

Enhanced Feasibility Assessment of Payload Adapters for NASA's Space Launch System

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Abstract— The first flight of NASA's new exploration-class launch vehicle, the Space Launch System (SLS), will test a myriad of systems designed to enable the next generation of deep space human spaceflight, and launch from Kennedy Space Center no earlier than December 2019. The initial Block 1 configuration for EM-1 will be capable of lofting at least 70 metric tons (t) of payload and send the Orion crew vehicle into a distant retrograde lunar orbit, paving the way for future crew missions to cislunar space and eventually Mars. A Block 1B version of SLS will lift at least 34 t to trans-lunar injection (TLI) in its crew configuration and at least 37 t to TLI in its cargo configuration no earlier than 2024. For Mars-class payloads, larger fairings and payload adapters for the Block 2 cargo vehicle are under consideration. For missions beyond the Earth-Moon system, SLS offers greater characteristic energy (C3) than any other launch vehicle, enabling shorter transit times or heavier payloads with more robust science packages for missions to the outer solar system. Indeed, the unmatched combination of thrust, payload volume and departure energy that SLS provides opens new opportunities for human and robotic exploration of deep space.

To support the delivery of infrastructure on all of these flights, a family of SLS Payload Adapters (PLA) is being developed to provide ELV class (1575mm, 2624mm, 4394mm) and larger spacecraft/payload interfaces for both crewed (Orion) and cargo (fairing) missions. These PLAs also provide the potential of accommodating various configurations of 6U, 12U and 27U Secondary Payloads (SPL). Work on demonstrating the manufacturing of these 8.4m diameter composite structures is already in progress at Marshall Space Flight Center in Huntsville, Alabama, which manages the SLS Program.

Because of the many potential configurations required to support SLS missions ranging from sending Europa Clipper to Jovian space to establishing a lunar orbiting Gateway, there is a critical need for establishing the fewest PLA designs that can accommodate the most SLS payloads possible. This paper will summarize applications from a NASA Engineering and Safety Center (NESC) led Model Based Systems Engineering (MBSE) pathfinder activity to develop a "digital" PLA feasibility assessment approach. This approach will help potential users optimize their interface to SLS by providing analysts with the means to reduce PLA feasibility definition cycle time/effort by over 75%. This also allows more feasibility assessment "turns" available to single and multiple payload elements on a single SLS launch. This translates into providing users with options that allows them to optimize upmass available to payload versus being required for PLA structure.

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1. INTRODUCTION

The first mission of the National Aeronautics and Space Administration's (NASA's) new super heavy-lift launch vehicle, the Space Launch System (SLS), and the Orion spacecraft, launching from revitalized facilities at Kennedy Space Center (KSC), will send the Orion crew vehicle into lunar distant retrograde orbit (DRO) on a flight test known as Exploration Mission-1 (EM-1) shown in Figure 1. This mission, scheduled to last about 25 days, will enable NASA to verify and validate new systems before sending astronauts



Figure 1. NASA's Space Launch System (SLS) and Orion spacecraft

to deep space on Exploration Mission-2 (EM-2). With these exploration missions, NASA will mark the return of its human exploration programs to cislunar space for the first time since Apollo 17 in 1972.

NASA plans to use the SLS Block 1 crew vehicle for the first two exploration missions. The SLS Program, managed at Marshall Space Flight Center (MSFC) in Huntsville, Alabama, USA, and its prime contractors have made significant progress toward first launch, with several major components of the vehicle complete and delivered to the Exploration Ground Systems (EGS) Program at Kennedy Space Center (KSC), which has responsibility for integrating and launching the system.

With a planned path forward of progressively more powerful vehicles available in both crew and cargo configurations, SLS will provide the lift capability, payload capacity, and departure energy to make the world's most demanding missions a success. In fact, SLS offers power, volume and characteristic energy (C3) that haven't been seen since the Saturn vehicles, opening options for transformative human exploration and science missions.

2. CORNERSTONE OF NASA'S DEEP SPACE EXPLORATION SYSTEM

SLS is not one launcher. Rather, it's a system of launch vehicles suitable for a variety of super heavy-lift missions to a variety of destinations beyond low-Earth orbit (LEO). The major variants, Block 1, Block 1B and Block 2, provide incrementally improved lift capabilities and each block variant will be available in crew and cargo configurations. Cargo configurations will utilize payload fairings (PLFs) in a variety of sizes, from industry-standard 5-meter (m) diameter

to 8.4-m diameter, with larger diameter fairings under evaluation.

For all vehicles in the series, primary propulsion will be supplied by two boosters and four liquid hydrogen/liquid oxygen (LH2/LOX)-fueled RS-25 engines. For the first two variants, Block 1 and Block 1B, the boosters and engines are derived from the Space Shuttle Program but upgraded to meet more stringent SLS performance requirements and more extreme operating environments. An all-new core stage will house the propellant tanks, the four RS-25 engines, the flight computers and provide the attach points for the boosters. Towering 64.6 m, the SLS core stage is the largest rocket stage ever constructed in terms of volume and length and required the world's largest spacecraft welding tool, the Vertical Assembly Center (VAC), for joining the sections. The VAC was installed at NASA's historic Michoud Assembly Facility near New Orleans, Louisiana, USA, and the friction-stir welding tool has produced a series of test and flight hardware for the first two missions. The upper stage and payload sections of the vehicles, in addition to required adapters, will vary according to block configuration and will be discussed below. To meet its ultimate lift capability of at least 45 t to TLI, Block 2 will feature upgraded boosters for maximum performance (see Figure 2).

