Exploration Missions to Host Small Payloads

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ABSTRACT

The next-generation heavy launch vehicle, the Space Launch System (SLS), will provide the capability to deploy small satellites during the trans-lunar phase of the exploration mission trajectory. We will describe the payload mission concept of operations, the payload capacity for the SLS, and the payload requirements. Exploration Mission 1, currently planned for launch in December 2017, will be the first mission to carry such payloads on the SLS.

INTRODUCTION

NASA has taken steps to increase the scientific and exploration capability of the Space Launch System by providing accommodations for cubesat class payloads on Exploration Mission (EM)-1. This first launch of the fully developed Space Launch System (SLS) and the Orion Spacecraft is planned to fly along a trans-lunar trajectory and test the performance of the SLS and Orion systems for future missions.

HARDWARE/SYSTEM OVERVIEW

Space Launch System

The SLS is the new heavy launch system for NASA. The SLS configuration for EM-1 is considered Block 1, the first configuration of the SLS evolution plan. The Shuttle-derived design takes advantage of resources established for the Space Shuttle, including the workforce, tooling, manufacturing processes, supply chain, transportation logistics, launch infrastructure, and LOX/LH2 propellant infrastructure. An overview of the initial SLS Block 1 configuration that will first fly with the Orion in 2017 is shown in Figure 1.[1] The SLS enables many aspects of the NASA core capabilities in addition to human exploration initiatives. These include the reduction in mission duration, increased mass margins, reductions in total spacecraft complexity, and significant increases in payload volume.

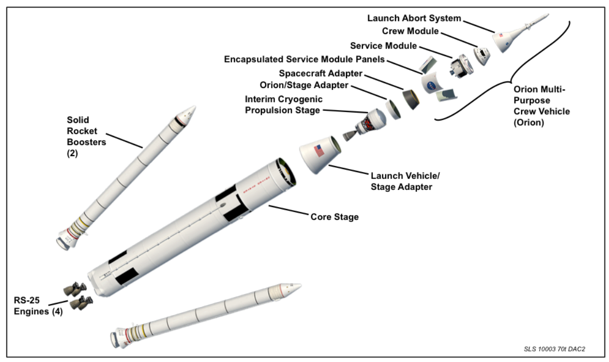

Figure 1: SLS Block 1 70t Initial Configuration

The secondary payload initiative for EM-1 takes advantage of several of these capabilities and enables new opportunities for small spacecraft developers. By utilizing planned unoccupied volume within the upper motor stage adapter ring, the MPCV Stage Adapter (MSA), increased mission science and technology missions can be accommodated.

SLS Block 1 is capable of deployment of 70 metric tons of payload into low Earth orbit building on the heritage of the Saturn and Ares systems. The C3 curve for SLS is provided in Figure 2.

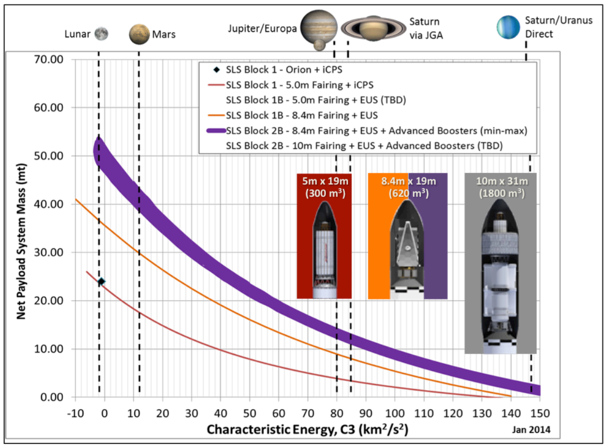

Figure 2: SLS Net Payload System Mass –Earth Escape[1]

SLS will launch from Kennedy Space Center with main engine start, booster ignition and primary ascent operations up to the point of upper stage separation. After upper stage separation and execution of the trans-lunar orbital injection burn, the upper stage will separate from the Orion spacecraft and Orion will begin autonomous operations. The upper stage will then complete a mission disposal maneuver that will slow the upper stage and attached interfaces, including the MSA, and thus place the expired motor on a non-contact with Orion, trans-lunar heliocentric disposal trajectory. The upper stage system will remain on battery power for several hours after the completion of the Orion separation and disposal trajectory maneuvers. Deployments of the secondary payloads will commence after sufficient separation of the Orion spacecraft to the upper stage vehicle to prevent any possible contact of the deployed cubesats to Orion. Currently this is estimated to require approximately 4 hours. The allowed deployment window for the cubesats will be from the time recontact likelihood with Orion has passed to up to 10 days after launch. The upper stage will fly past the moon at a perigee of approximately 1100km, and this closest approach will occur about 5 days after launch. The limiting factor for the latest deployment time is the available power in the sequencer system (described in subsequent section).

