

## **NASA's Space Launch System: An Enabling Capability for Discovery**

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### **Abstract**

The National Aeronautics and Space Administration's (NASA's) Space Launch System (SLS) Program, managed at the Marshall Space Flight Center, is making progress toward delivering a new capability for human spaceflight and scientific missions beyond Earth orbit. Developed with the goals of safety, affordability, and sustainability in mind, the SLS rocket will launch the Orion Multi-Purpose Crew Vehicle (MPCV), equipment, supplies, and major science missions for exploration and discovery. Making its first uncrewed test flight in 2017 and its first crewed flight in 2021, the SLS will evolve into the most powerful launch vehicle ever flown, capable of supporting human missions into deep space and to Mars.

This paper will summarize the planned capabilities of the vehicle, the progress the SLS Program has made in the years since the Agency formally announced its architecture in September 2011, and the path the program is following to reach the launch pad in 2017 and then to evolve the 70 metric ton (t) initial lift capability to 130 t lift capability. The paper will outline the milestones the program has already reached, from developmental milestones such as the manufacture of the first flight hardware and record-breaking engine testing, to life-cycle milestones such as the vehicle's Preliminary Design Review in the summer of 2013. The paper will also discuss the remaining challenges in both delivering the 70 t vehicle and in evolving its capabilities to the 130 t vehicle, and how the program plans to accomplish these goals.

In addition, this paper will demonstrate how the Space Launch System is being designed to enable or enhance not only human exploration missions, but robotic scientific missions as well. Because of its unique launch capabilities, SLS will support simplifying spacecraft complexity, provide improved mass margins and radiation mitigation, and reduce mission durations. These capabilities offer attractive advantages for ambitious science missions by reducing infrastructure requirements, cost, and schedule. A traditional baseline approach for a mission to investigate the Jovian system would require a complicated trajectory with several gravity-assist planetary fly-bys to achieve the necessary outbound velocity. The SLS rocket, offering significantly higher C3 energies, can more quickly and effectively take the mission directly to its destination, providing scientific results sooner and at lower operational cost.

The SLS rocket will launch payloads of unprecedented mass and volume, such as "monolithic" telescopes and in-space infrastructure, and will revolutionize science mission planning and design for years to come. As this paper will explain, SLS is making measurable progress toward becoming a global infrastructure asset for robotic and human scouts of all nations by harnessing business and technological innovations to deliver sustainable solutions for space exploration.

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## I. PROGRAM BACKGROUND

For more than half a century, NASA has served as the vanguard of human space exploration and operations in the United States, forging a path that is becoming increasingly open for the nation's industry to follow. As that national investment is resulting in a new era of public-private partnership in low Earth orbit (LEO), it becomes incumbent on the Agency to continue to undertake the projects that are beyond the scope of industry in order to further push that envelope. Such is the philosophy behind NASA's new Space Launch System, a new national infrastructure asset that will open up the solar system for human deep-space exploration, while providing enabling benefits for a wide variety of other missions.

Scheduled for a first launch in 2017, the NASA Space Launch System will serve as a cornerstone for a new era of international human exploration of deep space. Since the NASA Authorization Act of 2010 mandated the development of a heavy lift vehicle [1], rapid progress has been made on the world's first exploration-class launch vehicle since the Saturn V, designed to carry human beings beyond LEO for the first time since 1972, when the Apollo Program concluded its sixth and final landing on the Moon.

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 (Fig. I). 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) into a next-generation spaceport capable of supporting launches by multiple types of vehicles.



*Fig. I. Artist's concept of SLS and Orion in the KSC Vehicle Assembly Building.*

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, building on NASA's pathfinding

