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NASA's Space Launch System: SmallSat Deployment to Deep Space

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Abstract

Leveraging the significant capability it offers for human exploration and flagship science missions, NASA's Space Launch System (SLS) also provides a unique opportunity for lower-cost deep-space science in the form of small-satellite secondary payloads. Current plans call for such opportunities to begin with the rocket's first flight; a launch of the vehicle's Block 1 configuration, capable of delivering 70 metric tons (t) to Low Earth Orbit (LEO), which will send the Orion crew vehicle around the moon and return it to Earth. On that flight, SLS will also deploy 13 CubeSat-class payloads to deep-space destinations. These secondary payloads will include not only NASA research, but also spacecraft from industry and international partners and academia. The payloads also represent a variety of disciplines including, but not limited to, studies of the moon, Earth, sun, and asteroids. While the SLS Program is making significant progress toward that first launch, preparations are already under way for the second, which will see the booster evolve to its more-capable Block 1B configuration, able to deliver 105t to LEO. That configuration will have the capability to carry large payloads co-manifested with the Orion spacecraft, or to utilize an 8.4-meter (m) fairing to carry payloads several times larger than are currently possible. The Block 1B vehicle will be the workhorse of the Proving Ground phase of NASA's deep-space exploration plans, developing and testing the systems and capabilities necessary for human missions into deep space and ultimately to Mars. Ultimately, the vehicle will evolve to its full Block 2 configuration, with a LEO capability of 130 metric tons. Both the Block 1B and Block 2 versions of the vehicle will be able to carry larger secondary payloads than the Block 1 configuration, creating even more opportunities for affordable scientific exploration of deep space. This paper will outline the progress being made toward flying smallsats on the first flight of SLS, and discuss future opportunities for smallsats on subsequent flights.

Keywords: CubeSats, SmallSats, SLS, launch, BEO

1. Introduction

Designed with the purpose of launching very large payloads – massive human spaceflight systems needed for the exploration of deep space – NASA's new Space Launch System (SLS) presents a unique opportunity for the deployment of small satellites as well.

As the SLS Program prepares for the vehicle's first launch, NASA is making investments to expand the science and exploration capability of the SLS by leveraging excess performance to deploy smallsats.

Substantial work is taking place in two areas – payload integration for the first launch of SLS, which already has a full manifest of secondary payloads, and planning and development for accommodations of smallsats on future launches of SLS, using an evolved version of the vehicle.

That first launch, Exploration Mission 1 (EM-1), will include not only an uncrewed Orion spacecraft, but also 13 6U CubeSats that will be carried as secondary payloads and deployed beyond LEO. By providing an Earth-escape trajectory, opportunities are created for the advancement of small satellite subsystems, including deep space communications and in-space propulsion. This SLS capability also creates low-cost options for addressing strategic knowledge gaps and affordable science missions. The lessons learned from the EM-1 mission will be applied to processes and products developed for future block upgrades as payload accommodations increase for secondary opportunities.

2. SLS Overview and Status

Created to provide sufficient launch capability to enable human exploration missions beyond Earth orbit and ultimately to Mars, NASA's Space Launch System (SLS) rocket represents a new asset, not only for human spaceflight, but also for a variety of other payloads and missions with launch requirements beyond what is currently available. The initial configuration of the vehicle, on track for launch readiness in 2019, is designed to offer substantial launch capability in an expeditious timeframe and to support evolution into configurations offering greater launch capability via an affordable and sustainable development path.

NASA is developing SLS in parallel with two other exploration systems development efforts – the Orion crew vehicle program and the Ground Systems

Development and Operations (GSDO) program. Orion is a four-person spacecraft designed to carry astronauts on exploration missions into deep space. GSDO is converting the facilities at Kennedy Space Center (KSC) in Florida into a next-generation spaceport capable of supporting launches by multiple types of vehicles.

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

The initial configuration of SLS, known as Block 1, was designed to support initial demonstration of the vehicle's heavy-lift capability and is making progress toward launch in two years. This configuration, which can deliver greater than 70 t to LEO, will launch NASA's Orion crew vehicle into lunar orbit. For its second flight, SLS will evolve into a more-capable configuration, the Block 1B vehicle, which will increase the vehicle's payload-to-LEO capability to 105 t. The third configuration, Block 2, will be able to deliver 130 t to LEO. The Block 1B and Block 2 vehicles can be configured to carry either the Orion crew vehicle with an additional, co-manifested payload or to carry a large primary payload in a fairing as large as 10 meters in diameter.

