NASA'S HUMAN LANDING SYSTEM: ENABLING THE NEXT GENERATION OF LUNAR SCIENCE.

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Introduction: The Human Landing System (HLS) is the mode of transportation that will take astronauts to the lunar surface as part of NASA's Artemis exploration program. HLS also serves as a research platform both on the surface and in lunar orbit, enabling critical scientific investigations on and of the Moon. With support at NASA centers around the country, the HLS program, based at Marshall Space Flight Center in Huntsville, Alabama, is working closely with its commercial partners throughout the development process to design and build innovative and technically advanced lunar landers – new vehicles designed for the modern era of space travel – leveraging decades of human spaceflight experience and the speed of the commercial sector.

In 2019, NASA asked U.S. industry for proposals to design and develop a human lander for the first human mission to the lunar surface under Artemis. Initial contracts were awarded to Blue Origin Federation, Dynetics, and SpaceX to advance their designs. Following the execution of the ten-month Base Period, NASA announced in April 2021 that the agency selected SpaceX to move forward with its human landing system [1] and land the first two astronauts on the lunar surface during the Artemis III mission. Following two protest periods, NASA awarded the contract, known as Option A, to SpaceX in July 2021 and resumed work in November 2021 (Fig. 1).

In parallel, the HLS program has been preparing for the acquisition that will procure regular crewed transportation to the lunar surface following Artemis III. NASA released a request for information (RFI) in July 2021 asking U.S. industry for feedback to help inform the future solicitation, known as Lunar Exploration Transportation Services (LETS) [2]. Also in July 2021, NASA released the NextSTEP-2 Appendix N broad agency announcement soliciting new work from U.S. industry to mature their HLS designs and perform risk reduction activities in advance of the LETS procurement [3]. NASA selected Blue Origin Federation, Dynetics, Lockheed Martin, Northrop Grumman, and SpaceX to participate [4]. This work will also help better inform the LETS procurement and prepare industry to propose. NASA hopes to release a draft request for proposals (RFP) in Spring 2022.

HLS Utilization: "Utilization" refers to the use of a human exploration platform and/or mission to conduct science, research, development, test and evaluation, public outreach, education, and commercialization. Utilization is distinct from the systems designed to sustain the mission and health of the crew (e.g., launch vehicles, transportation vehicles, orbital modules, and space suits). Utilization goals for the Artemis program are defined in the Human Exploration and Operations Utilization Plan [5], and include Science (SMD), Space Technology (STMD), and Space Operations/

Figure 1: SpaceX Starship HLS concept.

Exploration Systems Development Mission Directorates (SOMD/ESDMD, formerly HEOMD), as well as multi-directorate objectives. SMD objectives specific to the first crewed surface mission were further refined in the Artemis III Science Definition Team report [6]. HLS is a key component in the execution of these goals, with both human and cargo elements for the delivery of crew, scientific experiments, pressurized and unpressurized rovers, habitat components, and technology payloads that enhance human exploration endeavors.

Utilization requirements: Lunar surface missions consist of two phases: Initial (referring to the first crewed landing, with two crew) and Sustained (referring to all subsequent landings building toward the Artemis Base Camp and a sustained human presence on the Moon, with up to four crew). Each phase has a specific set of Threshold and Goal requirements for Utilization defining the mass, volume, and in some cases, power allocation, for scientific payload delivery to (e.g., sample collection tools, sample containers, deployed surface payloads) and from (e.g., lunar samples) the lunar surface (Table 1).

HLS Utilization Down/Upmasses	Downmass (Threshold/Goal)	Upmass (Threshold/Goal)
Initial	100kg	35kg/100kg
App. N (2 crew)	150kg/1000kg	100kg/300kg
App. N (4 crew)	50kg/1000kg	100kg/300kg

Table 1: HLS Initial [7] and Sustained [8] mission downmass and upmass requirements for Utilization (refer to cited documents for full details). Note that the Sustained numbers are from the published Appendix N risk reduction solicitation only [8]. Updates to these numbers will be made for the forthcoming Lunar Exploration Transportation Services (LETS) solicitation. Companies are required to meet the Threshold requirements, but are encouraged the exceed them. The Goal requirements are notional examples of additional Utilization – companies may provide capability below or above the Goal, depending on capability.

Anticipated payloads: SMD chartered the Artemis III Science Definition Team to develop a candidate program capturing the highest-priority science objectives for the Initial mission and providing the greatest feed-forward to Sustained missions. It contains three cohesive elements: sample collection and return, *in situ* and field science, and deployed experiments [6]. Because the 100kg downmass allocation must first be reserved for sample collection tools (rakes, core tubes, etc.) and sample return containers, the remaining allocation must be skillfully split between handheld instruments and/or deployed experiments. Measurement techniques are preferred that maximize science return by addressing multiple objectives and have the ancillary benefit of increasing crew safety and/or reducing risk for future missions. Such investigations could include *in situ* volatile monitoring, deployed environmental and geophysical monitoring, *in situ* geochemical/mineralogical/geotechnical investigations, and traverse instrumentation. SMD intends to release a funding call for lunar surface instruments in 2022.

SOMD's Human Research Program (HRP) is also preparing payloads for use on the lunar surface. Crewed HLS missions represent an opportunity to gather data to characterize the effects of the deep space and operational environment on astronauts that has not been available or experienced since Apollo. HRP objectives aim to understand how humans adapt to the hazards of spaceflight and maintain high level mission performance in a constrained environment. Corresponding investigation could include ultrasound, crew/team performance measures, spaceflight standard measures, dry saliva sampling, crew health data management, heart rate monitoring, lunar ascent/descent dynamic loads injury assessment, alterations of multi-sensory integration due to combined hazards, and blood analysis.

STMD is currently developing plans for several capability areas under Sustained lunar missions, including power, ISRU, thermal, and excavation/ construction.

HLS Utilization Office: Responsible for HLS payload integration, ensuring payload interoperability across Artemis elements as relevant (e.g., Gateway and Orion), and interfacing with cross-program Utilization groups and control boards, the HLS Utilization Office can provide operational expertise to ensure crew safety, risk mitigation, and efficient execution of utilization and payload operations. Accordingly, operational insight into potential or proposed research investigations will be crucial to efficiently manifest and plan future Artemis missions. The office is currently drafting a Payload Users Guide. Interested payload developers should monitor NASA's Research Opportunities in Space and Earth Sciences [9] in anticipation of upcoming funding and flight opportunities.

References: [1] NASA press release 21-042. [2] NASA Lunar Exploration Transportation Services (LETS) RFI. [3] NASA NextSTEP App. N RFI. [4] NASA press release 21-115. [5] NASA HEO-006, Human Exploration and Operations Utilization Plan. [6] NASA SP-20205009602 The Artemis III Science Definition Team Report. [7] NASA NextSTEP App. H RFI, Attachment F. [8] NASA NextSTEP App. N RFI, Attachment B1. [9] NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES).