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NASA'S HUMAN LUNAR LANDING STRATEGY

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Abstract

In response to the 2018 White House Space Policy Directive-1 to lead an innovative and sustainable lunar exploration, and to the Vice President's March 2019 direction to do so by 2024, NASA is working to establish humanity's presence on and around the Moon by: 1) sending payloads to its surface, 2) assembling the Gateway outpost in orbit, and 3) conducting the first human lunar landings since 1972. NASA's Artemis program is implementing a multi-faceted and coordinated agency-wide approach with a focus on the lunar South Pole. The Artemis missions will demonstrate new technologies, capabilities and business approaches needed for future exploration, including Mars.

Assessing options to accelerate development of systems, NASA is utilizing public-private engagements to develop and demonstrate capabilities that meet the agency's human space exploration objectives while stimulating the commercial space industry. Utilizing efforts across mission directorates, the Artemis effort will benefit from programs such as the Science Mission Directorate's Commercial Lunar Payloads Services program and the Space Technology Mission Directorate's Tipping Point partnerships for Moon and Mars technologies.

This paper will discuss the strategic landscape for NASA's exploration campaign, the agency's approach to accessing the lunar surface with an affordable human-rated landing system, current status and role of U.S. industry, and future plans.

Keywords: Artemis, Human Landing System, Gateway, Lunar Surface Exploration,

1. Introduction

President Trump unveiled the administration's National Space Strategy in March 2018, which "builds on America's pioneering, spacefaring tradition, laying the groundwork for the next generation of American exploration in space" [1] and included the first Space Policy Directive, SPD-1. SPD-1 provides the direction to work more effectively with industry and develop commercially available services to enable a sustainable presence on the Moon. One year later, at the fifth meeting of the National Space Council, Vice President Pence further charged NASA to land U.S. astronauts on the lunar South Pole by 2024.

In order to meet this ambitious goal, NASA's human lunar exploration plans are based on a two-phase approach. The first is focused on speed of execution—landing the first woman and the next man on the Moon by 2024. The second phase involves establishing a sustained human presence on and around the Moon by 2028. A natural steppingstone to Mars, these efforts will help demonstrate technologies and expand business approaches and commercial opportunities needed for deeper space exploration.

2. NASA's Artemis Program

The Artemis program is NASA's next step in human exploration, returning astronauts to the Moon by 2024 and establishing a sustainable human presence by 2028 with the goal of sending humans to Mars [2].

Artemis I is an uncrewed test flight of the Space Launch System (SLS) and Orion crew vehicle as an integrated system. This will be followed by Artemis II, a mission that will bring a crew around the Moon aboard SLS and Orion. In 2024, Artemis III will send the first crew to the Gateway outpost in lunar orbit where they will transition to a commercial human landing system for transport to and from the lunar surface [3]. NASA's SLS will send four astronauts aboard the Orion spacecraft to lunar orbit. Astronauts will dock Orion at the Gateway. A two-person crew will board the Human Landing System for a lunar surface deployment of 4-6 days during which they will conduct extravehicular activities (EVAs) and science. The crew will return to the orbital outpost before boarding Orion for the return to Earth.

3. 2024 Mandate and Next Steps Program

In accepting the challenge of the March 2019 mandate by Vice President Pence to land humans on the lunar South

Figure 1: NASA's government concept for a Human Landing System includes an ascent, descent, and transfer module.

Pole by 2024, NASA assessed options to accelerate development of systems required to ensure success.

To develop and demonstrate the Artemis human lunar landing system, NASA is employing a research and development contracting model called Next Space Technologies for Exploration Partnerships, or NextSTEP. NextSTEP seeks commercial development of deep space exploration capabilities to support more extensive human spaceflight missions in and beyond cislunar space. This approach provides an opportunity for NASA and industry to develop capabilities that meet NASA's human space exploration objectives while stimulating the commercial space industry. To solicit concept studies, basic and applied research and technology development and demonstrations in support of NASA's Human Exploration and Operations Mission Directorate's Advanced Exploration Systems Division, NASA issued the original NextSTEP Broad Agency Announcement (BAA) to U.S. industry in late 2014 and issued the second NextSTEP BAA in April 2016.

To achieve long-term sustainability of the enterprise, NASA has focused on reducing costs and incentivizing more innovation through different acquisition models to increase competition and partnerships, planning our exploration architecture to utilize advances in the commercial marketplace, and refocusing investment toward technologies that will reduce costs and increase capabilities. Each of these aspects is an integral element in NASA's plans for a sustainable exploration architecture [3].