Substantial progress has been made toward EM-1, the first integrated launch of SLS rocket with Orion.

The SLS core stage, which stores the liquid oxygen (LOX) and liquid hydrogen (LH2) propellant for four liquid engines, represents almost two-thirds of the vehicle's 98-meter height, standing 64 m tall, and has a diameter of 8.4 m. At Michoud Assembly Facility (MAF), outside New Orleans, Louisiana, the forward skirt, intertank, and engine section are structurally complete and are all in various stages of equipment installation for flight. Welding of the LOX tank structural test and flight articles is complete and will be followed by a second liquid hydrogen flight tank. (Fig.1.) A test article for the engine section has already arrived at Marshall Space Flight Center (MSFC) to be tested. In the coming months, test articles for the hydrogen and oxygen tanks and intertank will be delivered from Michoud by the Pegasus barge.

The core stage will be powered by four RS-25 engines – which previously served as the Space Shuttle Main Engine (SSME). 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 in Mississippi. The engines, managed under a contract with

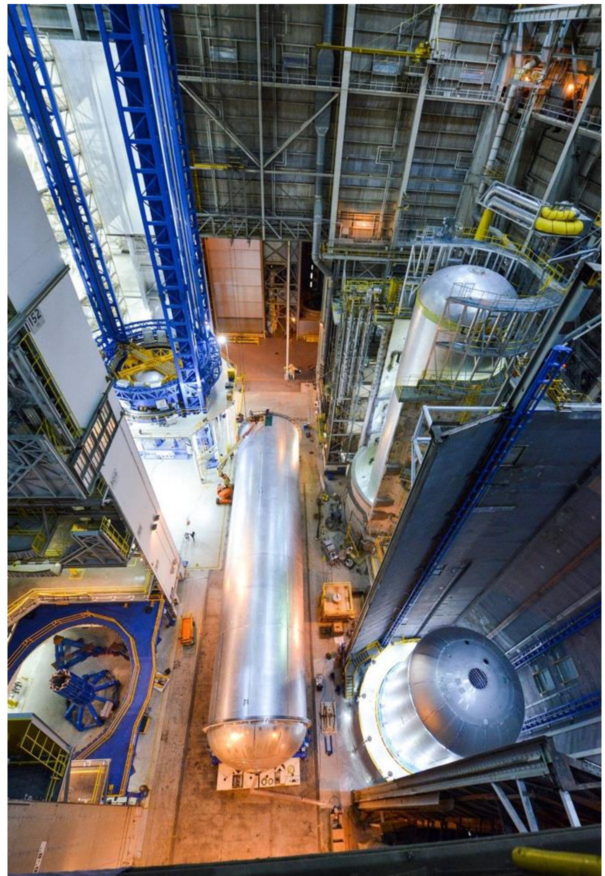

Fig. 1. Core stage hardware, including test and flight articles for the oxygen tank and a hydrogen tank built for flight at Michoud Assembly Facility

Aerojet Rocketdyne, are currently undergoing testing with the new engine controller unit developed for SLS.

The majority of the thrust for the first two minutes of flight will come from a pair of solid rocket boosters (SRB), also of Space Shuttle Program heritage. The SLS is upgrading the boosters from the four-segment version flown on the shuttle to a more-powerful five-segment version. Each booster measures 54 m long and 3.7 m in diameter and is capable of generating up to 3.6 million pounds of thrust, the most powerful flight boosters in the world. Qualification testing for the boosters is complete and 10 booster motor segments have been cast with propellant at Orbital ATK facilities and four segments are complete and in storage, awaiting shipment to Kennedy.

In-space propulsion for the Block 1 vehicle will be provided by an Interim Cryogenic Propulsion Stage (ICPS) derived from the proven Delta Cryogenic Second Stage (DCSS). The ICPS is being produced by United Launch Alliance (ULA) in Decatur, Alabama, under contract to Boeing. The ICPS flight unit has already been delivered to KSC to await stacking. (Fig. 2.)