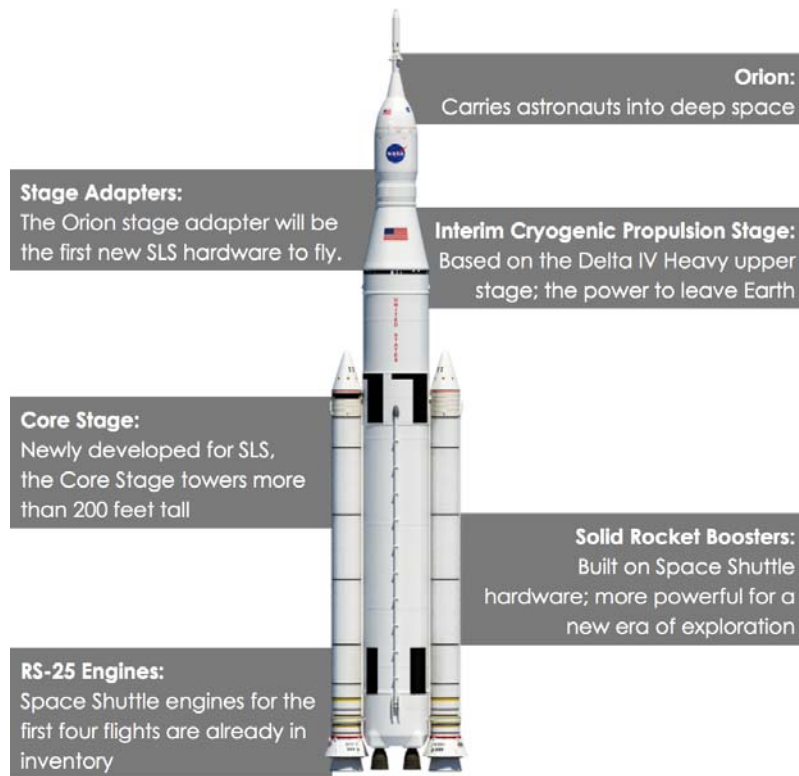
work with the Space Shuttle, while the Agency focuses its development efforts on blazing new trails via an incremental approach to developing systems necessary for human exploration beyond Earth orbit and eventually to Mars. Both Orion and SLS are being designed with enough performance margin and flexibility to support multiple missions and destinations rather than being limited to one particular mission or architecture.

Following the successful first flight of SLS, the vehicle will then be evolved, eventually reaching a full capability of delivering 130 t to LEO, making it the most powerful launch vehicle ever flown. This evolved configuration, baselined around NASA's Mars Design Reference Architecture studies, is designed to meet the requirements necessary to enable a human mission to Mars. Work is currently underway to do initial engineering studies and risk reduction work to support the evolution of the vehicle. While SLS was chartered for the purpose of supporting human space exploration, the vehicle, in both its initial and evolved configurations, will provide a robust capability that can be used to enable a wide variety of high-priority missions.

Over the last 2 1/2 years since NASA and the U.S. Congress formally announced the development of SLS on September 14, 2011, the launch vehicle matured from concept to design in only 21 months. By the time the Program completed its Preliminary Design Review and Key Decision Point-C programmatic review in 2013, it had already reached a high level of maturity compared to previous programs at those milestones, and that progress has continued as the Program has moved from its formulation phase into implementation. Tangible progress has been made on every aspect of the rocket. While operating within a constrained budget, the Program has effectively managed resources and finished each year with a positive balance sheet. The SLS Program's comprehensive progress attests to the Agency's commitment to provide a world-class launch vehicle that will take explorers and scientific spacecraft to deep space.

## II. Vehicle Overview

Space Launch System is designed to take advantage of NASA's heritage of success in human spaceflight, updated for a new era of exploration (Fig. II). The NASA Authorization Act of 2010 laid out the requirements for a powerful, versatile transportation system that could support a range of strategically important missions, such as the first Mars sample return on the course to eventual human journeys to explore another planet. NASA enlisted aerospace experts and stakeholders to participate in numerous studies that led to the Agency's selection of the SLS architecture in September 2011. Results of those trade studies are detailed in the "Preliminary Report Regarding NASA's Space Launch System and Multi-Purpose Crew Vehicle Pursuant to Section 309 of the NASA Authorization Act of 2010 (P.L. 111-267)" [2].



*Fig. II. Overview of the Space Launch System design.*

Based on requirements for a safe, affordable, and sustainable capability, the architecture selected is the best choice from among hundreds of concepts analyzed. A series of detailed trade studies was performed against numerous figures of merit with a common set of goals that included minimizing life-cycle costs, enabling challenging missions to deep space, and maintaining critical skills and transitioning the workforce effectively. From these concepts, three families of vehicles were chosen for further analysis including: a liquid oxygen/liquid hydrogen (LOX/LH<sub>2</sub>) Shuttle-derived vehicle, a liquid oxygen/hydrocarbon (LOX/RP-1) vehicle similar to the Saturn V, and a modular core vehicle utilizing commercially-available assets. In addition, NASA released a Broad Agency Announcement that sought technical solutions to support heavy-lift system concepts and architectures and to identify propulsion technology gaps to support NASA's goals.

The three vehicle concepts were presented during an Agency-led Mission Concept Review in March 2011 (Fig. II), while NASA's Procurement Office assessed the vehicle concepts from a fiscal perspective. This included the design, development, testing, and evaluation (DDT&E) investments needed, as well as the nonrecurring operations costs expected. The Shuttle-derived design was found to offer the safest, most capable transportation system in the shortest amount of time for the anticipated near-term and long-range budgets, and the SLS plan of action reflects this storied heritage. The SLS operational scheme takes advantage of resources established for the Space Shuttle, including the workforce, tooling, manufacturing processes, supply chains, transportation logistics, launch infrastructure, and LOX/LH<sub>2</sub> propellants.