The lunar Gateway will serve as a reusable command module, supporting repeated human missions to the surface of the Moon from a Near Rectilinear Halo Orbit (NRHO). This critical component will offer flexibility and long-term affordability for a cadence of lunar landings across the entire lunar surface and supporting future human missions to Mars.

The Human Landing System (HLS) will demonstrate delivering a crew from lunar orbit to the lunar surface, provide capabilities for surface extra-vehicular activities, and then return the crew to lunar orbit to enable their journey back to Earth. In order to meet these goals and directives, NASA seeks to develop the HLS utilizing fixed–price contracts with NASA-industry collaboration to reduce the cost of development, reduce the time required for the development cycle, and enhance U.S. competitiveness in the global space industry [4].

4. Human Landing System and Industry Partnerships

In February 2019, NASA released a solicitation called NextSTEP Appendix E: Human Landing System Studies, Risk Reduction, Development, and Demonstration, seeking proposals from industry in support of design analysis, technology maturation, and development

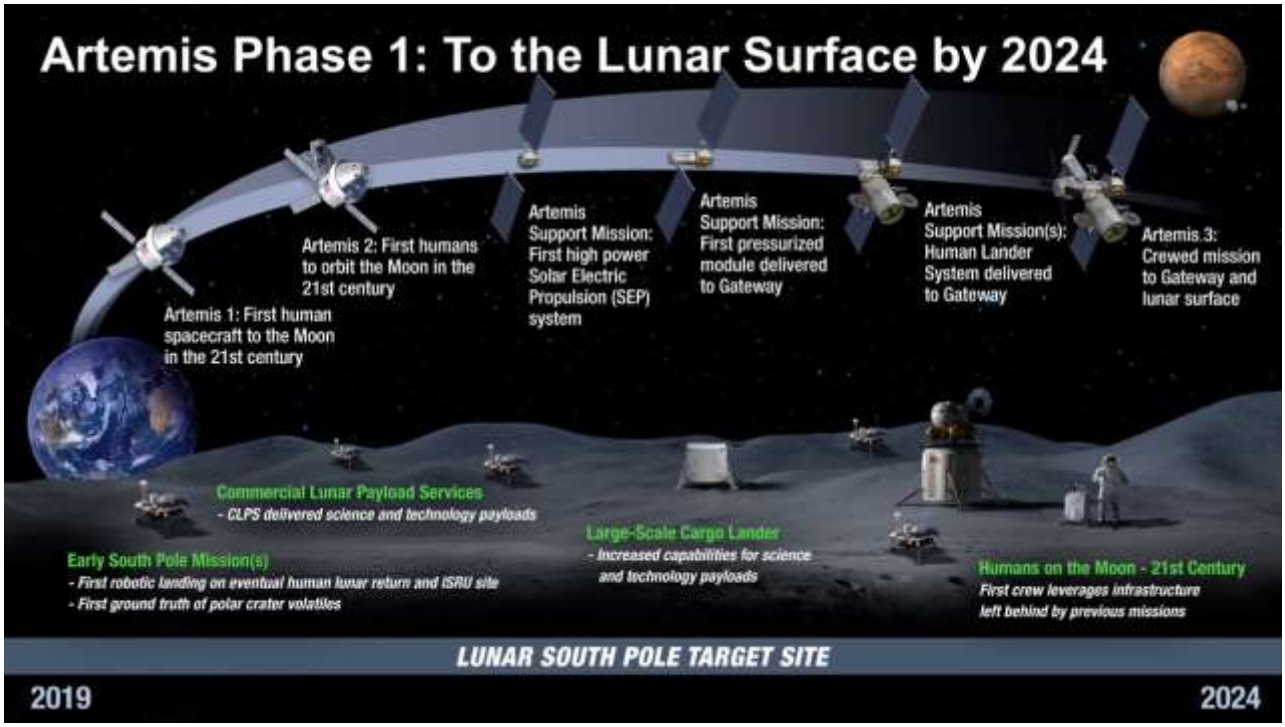

Figure 2: Artemis is NASA's path to the Moon and the next step in human exploration.

of HLS elements. Eleven companies were selected to conduct studies of HLS architecture and design, inform requirements, and produce prototypes, with multiple companies building multiple elements of an HLS that could be integrated by NASA for long-term deep space exploration. These six-month studies will conclude by January 2020.

After programmatic assessment of options to expedite the work in order to meet the Vice President's 2024 charge, it was determined that selecting a single prime contractor to deliver the fully integrated HLS is the most schedule-efficient approach. NASA issued a new solicitation, NextSTEP-2 Appendix H, for Integrated Human Landing System development and crewed flight demonstration.