The Block 1 spacecraft/payload elements include not only the ICPS but also two adapters, connecting that stage to the core stage and to the Orion spacecraft. The

Fig. 2. The Interim Cryogenic Propulsion Stage is delivered to Kennedy Space Center

Launch Vehicle Stage Adapter (LVSA), which connects the core stage with the ICPS, is being produced by Teledyne Brown Engineering of Huntsville, Alabama, and is in final preparation on-site at Marshall. The Orion Stage Adapter, which connects the Orion spacecraft with the ICPS, is being produced by Marshall. An OSA produced by the SLS Program flew successfully on the Exploration Flight Test-1 of Orion in December 2014; and the EM-1 flight unit has been welded at Marshall. A stack of test articles for all three elements recently underwent structural testing at MSFC, qualifying them for flight.

While the Program's focus is very much on preparation for the first launch in two years, work is already well underway on development for future missions and evolved configurations of the vehicle. (Fig. 3.)

The second variant of SLS, the Block 1B configuration of the vehicle, will be capable of delivering 105 t of payload to LEO. This configuration will be the workhorse for much of the 2020s, prior to evolution to a full Block 2 configuration capable of delivering 130 t to LEO. The Block 1B vehicle will replace the single-engine ICPS with a more-powerful, four-engine, dual-use Exploration Upper Stage, which will provide both ascent and in-space propulsion. The contract for the EUS has been awarded to Boeing and an agreement has been reached with Aerojet Rocketdyne to provide the stage's RL10-C3 engines. A Preliminary Design Review for the stage was concluded in early 2017 and initial hardware production has begun.

The change from the 5-meter ICPS to the 8.4-meter EUS means that the LVSA and OSA will be supplanted by a Universal Stage Adapter (USA), which will provide room for a co-manifested payload to fly on an SLS along with Orion. The USA will be managed by NASA's Glenn Research Center in Cleveland, Ohio, and Dynetics, of Huntsville, Alabama, was named as the prime contractor for the USA in June 2017. Within the USA will be a payload adapter, a demonstrator version of which is currently being built at Marshall.

Other work for Block 1B is also currently taking place. Welding for the second core stage has been taking place at Michoud Assembly Facility, and in March 2016, a test-firing of a Block 1B RS-25 engine was performed at Stennis Space Center. Wind tunnel testing is maturing

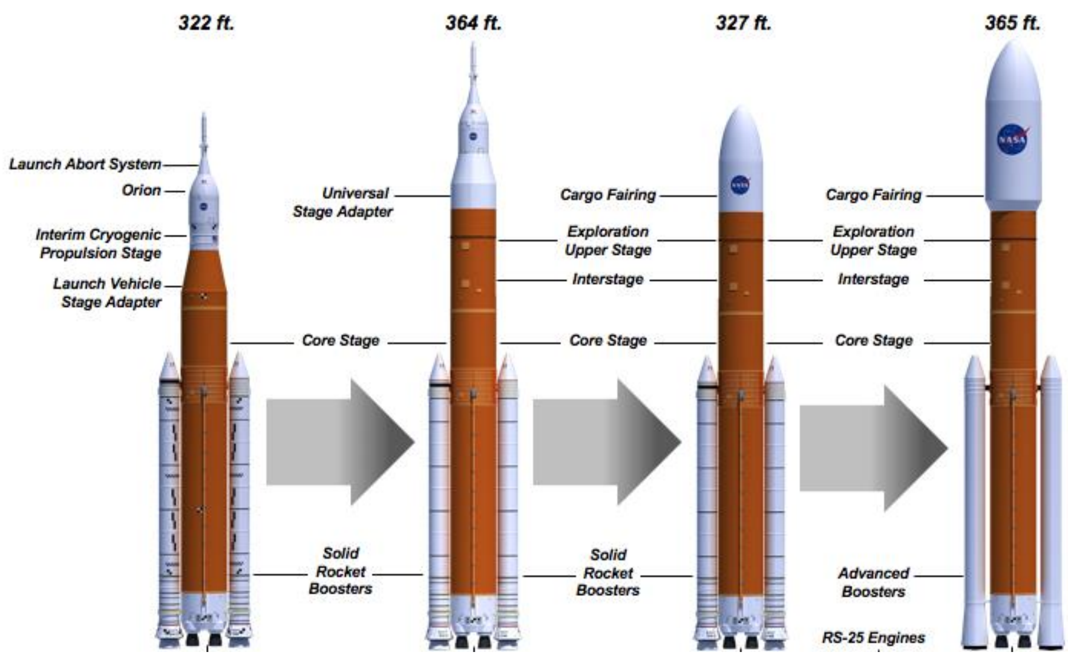

Fig. 3. SLS evolutionary path

understanding of crew and cargo versions of the Block 1B vehicle.