3. SLS MISSION OPPORTUNITIES

SLS offers substantial benefits to spacecraft designers and mission planners in terms of greater mass, volume and departure energy than Expendable Launch Vehicles (ELV) can provide. These primary benefits make possible a variety of secondary benefits too. For example, greater payload volume and mass can decrease the need for miniaturization and origami-like deployments, thus simplifying the spacecraft design cycle, as well as complexity and risk.

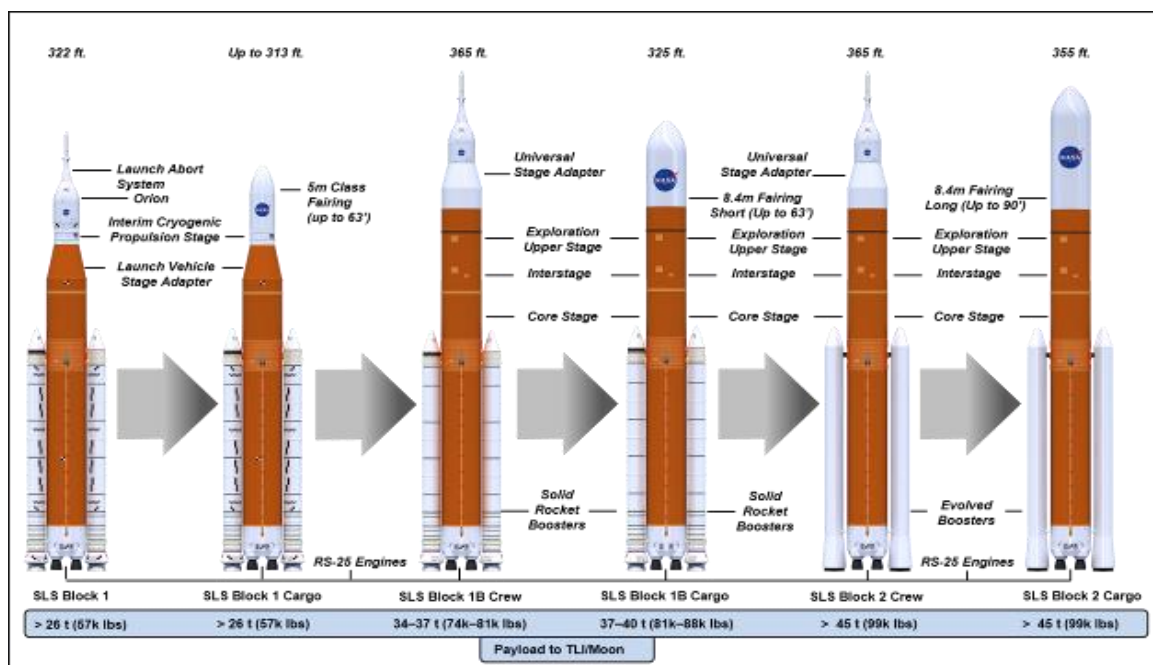


Figure 2. The evolutionary block upgrade path for SLS

Reducing transit time by enabling a direct trajectory without gravitational assists reduces mission risk and operational

cost, and can eliminate the need to design for inner solar system conditions.

Program managers envision an eventual flight processing throughput capacity of two to three SLS flights per year, making flight opportunities available to NASA mission directorates, international partners, private industry, academia and other government agencies. SLS can accommodate Primary Payload (PPL), Co-manifested Payload (CPL), and Secondary Payload (SPL) and is actively engaged with the science community to understand demand and provide information on the unique capabilities of the evolvable system. The SLS Program has a Mission Planner's Guide available in a downloadable PDF format, to provide basic technical details on the system: <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170005323.pdf>

While the primary purpose of SLS is to enable human exploration of the solar system with the Moon as a foundational proving ground, a myriad of mission types will benefit from the mass, volume and departure energy that SLS provides, including planetary science, astrophysics, heliophysics, planetary defense, and commercial endeavors.

Lunar Missions

NASA's Human Exploration & Operations Mission Directorate (HEOMD) has outlined plans for a new lunar orbiting science outpost, the Gateway, to be constructed in the 2020s. The Gateway will serve as a proving ground for technology and science missions to both better understand the Earth-Moon system and inform future missions to Mars and deeper into the solar system. The superior lift and payload volume abilities of SLS Block 1B will enable the Agency to send Orion and a CPL, such as a habitat module or a reusable lunar lander for astronauts, to the Gateway in a single launch, simplifying mission design (see Figure 3).

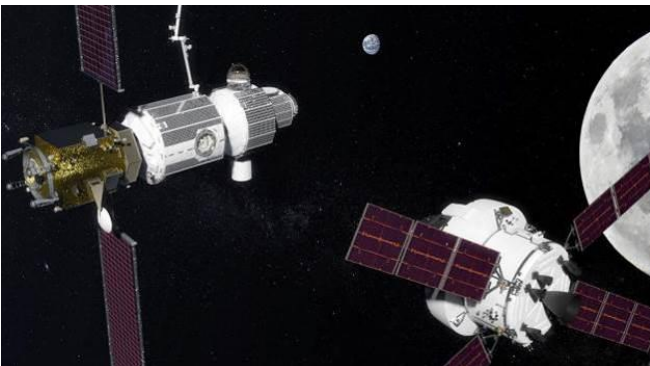


Figure 3. SLS delivers Orion crew vehicle and Co-manifested Payloads (CPLs) to NASA's lunar Gateway

Opportunities for international collaboration on Gateway components that will go to the outpost as CPLs will enhance

peaceful international cooperation while commercial vehicles have a role to play providing logistics flights and delivery of other elements. For deploying more massive Gateway infrastructure, Block 1B cargo flights featuring the 8.4 m fairing in varying lengths will be available by the mid 2020s. The super heavy-lift capability of SLS may yield a significant mass margin that can be used to carry additional consumables or secondary payloads in 6U, 12U or larger sizes.

