NASA's Space Launch System Capabilities for Ultra-High C3 Missions

A White Paper for the Heliophysics Survey

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1. Executive Summary

Designed to meet NASA's requirements for human exploration of the Moon, Mars and beyond, the Space Launch System (SLS) vehicle offers enhancing and enabling capabilities for a variety of missions. Using commercially available propulsion systems as third and/or fourth stages, SLS offers C3 performance double the highest-C3 missions ever flown. This capability can be game-changing for missions into the interstellar medium or for high-energy solar observation missions. Today, SLS is making progress toward its initial launch capability and toward both future launches and future capabilities. In addition, NASA has issued contracts with prime contractors for SLS hardware for delivery well into the 2030s.

2. Overview

The initial configuration of SLS, the Block 1 crew vehicle, is powered at launch by four RS-25 engines and two solid rocket boosters, with an almost 67 meter (m) tall core stage. In-space propulsion is provided by an interim cryogenic propulsion stage (ICPS). The Block 1 vehicle can be flown in a cargo configuration utilizing a commercially available 5 m fairing. The next configuration of SLS, Block 1B, upgrades the upper stage to an exploration upper stage (EUS) equipped with four RL10s. Block 1B can be flown in a cargo configuration with an 8.4 m fairing up to 27.4 m in length. The ultimate configuration of the vehicle, Block 2, upgrades the solid rocket boosters to more powerful evolved solid boosters. The Block 2 vehicle offers the potential to fly larger 10 m fairings. In these baseline configurations, SLS offers significant performance for a wide range of missions. The Block 1 vehicle is capable of launching 27 metric tons (t) to trans-lunar injection (TLI), approximately 20 t to Mars, and 6 t direct to Jupiter. The Block 2 vehicle offers the ability to deliver greater than 46 t to TLI, greater than 35 t to Mars, and approximately 8 t direct to Jupiter. More information about SLS performance and environments may be found in the Space Launch System Mission Planner's Guide. [1]

3. SLS for Ultra-High C3 Missions

The SLS Program has partnered with the Advanced Concepts Office (ACO) at NASA's Marshall Space Flight Center (MSFC), to perform studies to predict C3 performance of the Block 2 vehicle with the addition of commercially available third and fourth stages encapsulated with the spacecraft/payload in the 8.4 m 19.1 m long fairing. During this study, the approach to predicting the mass delivered targeted a balanced approach that assumed mean vehicle mass, nominal liquid engine performance, and a low-performance booster, allowing for a conservative approach that is below the nominal performance prediction. The stages selected for the study include LH2/LOX

and solid-propellant stages that are in production and flying. The predicted high C3 performance is shown in figures 1 and 2.

