

IAC-15-D2.8

NASA'S SPACE LAUNCH SYSTEM
MISSION CAPABILITIES FOR EXPLORATION

Stephen D. Creech

NASA Space Launch System, USA, steve.creech@nasa.gov

Christopher M. Crumbly

NASA Space Launch System, USA, chris.crumbly@nasa.gov

Dr. Kimberly F. Robinson

NASA Space Launch System, USA, Kimberly.f.robinson@nasa.gov

Designed to enable human space exploration missions, including eventual 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. Developed with the goals of safety, affordability and sustainability in mind, SLS is a foundational capability for NASA's future plans for exploration, along with the Orion crew vehicle and upgraded ground systems at the agency's Kennedy Space Center. Substantial progress has been made toward the first launch of the initial configuration of SLS, which will be able to deliver more than 70 metric tons of payload into low Earth orbit (LEO), greater mass-to-orbit capability than any contemporary launch vehicle. The vehicle will then be evolved into more powerful configurations, culminating with the capability to deliver more than 130 metric tons to LEO, greater even than the Saturn V rocket that enabled human landings on the moon. 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. Because of its substantial mass-lift capability, SLS will also offer unrivaled departure energy, enabling mission profiles currently not possible. Early collaboration with science teams planning future decadal-class missions have contributed to a greater understanding of the vehicle's potential range of utilization. This presentation will discuss the potential opportunities this vehicle poses for the planetary sciences community, relating the vehicle's evolution to practical implications for mission capture. As this paper will explain, SLS will be a global launch infrastructure asset, employing sustainable solutions and technological innovations to deliver capabilities for space exploration to power human and robotic systems beyond our Moon and in to deep space.

I. INTRODUCTION

As NASA's new Space Launch System rocket matures toward initial launch readiness, so too is the SLS Program maturing the vehicle's increasing capabilities to support a wide variety of missions and spacecraft.

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.

In the past year, the Program has not only made substantial progress in the design, fabrication, and testing of the initial configuration of the rocket, it has also matured concepts for payload accommodation options for the initial and future configurations.

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)

Currently under construction, the initial Block 1 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 Block 2 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. I: Artist's concept of the SLS vehicle and Orion spacecraft aboard the Mobile Launcher moving to the launch pad at Kennedy Space Center.

II. 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/LH2) propellants and allows the initial configuration of the vehicle to be delivered with only one major new development, the Core Stage. (Fig. II) The SLS Program has now 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.

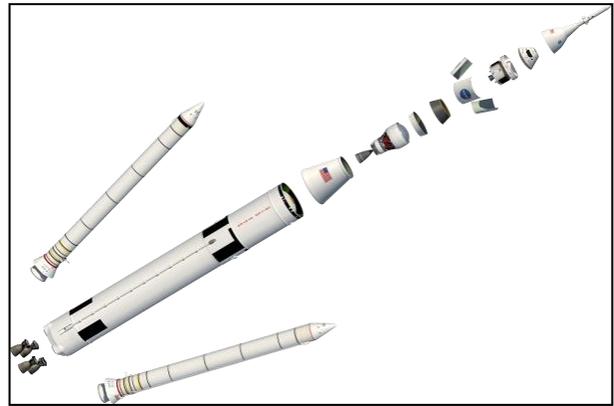


Fig. II: Expanded view of the Space Launch System Block 1 vehicle elements.

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 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 the fourth quarter of calendar 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 once calibration of the VAC is complete, the tool will be used to weld those pieces into test articles of the LOX and LH2 tanks that will be used for structural testing at NASA's Marshall Space Flight Center (MSFC) beginning in 2016. The majority of the segments for the tanks for the first flight Core Stage unit are currently complete at MAF as well.

The Core Stage will be powered by four RS-25 engines, previously 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.

In August 2015, the first series of tests on one of the two development engines was completed, verifying the engines' ability to handle the new loads and environments of SLS in comparison to the shuttle. (Fig. III) The next test series will use engine 2059, one of four engines designated for the second launch of SLS.

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.

Initial work is also underway toward procurement of the next six RS-25 engines to follow the current inventory of 16 engines. The new engines will be optimized for greater performance and expendability (and thus affordability).