Mars Missions

With the construction of the lunar Gateway and proving out deep space technologies as an intermediate step, Mars remains an Agency – and international – horizon goal. In addition to sending astronauts to the Moon to expand knowledge of working in deep space environments, SLS may be used to launch future missions to Mars from the Gateway using a fully evolved Block 2 SLS vehicle.

Missions to the Outer Planets

SM-1, the Europa Clipper mission currently launching on the Block 1 cargo vehicle, provides a case study for utilization of the superior SLS departure energy to shorten cruise time, enabling faster data return and simpler mission design. SLS can directly inject this flagship science mission into Jovian space, eliminating the seven-to-eight-year Venus-Earth-Earth gravitational assist trajectory a Delta IV Heavy would require to send the spacecraft to Jupiter's icy ocean moon. With the Block 1 SLS vehicle, transit to Europa will be less than three years, providing earlier science return and reduced operational costs (see Figure 4).

In addition, a shorter outbound cruise phase means the spacecraft needs less radiation shielding and saves mass, which can translate to a more robust science payload. If a follow-on Europa lander mission comes to fruition, that mission could use the performance of SLS, not for decreased transit time, but for increased mass, using a gravitational-assist trajectory to deliver a large payload with a launch mass of 16 t. In addition, the earlier science return of the Clipper mission will inform the lander study.

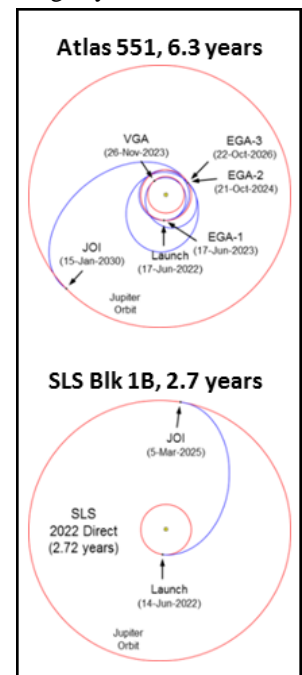


Figure 41. SLS can launch the “Europa Clipper” on a direct trajectory without gravity assists

Looking farther into the solar system, scientists could utilize the unique capabilities of SLS to send probes to the icy

worlds of Uranus and Neptune to investigate the atmospheric and magnetic properties and conduct flybys of larger satellites. SLS can send spacecraft on direct trajectories to these systems also, opening new horizons for exploration with faster data return for investigators.

Astrophysics

In the field of astrophysics, the unmatched payload volume in SLS fairings, whether 8.4 m diameter (Figure 5) or

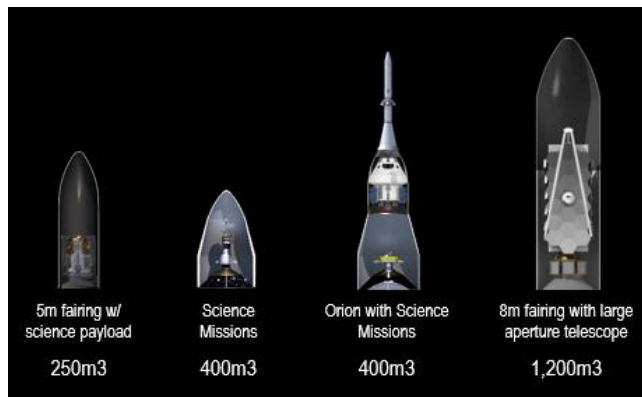


Figure 5. SLS provides unique benefits for a number of science missions

potentially larger fairings, facilitates launch of large-aperture telescopes that could put a view of cosmic dawn – or life on exoplanets -- within our reach. The unmatched payload volume of SLS could be used to deploy telescopes potentially as large as 16 m in diameter to make ultra-high-contrast spectroscopic observations of exoplanets or image the first galaxies. Such a capability would address a need identified in the 2013 NASA astrophysics roadmap, “Enduring Quests, Daring Visions.” A space telescope larger than the James Webb Space Telescope could be engineered to utilize the largest fairing under study – a 10 m-diameter, 27.4-m long PLF. Such a telescope could be stationed at a Sun-Earth Libration Point to allow scientists to explore the universe, characterize supermassive black holes, investigate the history of hundreds of galaxies and uncover the secrets of dark matter.

Interstellar Medium Missions

SLS could be used to send a small probe to interstellar space, in concert with a cleverly designed mission design to explore the interstellar medium. Maximizing the staging efficiency to reduce flight times could enable a project goal of achieving 1,000 astronomical units (AU) in 50 years. Mission concepts include investigation of the interstellar medium and its influence on the solar system, and the characterization of interstellar gas, low-energy cosmic rays, dust and magnetic fields

Using the Sun as a gravitational focus in order to study features on distant exoplanets is another mission concept that SLS could enable. Einstein’s Theory of General relativity predicts that light bends around a massive object – such as

the Sun. However, the effect is tiny and only observable at significant distance from objects of enormous mass. Consequently, the focal point of a solar lens must be at least 550 AU distant, beyond Pluto’s orbit and past the Kuiper Belt, which extends a mere 50 AU. SLS could be used to deploy a telescope at the focal line of the gravitational lens in order to study a distant exoplanet in unprecedented detail.