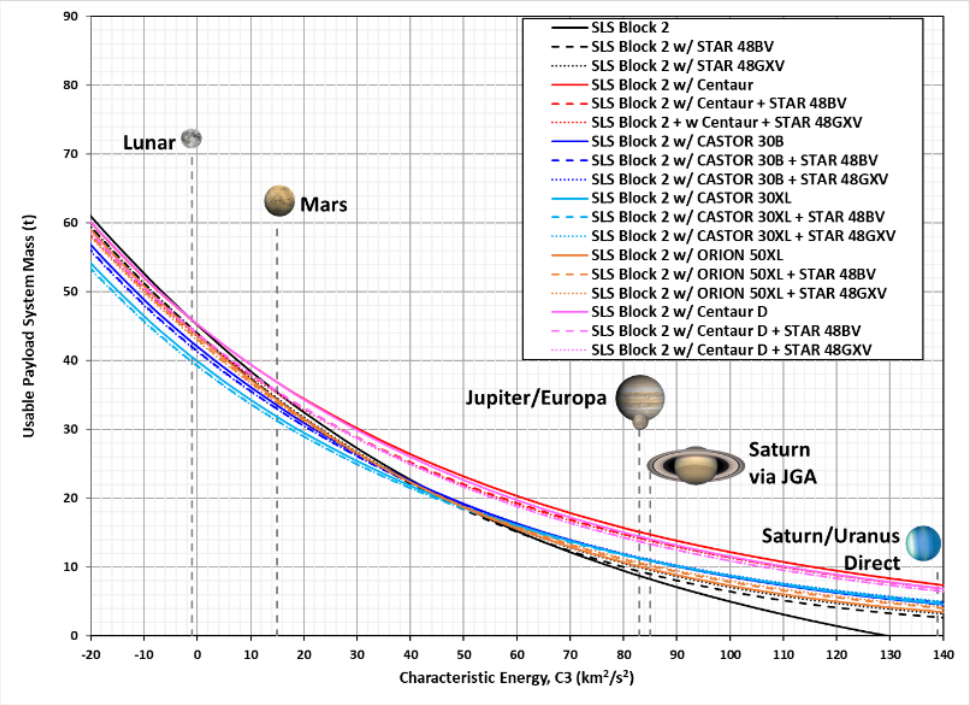

Figure 1. Low C3 range for SLS Block 2 with additional stages

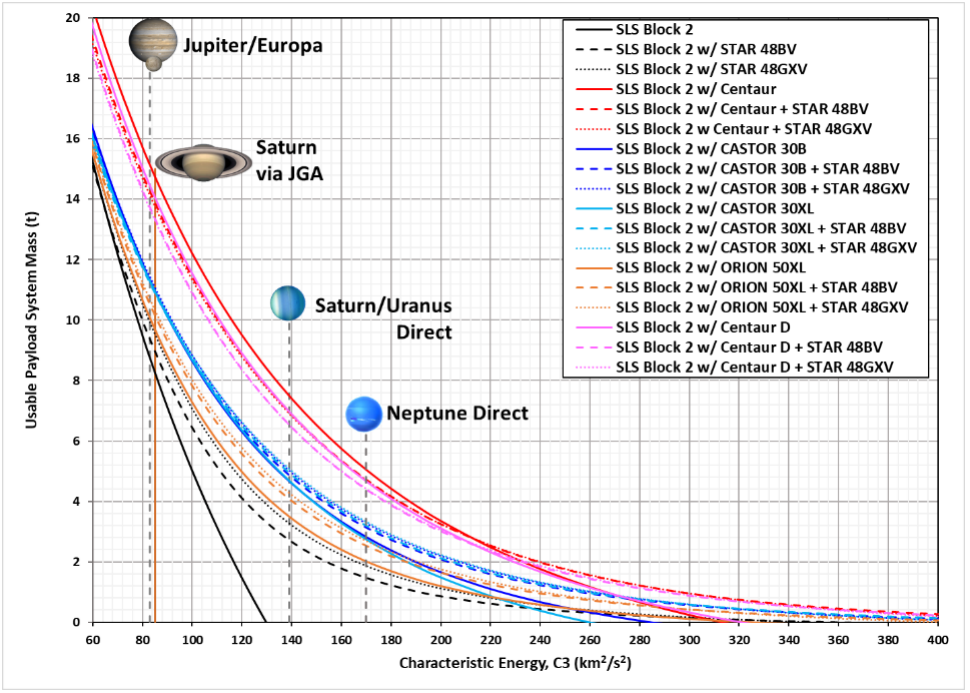

Figure 2 High C3 Range for SLS Block 2 with additional Stages

The highest payload mass delivered to high C3 ranges involves LH2/LOX third stages. The highest C3 on record is the New Horizons spacecraft at 157 km^2/sec^2. If a spacecraft with a mass similar to New Horizons (~0.8 t) were to launch on an SLS Block 2 with a Centaur third stage and a Star 48BV fourth stage, the resulting C3 is greater than 300 km^2/sec^2 -- nearly double the New Horizons mission. The second-highest C3 ever achieved was for the Parker Solar Probe mission. The aforementioned SLS Block 2/Centaur/Star 48BV configuration could launch a mission to Parker's 154 km^2/sec^2 with a launch mass approximately 10 times greater than Parker's 0.7 t.

Multiple mission concept teams have identified the additional stage capability of SLS as beneficial for science missions to the outer solar system and beyond. The Interstellar Probe team at Johns Hopkins University's Applied Physics Laboratory (APL) has identified the capability as enabling for launching a New Horizons-class spacecraft beyond the heliosphere with a transit time approaching a decade, depending on mission profile. [2] Initial internal capability studies show that SLS also offers benefits for high-energy solar observation missions, offering mission flexibility for both in- and out-of-plane solar observation.

4. Progress to the Pad and Beyond

The initial Block 1 vehicle is completely manufactured and all elements are at KSC with the exception of the core stage, which at the time of this writing is undergoing "Green Run" testing. After the Green Run hot-firing, the stage will be refurbished and shipped to KSC, where stacking of the vehicle inside the Vehicle Assembly Building (VAB) will continue in earnest. (At the time of writing, sections of the solid rocket boosters were being assembled at KSC). Following assembly, the vehicle is scheduled for late 2021.

With the Artemis I vehicle fully manufactured and assembly beginning, NASA and its industry partners have made significant progress manufacturing successive vehicles. While NASA's plans for the Artemis program continue to mature, the SLS vehicle remains a cornerstone capability for those evolving plans, with planning manifests showing at least an annual cadence of launches beginning in the mid-2020s, and more flights will be needed as the focus shifts to the first steps on Mars. NASA has shown its commitment to that capability with a series of contracts for the vehicle's elements. A contract is in place for long-lead items for boosters through the ninth launch of SLS, with a full contract expected next year. Contracts are in place for RS-25 engines through the tenth SLS launch, and NASA has announced that a contract is being negotiated for stages through the twelfth launch.

5. Conclusion

SLS is designed to return NASA's human spaceflight program to the Moon and to launch ambitious science missions into the far reaches of the solar system. A flexible system, SLS can be configured to launch the Orion crew vehicle as well as large infrastructure to cislunar space. As the vehicle evolves to progressively more powerful variants, available with 8.4 m and/or 10 m diameter payload fairings, opportunities for packaging third and fourth stages with a spacecraft in the large shrouds may be available. Studies show that using these stages (or similar stages available to a mission in the future) with the Block 2 vehicle can be a game-changer for science missions.

6. References

[1] Smith, D. A., Space Launch System (SLS) Mission Planner's Guide, https://ntrs.nasa.gov/citations/20170005323 (2018)

[2] McNutt, R. L., et al, Near-Term Interstellar Probe: First Step, Acta Astronautica Vol 162 pp. 284-299 https://www.sciencedirect.com/science/article/pii/S0094576519303650 (2019)