#### Core Stage

The core stage is the only major new development in the SLS acquisition plan. The massive 8.4-m-diameter, 61-m-tall tank that forms the rocket's structural backbone is being built by the Boeing Company at Michoud Assembly

Facility, where the Saturn stages and Shuttle external tanks were manufactured. The stage, made of Aluminum 2219, will hold the LOX/LH2 propellants for the vehicle's main engines.

Following a steady cadence of installing six substantial welding tools in MAF, the first LH2 tank barrel segment was completed in July 2013 (Fig. III). It is considered a "confidence" barrel segment because it validates the vertical weld center (VWC) is working the way it should. The VWC is a friction-stir-weld tool for wet and dry structures on the SLS core stage [3]. Completed in June, the VWC will weld barrel panels together to produce whole barrels for the core stage's 2 pressurized tanks, the forward skirt, and the aft engine section. The massive machine stands 3 stories tall and weighs 136,000 kilograms (kg). The finished barrel segment is 6.7-m tall and weighs 4,100 kg. The segment will be used in structural tests to ensure the integrity of the piece. Five similar barrels and 2 end domes will be constructed to make up the SLS core stage LH2 tank.



***Fig. III. First LH2 tank confidence barrel section welded at MAF, July 2013.***

The core stage also contains the instrument ring, which houses the vehicle-level avionics. The flight computers are currently in testing at the MSFC Software Development Facility in an effort to rapidly mature and ensure implementation of a safe and highly reliable avionics and software system. Following this testing, the software will be installed and tested in the System Integration Test Facility, also at MSFC. These facilities allow technicians to "fly" the vehicle through virtual space using a variety of nominal and off-nominal scenarios, and make adjustments accordingly.

Currently, over 200 design drawings are being released per month. The core stage PDR was completed in December 2012, 5 months ahead of schedule. The core stage CDR is slated for mid-2014. All avionics components have completed their PDRs, with some having completed CDR. In 2015, the avionics will be shipped to MAF for integration into the stage, where the RS-25 engines will also be integrated. The integrated stage is due to be delivered to KSC for launch processing in late 2016/early 2017.

#### RS-25 Main Engines

The SLS Core Stage will be powered by four RS-25 engines, which previously served as the Space Shuttle Main Engine, taking advantage of 30 years of U.S. experience LOX/LH2, as well as an existing 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 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.

The RS-25 main engine delivers more than 500,000 pounds of thrust at 109 percent rated power level. Produced by Aerojet Rocketdyne, the RS-25 is the first reusable rocket engine in history, as well as the most reliable and highly tested large rocket engine ever built. During the 30-year Space Shuttle era, the RS-25 achieved 100 percent mission success with a demonstrated reliability exceeding 0.9996. During 135 missions and related engine testing, the RS-25 system accumulated over 1 million seconds of hot-fire experience.

Since the RS-25 production concluded several years ago and the vendor and supplier chain has changed, the SLS Engines Element Office has done innovative research to prepare for future cost-effective engine production. One of these research areas is additive manufacturing, also known as three-dimensional (3-D) printing, which is reducing the time to manufacture certain parts from months to days, thereby reducing production costs to a fraction of their former expense. Another benefit is that quality can be improved by making a homogenous part with no welds. Parts manufactured to date include the hot gas duct and turbine housing cover, both with excellent results during J-2X hot-fire testing (Fig. IX) [4][5].

NASA plans to begin testing RS-25 engines in 2014. Fabrication recently began at Stennis Space Center on a new thrust frame adapter for the A-1 Test Stand to enable this testing. This will be followed by core stage/main engine green run testing in 2016 on the B-2 Test Stand at SSC; refurbishments are now in progress.

### 5-Segment Solid Rocket Boosters

The majority of the thrust at launch for SLS 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 the Constellation Program to upgrade the boosters from the four-segment version flown on the Shuttle to a more-powerful five-segment version. The 5-segment SRBs for 70 t SLS configuration are produced by Alliant Techsystems, Inc. (ATK) and will be the most powerful in the world, delivering 3.55 million pounds of thrust during the early boost phase of flight. Heritage hardware and design includes forward structures, metal cases, aft skirt, and thrust vector control. The upgraded hardware and expendable design includes the solid rocket motor, avionics, and asbestos-free insulation.

Following three successful developmental motor tests, the first qualification motor (QM-1) is being prepared for testing (Fig. VIII). Following the QM-1 test in 2014, the instrumented motor will be disassembled and inspected prior to casting QM-2 segments. QM-2 testing is scheduled for 2015. Following disassembly, inspection, and analysis of QM-2, decision gates will lead to booster fabrication for Exploration Mission 1 (EM-1) [6].