4. SLS PAYLOAD ACCOMMODATIONS

SLS offers substantial benefits to spacecraft designers and mission planners by being sized to enable crewed Orion and un-crewed cargo exploration missions beyond LEO. Figure 6 details the four types of Spacecraft/Payload that can be accommodated within SLS as it evolves from Block 1 to Block 1B/2.

SLS Payload Types and Payload Enclosures

SLS payload types include:

- Orion spacecraft – crewed spacecraft accommodated on an SLS Block 1 Orion Stage Adapter (OSA) or Block 1B/2 Universal Stage Adapter (USA) that determines primary mission trajectory via an upper stage injection burn
- PPL – uncrewed spacecraft/payload accommodated in an SLS Block 1/1B/2 PLF or Payload Adapter (PLA) that determines primary mission trajectory via an upper stage injection burn
 - 16.4 ft (5 m) class diameter payloads to be accommodated on Block 1
 - 27.6 ft (8.4 m) diameter payloads to be accommodated on Block 1B
 - 27.6 (8.4 m) and 33 ft (10 m) diameter payloads to be accommodated on Block 2
- CPL – uncrewed spacecraft/payload accommodated within an SLS Block 1B/2 USA/PLA; compatible with an Orion-determined trajectory via an Exploration Upper Stage (EUS) injection burn
 - Orion docks to CPL and delivers CPL to its final destination (Orion CPL)
 - Or, post-Orion separation, CPL delivers itself to final destination (independent CPL)
- SPL – accommodated within an SLS Block 1 OSA, Block 1B/2 USA/PLA, or Block 1B/2 PLF/PLA; compatible with an Orion- or PPL-determined trajectory via an EUS injection burn
 - SPL opportunity for flight is based on minimizing impacts to overall flight and ground systems architecture and not jeopardizing crew safety
 - Multiple OSA locations for ≤12U-sized CubeSats
 - Multiple PLA locations for ≤27U-sized CubeSats
 - Accommodation of larger than 27U SPL above the PLA

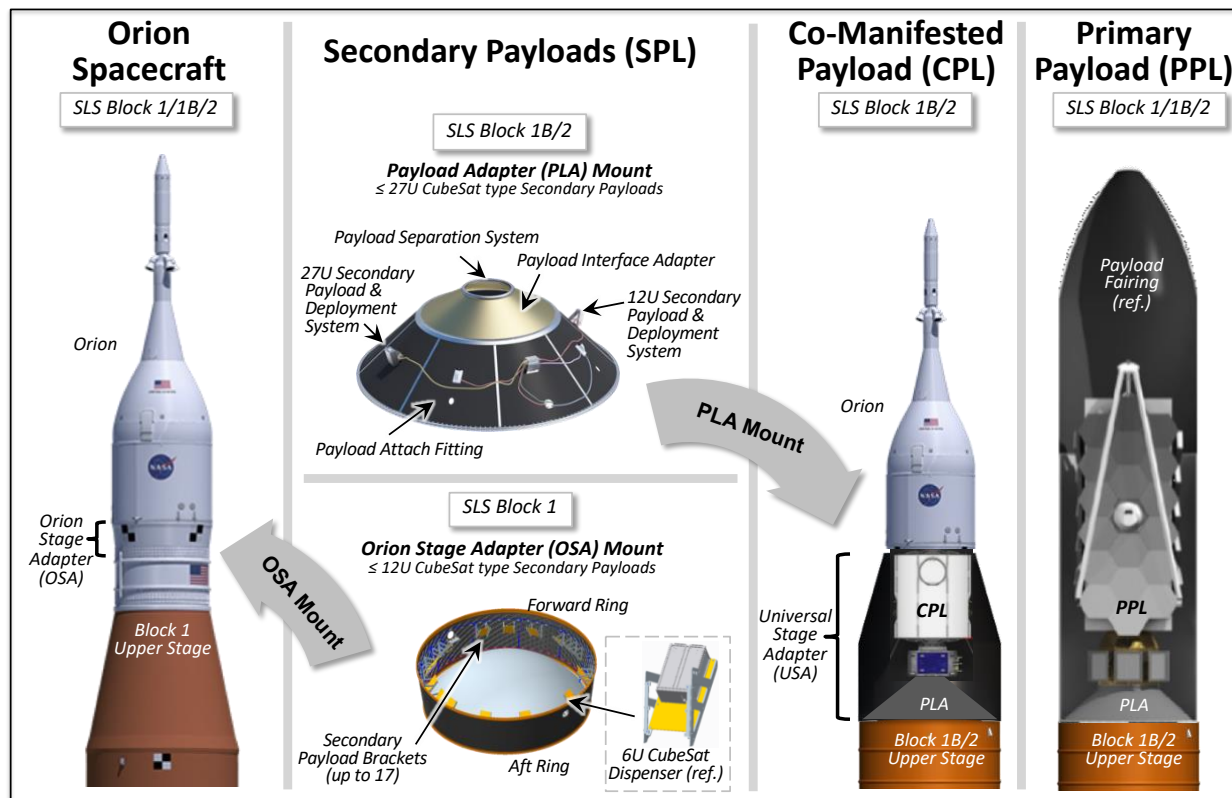


Figure 6. Range of SLS Spacecraft/Payload Accommodations

Figure 7 provides detail on a range of payload enclosure concepts potentially available depending on mission definition and timing. A commercial off-the-shelf (COTS)