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 configuration 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, which will make them the most powerful ever flown. 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 completed the first of two Qualification Motor tests, and preparations are well underway for the second of the qualification tests to take place during the first half of 2016. (Fig. IV)

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 Block 1 version of SLS will generate 8.4 million pounds of thrust at launch, approximately 10 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 October 2015, United Launch Alliance, the contractor for the ICPS will complete the structural test article of the stage. At Marshall Space Flight Center, work is on-going on the construction of a structural test article for the Launch Vehicle Stage Adapter (LVSA), which will

connect the ICPS with the core stage. In 2016, the ICPS and LVSA test articles will be stacked with a test article of the Orion Stage Adapter (OSA), which connects the ICPS with the Orion crew vehicle. The stack will undergo structural testing at MSFC.

The OSA test article was completed earlier in preparation for the first flight of the OSA on Orion's Exploration Flight Test-1 on a Delta IV Heavy rocket in December 2014, the first time original SLS hardware has flown into space.



Fig. III: Testing of an RS-25 engine in the A-1 test stand at NASA's Stennis Space Center in August 2015.



Fig. IV: Qualification testing of a five-segment solid rocket motor at an Orbital ATK facility in March 2015.

While the SLS Program is primarily focused on first flight, it is simultaneously 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 – an upper stage and advanced boosters. (Fig. V) The SLS evolution approach makes it possible to fly an interim 105-t-class Block 1B 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.

The first of those two developments will be an Exploration Upper Stage, a low-thrust, dual-use stage that will provide propulsion both for ascent and in-space use. The stage, which could potentially be available as early as the second flight of the vehicle, recently completed a checkpoint signifying adequate maturity to proceed into a Preliminary Design Review of the Block 1B configuration of the vehicle.

Conceptual development and risk reduction work has already been conducted on the advanced boosters that will provide a performance 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. The work conducted under the Advanced Booster Engineering Demonstration and/or Risk Reduction effort has produced data on innovative uses of friction stir welding, composites, and additive manufacturing which offer the potential for benefits not only to SLS but to the larger U.S. launch industry.

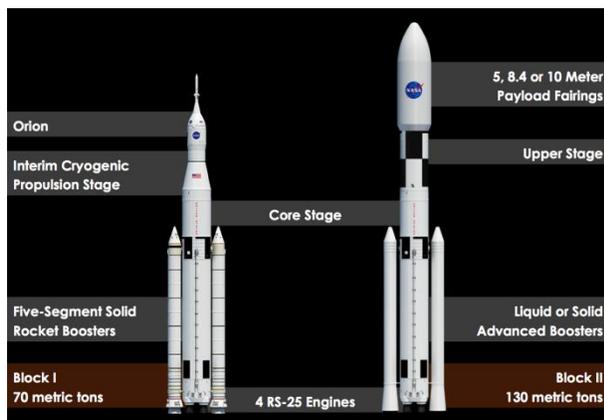


Fig. V: SLS evolution strategy from Block 1 to Block 2.

III. VEHICLE CAPABILITIES

Three interrelated areas have been identified in which SLS offers distinct advantages which make 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.
- Reduced number of launches necessary for high-mass or –volume payloads, resulting in decreased assembly mass and time, and reduced complexity and risk.

By offering greater launch mass capability than any vehicle currently in operation or development in its initial configuration and than any historic vehicle in its evolved configuration, SLS enables deployment of massive systems into Earth orbit or assembly of larger systems, either in Earth orbit or cislunar space.

Enabled by that high mass-lift capability, SLS also offers uniquely high departure, or characteristic, energy, which offers the potential to reduced transit time or increase spacecraft mass to a given destination. For example, contemporary EELVs offer a maximum mass to a Mars-transit C3 of approximately 11 km²/s² of about 9 metric tons. The initial Block 1 configuration of SLS will be able to double that capability; the Block 1B configuration will be able to triple it, and the Block 2 will quadruple it. (Fig VI)

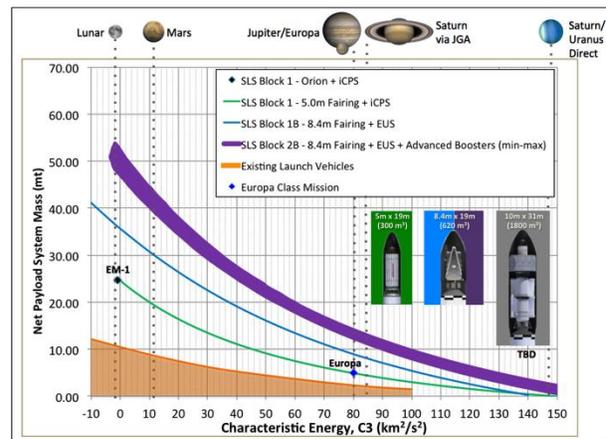


Fig. VI: SLS characteristic energy.

