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# NASA'S SPACE LAUNCH SYSTEM: AN EVOLVING CAPABILITY FOR EXPLORATION

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**Abstract**: Designed to enable human space exploration missions, including eventually landings on Mars, NASA's Space Launch System (SLS) represents a unique launch capability with a wide range of utilization opportunities, from delivering habitation systems into the lunar vicinity to high-energy transits through the outer solar system. The vehicle will be able to deliver greater mass to orbit than any contemporary launch vehicle. SLS will also be able to carry larger payload fairings than any contemporary launch vehicle, and will offer opportunities for co-manifested and secondary payloads.

**Keywords:** Launch, Vehicle, Payload, Accommodations, SLS, Mars

## 1. INTRODUCTION

Designed around the mandate to provide sufficient launch capability to enable human exploration missions beyond Earth orbit, NASA's Space Launch System 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 later configurations offering greater launch capability via an affordable and sustainable development path.

NASA is developing SLS in parallel with two other exploration systems development efforts – the Orion Multi-Purpose Crew Vehicle (MPCV) Program and the Ground Systems Development and Operations (GSDO) Program. The Orion MPCV is a four-person spacecraft designed to carry astronauts on exploration missions into deep space. GSDO is converting the facilities at NASA's Kennedy Space Center (KSC) in Florida into a next-generation spaceport capable of supporting launches by multiple types of vehicles. (Fig. 1)

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.

Currently under construction, the initial configuration of the vehicle will have the capability to deliver a minimum of 70 t into low Earth orbit and will be able to launch a crew aboard the Orion spacecraft on near-term exploration missions into cislunar space. 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 Mars.

**Fig. 1. Artist's concept of SLS aboard the Mobile Launcher moving to the launch pad.**

## 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 schedule and payload mandates for heavy-lift in the U.S. congressional NASA Authorization Act of 2010 in a manner that is safe, affordable, and sustainable. 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/$LH_2$) propellants and allows the initial configuration of the vehicle to be delivered with only one major new development, the Core Stage. (Fig. 2) In the summer of 2015, the SLS Program is undergoing 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.

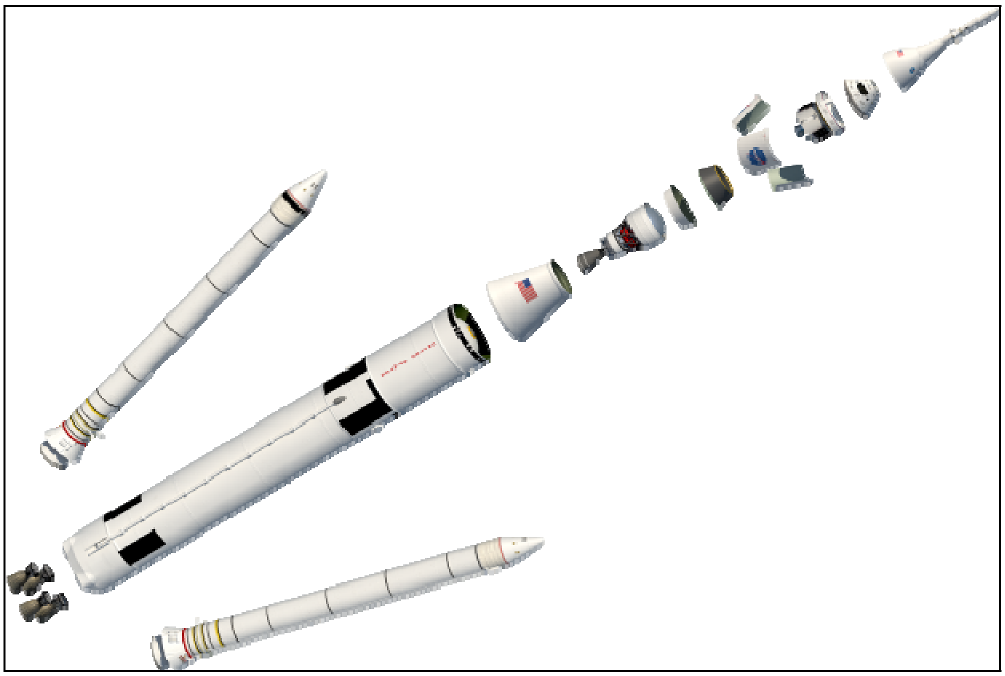

**Fig. 2: Expanded view of Space Launch System Block 1 vehicle elements.**

The SLS Core Stage, which stores the liquid oxygen (LOX) and liquid hydrogen ($LH_2$) 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 shuttle-era equipment and facilities at NASA's Michoud Assembly Facility (MAF) in Louisiana and at Kennedy Space Center.