5.1 m diameter PLF is planned for SLS Block 1 cargo flights. For Block 1B/2 crewed flights, the SLS USA is required to accommodate Orion. The USA volume, which is larger than

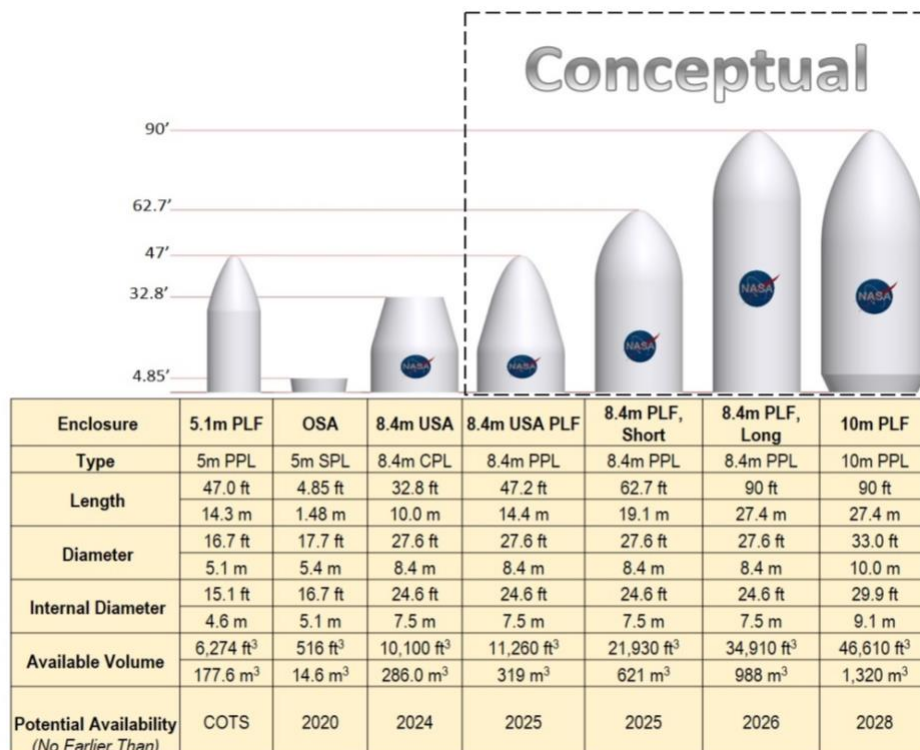


Figure 7. Range of Potential SLS Payload Fairings and Stage Adapter Concepts

that provided by the largest available 5 m diameter PLF, allows payload to be co-manifested with Orion on every crew flight, if needed. An option exists to add a nose cone to convert the USA into the 8.4 m USA PLF concept, if needed prior to the availability of a purpose-built 8.4 m PLF. The SLS 8.4m PLF, Short concept is equivalent in height to today's tallest Expendable Launch Vehicle (ELV) fairings and the 8.4m PLF, Long concept is the tallest fairing length that can be accommodated within existing launch site encapsulation facilities. These lengths are representative of the total range of 8.4m PLFs under consideration, and not meant to imply a particular design implementation at this time. The SLS 10m PLF concept is currently envisioned to support Mars exploration flights, as well as large-volume payloads (e.g., nuclear thermal propulsion, large-aperture

- Payload Interface Adapter (PIA): an optional structural/service interface between the PAF and PSS available to maximize diameter and/or height available based on spacecraft/payload needs.
- Payload Separation System (PSS): a spacecraft/payload structural separation interface mounted on a PAF or optionally on a PIA. Depending on the interface diameter required, the PSS can support a variety of COTS PSS (e.g., D1666 or 1666VS) or larger, new-development PSS as needed.

Figure 8 also details the physical characteristics of three representative SLS Block 1B 8.4m PLAs. All PLAs interface to the 8.4 m diameter upper stage at the bottom and utilize the

