2969511 Space Propulsion 2014, 19-22 May 2014, Cologne, Germany

NASA's Space Launch System: A New Capability for Science and Exploration

Christopher M. Crumbly, Advanced Development Manager
Todd A. May, Program Manager
Kimberly F. Robinson, Ph.D., Strategic Communications Manager
Space Launch System Program
NASA Marshall Space Flight Center, Alabama 35812 U.S.A.

Abstract

The National Aeronautics and Space Administration's (NASA's) Marshall Space Flight Center (MSFC) is directing efforts to build the Space Launch System (SLS), a heavy-lift rocket that will launch the Orion Multi-Purpose Crew Vehicle (MPCV) and other high-priority payloads into deep space. Its evolvable architecture will allow NASA to begin with human missions beyond the Moon and then go on to transport astronauts or robots to distant places such as asteroids and Mars. Developed with the goals of safety, affordability, and sustainability in mind, SLS will start with 10 percent more thrust than the Saturn V rocket that launched astronauts to the Moon 40 years ago. From there it will evolve into the most powerful launch vehicle ever flown, via an upgrade approach that will provide building blocks for future space exploration. This paper will explain how NASA will execute this development within flat budgetary guidelines by using existing engines assets and heritage technology, from the initial 70 metric ton (t) lift capability through a block upgrade approach to an evolved 130-t capability, and will detail the progress that has already been made toward a first launch in 2017. This paper will also explore the requirements needed for human missions to deep-space destinations and for game-changing robotic science missions, and the capability of SLS to meet those requirements and enable those missions, along with the evolution strategy that will increase that capability. The International Space Exploration Coordination Group, representing 12 of the world's space agencies, has worked together to create the Global Exploration Roadmap, which outlines paths towards a human landing on Mars, beginning with capability-demonstrating missions to the Moon or an asteroid. The Roadmap and corresponding NASA research outline the requirements for reference missions for all three destinations. The SLS will offer a robust way to transport international crews and the air, water, food, and equipment they would need for extended trips to asteroids, the Moon, and Mars. SLS also offers substantial capability to support robotic science missions, offering benefits such as improved mass margins and radiation mitigation, and reduced mission durations. The SLS rocket, using significantly higher characteristic energy (C3), can more quickly and effectively take the mission directly to its destination, reducing trip time and cost. As this paper will explain, the SLS is making measurable progress toward becoming a global infrastructure asset for robotic and human scouts of all nations by providing the robust space launch capability to deliver sustainable solutions for advanced exploration.

I. PROGRAM BACKGROUND

Scheduled for a first launch in 2017, NASA's new Space Launch System will serve as a cornerstone for a new era of international exploration of deep space. Developed to fulfill the NASA Authorization Act of 2010 [1] mandate for a new system to support human space missions beyond Earth orbit, SLS will provide an enabling capability for a variety of other missions. In less than 3 years since inception, rapid progress has been made on the world's first exploration-class launch vehicle since the Saturn V, designed to carry human beings beyond low Earth Orbit (LEO) for the first time since 1972, when the Apollo Program concluded its sixth and final landing on the Moon. Beginning with an initial capability of delivering 70 metric tons to low Earth orbit, following its first flight, SLS will undergo block upgrades to an eventual full capability of delivering 130 t to LEO, making it the most powerful launch vehicle ever flown.

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.

In addition, NASA is developing these new exploration systems as part of a larger human spaceflight portfolio, including the International Space Station and commercial orbital crew transportation capability. This complete portfolio – arguably the Agency's most ambitious collection of human spaceflight efforts ever – will be used synergistically to pave the way for human voyages into the solar system. Ultimately, these missions will require massive space launch capability, and NASA is building its new Space Launch System to be the vehicle that will serve as a platform to expand international human presence and science missions into the solar system.

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

II. VEHICLE OVERVIEW

The Space Launch System is designed to take advantage of NASA's heritage of success in human spaceflight, updated for 21st century exploration (Fig. II). Based on requirements for a safe, affordable, and sustainable capability, a 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. 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 liquid oxygen and hydrogen (LOX/LH2) propellants.