The reduced transit times enabled by SLS' characteristic energy (C3) offer the obvious benefit of return of scientific results years earlier than contemporary EELVs, but also produce the potential for secondary benefits such as reduced power requirements and decreased 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 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.

The third major area in which SLS offers substantial capability advantages over existing vehicles is in payload volume, with the potential to carry fairings more than five times larger than any existing rocket can carry. (Fig VII)

The basic Block 1B and 2 crew configurations of SLS has the capability to offer a unique accommodation to a co-manifested payload flying with an Orion crew vehicle in the Universal Stage Adapter connecting the spacecraft to the Exploration Upper Stage, in a manner similar to that in which the Saturn V rocket carried the Apollo Lunar Module in the Spacecraft-Lunar Module Adapter between the Apollo Command and Service Module and the launch vehicle's S-IVB stage. For human exploration missions, this accommodation offers 400 m³ of space for delivery of multi-ton payloads to a destination alongside Orion, allowing, for example, deployment of crew vehicle and a habitat with crew to cislunar space with a single launch.

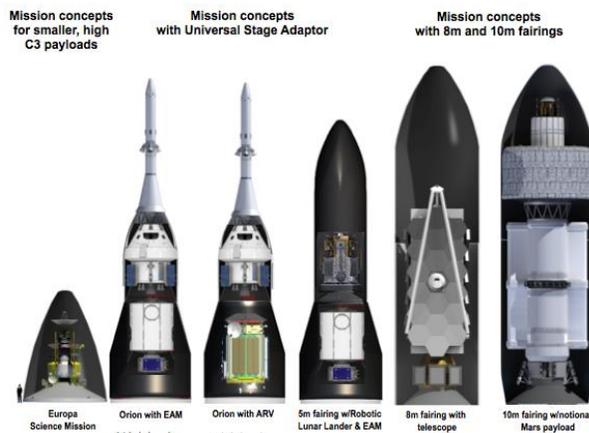


Fig. VII: SLS fairing options.

When used for other missions, SLS has the capability of carrying a variety of sizes of traditional payload fairings. 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. A 5-m fairing could be flown on either a Block 1 vehicle, or on a Block 1B or 2 with a Universal Stage Adapter, which would allow for even greater payload volume. Assuming a fairing height of 14 to 19 meters, these fairings would provide an industry-high volume of 200-300 m³.

The evolved vehicle will also be able to carry larger 8.4-m and 10-m fairings, which would be able to offer payload volumes of up to 1,200 m³ and 1,800 m³

respectively. As a near-term solution during development of those larger fairings, the vehicle also has the capability of carrying a shorter 8.4-m fairing derived from the Universal Stage adapter, which would offer a payload volume around 350 m³.

SLS also offers the capability to carry smaller secondary payloads along with the Orion crew vehicle and other primary and co-manifested payloads. The Block 1 configuration will be able to carry several 6U CubeSat-class payloads, weighing less than 14 kg each, within the Orion Stage Adapter, and the Block 1B and 2 vehicles will be able to carry up to six larger payloads (greater than 180 kg each) inside the Universal Stage Adapter between a payload attach fitting and the primary (or co-manifested) payload. (Fig VIII) These accommodations open opportunity for delivering smaller, lower-cost experiments to deep-space destinations.

IV. 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.

Toward that end, NASA is developing a capabilities-driven "Journey to Mars," combining the efforts of the agency's Human Exploration and Operations (HEO) Mission Directorate, Science Mission Directorate, and Space Technology Mission Directorate to gain knowledge and development systems and capabilities that will be necessary for human exploration of Mars.