On September 30, 2019, NASA released the final version of the NextSTEP-2 Appendix H BAA seeking Firm Fixed-Price, milestone-based proposals to enable rapid development and 2024 crewed flight demonstration of a Human Landing System.

NASA has expedited the procurement process to meet the 2024 target. While preserving all of the agency's human safety measures, NASA has removed requirements that industry perceived as potential barriers to meeting the schedule.

For example, industry members expressed that delivery of a high number of formal technical reports would require a company to spend considerable resources and incur undue schedule risk. Taking this into consideration, NASA has designed a less formal insight model that will be used for accessing critical contractor data while minimizing administrative overhead. As a result, NASA reduced the number of required contract deliverables by more than 30 percent.

NASA also minimized the number of functional and performance requirements, establishing minimum thresholds for the requirements such as total return mass and number of EVAs.

The agency's baseline approach to a lunar landing involves the crew in the Orion spacecraft and the uncrewed HLS launching separately and connecting in lunar orbit at the Gateway, which is critical to long-term exploration of the Moon. NASA intends to explore all options to achieve the 2024 mission and remains open to alternative, innovative approaches [5].

After a deliberate, iterative process of solicitation drafts, NASA incorporated extensive industry feedback into the final BAA. The agency is positioned to award multiple contracts to safely deliver humans to the lunar surface annually, beginning in 2024. NASA expects to make announcement of at least three offerors in January 2020. Down-selection will occur through continuation reviews, with the goal of at least two offerors to demonstrate taking designs to flight. The first one will launch in 2024, the other will launch in 2025.

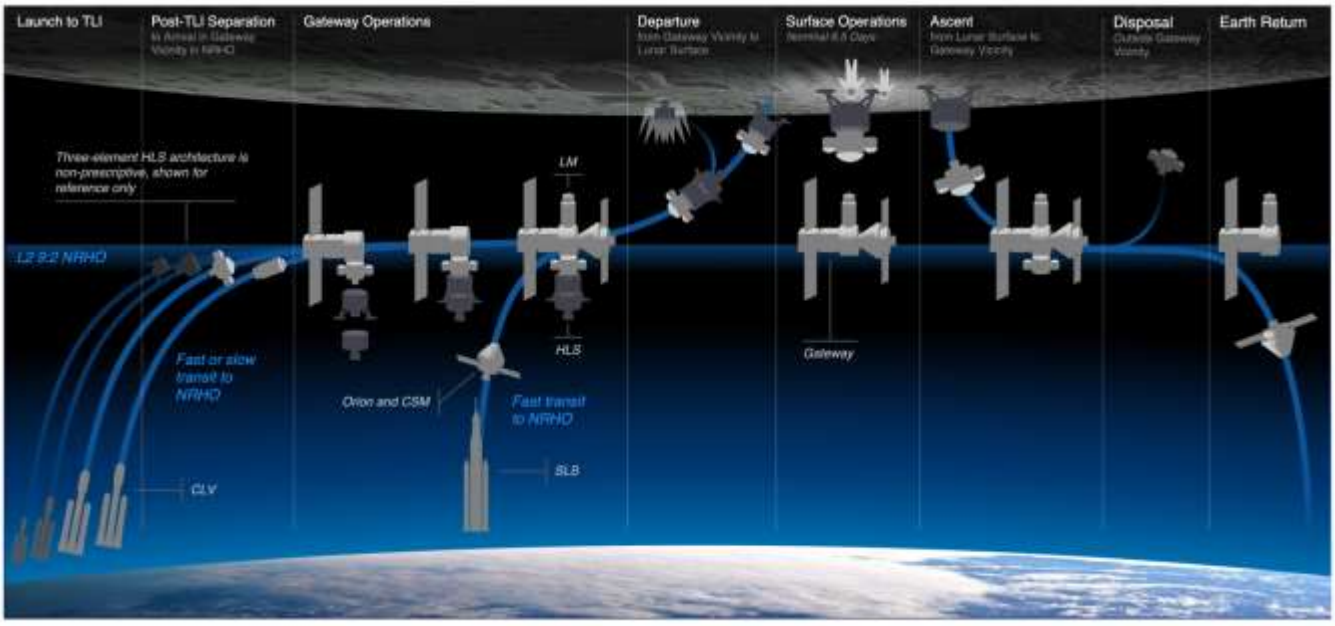

Figure 3 provides a generic concept of operations diagram for the initial mission capability, outlining the various waypoints in the HLS mission. While Figure 1 with a three-element architecture is for reference only and one of many possible design solutions

5. Details of the Human Mission

The crew will be taken to the Gateway by SLS in an Orion spacecraft, where the Gateway will be used to support the transfer of crew and supplies into the HLS.
The nominal HLS mission will collect the crew and mission materials at the Gateway, transport them to the lunar surface, provide surface and EVA support, then return the crew and surface samples to the Gateway.