The core stage is the only major new development in the SLS acquisition plan. The massive 8.4-meter diameter, 61-m-tall tank that forms the rocket's structural backbone is being built by 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. The core stage also contains the instrument ring, which houses the vehicle-level avionics.

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 with 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.

The majority of the thrust at launch for SLS will come from a pair of solid rocket boosters, also of Space Shuttle Program heritage, but upgraded from the 4-segment version flown on the Shuttle to a more-powerful 5-segment version. The 5-segment SRBs for the 70 t SLS configuration will be the most powerful in the world, delivering 3.55 million pounds of thrust during the early boost phase of flight.

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).

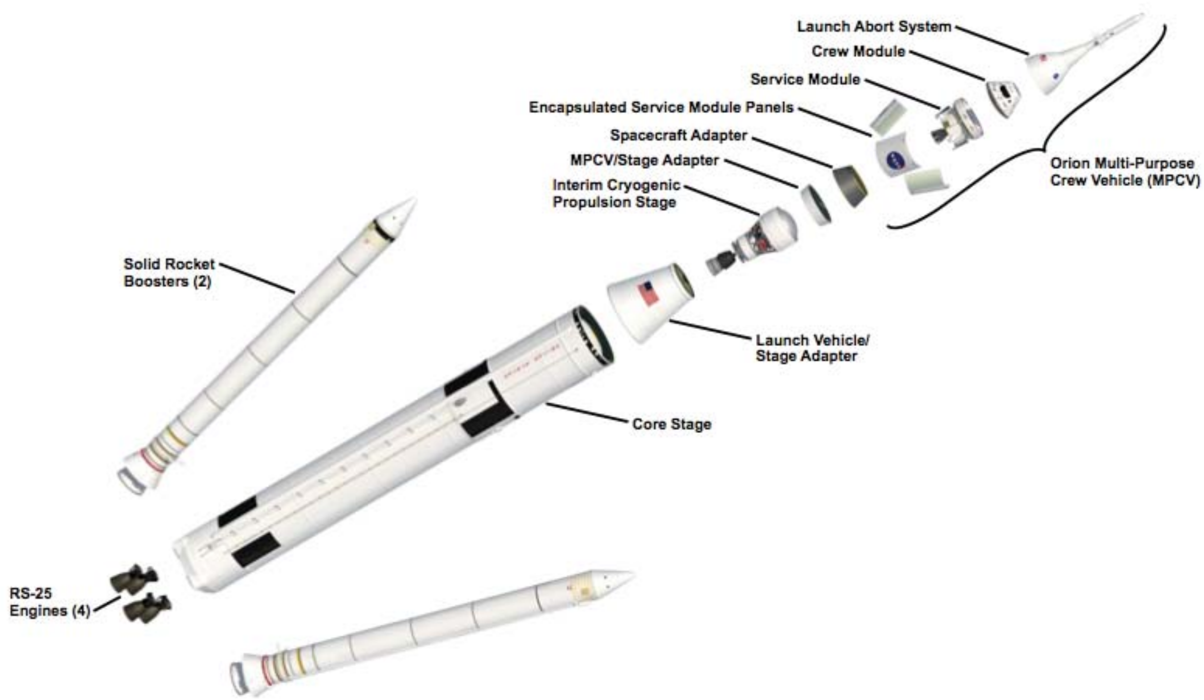

Fig. II. Overview of the Space Launch System design.

III. ADVANCED DEVELOPMENT

While the SLS Program is primarily focused on first flight, the Advanced Development 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. III). 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 will foster consistency in the SLS interfaces with the ground systems at KSC and with the spacecraft and payloads it carries. As the Advanced Development Office lays the groundwork for the vehicle's evolutionary developments and matures new technologies for introduction into the vehicle, it also seeks partnerships for leveraging these investments for the benefits of the larger launch industry.

Conceptual development and risk reduction work has already begun on the advanced boosters that will provide a thrust advantage over the Shuttle-heritage solid rocket boosters. The future inclusion of advanced boosters in the architecture 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 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 contracts, awarded to Northrop Grumman, Aerojet Rocketdyne, and Dynetics, focus on a combination of composite structures and engines for liquid hydrocarbon fuel boosters. In addition to maturing liquid booster concepts for SLS, a partnership with the U.S. Air Force is allowing for the evaluation of these concepts as the basis for a future EELV-class American kerosene engine.