On a high-level, the Journey to Mars involves three phases. The agency is currently in an "Earth Dependent" phase, in which our human spaceflight endeavours rely on the close proximity of Earth. Research being conducted aboard the International Space Station, such as the current "One Year Crew" mission, will help the agency gain knowledge in areas such as the biomedical effects of human spaceflight exposure and adaptation that will be necessary for lengthy missions to Mars. Development of a commercial crew transportation capability to complement the current commercial cargo capability will allow the agency to pursue more robust precursor research about the space station. During this time that human spaceflight is still in the "Earth Dependent" phase, robotic orbiters and landers will continue to study the Red Planet, gaining greater scientific knowledge that will be needed for human exploration. In the 2020s, upon readiness of SLS and Orion for crewed missions, NASA will move into a "Proving Ground" phase, developing and testing on increasingly ambitious missions in cislunar space the capabilities and systems needed for exploration farther

into space. Ultimately, “Earth Independent” systems will be used to conduct missions to the Mars vicinity and ultimately the first human landings on the Martian surface.

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 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 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. VIII) 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.

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, Mars flyby or orbit could become possible destinations. The moons of Mars also 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.

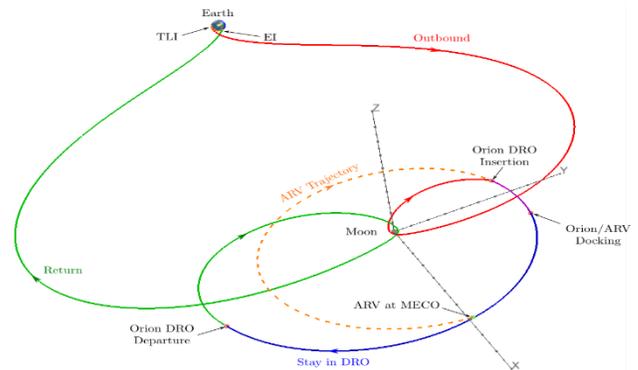


Fig. VIII: A Distant Retrograde Orbit trajectory.

V. SCIENCE UTILIZATION

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

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 utilization is currently being considered for NASA’s proposed Europa Multiple Flyby 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. (Fig. IX)

While launch on an Atlas V 551 EELV-baseline vehicle would require a Venus-Earth-Earth gravitational assist trajectory potentially 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. The Europa Multiple Flyby Mission analysis also serves as a test case for how SLS could benefit outer-planet exploration. One of the major opportunities NASA’s Mars exploration program has benefited from has been the ability to learn from one mission and use that knowledge when formulating a near-term future investigation, taking advantage of the opportunity to fly iterative missions around the planet’s 26-month opposition cycles. 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 icy moons of the outer planets possess. The availability of

the SLS breaks this model, and allows for significant transit-time reduction. As interest grows in a larger ocean-worlds exploration program, this capability could be substantively beneficial.

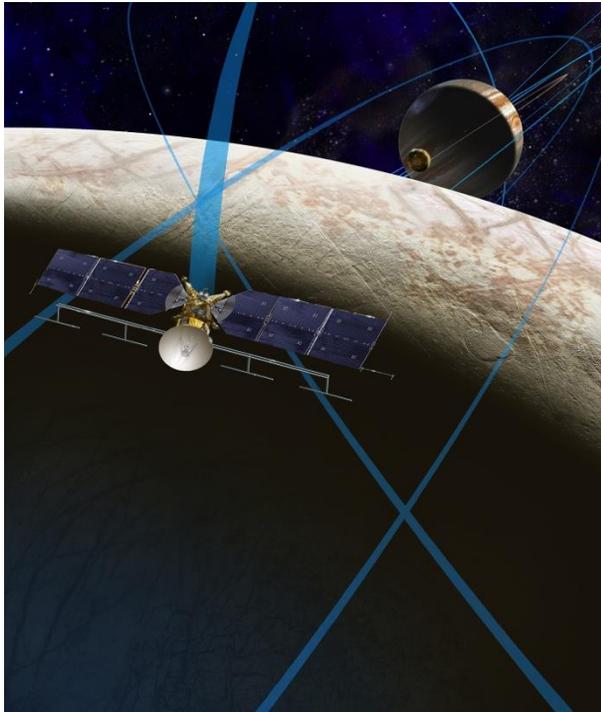


Fig. IX: Artist's concept of Europa Multiple Flyby Mission spacecraft.

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.

VI. 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. The vehicle, which is making rapid progress toward initial launch readiness, will offer substantial benefits for human and robotic utilization stemming from its unique mass-lift, volume, and departure energy capabilities. 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 human landings on Mars and robotic studies of other destinations that will reveal an unprecedented wealth of knowledge about our solar system and universe.