Booster avionics boxes control the stage, take measurements, and communicate with the vehicle using an ignition separation controller, hydraulic power unit controller, booster control power distribution unit, and actuator control unit. Demonstration tests and flight control tests have been conducted to support QM-1 and -2 full-scale static tests [7]. In addition to contractor facilities, an avionics hardware-in-the-loop facility at MSFC allows end-to-end control system testing under simulated load conditions for development and certification testing.

In 2012, the Booster Element Office conducted extensive value stream mapping processes, which helped gain efficiencies and improvements by reducing hardware moves and eliminating unnecessary requirements by up to 40 percent throughout the manufacture and assembly process at ATK facilities. The booster flight set is slated for delivery to KSC for processing in mid-2017.

### Spacecraft and Payload Integration

The first original SLS Program flight hardware to be completed is the Multi-Purpose Crew Vehicle (MPCV) Stage Adapter (MSA), a structural ring (Fig. IV) that will mate an Orion mockup to a Delta IV rocket for a high-Earth orbit test flight in 2014 [8]. Reflecting the SLS Program's "design once, build many times" affordability tenet, this same design will be used for full-up SLS missions, as well. The MSA is an in-house development for the Exploration Flight Test in 2014, and is currently at Kennedy Space Center awaiting launch. Also in late 2013, the larger Launch Vehicle to Stage Adapter was competitively procured.



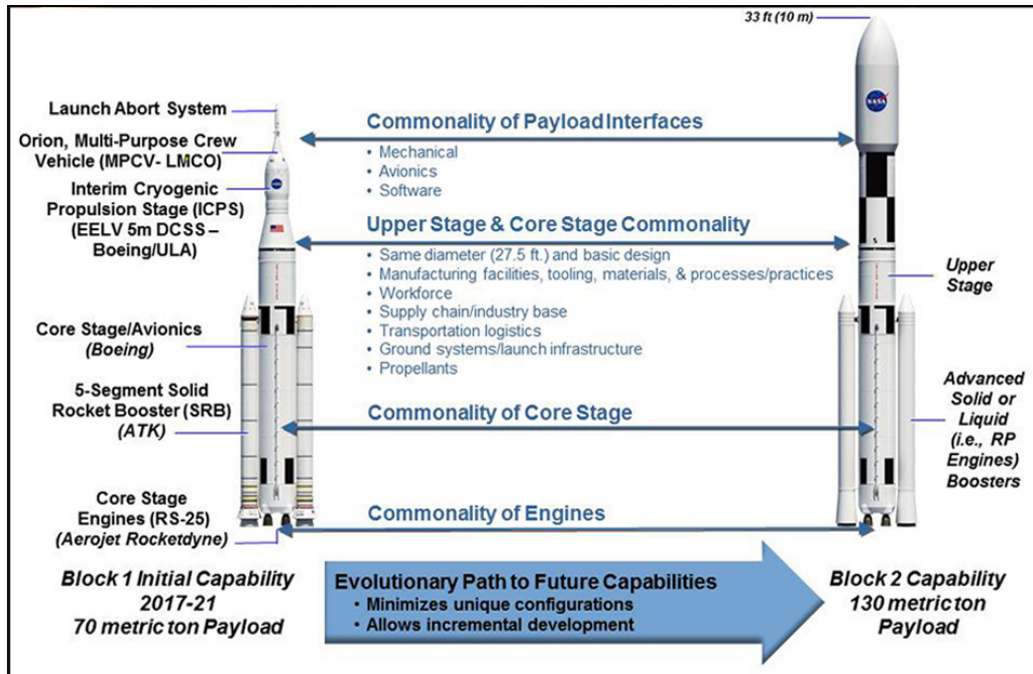


***Fig. IV. Stage adapter fit-check at Marshall Space Flight Center, June 2013.***

In-space propulsion for the 70 t Block 1 version of SLS will be provided by the Interim Cryogenic Propulsion Stage (ICPS), derived from United Launch Alliance's Delta Cryogenic Second Stage (DCSS) flown on more than 20 launches of the Delta IV Evolved Expendable Launch Vehicle (EELV). The RL10B-2 engine was rated for a certain set of loads and environments, so analyses are in progress to determine modifications that might be needed to handle the higher performance of the SLS. Specifically, the lateral loads imparted at liftoff due to winds at the launch pad and the ascent loads generated by aerodynamic buffeting exceed those of the DCSS environments for which the original hardware was designed. Mitigations include a T-zero stabilizer liftoff restraint and release system at the launch pad, as well as system damping. For ascent, additional analyses are being conducted to determine the optimum solution such as active electromechanical actuators in the thrust vector control system that will adjust to the predicted aerodynamic environment. Using heritage and commercial hardware ultimately saves time and money, but comes with a set of engineering challenges and programmatic risks that must be managed to achieve the desired results.

