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Booster Obsolescence and Life Extension (BOLE) for Space Launch System (SLS)

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***Abstract* – A human mission to the moon and Mars is the stated space exploration goal of the United States and the international community. To achieve these goals, NASA is developing the Space Launch System (SLS) and the Orion crew capsule as key elements in the architecture for missions to the moon and Mars. As part of the SLS Booster Obsolescence and Life Extension (BOLE) program, Northrop Grumman Innovation Systems is working to address booster obsolescence issues in design and manufacturing. The upgraded boosters will also provide increased performance that will benefit future lunar campaigns, science missions, and the eventual Mars campaign.**

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1. INTRODUCTION

NASA is currently working towards the goal of returning humans to the surface of the moon, followed by human missions to Mars [1], leading to the eventual establishment of a permanent human-tended outpost on the surface of Mars [2]. This ambitious exploration campaign is being undertaken using an incremental approach, as shown in Figure 1.

As shown, the initial steps have already begun, with research being carried out in low earth orbit (LEO) at the International Space Station. The next steps push into cislunar space in 2020 with the launch of the first Space Launch System (SLS) and Orion spacecraft. SLS and Orion will enable the delivery of crewed missions to the Lunar Orbital Platform – Gateway. The Gateway will enable research into technologies and procedures for living farther away from Earth.

With the Gateway in place to act as a staging ground, the next step is to the lunar surface. Lunar surface missions would build up architecture on the surface, eventually expanding to a lunar outpost. This would provide practice in living and thriving on the surface of another body, lessons that would eventually be useful to Mars surface missions.

Building on the earlier steps, we would finally have the experience to begin initial human forays into the Martian system. The initial mission will be a human orbital mission with attendant systems to allow for direct human exploration of the Martian moon Phobos, as well as the telerobotic exploration of the Martian surface, utilizing either prepositioned robotic assets or assets that are brought along with the crew. Future missions to the Martian system will involve the buildup of a permanent infrastructure on the Martian surface to enable long-term human exploration of the planet.

This approach is supported by the heavy lift capability of SLS, necessary to deliver the large components necessary to live in space, land on the moon, and eventually travel away from Earth's vicinity.

Northrop Grumman Innovation Systems is currently working to support all these missions by providing the booster stage for SLS. Part of the ongoing effort to support the SLS program is ensuring that the vehicle has the ability and performance required to meet future mission goals. The SLS Booster Obsolescence and Life Extension (BOLE) program ensures that the vehicle can meet those ambitious goals.