At MAF, the last of six major welding manufacturing tools for the Core Stage, the 52m-tall Vertical Assembly Center (VAC), has been installed and is expected to be fully operational in fall 2015. The Boeing Company, Core Stage prime contractor, will use the VAC to weld barrel sections, rings and domes together to form the propellant tanks for the stage. Confidence barrel sections and domes have been completed, and work is underway on completing development LOX and $LH_2$ tanks for structural testing at NASA's Marshall Space Flight Center (MSFC) (Fig. 3 and 4) Rings for the first flight vehicle have been completed, and production has begun on flight barrel sections, and will continue throughout 2015.

**Fig. 3: NASA's Vertical Assembly Center.**


**Fig. 4: Core Stage barrel section.**

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.

Modifications to Stennis Test Stand A-1 to support RS-25 testing were completed in 2014, and testing of engine #0525 has begun in preparation for developmental and flight certification of the SLS configuration of the engine, including a new engine controller unit. The engine will be used to test propellant pressure and temperature inlet conditions that will both be higher 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. (Fig. 5)

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 in 2017, which will be NASA's largest engine ground firing since stage tests of the Saturn V.

**Fig. 5: RS-25 engine #0525 ready for installation on the A-1 test stand.**

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 Program is leveraging research, development, and testing conducted under NASA's Constellation Program to upgrade 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 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.

By using four main engines operating at 109 percent thrust versus three engines operating at 104.5 percent thrust on shuttle, and by adding a fifth segment to each of the solid rocket boosters, the initial 70 t version of SLS will generate 8.4 million pounds of thrust at launch, approximately10 percent greater than the Saturn V or the space shuttle.

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 the Orion MPCV on a circumlunar trajectory, the $LH_2$ tank of the SLS ICPS will be stretched 46 centimeters longer than the standard DCSS.

While the SLS Program is primarily focused on first flight, the Spacecraft/Payload Integration and Evolution office is working to lay the groundwork for the evolution of SLS beyond the 70 t Block 1. Reaching the full 130 t Block 2 capability will require supplementing the architecture developed for the initial configuration with two major new developments – advanced boosters and an upper stage (Fig. 6). The SLS evolution approach makes it possible to fly an interim 105-t-class vehicle after the completion of one of those upgrades. The 105-ton vehicle has been identified as fitting a potential "sweet spot" for the next set of human missions beyond LEO. The commonality-based evolution strategy will reduce the cost of reaching the full capability and will foster consistency in the SLS interfaces with the ground systems at KSC and with the spacecraft and payloads it carries.

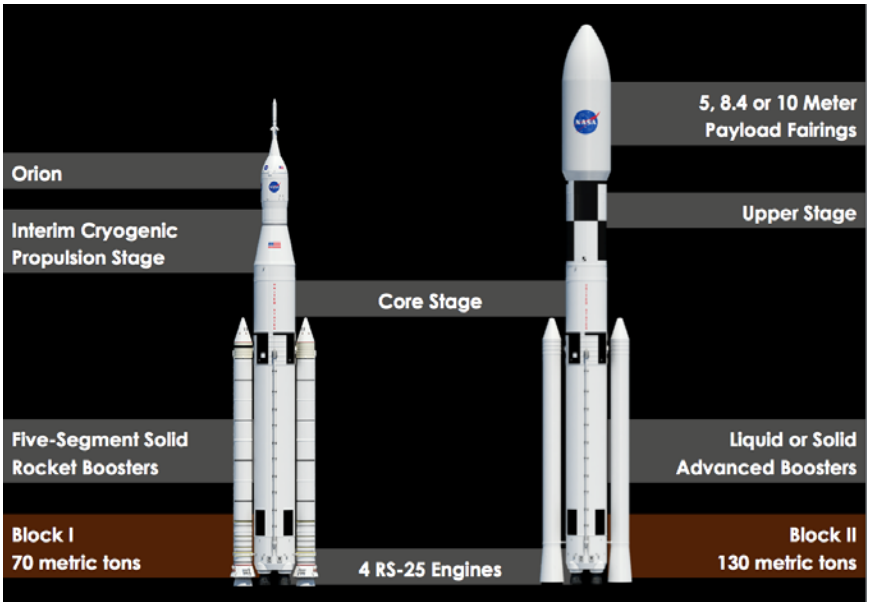


**Fig. 6: SLS evolution strategy.**

The first of the two upgrades involves research into upper stage options for the vehicle. While initial plans for the vehicle called for a combination of a large upper stage for ascent and a cryogenic propulsion stage for in-space propulsion, the Program is seeing benefits to the development of a low-thrust dual-use Exploration Upper Stage (EUS) providing both capabilities, which would enable greater mission capture on an early timeline by reducing the number of new developments required.