### III. Vehicle Evolution

While the SLS Program is primarily focused on first flight, early development work has already begun for the evolution of SLS beyond the 70 t Block 1. Reaching the full 130 t Block 2 capability will supplement the architecture developed for the initial configuration with two major new developments. The SLS evolution approach makes it possible to fly an interim 105-t-class vehicle after the completion of the first 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 means that the SLS connections with the ground systems at KSC and with the spacecraft and payloads it carries will remain consistent over time. (Fig. V)



*Fig. V. SLS commonality-based evolution approach.*

Conceptual development and risk reduction work has already begun on one of those two upgrades, advanced boosters that will provide a thrust advantage over the Shuttle-heritage solid rocket boosters. This requirement provides a competitive opportunity for industry to deliver cost-effective, innovative hardware for deep-space missions to be conducted after 2021. Through the Advanced Booster Engineering Demonstration and Risk Reduction task, contracts were awarded beginning in 2012 to four industry teams to perform tasks that could later inform the selection of a design for SLS advanced boosters. One of the contracts, awarded to ATK, involves research into propellant mixes and composite materials for advanced solid rocket boosters. The other three contracts, awarded to Northrop Grumman, Aerojet Rocketdyne, and a team consisting of Dynetics and Aerojet Rocketdyne, focus on a combination of composite structures and engines for liquid hydrocarbon fuel boosters (Fig. VI).

The other of the two upgrades involves research into upper stage options for the vehicle. Current plans call for a dual-use Exploration Upper Stage for ascent and in-space propulsion, which would enable greater mission capture on an early timeline by reducing the number of new developments required.

Development of either an advanced booster or an upper stage would enable evolution of SLS into a 105-t-class vehicle. At this time, risk reduction work on advanced boosters and trade space evaluation of upper stage options are being conducted concurrently, with a goal of concept maturation to support an evolutionary path decision in 2016 and upgrade to 105 t capability in the early 2020s.

Both the initial 70 t configuration and the later evolved configurations of SLS have the capability to support cargo launches using a payload fairing. While the baseline use of the initial vehicle configuration is crew launch capability, the vehicle is capable in the near-term of supporting cargo launch using existing industry 5 meter fairings, providing a payload environment compatible with extant launch vehicles, but with higher characteristic energy (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.



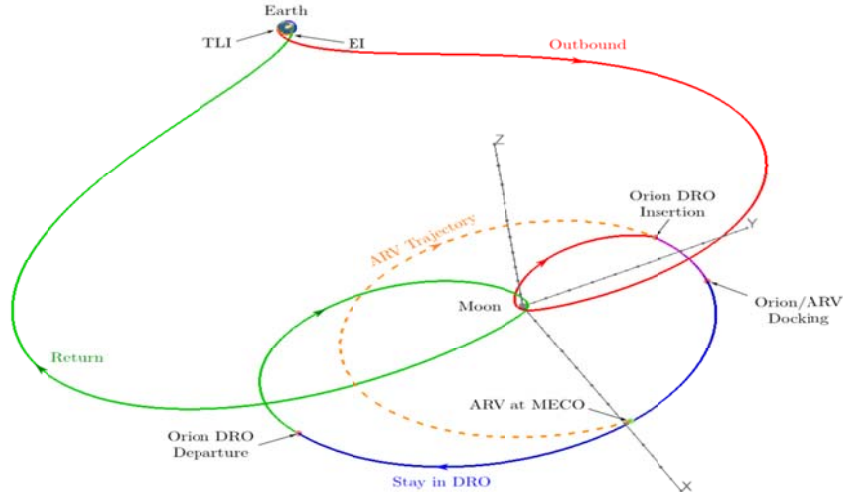


*Fig. VI. Test-firing of an F-1 gas generator at NASA' Marshall Space Flight Center.*

#### IV. HUMAN SPACEFLIGHT UTILIZATION

The Space Launch System was authorized with the intent of providing an enabling capability for human exploration into deep space, including, but not limited to, the eventual goal of landings on Mars. For missions beyond cislunar space, SLS will be one of several new system developments that will be required. By investing in the launch vehicle as the first development, NASA will enable test flights and near-term exploration—and potentially game-changing robotic science missions and uniquely large space hardware—while the other systems are being developed concurrently. Subsequent developments will include landers, habitats, and power-generation systems.

For human missions, SLS will launch the Orion spacecraft. The Orion MPCV is designed for beyond-Earth-orbit human spaceflight, with such supporting capabilities as a thermal protection system designed for high-velocity Earth-atmosphere reentry from deep space, and SLS is uniquely capable among contemporary vehicles to provide the mass-lift needed to launch Orion on these missions. Plans currently under evaluation call for the first flight of SLS to send an uncrewed Orion MPCV into lunar distant retrograde orbit (DRO) (Fig VII). This trajectory would support NASA's plans for carrying out a robotic asteroid redirection mission to move a small asteroid into lunar DRO where astronauts could rendezvous with it. Plans are for the second launch of an Orion spacecraft on SLS would be for a crewed mission along the same trajectory.