The other 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 providing both capabilities, which would enable greater mission capture on an early timeline by reducing the number of new developments required. In another partnership with the U.S. Air Force, the Advanced Development Office has conducted the Affordable Upper Stage Engine Program, designed to mature technologies, which could modernize upper stage engines for both SLS and EELVs.

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 leading to 105 t capability in the early 2020s. The Advanced Development Office is also conducting in-house research and has awarded grants to academia to seek innovative solutions to specific technological challenges.

While the baseline initial version of the vehicle is the Orion crew configuration, both 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 with 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.

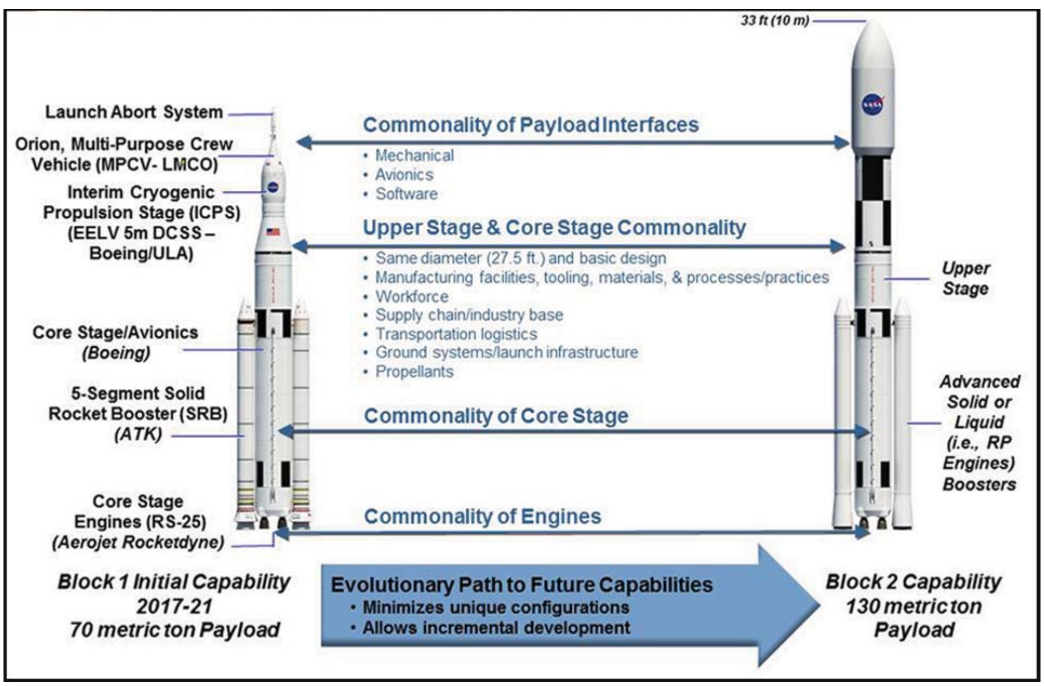

Fig. III. SLS commonality-based evolution approach.

IV. PROVING GROUND

When United States President John F. Kennedy announced in 1961 a national goal to land humans on the Moon by the end of the decade and bring them safely home, the country had only minutes of spaceflight experience from one suborbital flight. In order to meet that goal, a variety of new capabilities were developed to bridge the gap between that one suborbital flight and a lunar landing. Over the course of the next 8 years, NASA incrementally developed, tested, and demonstrated those capabilities, including such things as weeks-duration spaceflight, rendezvous and docking, and extravehicular activities. By gradually increasing capabilities and reducing risk, the Agency was able to accomplish the goal of a lunar landing by President Kennedy's deadline.

Today, members of the international spaceflight community have identified Mars as the next significant goal for human space exploration. Accomplishing a human landing on Mars from the present status of human spaceflight will present challenges and require new developments that will dwarf those necessary to reach the Moon in the 1960s. Numerous new systems will be required, including in-space propulsion, in-space and surface habitation, in-space and surface power generation, landers, and surface operations equipment, among others. Together, the systems needed for a human Mars mission will be massive, possibly of substantially greater mass than the International Space Station (thus requiring massive space launch capability).