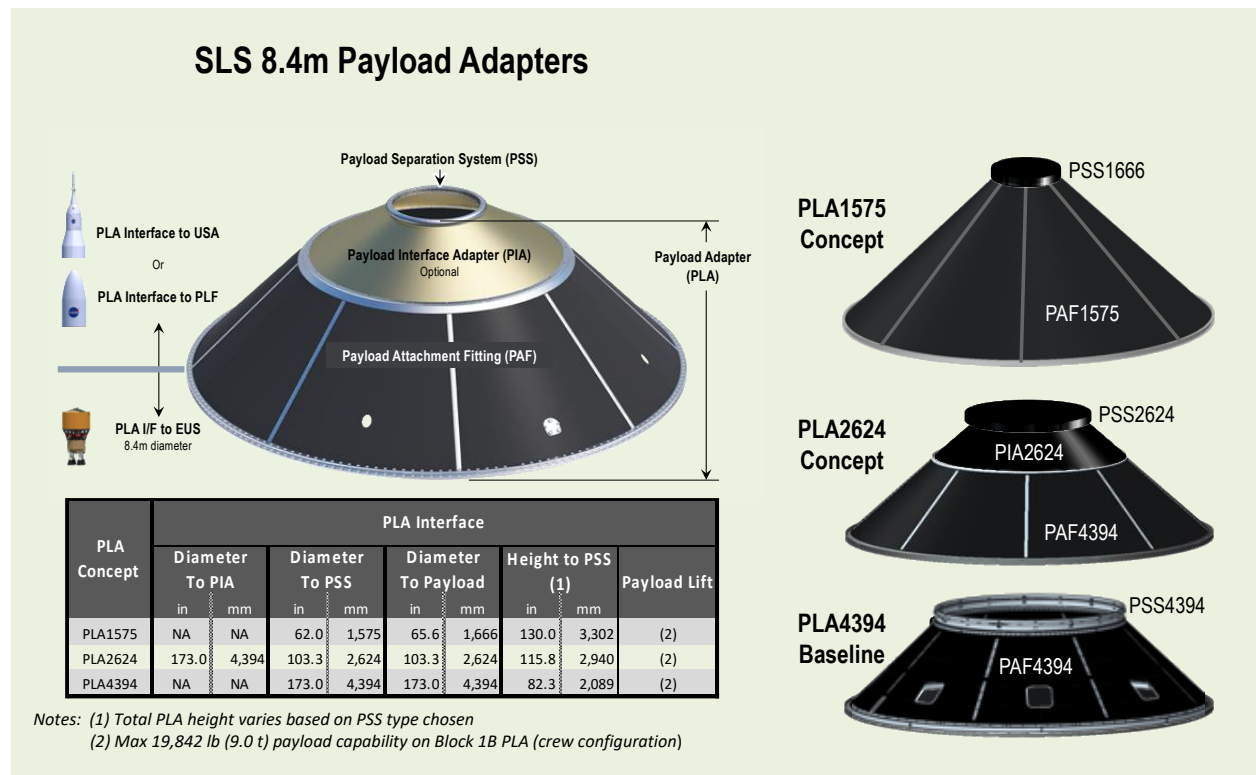


Figure 8. Range of Potential SLS Payload Adapter Baselines and Concepts to Date

telescopes).

SLS Payload Adapters

Similar to ELVs, the mechanical interface between the SLS Block 1B/2 launch vehicle and a PPL or CPL is provided by a mission-dependent PLA, consisting of up to three components, as shown in the upper left of Figure 8:

- Payload Attach Fitting (PAF): a structural/service interface to the 8.4 m-diameter SLS EUS Forward Adapter. The PAF is configured with a Payload Separation System (PSS) and optionally with a Payload Interface Adapter (PIA) to accommodate various spacecraft/payload interfaces as needed.

same cone angle. However, as SLS is an 8.4 diameter launch vehicle, providing larger than 5 m-class ELV diameter PLA interfaces to spacecraft/payload (i.e., > 4 m diameter) is more efficient in terms of mass and volume. Therefore, the baseline PLA for initial SLS Block 1B flights is the PLA4394. The other PLA concepts shown are provided for reference only to demonstrate accommodation commonality with current 5 m diameter ELV-class payloads. It would seem that this family of PLAs will grow as more and more payloads take advantage of unique payload diameter and volume of SLS. Hence, it is expected that larger PLAs than the current PLA4394 may be needed in the future as additional exploration missions are defined.

Typically, the SLS Block 1B/2 PAF is constructed of composite sectors with horizontal and vertical joints. Payload

performance can be increased or decreased depending on the number of composite plies used and the amount of resource access (connector and bracket support interfaces) needed. Depending on the spacecraft/payload interface diameter required, the composite PAF sectors can also be lengthened or shortened as well. In general, PLAs that are shorter, and/or do not require a PIA, will have a lower mass compared to those that do. This flexible SLS Block 1B/2 PLA approach allows use of a family of components to provide a required interface, height and volume for specific spacecraft/payloads.

5. MBSE PATHFINDER: SLS PAYLOAD ADAPTER DESIGN DEFINITION

SLS Program and NASA MBSE Challenge

Over the last 20 years we have learned how to effectively accommodate 4 m and 5 m class ELV payloads by developing a family of 5 m payload adapters. However, the unique nature of SLS in terms of payload lift and volume beg a number of questions as we push towards the moon. How many payloads exist today that need 8.4 diameter accommodations? How many require 34 to 45 t to lunar vicinity? How many need over 600 m3 in volume?

While no payload exists today that requires that support, human habitats in orbit around the moon and on the moon's surface will. We will require quick and efficient payload transport to/from the lunar surface and outside the Earth-Moon system to Mars and beyond as well. At this time, we don't know what the size or sizes the optimal 8.4 m class PLA should be. SLS is starting with the PLA4394 due to heritage with ELV equivalents and the potential to accommodate Lunar Gateway 4.5 m diameter modules. However, due to the SLS performance available, even more capability will be needed. Other questions arise like, how should the PLA best accommodate SPL when opportunities arise? What about the accommodating large SPL with an Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) type interface on or above a PLA?

Helping SLS evaluate 10's to 100's of PLA concepts over the next 10 years requires new ways of thinking. This is where the NASA Engineering and Safety Center (NESC) stepped in and developed a Model Based Systems Engineering (MBSE) PLA Pathfinder for SLS to investigate this issue. The premise was to use MBSE to tie together a number of existing tools in order to significantly reduce the initial resources and time required to get to a 75% to 90% PLA solution. This allows SLS engineering personnel to eliminate a majority of their initial evaluation cycle time by utilizing higher fidelity PLA MBSE data up front instead.