**Fig. VII. Notional concept of a lunar distant-retrograde-orbit trajectory.**

In addition to those planned missions, SLS and Orion could support other human exploration missions in and around cislunar space, including crewed flights into low lunar orbit and to the Earth-Moon Lagrange points. Studies have also shown that with one additional development derived from existing technologies and systems, SLS could be used to launch a deep space habitat into lunar space that could then be crewed using the Orion MPCV.

Beyond cislunar in-space missions, options exist for furthering exploration towards Mars. The NASA Authorization Act of 2010, which outlined requirements for SLS, also included a capabilities-driven-framework approach to space exploration, intended to open up vast opportunities for new destinations, including near-Earth asteroids and Mars. This followed the 2009 Review of U.S. Human Spaceflight Plans Committee Report [9]. The committee that produced that report, chaired by Norman Augustine, recommended a flexible path as one of three potential options for human exploration beyond Earth orbit.

A flexible path, in the words of the Augustine Commission, represents a different type of exploration strategy, one that would allow humans to learn how to live and work in space, to visit small bodies, and to work with robotic probes on planetary surfaces. It would provide the public and other stakeholders with a series of interesting “firsts” to keep them engaged and supportive. Most important, because the path is flexible, it would allow for many different options as exploration progresses, including a possible return to the Moon’s surface, missions to near-Earth objects or the moons of Mars, or a continuation directly to the Martian surface. SLS is intended to serve as a key cornerstone of the flexible path approach to space exploration, and the SLS architecture and block design approach reflect this strategy. [10]

The International Space Exploration Coordination Group (ISECG), consisting of 12 space agencies, including NASA, from nations around the world, has identified three primary “mission themes” for precursors towards human missions to the surface of Mars. Just as the development of SLS as the first step in a larger exploration architecture enables early flights while other systems are being developed, so too does the ISECG approach enable earlier exploration while working towards Mars. Those themes, as outlined in the Global Exploration Roadmap (GER), are exploration of a near-Earth asteroid, extended duration crew missions in the lunar vicinity, and humans to the lunar surface. [11] The first two would involve sending humans farther into space than they have ever been before and would require the development of the in-space systems, such as habitation and propulsion, that will eventually be needed for humans to travel through space to get to Mars. The latter theme would involve establishing a long-term human presence on the lunar surface, and would require the development of surface systems, including surface habitats and power-generation systems that will be needed for human exploration of the surface of Mars. Since SLS was designed to provide the capabilities necessary to support human missions to Mars, it also provides the capability to support incremental missions leading to that goal, and the GER recognizes SLS as an enabling resource for its mission themes.

Design of SLS as an enabling capability for human missions to Mars was based on meeting the requirements outlined in NASA's Mars Design Reference Architecture 5 (DRA5), the Agency's most-recently completed study of options for human Mars exploration. [12] The study outlines all of the systems and supplies that will be needed to execute a crewed Mars landing and identifies the Earth-orbit-departure mass for those payloads as being approximately 825 metric tons, double the mass of the International Space Station. Among the largest single systems required will be the in-space propulsion, for which the DRA5 identifies multiple options, including traditional chemical, nuclear thermal, nuclear electric, and solar electric propulsion (Fig. VI). Regardless of the option chosen, launching the in-space propulsion system as defined by DRA5 will require the mass- and volume-lift capability provided only by an evolved SLS, with a minimum mass-lift requirement of 105 t and a minimum volume lift capability of a 10 m fairing. Even for non-monolithic Mars-mission hardware that does not require launch on a single rocket, SLS offers substantial benefits. Breaking systems down into separately launched components requires including in them mating adapters for in-space assembly, adding a mass penalty and increasing complexity and thus mission risk. Studies also show that decreasing the number of launches also substantially decreases mission risk; launching payloads for a Mars mission via an SLS-class vehicle can double the probability of mission success over a contemporary Evolved Expendable Launch Vehicle [EELV] approach.

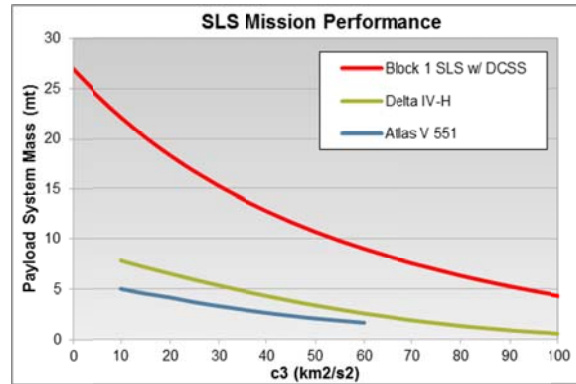
In addition to the human spaceflight utilization options outlined by NASA and its partner agencies, private entities have also begun identifying enhancing or enabling capabilities of SLS for human operations and exploration. Inspiration Mars, an organization working toward a crewed flyby of Mars, has identified substantial potential benefits of SLS for that mission, and Bigelow Aerospace has likewise identified substantial potential benefits of SLS for the launch of a 2,100 m<sup>3</sup> space habitat that would offer double the pressurized volume of the International Space Station [ISS]. A total of approximately 30 Space Shuttle and Russian vehicle launches were required to assemble ISS in orbit; the launch of a Bigelow BA-2100 would require only one SLS.