Conceptual development and risk reduction work has already begun on the advanced boosters that will provide a thrust advantage over the Block 1 boosters. The future inclusion of advanced boosters in the architecture provides an opportunity for industry to deliver cost-effective, innovative hardware for deep-space missions to be conducted beginning in the late 2020s or the 2030s.

While the baseline initial version of the vehicle is the Orion crew configuration, the initial and evolved configurations of SLS can conduct cargo launches using a payload fairing. The vehicle is capable in the near term of supporting cargo launch using existing industry 5-m fairings, providing a payload environment compatible with extant launch vehicles, but taking advantage of the vehicle's higher C3 and greater mass margins. Early research has also been conducted into options for larger 8.4- and 10-m fairings, with which SLS would offer greater payload volume lift capability than any other launch vehicle. With a 10-m fairing, the vehicle will be able to offer payload volumes five times greater than any 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 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.

## 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 United States national space policy and international collaborative planning are increasingly focusing 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 and precursor robotic science missions to the Red Planet, both of which are already ongoing. From there, the Agency will move from being "Earth dependent" in its human spaceflight capabilities into a "proving ground" approach and capabilities, where new systems, beginning with SLS and Orion, will be tested and demonstrated on increasingly ambitious missions, beginning in the lunar vicinity and moving outward. 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 several years in length, and moving from close proximity to the 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, would send the Orion crew vehicle into cislunar space. The first of these test flights, Exploration Mission-1 (EM-1) would launch an uncrewed MPCV on a 22-day flight into lunar Distant Retrograde Orbit (DRO), and the follow-up flight, Exploration Mission-2 (EM-2), will demonstrate a crewed Orion. (Fig. 7) This trajectory would support NASA's plans for carrying out a robotic asteroid redirection mission to move a small asteroid into lunar DRO, and could lay the groundwork for future staging of deep-space missions in near-lunar space.

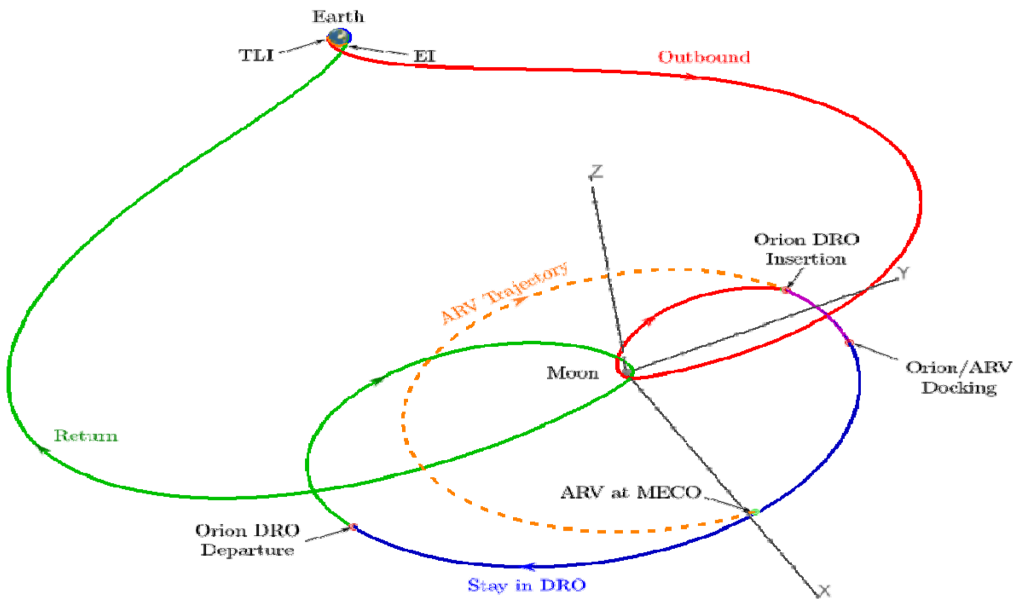


**Fig. 7: Notional distant retrograde orbit mission profile.**

As the initial development of SLS and Orion conclude, additional funding will become available for 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 cislunar space become possible. With a habitat and in-space propulsion, missions to Near-Earth Asteroids in their native environments could become possible, as could Mars-orbit missions. 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. THE JOURNEY TO MARS

While designed around the goal of enabling human exploration of the solar system, the capabilities the Space Launch System will provide to fulfill that charter will also provide game-changing benefits for a range of promising space science missions. Three interrelated areas have been identified in which SLS makes possible new missions or mission profiles – mass-lift capability, volume-lift 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. Fully 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.