Just as NASA reached the Moon almost 50 years ago via a series of incremental steps beginning in Earth orbit and moving into cislunar space, NASA has outlined a strategy for using a similar approach to reducing risk while developing new capabilities to support human mission to Mars (Fig. IV)

The first steps in this path will be "Earth Dependent," utilizing existing or near-term capabilities. The International Space Station offers a platform for conducting research and testing systems that will enable human exploration missions, and an environment that poses relatively lower risk than deep-space voyages. Biomedical research such as the planned year-long Station increment of astronaut Scott Kelly will give NASA greater understanding of adaptation issues crew members will face during Mars missions, and hardware utilization such as the upcoming launch of an microgravity-compatible three-dimensional printer will test new capabilities that will support these missions. NASA's orbital commercial crew transportation will maximize the Agency's ability to utilize the Station for exploration precursor efforts.

While the International Space Station provides a convenient testbed for this research and development, preparing for human journeys to Mars will require more ambitious missions to prove out the necessary systems. While the International Space Station is located only hours from launch pads, deep-space missions will not enjoy the ability to have regular resupply flights or to have immediate abort return capability in the event of problems. These "Proving Ground" missions will send humans to cislunar space and then gradually farther out to incrementally test systems and develop capabilities that will reduce crews' dependence on their home planet. Initial and intermediate configurations of SLS will enable these missions.

Ultimately, the goal is to develop "Mars Ready" systems, capable of functioning self-sufficiently for the duration of a potentially years-long mission. Robotic missions in the interim will mature our understanding of Mars and prepare for eventual crewed missions, but pnly once the Agency has completed its precursor preparations in Earth orbit and in the proving ground of cislunar space and beyond will it be ready for human landings on the Red Planet. These missions will be powered by the fully evolved 130 t configuration of SLS.