## V. ROBOTIC SCIENCE UTILIZATION

While designed around the goal of enabling human exploration of the solar system, the mass and volume lift capability Space Launch System will provide to fulfill that charter will also provide game-changing benefits for a range of promising space science missions.

The primary consideration for most robotic space missions has been the need to fit the payload inside existing launch vehicle fairings, which constrain spacecraft mass and size and often result in complex, origami-type folded designs that increase vehicle complexity and risk. SLS provides enough space to allow designers to relax volume constraints and concentrate on developing the instruments necessary to accomplish the primary science mission.

Another constraint for current science missions is the limit on C3 available to send spacecraft to BEO. The additional energy SLS offers reduces mission time, thereby reducing power requirements as well as the amount of time that scientific instruments are exposed to space (Fig. VIII). While commercial launchers have and will continue to serve as the workhorse for many of NASA's science missions, the 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.



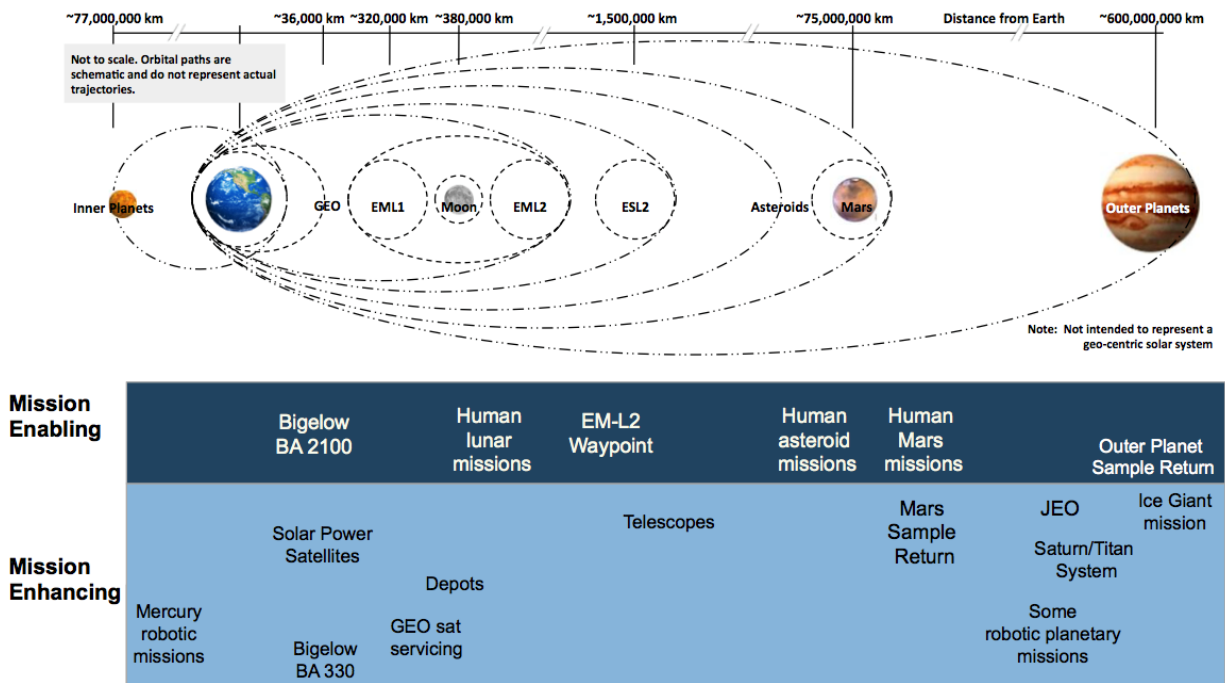
*Fig. VIII.  $c_3$  comparison of SLS to EELVs*

Primary advantages of SLS for robotic science missions include:

- Volume and mass capability and less-complex payload designs needed to fit in the fairing, leading to increased design simplicity.
- Fewer deployments and critical operations, 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 begin a dialogue on the vehicle's benefits for future missions and to better define how the rocket could enable them. Fully taking advantage of the mass and volume capacity SLS offers will require spacecraft designers and mission planners to change fundamental assumptions about spacecraft and mission design. However, if put to its greatest advantage, SLS could facilitate single-launch missions to the outer solar system, including first-ever sample return missions to Mars, Jupiter/Europa, and Saturn/Titan (Fig. IX).