3. Capabilities

Space Launch System offers substantial benefits in three primary areas, which offer game-changing opportunities for spacecraft designers and mission planners – volume, mass and departure energy.

SLS offers greater volume than any other launch vehicle. The Universal Stage Adapter will allow a payload to fly with Orion with as much accommodation volume as the current industry-high 5-meter fairing. The Block 1B configuration will also enable the use of an 8.4-meter (m) fairing for primary payloads, and the Block 2 vehicle will be able to carry 10 m fairings with a volume of up to 1,800 cubic meters, several times greater than any currently available fairing. (Fig. 4.)

For missions to, or staging in, the Earth-moon vicinity, SLS offers unrivaled mass lift capability. The Block 1B configuration of the vehicle, which will be the version available for payloads during most of the 2020s, will be able to lift more than 105 t to LEO and will be able to deliver 41 metric tons to translunar injection (TLI). The crew configuration of the Block 1B vehicle can carry up to an additional 10 t of payload along with the Orion spacecraft. The Block 2 configuration will increase that performance to more than 130 t to LEO and at least 45 t to TLI.

For missions beyond the Earth and moon, SLS offers substantially greater characteristic energy (C3) than contemporary evolved expendable launch vehicles (EELVs). For the missions to the outer planets, for example, this can enable a larger science package, reduced transit times, or both.

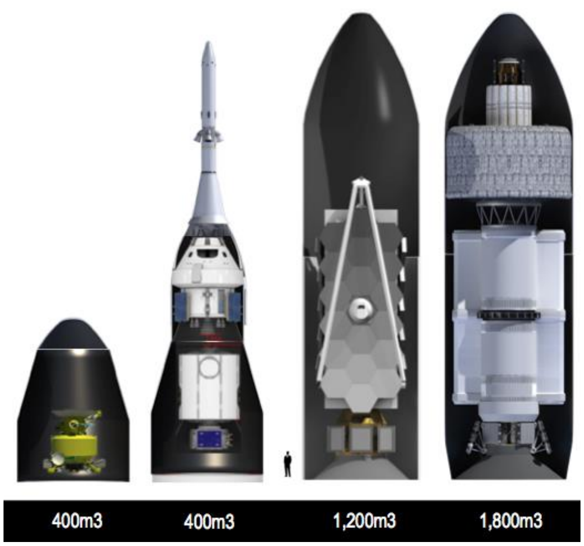

Fig. 4. SLS Fairing options

4. SmallSat Utilization

While the most obvious mission profiles to benefit from SLS are those with requirements beyond the performance of current launch vehicles, SLS will also offer unique opportunities for smaller experiments in the form of secondary payload berths. Thirteen secondary payload locations have been allocated in the OSA in the initial SLS configuration, allowing payload deployment following Orion separation. (A total of fourteen brackets will be installed, allowing for thirteen payload locations. The final location will be used for mounting an avionics unit, which will include a battery and sequencer for executing the mission deployment sequence.) The deployment berths are sized for 6U CubeSats, and on EM-1 the spacecraft will be deployed into cislunar space following Orion separation from the SLS ICPS. (Fig. 5) Secondary payloads in 6U class will be limited to 14 kg maximum mass.

The avionics unit will interface with each dispenser through cables mounted in the OSA. Secondary payloads will remain powered off until the sequencer transmits the deployment signal to each dispenser and the payload is released. Secondary payloads will exit the dispenser at an approximate rate of 1.2 m/sec with deployments

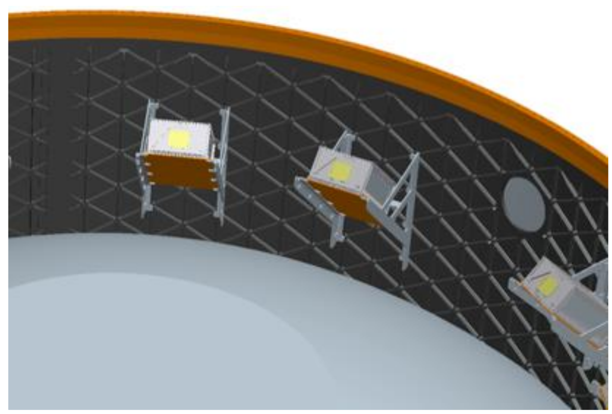

Fig. 5. SLS Block 1 secondary payload accommodations

separated by a minimum of 1 minute.