Payload Accommodations

Secondary payloads on EM-1 will be launched in the Multi-purpose Stage Adapter (MSA). Payload deployers will be mounted on specially designed brackets, each attached to the interior wall of the MSA as shown in Figure 3. A total of twelve brackets will be installed, allowing for eleven payload locations. The final location will be used for mounting an avionics component, which will include a battery and sequencer for executing the mission deployment sequence.

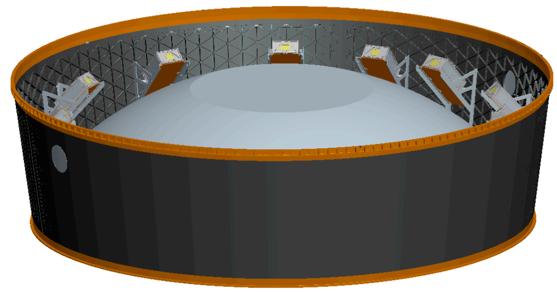

Figure 3: MSA with payload locations

Each bracket is designed to hold the volume equivalent of 6U and 12U deployers. The current design baseline is for payloads to be compatible with 6U class deployers. Further analysis is ongoing to assess 12U accommodations. Payloads in 6U class will be limited to 13.76 kg maximum mass. Mass for 12U payloads are still being analyzed. Detailed physical accommodations are documented in Figure 4 and Table 1.

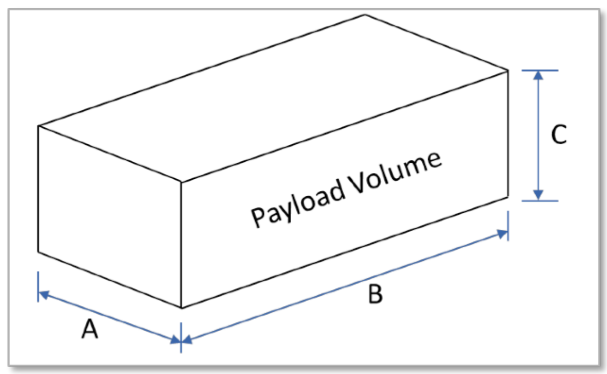

Figure 4: Payload volume dimensions

Table 1: Payload maximum dimensions

Deployer	A		B		C	
	in.	mm	in.	mm	in.	mm
6U	9.43	239.4	14.4	366	4.197	106.6
12U	9.43	239.4	14.4	366	8.65	219.7

The avionics sequencer will interface with each deployer through cables mounted in the MSA. Payloads will remain powered off until the sequencer transmits the redundant signal to each deployer, and the payload is released. Payloads will exit the deployer at an approximate rate of 1.4 m/sec, with deployments separated by a minimum of 3 seconds. No other payload services are currently planned for EM-1.

Ground Systems

The Ground Systems Development and Operations (GSDO) program at the Kennedy Space Center (KSC) will perform SLS ground processing. Payloads will be fully integrated into their deployer at the time of delivery to GSDO. Once delivered, integrated payloads will be installed into the MSA, prior to stacking operations with the Orion system.

MANIFEST PROCESS

Several NASA Mission Directorates have developed programs for the competition, selection and development of EM-1 payloads that support Directorate priorities. Specific plans for payloads supported by these Directorates are explained in subsequent sections. There are several steps toward final determination of the planned manifest for the first mission. In the fall of 2014, each supporting mission directorate, the program directors for SLS, Orion, GSDO and the Human Exploration and Operations senior leadership will meet to determine the initial payload complement. There is no planned initial number for this assignment, and this initial planning exercise is simply intended to better assess the required resources needed to support the mission directorate's selected payloads. Using this initial manifest, additional integrated safety hazard analysis and mass allocation reviews will be completed. Critical Design Review for the mission is planned for completion in 2015, and a final mass allocation for the EM-1 secondary payload complement will be determined. With these assessments and allocations made, any reductions in the total number of allowed payloads below the maximum of 11 will also be resolved and a final manifest plan presented to the EM-1 manifest board.

MISSION INTEGRATION

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 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.

The SLS Spacecraft/Payload Integration and Evolution (SPIE) office is responsible for developing the payload interfaces for primary payloads, including the primary payload adapters, separation systems and fairing. The Flight Programs and Partnerships Office has formed a unique partnership with the SLS Program to perform the Secondary Payload mission integration functions for exploration missions.

The Secondary Payloads Mission Integration Team (SPMIT) will be responsible for serving as liaison to the secondary payload community and facilitating end-to-end payload mission planning, integration and execution. The mission integration team, in conjunction with the engineering and launch facility integration teams, will support secondary payload manifest planning, coordination and end-to-end payload integration.

Each payload, once identified, will be assigned a Payload Integration Manager (PIM) to assist the payload through the entire integration process. The PIM will serve as the single point interface to coordinate all mission-specific integration activities for the assigned payload. The PIM will be responsible for developing a payload-unique integration schedule to define the documentation and analysis required from the payloads. The PIM will also capture payload requirements, engineering interfaces, and required verification through the payload-specific Interface Control Document (ICD).

The PIM will coordinate the payload's requirements to all of the functional organizations involved in the mission. As the responsible point of contact, the PIM will ensure that payload integration is accomplished by coordinating with these teams throughout the process.

Payload development schedules will vary based on many factors including hardware availability, complexity, resource profiles, etc. The payload life cycle is depicted in Figure 5 and can be defined in four phases of integration: Strategic, Tactical, Physical and Operations.

Strategic – Early payload development occurs in the strategic timeframe and includes payload design and schedule development to ensure that an SLS compatible payload is built. The payload questionnaire is also submitted to support the manifest process, as well as early compatibility assessments.

Tactical – Focused mission integration is performed in the tactical phase of payload integration. During this phase, requirements and interfaces are finalized, verification is mostly completed and the initial Certificate of Flight Readiness (CoFR) is developed.

Physical – This phase begins with the payload's on-dock arrival at the launch site and includes all ground processing, vehicle stacking and integration. Final verifications are submitted and the CoFR process is completed with closure of all remaining open work.

Operations – This phase begins with launch, through the end of payload operations. Post flight reporting and anomaly assessments will be conducted, as required.

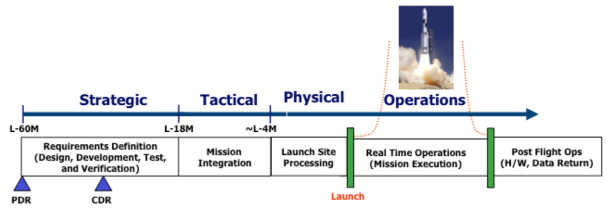

Figure 5: Integration Phases

The typical SLS mission integration process begins at L-18 months, but can be tailored to meet payload needs within the constraints of the overall mission planning. The SPMIT may engage during the strategic phase to ensure early design requirements reflect the expected interfaces and environments to be verified during the mission integration process. The process will begin once a potential payload is identified and a PIM is assigned. The payload will be provided with the questionnaire to return to the PIM and normal and regular communication/coordination will commence.

Throughout the mission integration phases, various reviews and milestones will require payload developer participation and coordination with the mission integration team. The major milestones for each integration phase are outlined in Figure 6. These include payload Preliminary Design Review (PDR), Critical Design Review (CDR), Safety Reviews, major documentation baseline and physical integration. Detailed mission-specific milestones and reviews will be documented in the payload integration schedule once a flight manifest is baselined.

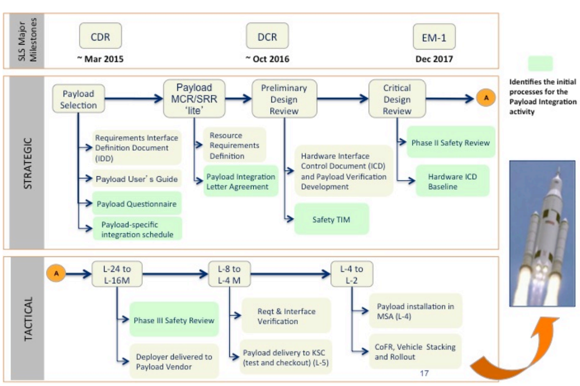

Figure 6: Payload Integration Lifecycle

To facilitate early integration and communication, payloads identified for SLS missions will be provided a payload questionnaire to provide NASA with pertinent data. This data will be used to evaluate manifest opportunities for primary and secondary payloads. The questionnaire will also be used as a starting point for developing the payload-unique ICD and other integration documentation.

The Interface Control Document (ICD) defines the payload-to-vehicle and payload-to-ground system interfaces. The ICD will be derived from the Interface Definition and Requirements Document (IDRD) and will identify the specific technical and functional requirements that apply to the payload design. Mission-specific or payload-specific requirements will also be captured in the ICD. The PIM is responsible for developing the payload-unique Interface Control Document (ICD) for each payload assigned to a mission.

Based on the set of requirements defined in the ICD, the applicable verification data required will be documented to ensure payload compatibility. The IDRD will define the verification data sheets for each requirement, including required data, success parameters and deliverable schedule. Once the payload-specific requirements are baselined, the PIM will use the deliverables captured in the IDRD to document the plan for verification in the payload integration schedule. As the payload hardware development is completed, required verification data will be submitted to the mission integration and engineering integration teams for review and approval.