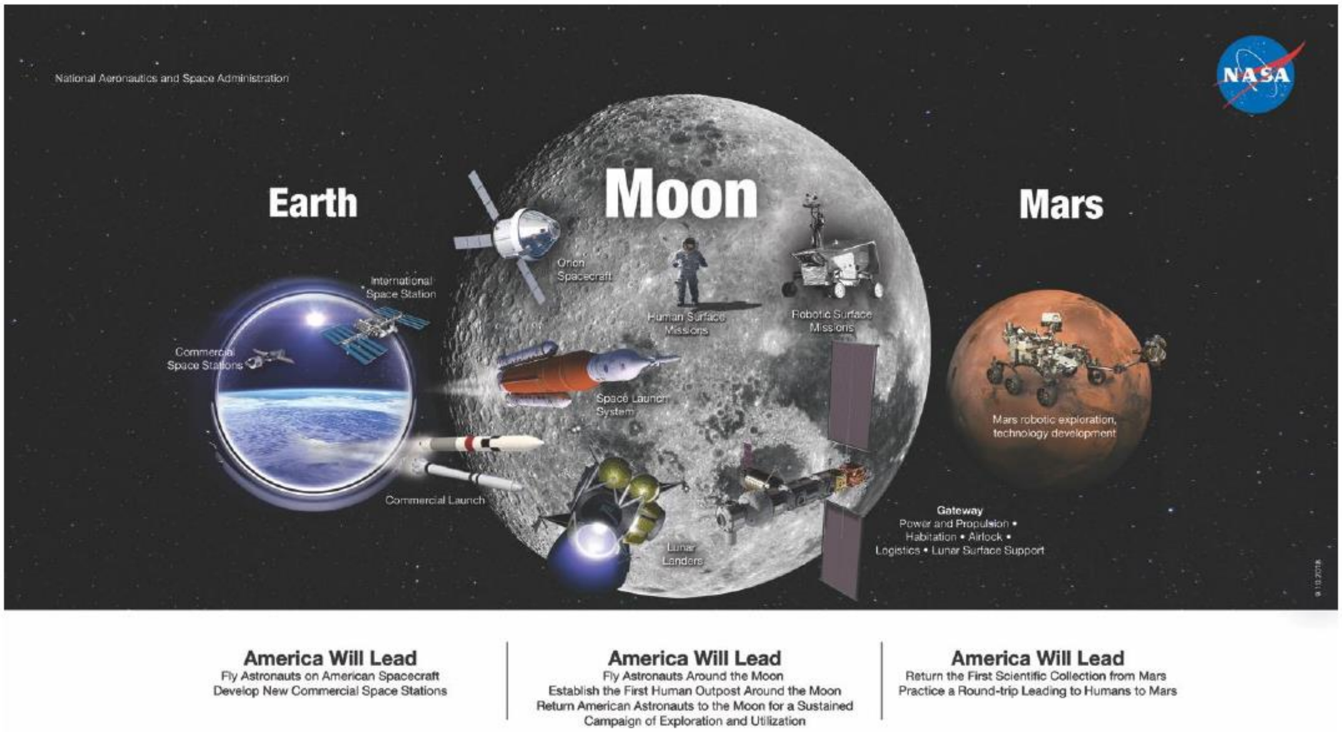

Figure 1. Incremental Approach to Mars Exploration. Source: NASA

2. SLS DETAILS

SLS is the keystone heavy lift vehicle for the lunar and Mars campaign. SLS consists of a liquid oxygen/liquid hydrogen powered core with two solid rocket boosters, designed and built by Northrop Grumman Innovation Systems (formerly Orbital ATK). The SLS boosters are based on the reusable solid rocket motor (RSRM) design built for the Space Shuttle, using many of the same technologies, including the heritage steel cases. The core is powered by the RS-25, initially using remaining Space Shuttle main engines followed by non-reusable versions of that engine. The initial Block 1 configuration includes the Interim Cryogenic Propulsion Stage (ICPS), a liquid oxygen/liquid hydrogen stage powered by a single RL-10 engine based on the Delta IV cryogenic second stage. The vehicle is topped by a 5.4-meter fairing.

SLS then evolves to the Block 1B configuration with a new, more powerful 8.4m diameter Exploration Upper Stage (EUS), as shown in Figure 2, powered by four RL-10 engines that will replace the ICPS. The addition of the EUS gives SLS added payload capability, especially for beyond earth orbit (BEO) missions. Both the SLS Block 1 and Block 1B vehicles will be capable of being flown in crew and cargo variants.

The first mission is currently scheduled to launch in mid-2020 for an uncrewed trip around the moon [3]. A crewed mission will follow in 2021. The more capable SLS Block 1B vehicle with the EUS will first fly in 2024 for EM-3.

The crewed variants will utilize the Orion crew capsule to transport astronauts to their intended destination. Along with delivering Orion to cislunar destinations, the Block 1B vehicle has additional payload capability. This capability will be utilized to deliver co-manifested payload (co-manifested with Orion) carried inside the payload attachment hardware. Figure 2 shows a cutaway of the top of SLS, including Orion, and an example of a co-manifest payload inside the universal stage adapter. Co-manifesting payload with Orion provides additional flexibility in achieving human exploration, operations, and science objectives on any given mission.

The cargo variant of the Block 1 vehicle will utilize a 5.4m fairing while the Block 1B vehicle will initially use a new 8.4m fairing with a possibility of evolving to a 10m fairing if the need arises.

Based on trajectory models, SLS Block 1B configuration can deliver 37 mT of payload to near rectilinear halo orbit (NRHO). Of this payload, 27.2 mT is assumed to be Orion, leaving 9.8 mT for co-manifested payload. It is assumed that Orion would provide the ΔV to insert from an initial translunar insertion (TLI) orbit into NRHO.

