).

The Europa Clipper mission analysis also serves as a test case for how SLS could benefit outer-planet exploration. One of the major benefits to the science community from the Mars Program has been the ability to learn from one mission and use that knowledge when formulating a near-term future investigation. The paradigm for outer planet exploration has necessitated very long cruise times, which, among other things, make it impossible to have a rapid turnaround in penetrating the mysteries

that the “ocean world” icy moons of the outer planets possess. The availability of the SLS breaks this model, and allows for significant transit-time reduction.

In the area of mass-lift benefits, a strong case study example is a Mars sample return mission, which has been a long-term goal for the Mars Program. A 2011 National Research Council (NRC) planetary science Decadal Survey concluded that a Mars Sample Return (MSR) mission is not only a top science priority, but also a good opportunity to blend the science and human spaceflight elements of NASA. An SLS utilization study by MSFC’s Advanced Concepts office identified MSR as a potential mission SLS could enable or enhance, particularly in the areas of mission complexity and sample size. The Mars Program Planning Group (MPPG) has recognized that the SLS may provide a “single shot” MSR opportunity. An SLS-enhanced Mars sample return could also be executed as a two-launch effort in connection with the Mars 2020 rover project, which is planned to cache material samples for future retrieval.

In the area of payload volume capacity, a large-aperture space telescope offers a good case study. Concept evaluation has demonstrated potential benefits of a large 8.4- or 10-m SLS payload fairing for the science community. Such a fairing would enable the launch of a large aperture (potentially 16-m class) telescope that would be able to make ultra-high-contrast spectroscopic observations of exoplanets. Such a capability would address a need identified in the 2013 NASA astrophysics roadmap, “Enduring Quests, Daring Visions.” Concept evaluations of such a project have also identified opportunities for further collaborations between science and human exploration systems in the form of assembly and servicing of an observatory in deep space.

While the most obvious mission profiles to benefit from SLS are those with requirements beyond the performance of current launch vehicles, SLS will also offer unique opportunities for smaller experiments in the form of secondary payload berths. Thirteen secondary payload locations will be available in the Orion-to-Stage Adapter in the initial SLS configuration, allowing payload deployment following Orion separation. The deployment berths are sized for “6U” CubeSats, and on EM-1 the spacecraft will be deployed into cislunar space following Orion

separate from the SLS Interim Cryogenic Propulsion Stage. Payloads in 6U class will be limited to 14 kg maximum mass. CubeSat payloads on EM-1 will include both NASA research experiments and spacecraft developed by industry, international and potentially academia partners.

Concepts are still being reviewed for secondary payload accommodations on the evolved configurations of SLS. There is potential for these configurations to carry a larger class of secondary payload, which could also be deployed either into cislunar space with Orion or to another deep-space destination, accompanying a primary science payload.

5. CONCLUSION

Through the development and operation of the Space Launch System, NASA is creating a new exploration-class capability designed for the most demanding and challenging missions of exploration and utilization. Following its first flight, SLS will return humans to deep space for the first time in decades, beginning a series of exploration missions that will lead to Mars and other destinations that will reveal an unprecedented wealth of knowledge about our solar system and universe.