For each mission, the Secondary Payload team will develop mission-specific analyses to verify compatibility with the launch vehicle, ground systems, data systems and overall mission requirements. Required mission-specific analysis will be identified with the required interfaces, in the payload-unique applicability matrix listed in the payload's Interface Control Document (ICD). Payload-unique mission analysis will also be documented in the ICD, with the appropriate analysis parameters captured in an appendix. It is expected that test data will only be required to satisfy vibration, shock, mass, center of gravity and electro-magnetic interface requirements.

As part of the overall vehicle flight readiness process, payloads will participate in the Certificate of Flight Readiness (CoFR) process. The CoFR process is established to ensure an integrated flight vehicle has met requirements at all levels and is safe to fly. The payload CoFR process certifies flight readiness of payloads by all organizations involved in payload development, integration, launch, and on-orbit operation. The payloads CoFR process is defined by the SLS office and will be documented in the Certificate of Flight Readiness Plan.

The CoFR process starts approximately 4 months prior to launch. All organizations supporting the mission complete a CoFR endorsement checklist that identifies the open work remaining to complete the readiness process. Open work will be tracked until closure to ensure all requirements are met. Final CoFR approval occurs at the SLS Flight Readiness Review at L-2 weeks.

SAFETY AND MISSION ASSURANCE

Payloads manifested on SLS will "do no harm" to the vehicle or crew and maintain the appropriate controls for critical or catastrophic hazards. Safety requirements will be documented in the IDRD for inclusion in payload designs. Payload developers will be required to submit safety data packages for each safety review identified in the payload integration schedule. Review requirements will be captured in the Payload Safety Requirements document. Typically, the Safety Technical Interchange Meeting (TIM) will outline the payload design and initial hazard identification. During the Phase II review, the final payload design is reported, including hazard controls. Ideally, all hazard reports are submitted for approval during this review. The Phase III review will evaluate the payload hazard verification and any final changes to the payload design and controls. All safety verification will require closure prior to the Flight Readiness Review process.

GROUND PROCESSING

Payloads will be turned over to GSDO fully integrated in their deployer, ready for installation in the MSA at approximately L-4 months. GSDO will install the integrated deployers onto the MSA brackets and mate all required connections for deployment signals. 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 payload exposure to documented natural environments. Payloads should consider this additional time into their design requirements for materials selection and battery life.

OPERATIONS

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

Payloads will have opportunity to deploy beginning at approximately T+4 hours. All deployments will be completed before avionics batteries are expended, planned for 10 days from activation. Figure 7 provides an overview of the mission profile.

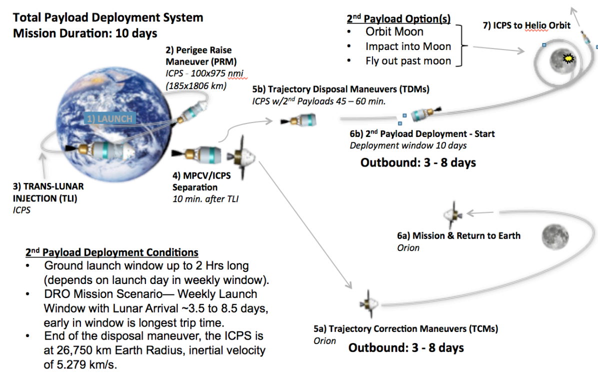

Figure 7: Mission Profile

Once deployed, 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 payload project, with no resources being provided by SLS.

PAYLOAD USERS

Advanced Exploration Systems (AES)

The Human Exploration and Operations Mission Directorate Advanced Exploration Systems has selected three payloads to fly on EM-1. 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 the same solar sail as NEA Scout and will search for potential ice deposits in the Moon's permanently shadowed craters. Sunlight will be reflected off the sail to 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.

Space Technology Mission Directorate (STMD)

NASA's Space Technology Mission Directorate 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. STMD is currently accepting proposals for possible manifest on EM-1.

Science Mission Directorate (SMD)

The NASA Science Mission Directorate has issued an amendment (B-3) to its annual Announcement of Opportunity in the Research Opportunities in Space and Earth Sciences-2014 Solicitation NNH14ZDA001N-HTIDS Heliophysics Technology and Instrument Development for Science. Within this Amendment is the request for Cubesat proposals specific to the Exploration Mission 1 launch opportunity. These missions should focus on the Heliophysics science enabled through the unique deployment location and trajectory afforded though the planned EM-1 mission.

Step 1 proposals to this AO were submitted on June 13, 2014 and the step 2 proposal is due August 15, 2014. Announcement of the selected proposal(s) will be made sometime within CY2014. For a detailed description of the science goals and priorities for the Heliophysics Division please refer to the current division roadmap: http://heliophysics.nasa.gov/Roadmap2013.htm

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 fully utilize excess capability on the planned exploration missions. With the planned mission trajectories, cubesat payload developers will have an opportunity to operate in deep space, a capability not realized to this point.

References

1. SLS-RPT-xxx, SLS Mission Planners Guide Executive Overview, Draft Feb. 2014