SLS Block 1B can also deliver 41 mT of cargo-only payload to TLI. As with the crew configuration, the payload is assumed to be responsible for its own orbital insertion burns.

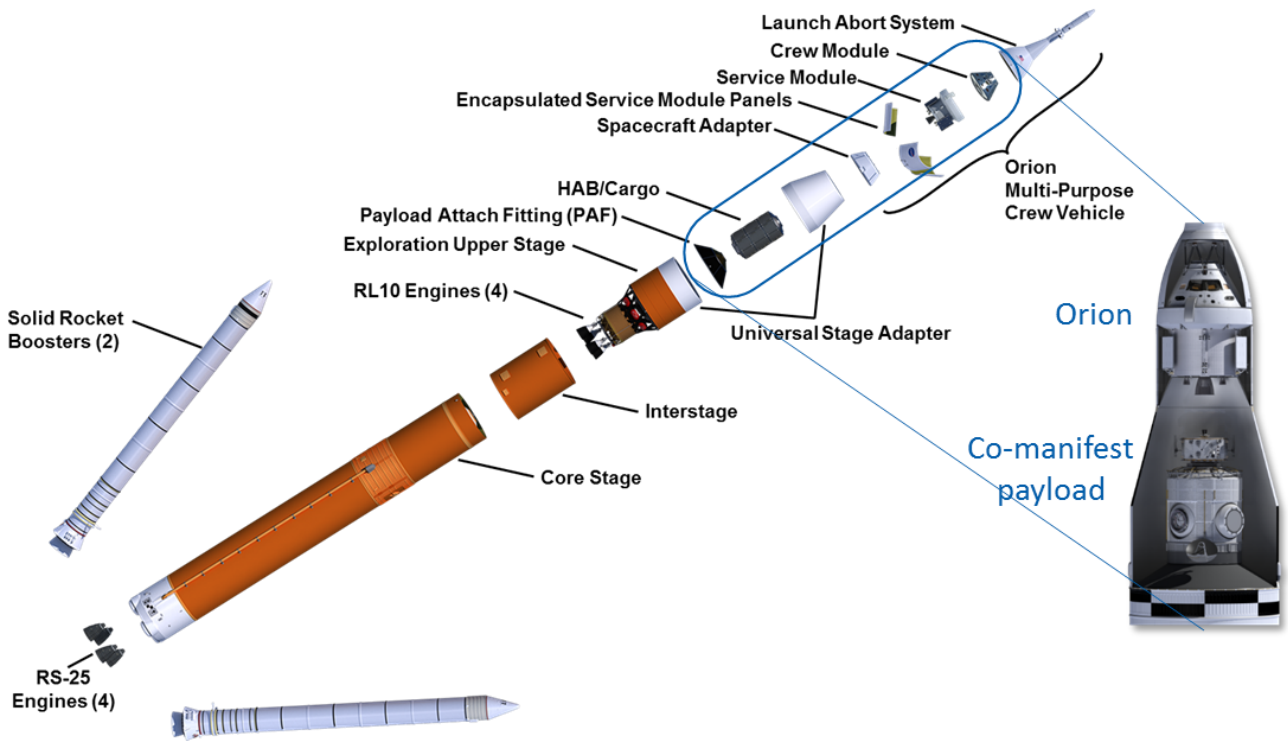

Figure 2. Expanded View of SLS Block 1B, Crew Configuration and Cutaway Showing Orion and Co-manifest Payload. Source: NASA and Boeing Corporation

3. BOLE DESIGN CHANGES

The selected SLS architecture removed systems necessary for booster recovery and reuse that were employed during NASA's Space Shuttle program. At the time, this meant that eight flight sets of hardware (steel cases, structures, etc.) were available for use before parts and processes would need to be redesigned, requalified, and rebuilt. The BOLE program is NASA's plan to continue use of the current SLS system through redesigned hardware that can be produced to support missions for the foreseeable future.

The BOLE boosters are built on the back of heritage SLS technologies combined with insertion of discreet enhancements for operations efficiency and performance. Many of these technologies have been successfully employed in fielded systems such as Titan Solid Rocket Motor Upgrade, CASTOR®, and Graphite-Epoxy Motor (GEM) programs, and will be used on Northrop Grumman's OmegA™ vehicle.