Currently, the most mature science-mission concept that could benefit from SLS would take advantage primarily of the launch vehicle's departure energy capability. 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. (Fig. 8) 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 outer planets such as Jupiter or Saturn. These maneuvers increase mission times by years and increase risk to onboard instruments because of the extended time in the space environment.

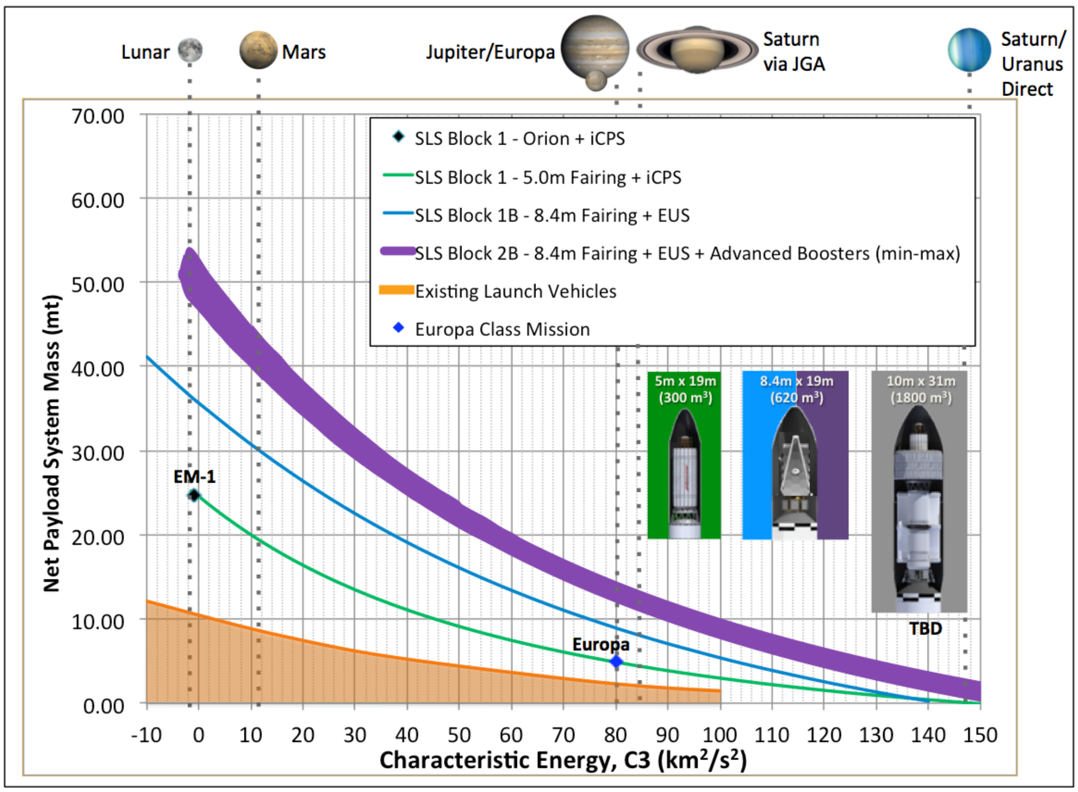


**Fig. 8: SLS characteristic energy.**

SLS utilization is currently being considered for NASA's proposed Europa Clipper mission, which would provide an unprecedented look at the icy Jovian moon, which is believed to hold a subsurface ocean with more than twice the quantity of water on Earth, and investigate the possibility that it could host life. While launch on an Atlas V 551 EELV-baseline vehicle could require a Venus-Earth-Earth gravitational assist trajectory requiring longer than 7.5 years, launch on SLS would enable a direct transit to the Jovian system in less than three years, providing far earlier science return and reduced operational costs, among other benefits. (Figs. XI and XII)

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 plant 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 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 volume-lift 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 12- to 20-m) telescope that would be able to make spectroscopic observations of exoplanets and search for life on other worlds. 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. Eleven secondary payload locations will be available in the Orion-to-Stage Adapter in the initial SLS configuration, allowing payload deployment following Orion separation. In its initial and evolved configurations, SLS offers rare opportunities for delivery of secondary payloads to destinations beyond Earth orbit.

## 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.