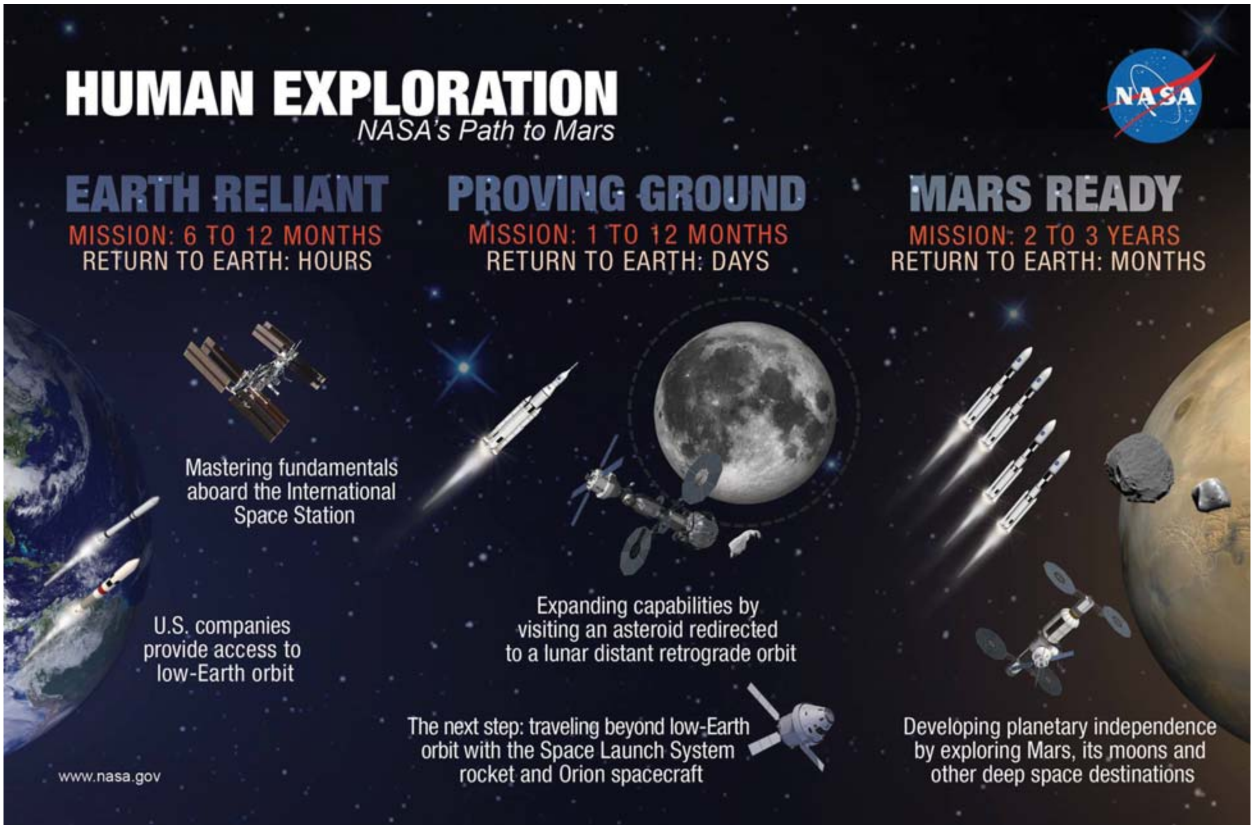

Fig. IV. NASA's incremental approach to Mars exploration.

IV. THE PATH TO MARS

The Space Launch System was authorized with the intent of enabling 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.

For human missions, SLS will launch the Orion MPCV, 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. SLS is uniquely able 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). 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 to be a crewed mission along the same trajectory (Fig. V).

Beyond cislunar in-space missions, options exist for furthering exploration towards Mars. A flexible path 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. 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. [2]

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, enable earlier exploration while working toward the goal of the Red Planet. 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. [3] 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. GER recognizes SLS as an enabling resource for its mission themes.

Design of SLS as enabling for human missions to Mars was based on meeting the requirements outlined in NASA's Mars Design Reference Architecture 5 (DRA5) study of options for human Mars exploration. [4] While subsequent studies are outlining more optimized Mars architectures, the DRA5 study provides a thorough baseline for establishing the capabilities necessary for human Mars missions. Among the largest single systems the study identifies as required for these missions are in-space propulsion, for which the DRA5 identifies multiple options, including traditional chemical, nuclear thermal, nuclear electric, and solar electric propulsion, any of which would require the mass and volume lift 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.

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 SLS as an enabling requirement for that mission, and Bigelow Aerospace has likewise identified enabling benefits of SLS for the potential utilizations of the company's inflatable space habitats.

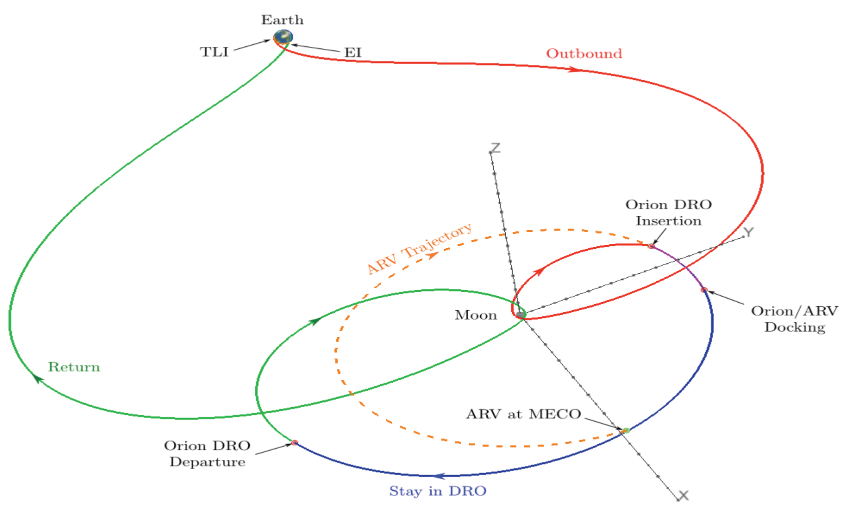

Fig. V. Notional concept of a lunar distant-retrograde-orbit trajectory.

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.

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.

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 (Fig. VI). [5] 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. 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.[6] 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. 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.