The C300 and C600 motors that will be used as the first and second stages of OmegA are of similar size and design as the BOLE motor, and are scheduled for first static tests in April and August of 2019 and have already achieved significant program milestones including full-scale case burst and first live cast [4]. The similarity of the BOLE design with the C300 and 600 motors will lead to efficiencies, modularity, and affordability in launch vehicle design for many years to come.

The major BOLE design deltas from current SLS production, shown below in Figure 3, are as follows:

Motor Design Updates

- Composite case with industry-leading composite joint and fiber technology resulting in nearly 30% weight savings and improved joint functionality to replace obsolete steel segments that are no longer cost effective to produce
- Upgraded hydroxyl-terminated polybutadiene (HTPB) propellant – the industry standard - to handle higher strain levels inherent to the composite case and to eliminate reliance on five-segment reusable solid rocket motor (RSRMV) unique polymer system
- Wound Elastomeric Insulation® (WEI) with newer more cost effective materials to improve processing and compatibility with new propellant
- New nozzle optimized for use with new propellant and enhanced vehicle performance

Improved Booster Structures and Thrust Vector Control (TVC)

- Updated booster structures to address obsolescence, simplify processing and interface with updated motor design
    - Combined nose cone and frustum
    - Optimized forward skirt with increased structural capability
    - Simplified systems tunnel architecture designed for BOLE systems