The SLS Program will perform all mission and payload integration for the baseline vehicle manifest. The mission integration process defined in this section has been developed to ensure safety and mission success, while reducing the amount of data required from the secondary payload developers.

The integration process is designed to support the payload requirements as well as the requirements of the launch vehicle and ground systems. The typical integration process encompasses the entire cycle of payload integration activities including analytical and physical integration.

Secondary payloads will be turned over to GSDO fully integrated in their dispenser, ready for installation in the OSA at approximately L-6 months. GSDO will install the integrated dispensers onto the OSA brackets and mate all required connections for deployment signals. Secondary payloads will not be accessible once stacking operations begin. For EM-1, additional tests and pad stay time is required to fully check out the vehicle configuration. Due to this "first flight" test activity, the vehicle will remain at the launch pad for up to two months, which will increase secondary payload exposure to documented natural environments.

Secondary payloads on SLS will remain powered off during the ascent phase of the launch vehicle, through separation of the Orion spacecraft. Once separation is confirmed, the ICPS will send a discrete signal to the Secondary Payload Deployment System's avionics unit to activate. The schedule for deployments will be loaded prior to vehicle stacking. No real-time commanding or telemetry is available; therefore, payloads will be deployed automatically through the pre-determined mission timeline sequence.

Secondary payloads will have opportunity to be deployed after the ICPS disposal sequence is complete (approximately T+4 hours) and up to 10 days from launch. (Fig. 6.) All deployments will be completed before avionics batteries are expended.

Once deployed, secondary payloads will be required to wait 15 seconds before deploying antennas, solar panels, sails, etc. to ensure adequate clearance from ICPS. Payload communications following deployment will be the responsibility of the secondary payload project, with no resources being provided by SLS.

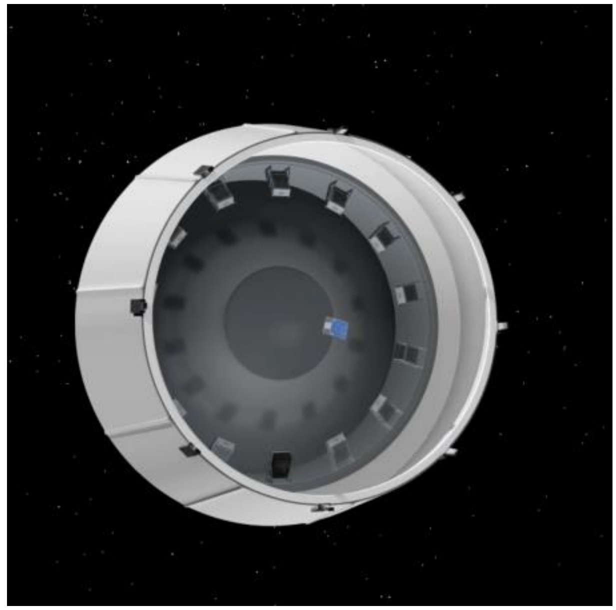

Fig. 6. Deployment of CubeSat on EM-1

5. EM-1 Secondary Payloads

CubeSat secondary payloads on EM-1 will include both NASA research experiments and spacecraft developed by industry, international, and academia partners. The Human Exploration and Operations Mission Directorate (HEOMD) Advanced Exploration Systems (AES) Division was allocated five payload opportunities on the EM-1 mission. AES selected the first three payloads to fly on EM-1 at the same time the capability for accommodating secondary payloads on the SLS was being developed.

Near Earth Asteroid (NEA) Scout is a 6U CubeSat designed to rendezvous and characterize a candidate NEA. A solar sail, another innovation to be demonstrated in the CubeSat class, will provide propulsion.

Lunar Flashlight is the second AES payload planned for manifest on EM-1. It will use a green propellant system and will search for potential ice deposits in the moon's permanently shadowed craters. Pulsed lasers will be used to illuminate the surface. Surface reflection will be measured by a spectrometer to distinguish water ices from regolith.