For the initial capability phase missions, two crew members will transfer to the HLS for transport to and from the surface, while two will remain with Gateway/Orion. Later missions in a sustainable program are expected to have four crew members traveling to and from the surface [4].

The list below contains the objectives for the initial HLS, reflecting a typical reference mission from lunar orbit to the lunar surface and back. The initial HLS will:

1. Support a minimum of two crew as a sortie mission without pre-deployed assets.
2. Provide a habitable environment for 8 Earth days without pre-deployed assets.
3. Accommodate the transfer of crew and cargo between HLS and a crewed staging vehicle for lunar surface missions.
4. Provide automated rendezvous and docking.
5. Support sustainable presence on the Moon beyond the initial HLS by providing a regular cadence of reliable transportation services for humans and cargo.
6. Provide crew transfers between lunar orbit and a landing site located between 84*S and 90*S, and from the landing site to lunar orbit.
7. Provide the capability of operating in continuous daylight conditions on the lunar surface.
8. Provide the capability to perform automated transfers between lunar orbit and the lunar surface, and from the lunar surface to lunar orbit.
9. Accommodate at least 100 kg of science experiments and technology demonstrations, including at least 35 kg of return mass to lunar orbit.
10. Provide the capability for EVA excursions on the lunar surface.
11. Provide vehicle design and capabilities to enable effective and efficient crew performance throughout the mission.

In future sustained missions, the objectives above will be shifted such that the HLS will support a minimum of four crew as a sortie mission, provide global lunar surface access for round trip crew and cargo transfers from the Gateway, and survive eclipse periods with pre-emplaced surface infrastructure [4].

6. Commercial Lunar Payload Services

Ahead of a human mission, NASA will utilize industry advancements in small robotic lander technology by sending science instruments and technology demonstrations to the lunar surface. Through the Science Mission Directorate's (SMD) Lunar Discovery and Exploration Program (LDEP), NASA will solicit lunar surface payloads to enhance our

knowledge of the Moon and its resources via commercial delivery. The SMD Commercial Lunar Payload Services (CLPS) initiative will procure commercial lunar delivery services and the development of science instruments and technology demonstration payloads, building on the work of HEOMD's former Morpheus, Mighty Eagle, and Lunar Cargo Transportation and Landing by Soft Touchdown (CATALYST) activities. These services will be procured through indefinite delivery, indefinite quantity (IDIQ) contracts with a combined value of $2.6 billion.

Payloads from worldwide governments, academia, and private sectors will be considered to fly aboard robotic lunar landers developed by U.S. industry and contracted through SMD's CLPS effort.

The payloads are initially expected to be smaller instruments and investigations (less than 500 kg), but NASA will also use the deliveries for risk-reduction demonstrations to help evolve lander capabilities and capacities, and inform larger, human-class lander development. These robotic lander services, beginning as early as 2021, may be leveraged to validate precision landing technologies, cryogenic propulsion systems, and in-situ resource utilization technologies that are critical for a sustained human presence on the Moon [7].

7. Technology Development

The Space Technology Mission Directorate (STMD) portfolio includes technology advancements relative to HLS, such as components and technologies for pointing, navigation and tracking, fuel storage and transfer, autonomy and mobility, communications, propulsion, and power.

NASA's Tipping Point program is designed to provide the extra push a company needs to significantly mature a capability. These U.S. industry partnerships occur through competitive solicitations that develop, demonstrate, and infuse revolutionary, high-payoff technologies.

STMD selected fourteen companies in September 2019 with a combined total award value of about $43.2 million. These Tipping Point selections address technology areas that will prepare NASA for the next phase of lunar exploration. The strategic focus areas are cryogenic propellant production and management, sustainable energy generation, storage and distribution, efficient and affordable propulsion systems, autonomous operations, rover mobility, and advanced avionics [8].

8. Conclusion

With the release of the final NextSTEP-2 BAA Appendix H in September 2019, NASA has streamlined the partnering approach, combining new innovative ideas and empowering industry to meet the functional requirements of sending the first woman and the next man to the lunar surface by 2024. NASA is expected to make multiple awards for the HLS. Through a down-selection process, the final two offerors will fly in 2024 and 2025. Supported across mission directorates with SMD's CLPS program and STMD's technology development programs such as Tipping Point, the Human Landing System for 2024 will demonstrate capabilities for future sustainable lunar surface exploration.

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