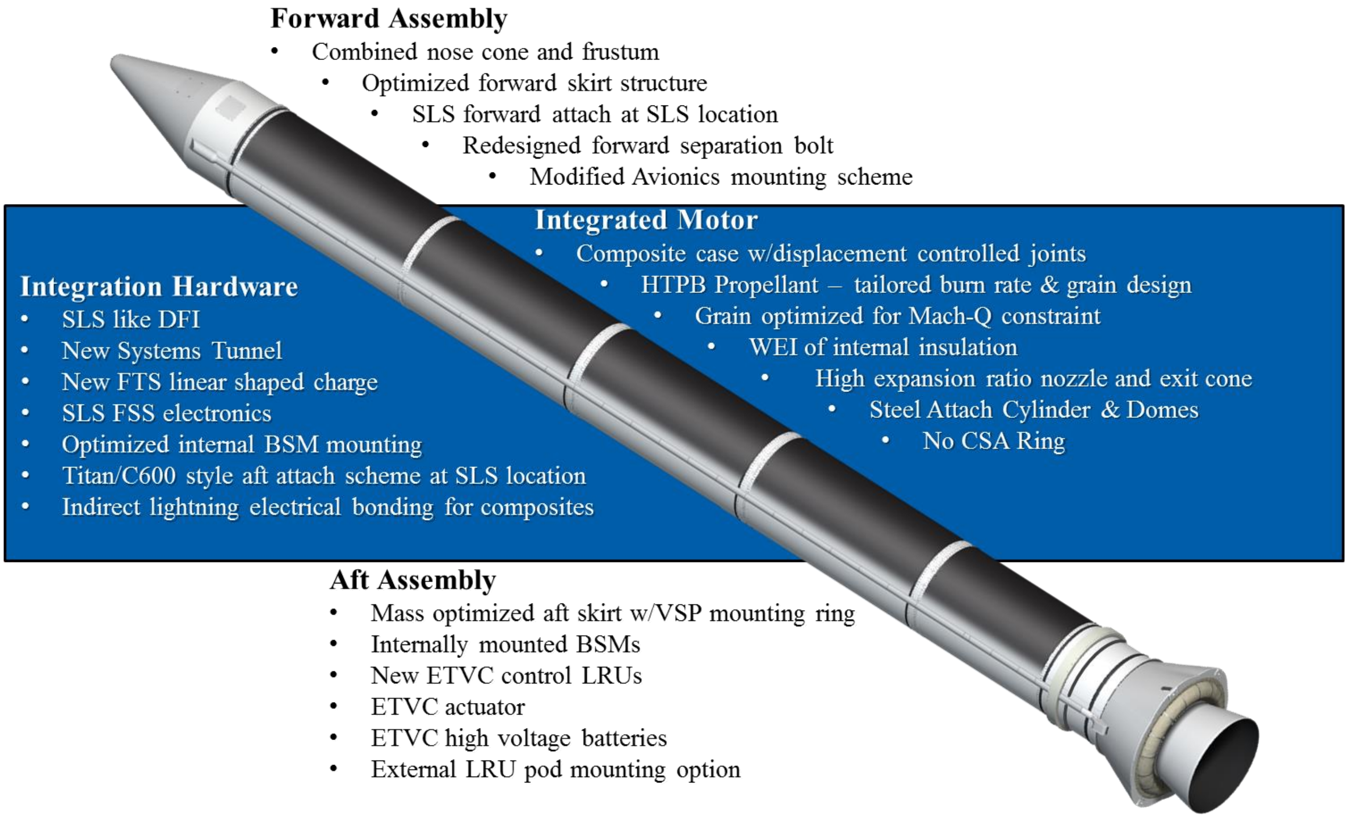

Figure 3. BOLE Design Changes Overview

  - Improved booster to core attach and in-flight booster separation systems
  - New aft skirt designed for manufacturability and load path efficiency
- Electric thrust vector control (eTVC) system to replace heritage TVC system and reduce use of hazardous materials to simplify ground processing at Kennedy Space Center (KSC) and address obsolescence of legacy technology

These changes address the current obsolescence issues and help streamline production at both Northrop Grumman's facilities and at the KSC launch site – while providing an added benefit of increased performance as compared to the current SLS boosters.

4. BOLE EMPOWERS SLS MISSIONS

As mentioned above, SLS will continue to evolve into a more and more capable vehicle. The evolutionary path is shown in Figure 4. The first mission will launch on the Block 1 configuration. The EUS will be added, increasing the payload capability. The current RS-25 inventory will be expended, and the non-reusable version will offer increased performance. Then the current inventory of steel booster cases will be expended, and BOLE will further empower additional capability. Based on our trajectory models, the BOLE boosters provide 3 mT of additional TLI performance. That additional capability will be useful for all NASA missions using SLS going forward.

In a previous paper, we presented a possible lunar/Mars campaign showing the cadence and components for SLS launches to build up a lunar outpost before making the much longer trip to the Mars system [5]. That campaign showed the Lunar Orbital Platform – Gateway being operational in 2028 after six SLS launches, with two more launches allocated for Europa Clipper and Lander missions. Thus the first launch of SLS with BOLE would begin the lunar campaign.

Empowering the Lunar Outpost Campaign

The lunar campaign begins in 2029 with an initial cargo lander. The study assumed lunar landers similar to what Boeing has proposed [6], and would include crew and cargo variants. The fully loaded descent module (DM) was estimated at 43.5 mT, within the capability of SLS with BOLE, while the ascent module (AM) was estimated to be 7.5 mT, within the co-manifest capability of the crew