The third payload being developed by AES is BioSentinel. The payload is a yeast radiation biosensor, planned to measure the effects of space radiation on deoxyribonucleic acid (DNA). This will be accomplished by entering into a heliocentric orbit, outside of the Van Allen belts, to expose the payload to a deep space radiation environment.

Two additional payloads were selected for the EM-1 mission by AES from the Next Space Technologies for Exploration Partnerships (NextSTEP) Broad Agency Announcement (BAA). The payloads selected are Lunar Icecube, a collaboration with Morehead State University, and LunIR, a partnership with Lockheed Martin. Lunar Icecube will prospect for water in ice, liquid, and vapor forms as well as other lunar volatiles from a low-perigee, highly inclined lunar orbit using a compact Infrared spectrometer. LunIR is a technology demonstration mission that will perform a lunar flyby, collecting spectroscopy and thermography data to address questions related to surface characterization, remote sensing and site selection.

NASA's Space Technology Mission Directorate (STMD) was allocated three payload opportunities on the EM-1 mission. NASA's STMD is innovating, developing, testing, and flying hardware for use in NASA's future missions through the Centennial Challenges Program. The Centennial Challenges Program is NASA's flagship program for technology prize competitions (www.nasa.gov/challenges). The program directly engages the public, academia, and industry in open prize competitions to stimulate innovation in technologies that have benefit to NASA and the nation. STMD has released the CubeSat Lunar Challenge to foster innovations in small spacecraft propulsion and communications.

There are two concurrent In-Space Competitions, the Lunar Derby and the Deep Space Derby. In the Lunar Derby, there are prizes awarded for successfully achieving lunar orbit, downlinking the largest volume of error-free data and surviving the longest. In the Deep Space Derby (> 4 million km), there are prizes awarded for farthest data transmission distance, largest volume of error-free data, and longest duration of operability. Potential candidates for the three STMD opportunities on the EM-1 mission competed in a series of four Ground Tournaments before final selection was made.

The three STMD selectees were announced in June 2017. The three teams are Cislunar Explorers, from Cornell University, in Ithaca, New York; CU^3, from the University of Colorado; and Team Miles, from Fluid & Reason, LLC, in Tampa, Florida. The Cislunar Explorers' CubeSat is focused around a water-electrolysis-based propulsion system, CU^3 is designed for a communications demonstration mission, and Team Miles will demonstrate evolutionary plasma thrusters.

The NASA Science Mission Directorate (SMD) was allocated two payload opportunities on the EM-1 mission. The NASA SMD issued an amendment to its annual Announcement of Opportunity (AO) in the Research Opportunities in Space and Earth Sciences-2014 (ROSES-2014) Solicitation NNH14ZDA001N-HTIDS Heliophysics Technology and Instrument Development for Science. Within this Amendment was the request for CubeSat proposals specific to the Exploration Mission 1 launch opportunity focusing on the heliophysics science enabled through the unique deployment location and trajectory afforded though the planned mission. The CubeSat Mission to Study Solar Particles (CuSP) payload was selected under this AO. CuSP will study the sources and acceleration mechanisms of solar and interplanetary particles in near-Earth orbit, support space weather research by determining proton radiation levels during Solar Energetic Particle (SEP) events, and identify suprathermal properties that could help predict geomagnetic storms. A Small Innovative Missions for Planetary Exploration (SIMPLEx) NASA Research Announcement (NRA) was also released as part of the ROSES-2014 AO. The LunaH-Map payload was selected from this NRA. The LunaH-Map objectives are to understand the quantity of H-bearing materials in lunar cold traps (~10 km), determine the concentration of H-bearing materials with 1 m depth, and constrain the vertical distribution of H-bearing materials.

The final three payload opportunities for the EM-1 mission were allocated for NASA's international space agency counterparts. The flight opportunities are intended to benefit the international space agency and NASA as well as further the collective space exploration goals. A joint process with NASA and the international partners was employed to review, evaluate, and recommend the payloads to fly on EM-1. From that joint process three payloads were chosen: Outstanding MOon exploration TEchnologies demonstrated by NAno Semi-Hard Impactor (OMOTENASHI), EQUilibriUm Lunar-Earth point 6U Spacecraft (EQUULEUS), and ArgoMoon.