To inform those conversations, NASA's Marshall Space Flight Center's Advanced Concepts Office performed an SLS Utilization Study, conducted as a follow-on to earlier Constellation-era decadal surveys, astronomy workshops, and planetary workshops, investigated arenas of opportunity that extend beyond human exploration goals into other areas of space exploration. [13] The initial process of the study was to perform a literature survey of all potential arenas in order to identify key mission goals and objectives. The literature survey included the various decadal surveys, previous utilization efforts conducted under the Constellation Program, and other special studies. Missions were organized and classified into arenas based on their destinations and goals. Over 40 potential mission candidates were identified, for destinations including inner planets, outer planets, Mars, near-Earth objects and the Earth-Moon Lagrange (EML) Points and Earth-Sun Lagrange (ESL) Points. [14]



**Fig. IX. Summary of SLS mission capabilities**

Among the candidates identified in that study was returning a sample from the surface of Mars, which has been a long-term goal for the Mars program for some time. 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.[15]

The SLS Utilization Study identified MSR as a highly regarded potential mission SLS could enable or enhance. Two primary areas that the study focused on were mission complexity and sample size. The Mars Program Planning Group (MPPG) has recognized that the SLS may provide a “single shot” MSR opportunity. The MPPG, chartered to provide options that integrate science, human exploration, and technology at an Agency level with Mars exploration as a common objective, found that a sample return orbiter can be integrated into a single launch with a Mars Ascent Vehicle (MAV) lander or combined/co-manifested with other missions.[16] 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. A baseline approach to retrieval would require two additional launches, one to bring the samples from the surface to Martian orbit, and another to return them from orbit to Earth. SLS could combine those two launches into one, expediting the sample return and increasing the probability of mission success.

Since the completion of the SLS Utilization Study, the Program has worked with the NASA science community to further refine concepts and requirements for some of the identified missions and to discuss opportunities for future collaboration. One such mission is an advanced-technology large-aperture space telescope. Although such a mission could likely be decades away, 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 to 20 m) telescope that would be able to make spectroscopic observations of exoplanets, enabling a search for life in other solar systems. 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.

Another mission that has been the subject of further concept definitization with the science community is the Europa Clipper pre-project. Jupiter’s moon Europa is believed to have a subsurface ocean, covered by a layer of water ice, that contains twice as much water as Earth, making the Jovian moon a high-interest target in the search for signs of



past or present life on other worlds, and a high priority of the planetary science Decadal Survey. Collaborative evaluation has revealed that by enabling a direct trajectory outbound flight to the Jovian system versus a Venus-Earth-Earth gravity assist (VEEGA) trajectory required by a baseline EELV approach, SLS could reduce transit time from over 6 years to under 3 years. Not only does this greatly expedite science return from the mission, it also has a corresponding impact on mission operation cost, potentially eliminates mass impacts of designing for the hotter environment of an inner-solar system flyby, eliminates permitting requirements for flyby of Earth with a radioisotope generator, and potentially allows for a longer science mission at the destination with quicker science return. While SLS would offer trade space for a spacecraft with much greater mass by longer transit time, this evaluation chose to focus on spacecraft mass compatible with an EELV baseline and decreased transit. By reducing transit time to the outer solar system in half, SLS could enable an iterative approach to exploration to those targets similar to what is currently used for robotic exploration of Mars.

## VI. SUMMARY

Through the development and operation of the Space Launch System, NASA is creating a new international capability that will serve as a cornerstone for a wide variety of utilization of space for decades to come, complementing contemporary systems for human operations in low Earth orbit by enabling ambitious missions that would not otherwise be possible. 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. (Fig. X) That same capability will also enable a wide variety of other missions, including science spacecraft that will reveal an unprecedented wealth of knowledge about our solar system and universe.



*Fig. X. Artist's concept of SLS 130 t vehicle launching from the Kennedy Space Center*

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The Space Launch System will provide an entirely new capability for human and scientific exploration beyond Earth orbit. It also will back up commercial and international partner transportation services to the International Space Station. Designed to be flexible for crew or cargo missions, the SLS will be safe, affordable, and sustainable, to expand boundaries and knowledge.

He previously served as the Ares V integration manager, and managed the Engineering Cost Group in the Office of Strategic Analysis and Communications at the Marshall Center.

Mr. Creech holds a bachelor's degree in Industrial Engineering from Mississippi State University. Honors include NASA's Medal for Exceptional Service and Distinguished Performance Award and the agency's prestigious Silver Snoopy, awarded by the Astronaut Office for professionalism, dedication and outstanding support that greatly enhanced space flight safety and mission success.