Based on management support from NASA's System Engineering Deputy Division Chief, Mike Danford, and Jacobs Technologies Engineering and Science Services and Skills Augmentation (ESSSA) Contract Deputy General Manager, Jan Davis, the Pathfinder effort included the PLA Team. This team consisted of six NASA/Contractor engineers and three aerospace engineering students from Georgia Tech. The Georgia Tech students identified PLA requirements and put together the verification module. The NASA/Contractor engineers had programming, modelling, manufacturing, systems engineering, operations, and CAD skills. This cross-NASA enterprise and academic team effectively applied their diverse skill sets to PLA model.

PLA MBSE Pathfinder Approach

System modeling approaches were evaluated to integrate key user requirements within the range of SLS payload accommodation capabilities to identify preferred SLS PLA designs. The SLS Engineering Team was evaluating a one-piece composite cone design so the Payload Adapter Pathfinder Team used a truss system design to simplify initial evaluation. A System Modeling Language (SysML) model in MagicDraw was developed. We also identified key models (e.g., CAD, loads, composite manufacturing) that would interface with our SysML model. In this case, we used CREO for our Computer-Aided Design (CAD) system since we could import data, update the model, run loads analyses, and export the data back into our SysML model for

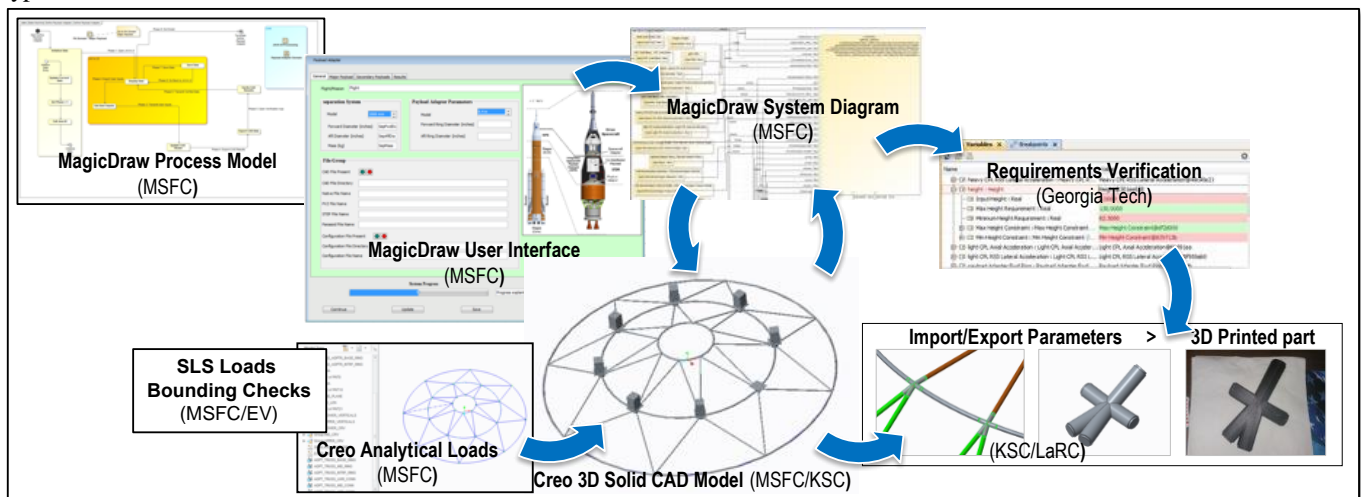


Figure 9. NESC PLA Pathfinder: User Inputs > Model > Analysis > Verification > 3D Part

verification of the requirements. This approach is shown in Figure 9.

The PLA model was setup for a variety of user inputs – either by the payload user or by the SLS design team at NASA MSFC. These inputs had some unique design parameters for specific payload sizes and masses, separation system sizes, and payload adapter size and mass which were used to develop the range of notional PLA designs and to provide findings for SLS to enhance related SLS Payload Adapter products (e.g., SLS Mission Planner’s Guide, PLA Requirements document, related payload mission unique Interface Control Documents). Figure 8 provides a summary of our pathfinder approach.

Figure 10 shows part of the input dialog window used to enter data. Some of the data is dependent on other data entries and the dialog does not have input fields for those dependent parameters. Through the use of a dialog like this, the User can communicate what is needed for their mission.

Payload Adapter (PLA)		Inputs
Aft Ring Dia	8.400 Meters	8.400
Fwd Ring Dia	1666.000 mm	
Total Height	0.000 inches	
Total Mass	0.000 kg	
Aft Ring Height	4.750 inches	4.750
Aft Ring Mass	40.000 kg	40.000

Payload Attach Fitting (PAF)		Inputs
Fwd Ring ...	92.402 inches	
Height	31.000 inches	31.000
Mass	40.000 kg	40.000

Figure 10. Parameter Input Example

Once the parameters are complete in the model, they can be exported to an Excel file which is then loaded into a CREO Control Skelton File. As noted previously, the SLS Engineering team is using a composite PLA design while the PLA Pathfinder team used a Truss design. As long as both files have the same parameters defined in the model, the parameters from the SysML model can affect either design. Once the parameters have been used to update the 3D model, loads and other analyses can be executed and the results will flow into output parameters that can be saved in a file which can be imported into the SysML model and the results verified through the verification module. Enhancing our initial approach, the team also investigated using additive manufacturing to produce a scale model of the adapter defined by the SysML model and Creo Parametric 3D Modeling Software. The results of this additive manufacturing experiment is shown in Figure 11.