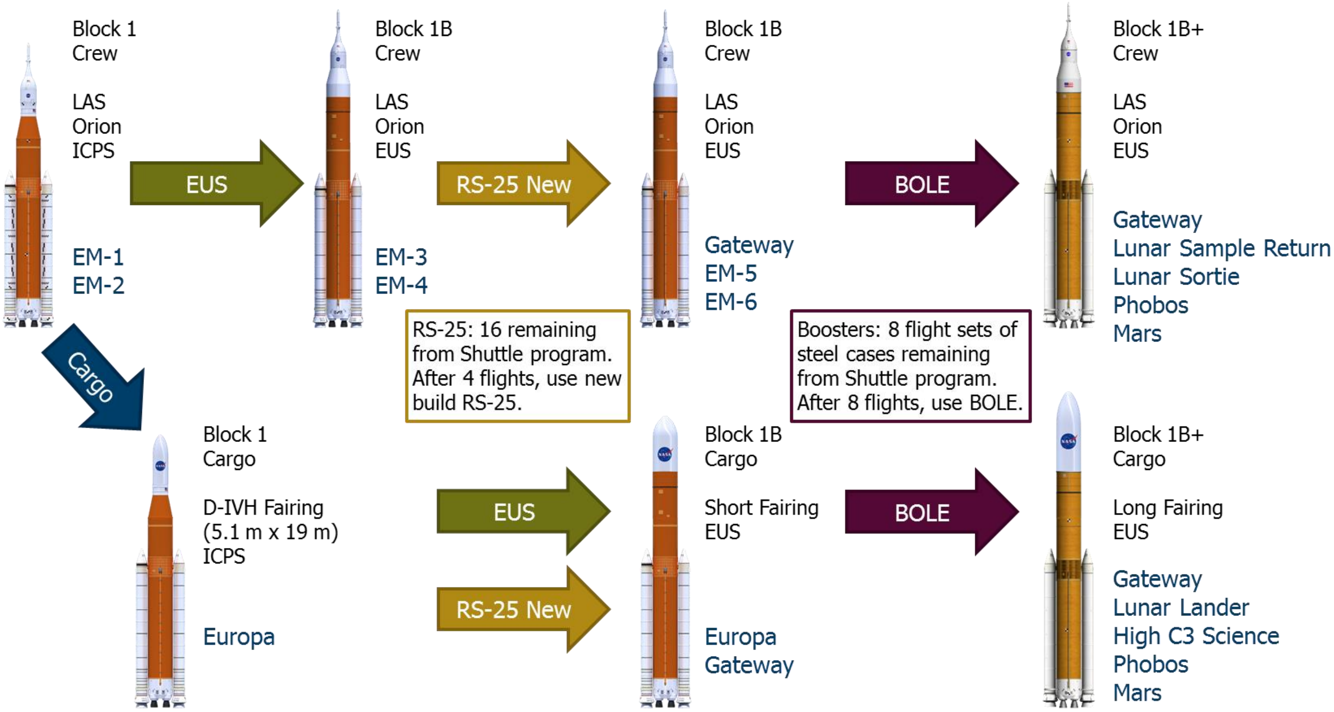

Figure 4. SLS Configuration Evolution

configuration [6]. The DM and AM would rendezvous separately with the Gateway, where they would mate up prior to the crew departing on the lunar surface mission.

The lunar campaign would alternate cargo and crew landers, delivering crew to the lunar surface in 2031, 2033, and 2035. After 2035, the outpost would be fully operational, consisting of two habitat modules and a power and communication module.

The lunar outpost campaign consists of 12 SLS launches, beginning in 2029 and stretching through 2035. The added capability that BOLE brings to each launch removes the need for additional launches to carry fuel or supplies for these missions.

After 2035, the lunar outpost continues to operate, supplied from the Gateway by commercial launch services or additional SLS launches.

Empowering the Mars Campaign

The Mars campaign will similarly aggregate at the Gateway, meaning that the added payload to TLI provided by BOLE will also greatly benefit the Mars campaign. The initial Mars mission will likely be a Phobos rendezvous mission. While that mission does not require a Mars lander or ascent vehicle – those will come later – it still requires the Deep Space Transport, as well as the Phobos Habitat Module and the fuel and supplies necessary for the three-year mission. The added capability of SLS with BOLE allows for more mass to be available for the mission.

And for eventual follow on missions to the surface of Mars, SLS with BOLE will be better able to lift the lander and Mars Ascent Vehicle that the crew will need to access the surface and return safely.

Empowering Science Missions

Along with the benefits to the crewed lunar and Mars missions, BOLE also brings benefits to science missions launched on SLS. For example, using SLS allows for direct insertion trajectories for outer planet missions, reducing the time of flight by removing gravity assist flyby maneuvers.

Outer planet missions require significantly more departure energy (C_3) than missions to the moon or Mars – lunar missions typically have a C_3 of around -1 km²/s², while typical Mars departure C_3 are around 10 km²/s², C_3 directly to Jupiter is around 85 km²/s² and directly to Saturn is around 105 km²/s² [7]. Adding BOLE increases SLS's capability to these high C_3 missions.

Figure 5 shows the payload capability of SLS Block 1B and Block 1B with BOLE to various departure C_3. For a direct departure to Jupiter, adding BOLE improves SLS payload capability by about 13%. To Saturn, the improvement is about 24%. This means more spacecraft mass – either more propellant for longer missions or more scientific instruments or both.