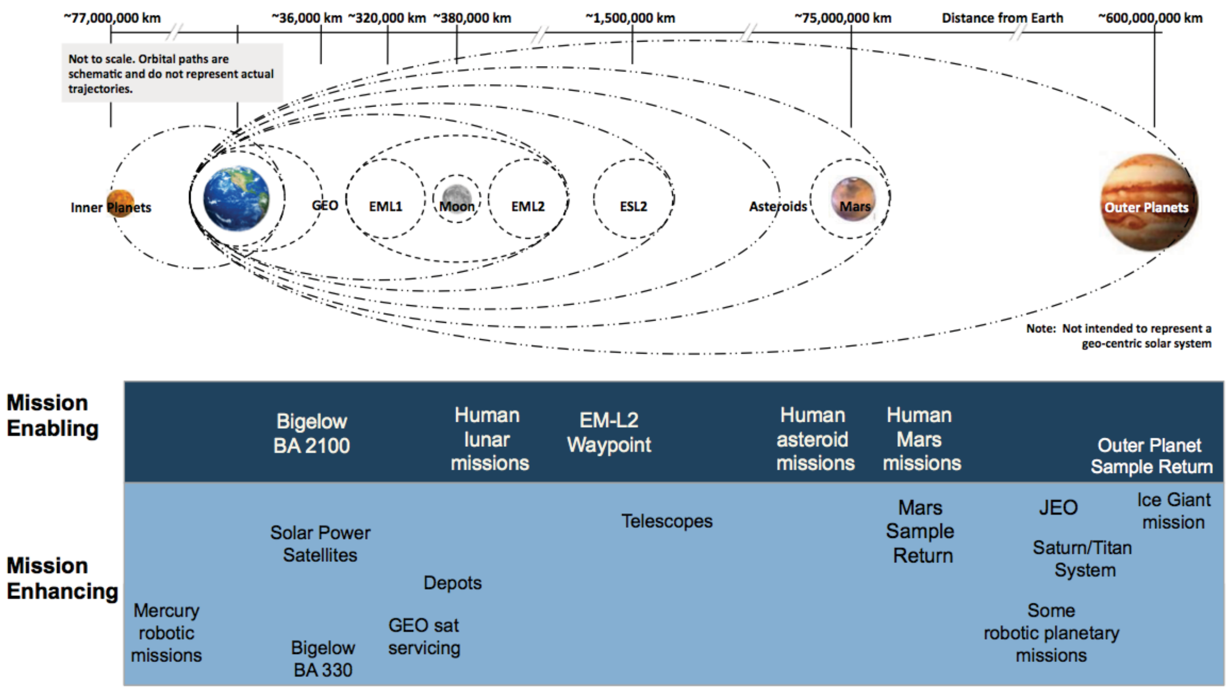

Fig. VI. SLS mission capabilities

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. Concept evaluation has demonstrated potential benefits of a large 8.4- or 10-m SLS payload fairing, which would enable the launch of a large aperture telescope that would be able to make spectroscopic observations of exoplanets, enabling a search for life in other solar systems.

Another mission that has been the subject of further concept definitization with the science community is the Jet Propulsion Laboratory's 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 more than 6 years to under 3 years.

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. VII). 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. VII. Artist's concept of SLS 130 t vehicle launching from the Kennedy Space Center

REFERENCES

[1] NASA Authorization Act of 2010: http://commerce.senate.gov/public/?a=Files.Serve&File_id=20a7a8bd-50f4-4474-bf1d-f0a6a8824b01.
[2] "Voyages: Charting the Course for Sustainable Human Space Exploration," June 2012, http://www.nasa.gov/exploration/whyweexplore/voyages-report.html#.UhZwPOBcTh4
[3] "The Global Exploration Roadmap," August 2013, http://www.nasa.gov/sites/default/files/files/GER_2013_for_release.pdf
[4] Mars Design Reference Architecture 5.0, July 2009: http://www.nasa.gov/pdf/373665main_NASA-SP-2009-566.pdf
[5] The National Academies Press, "Launching Science: Science Opportunities Provided by NASA's Constellation System," 2008: http://www.nap.edu/openbook.php?record_id=12554&page=R1
[6] National Research Council, "Visions and Voyages for Planetary Science in the Decade 2013-2022," 2011: http://solarsystem.nasa.gov/multimedia/downloads/Vision_and_Voyages-FINAL1.pdf