PLA MBSE Pathfinder Benefits

There are a number of benefits that can be realized by the use of these Model Based Engineering techniques and models:

- Identification of early SLS Adapter design constraints to support initial Orion (CPL/SPL) and later Cargo (PPL/SPL) missions
- A 75% (Threshold) - 90% (Goal) performance solution to support payload feasibility assessments and manifesting exercises
- Initial target identification reduces formal analysis effort once payload is manifested
- Internal NASA communication/education of the utility of the SLS “payload bay,” aka PLA and PLF
- A lower cost/schedule enhancement of critical SLS documentation for potential users
- Support for SLS efforts to enhance the SLS user experience via net-based payload feasibility tools



Figure 11. Scale Model of PLA/PAF (Truss-based)

6. NEXT STEPS

As the future of engineering moves toward more digitally integrated solutions that span the life-cycle from concept to manufacturing, opportunities arise to more efficiently tailor implementations to better balance performance, cost and schedule. The SLS, designed as a national (and international) capability for exploration, includes the largest spectrum of utility with delivery to a similarly large set of destinations. While SLS is focused on big NASA missions, NASA is also working to improve our smallest class of launch vehicles, by applying similar approaches with Model Based Systems Engineering, across low risk, rapid cycle, sounding rocket missions. Like working a puzzle, the pieces are coming together on how we can demonstrate and grow opportunity

from MBSE into all of our missions. With an example from concept to manufacturing performed by the largest launch vehicle in history, we can look at how that can be leveraged across all missions, down to our smallest sounding rockets. Work being performed on mission integration by small launchers, can also be shared with commercial entities and larger vehicles to refine and accelerate the approach.

With dozens of use cases demonstrating the technical value of MBSE for engineering systems, the System Engineering (SE) community, led by the SE Technical Fellow out of the Office of the Chief Engineer, is looking toward how the capability best aligns with the NASA workforce at large as well as other Government Agencies and commercial providers. Working with 5-10 SE strategies now in place, more focus is being placed on a 10-20 year time frame, where digital twins (digital replica of physical assets and processes) are fully expected to have been achieved. Where those twins integrate engineering with programmatics, the question of “standard” engineering designs and the cost of associated change, is no longer a major consideration.

7. SUMMARY

SLS is a new breed of vehicle, one that offers a unique blend of performance and accommodation. Unfortunately, being unique leads to challenges in determining effective payload interfaces. An MBSE approach shows promise in reducing a traditional, full analysis cycle ELV payload adapter development to something much shorter by tying existing tools together in a smart way. It also offers the potential of more seamlessly integrating data from verification all the way to PLA fabrication. Specifically, this pathfinder was able to develop user interfaces to feed MagicDraw parameters directly into CAD/analytical models and then verify those requirements were met by PLA concept. It produced a 75% to 90% fidelity solution that was “good enough” for designers to begin detailed analysis. It used an outward facing graphical user interface for capturing potential SLS payloads and automated the process to minimize errors as concept was additively manufactured. Future work promises to integrate these finding more directly within SLS and the larger contingent of NASA missions from Super Heavy missions to those smaller than a nanosat. In the end it’s expected that models and data can flow more easily and efficiently both internally to a vehicle or spacecraft as well as externally across the varied availability of delivery providers, both launch vehicle and spacecraft. The result being more detailed evaluations, less re-work and improvements across not only the physical interface, but the entire federated infrastructure.

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BIOGRAPHY



Jon Holladay is the NASA Technical Fellow for Systems Engineering. His responsibilities include assessment of critical NASA Programs as well as the Agency’s SE discipline state and its future capability needs. He has over thirty years of experience in the human spaceflight arena involving both spacecraft and launch vehicle development and operations serving as both Chief Engineer and Engineering Project Manager. He holds a Bachelors and a Master’s degree in Mechanical Engineering from the University of Alabama, has completed the Legislative Studies Program at Georgetown University and the Senior Executive Fellows Program at Harvard’s Kennedy School of Government. He most recently served as the Project Lead/Chief Engineer in the SLS Advanced Development Office, where he focused on strategic analysis and planning for evolvability of NASA’s SLS.



Terry Sanders is a Systems Engineer at Jacobs Technology providing engineering services to NASA’s MSFC. He received a B.S. in Computer Science from Rockford College and a M.S. degree in Systems Management from Florida Institute of Technology. He has been a Payload Operations Flight Controller for two Space Shuttle missions and on four expeditions for the international Space Station (ISS). Subsequently, he served a Lead Systems Engineer for the First Material Science Research Rack (MSRR-1) currently operating onboard the ISS, and is now working on the Verification and Validation (V&V) Team for the Space Launch System. He has been a member of IEEE for twenty-five years.



David Alan Smith is a NASA MSFC System Engineering Subject Matter Expert for the Space Launch System (SLS) in the areas of architecture development and launch vehicle block evolution. He is also Senior VP, Advanced Programs for Victory Solutions in Huntsville, Alabama and has over 30 years’ experience in management, development, design, analysis, and invention of human spaceflight systems. Mr. Smith holds a Bachelor of Aerospace Engineering from the Georgia Institute of Technology and was a System Design Technical Fellow at the Boeing Company. He has a number of human space

transportation patents and is a published author of 14 technical papers on the implementation of affordable human space payload delivery systems. He is the recipient of the Rotary National Award for Space Achievement (the Stellar Award), the Boeing Special Invention Award, and the McDonnell Douglas Golden Eagle Award.