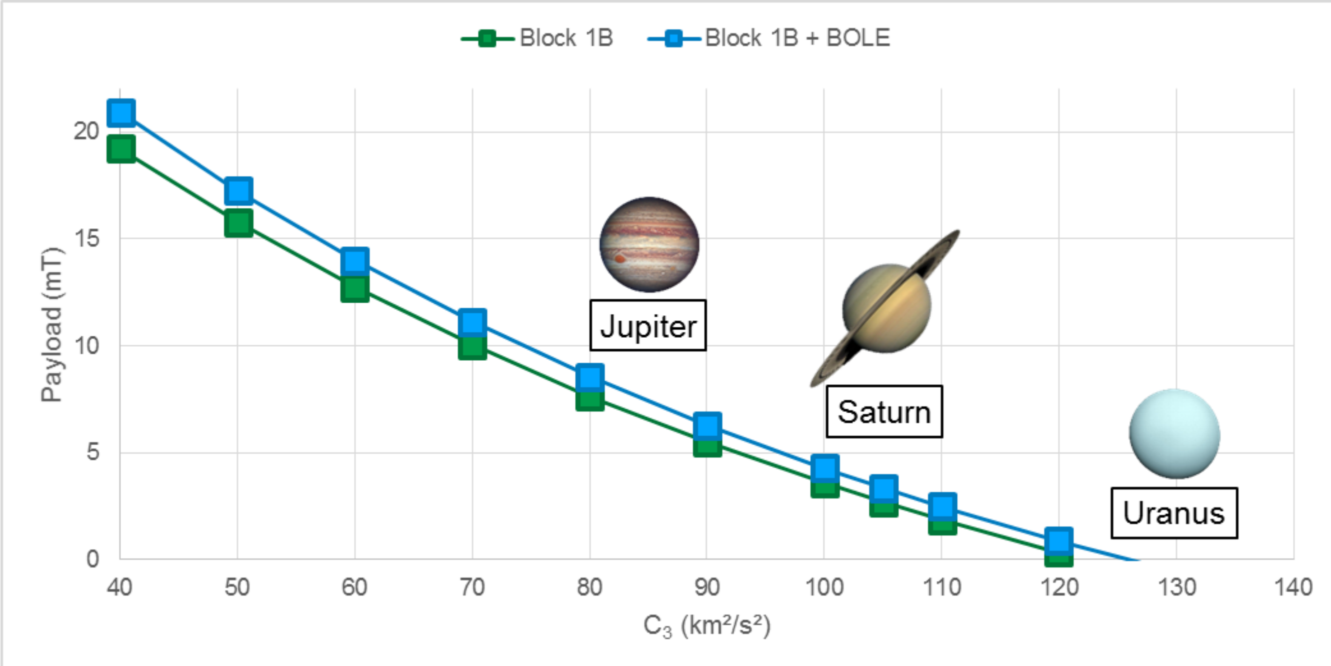

Figure 5. SLS Block 1B and Block 1B with BOLE Payload Capability to Mission C_3 (Planet graphics courtesy NASA [8-10])

5. SUMMARY

The flexibility of the SLS vehicle to transport crew, cargo or both facilitate the exploration of cislunar space, the lunar surface and eventually Mars. BOLE will resolve the obsolescence issues associated with the use of the heritage Space Shuttle hardware. Once the BOLE booster is fully developed, significant new mission space is unlocked for planners to enable lunar and Martian missions as early as 2029. Additionally, BOLE will build off of commercial best practices and materials while utilizing existing infrastructure to produce a booster that will increase the overall capabilities of the SLS launch vehicle. By utilizing standard processes and materials, future obsolescence issues will be minimized. The BOLE booster is one additional step on the SLS evolution path, making it an ever more capable heavy lift launch vehicle that will propel us to the moon, Mars and beyond.

REFERENCES

[1] NASA, "New Space Policy Directive Calls for Human Expansion Across Solar System," Dec. 11, 2017. [Online] Available: https://www.nasa.gov/ press-release/new-space-policy-directive-calls-for-human-expansion-across-solar-system

[2] NASA, "NASA Affirms Plan for First Mission of SLS, Orion," May 12, 2017. [Online] Available: https://www.nasa.gov/feature/nasa-affirms-plan-for-first-mission-of-sls-orion .