ArgoMoon is sponsored by the European Space Agency and the Italian Space Agency, ASI, and will fly-along with the ICPS on its disposal trajectory. The primary objectives are to perform proximity operations with the ICPS post-disposal, take external imagery of engineering and historical significance, and perform an optical communications demonstration.

The EQUULEUS spacecraft sponsored by the Japanese space agency, JAXA, will fly to a libration orbit around the Earth-Moon Lagrange Point 2 point and demonstrate trajectory control techniques within the Sun-Earth-Moon region for the first time by a CubeSat spacecraft. The mission will also contribute to the future human exploration scenario by understanding the radiation environment in geospace and deep space, characterizing the flux of impacting meteors on the far side of the moon, and demonstrating the future deep space exploration scenario using the "deep space port" at Lagrange points.

The OMOTENASHI mission, also sponsored by JAXA, will land the smallest lunar lander to date on the lunar surface to demonstrate the feasibility of the hardware for distributed cooperative exploration system. Small landers will enable multi-point exploration, which is complimentary with large-scale human exploration. Once on the lunar surface, the OMOTENASHI spacecraft will observe the radiation and soil environments of the lunar surface by active radiation measurements and soil shear measurements.

Progress is being made in preparations for the launch of these secondary payloads on EM-1. The brackets for the CubeSat deployers have been mounted on the Orion Stage Adapter for the flight; the deployers and payloads will be integrated at Kennedy Space Center. The secondary payloads team within the SLS Program is conducting ongoing safety reviews with the teams responsible for the payloads.

6. Future Opportunities

With the evolution from Block 1 to Block 1B, the rocket will replace the one-engine ICPS in-space stage with the four-engine EUS upper stage, and, as a result, replace both the LVSA and the OSA, where the EM-1 CubeSat payloads will be mounted, with the new Universal Stage Adapter. The USA will allow the rocket to carry large co-manifested payloads along with the Orion spacecraft and these payloads will be mounted within the USA on a Payload Adapter. These hardware elements will also be part of the 130 t Block 2 configuration of the vehicle, so planning for secondary

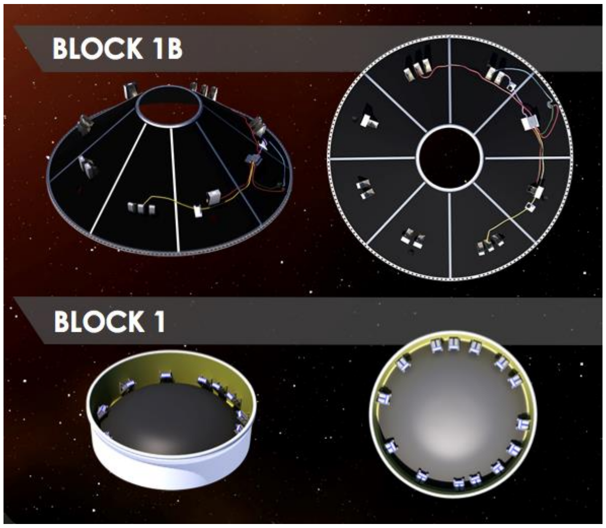

Fig. 7. Block 1 and 1B accommodations

payload accommodations on the Block 1B vehicle will be relevant to Block 2 as well.

Current plans are for this Payload Adapter to carry CubeSat-class small satellite secondary payloads. In this arrangement, SLS would be able to carry larger CubeSats than EM-1 and more of them. The Payload Adapter would have eight areas for mounting secondary payload hardware. One of those areas would be used for an avionics unit. Each of the remaining areas could be used to carry either one 27U CubeSat, two 12U CubeSats, or three 6U CubeSats, in any combination. Depending on vehicle mass allocation, it could for example, carry seven 27U CubeSats or 21 6U CubeSats or two 27U, six 12U, and six 6U payloads. (Fig. 7.)

Possibilities are still being evaluated for enabling even larger smallsats, including, potentially, ring-mounted smallsats, or adding more berths for CubeSats in the future.

7. Conclusion

NASA's Space Launch System (SLS) will provide unprecedented capability to further advances in science and exploration. The capability to deploy small satellites allows SLS to utilize excess capability on the planned exploration missions. With the planned mission trajectories, small satellite payload developers will have an opportunity to operate in deep space, a capability not realized to this point. As the SLS vehicle evolves its configuration and becomes more capable, the opportunities for secondary payloads of different types and sizes will increase.