[3] NASA, "NASA Completes Review of First SLS, Orion Deep Space Exploration Mission," Nov. 8, 2017. [Online] Available: https://www.nasa.gov/ feature/nasa-completes-review-of-first-sls-orion-deep-space-exploration-mission.

[4] Northrop Grumman, "Common Boost Segment Program," Aug. 17, 2018. [Online] Available" http://www.northropgrumman.com/Capabilities/OmegA/Documents/CBS_FactSheet.pdf.

[5] T. Haws, J Zimmerman, and M. Fuller, "SLS, the Gateway, and a Lunar Outpost in the Early 2030s," presented at the 2018 Joint Propulsion Conference in Cincinnati, OH, 2018. AIAA 2018-4638

[6] X. Simon, J. Engle, M. Duggan, T. Moseman, and K. Manyapu, "A Crewed Lunar Lander Concept Utilizing the Cislunar Gateway," presented at the AIAA SPACE Forum, Orlando, FL, 2018. AIAA 2018-5344.

[7] See NASA Ames Research Center Trajectory Browser, [Online] Available: https://trajbrowser.arc.nasa.gov /index.php.

[8] Jupiter image from NASA: https://www.nasa.gov/sites/default/files/thumbnails/ image/jupapr3color-jd-170304_0.png

[9] Saturn image from NASA: https://www.nasa.gov/sites/default/files/images/365640main_PIA11141_full.jpg

[10] Uranus image from NASA: https://www.nasa.gov/ sites/default/files/thumbnails/image/pia18182-16.jpg

BIOGRAPHIES

Mark E. Tobias *has nearly 30 years experience in a variety of design, analysis, and leadership positions. These positions include assignments in bolted joint design, ignition system design, motor performance grain design and analysis, propellant formulation, systems engineering, post-flight assessment, and testing. His leadership experience includes project engineering, management of frontline engineering groups, Systems Integration Team Chief and most recently SLS Booster Deputy and Advanced Booster Chief Engineer. He has either been a significant contributor to or leader for several major propulsion system development activities, including ETM-03, Five-Segment Reusable Solid Rocket Motor (RSRMV), Ares I-X, Ares I, Advanced Booster NASA Research Announcement (NRA) and SLS. As SLS Deputy and BOLE Chief Engineer, Mark is responsible for technical execution of the SLS Booster project and development of an evolved booster eliminating future obsolescence challenges. He has also served in a variety of business development and technical proposal lead roles.*

David R. Griffin *received his BS in chemical engineering from Brigham Young University in 2004. He joined Northrop Grumman Innovation Systems in 2004 working on insulation development for the now retired Space Shuttle booster. His background includes insulation and propellant material development and characterization and rocket motor performance analysis. He has spent the last two years as a principal investigator for Northrop Grumman Innovation Systems' efforts on BOLE motor design.*

Joshua E. McMillin *received his BS in mechanical engineering from Purdue University in 2000. He joined Northrop Grumman Innovation Systems in 2000. He started in the Ballistics and Grain Design Team and has supported the preliminary design of all Northrop Grumman Innovation Systems' large segmented solid rocket motor designs supporting NASA programs since 2000. He has also served as a science and English educator for grade school students in Maldives. He currently supports the BOLE program as the Chief Booster Architect.*

Terry D. Haws *received his BS and MS in mechanical engineering from Brigham Young University in 1997 and 1999, respectively. He worked for Pratt & Whitney for five years modeling jet engine performance before joining Northrop Grumman Innovation Systems in 2005. Terry performs conceptual design and analysis, trajectory modeling, and interplanetary mission modeling and is a licensed professional engineer and a senior member of the American Institute of Aeronautics and Astronautics.*

Michael E. Fuller *received his BS in ceramic engineering and MS in materials science and engineering from the Ohio State University in 1992 and 1995, respectively. He worked for 10 years at a small materials development company prior to joining Northrop Grumman Innovation Systems in 2005 as a research scientist. He has spent the last three years leading Northrop Grumman Innovation Systems' efforts with industry partners and NASA on the Journey to Mars. He is currently a Senior Member of the American Institute of Aeronautics and Astronautics.*