Human Landing System Concept of Operations

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Table of Contents

Take a Moment And Read This Intro

The purpose of this document is to provide a baseline concept of operations for NASA's Human Landing System (HLS). The scope of this con ops is the HLS. Other elements of the lunar architecture, such as Orion and the Gateway, are discussed to the extent that they have interfaces and dependencies with the HLS.

We describe operational sequences, major operational constraints, and interfaces, for a non-design specific HLS. Our intent is to be informative, while being minimally prescriptive, to provide maximum room for innovation by industry, and by the NASA/industry team.

The Administration has given NASA two goals (1) to return humans to the Moon by 2024 and (2) enable sustained exploration of the Moon, Mars and other deep space destinations. NASA is implementing the necessary parallel developments to accomplish both of these goals. NASA has devoted significant study that shows for long term sustainability and to enable other deep space objectives, the Gateway is a critical component to the sustained exploration of the Moon and for human missions to Mars and other destinations. NASA intends to develop the capabilities for long-term exploration as fast as possible; and given fiscal realism, the need to incrementally establish initial capabilities are key in maintaining the development cadence. The goal is to use the Gateway for the Human Landing System as soon as possible and the Gateway will be ready to support the 2024 HLS mission. Proposals that do not use the Gateway must demonstrate substantial technical depth, including impacts on the Artemis III mission, as well as show how the system would evolve to support Gateway operations by 2026. For those proposals that do not choose to use the Gateway for the 2024 mission, the Gateway will continue to be available to provide functions such as serving as a communications relay in NRHO. The Gateway will be required for the sustained missions starting in 2026.

A note about alternatives available for the use of other NASA assets to complete the Lunar surface mission. The HLS program assumes that the HLS Integrated Lander will be delivered to the Lunar vicinity separate from the crew and that the crew will be delivered using the Orion spacecraft. Per the general guidelines outlined above, for the Initial Capability missions the HLS Integrated Lander may use the Gateway to facilitate lunar mission operations, including crew access from Orion, or it may dock directly to Orion for crew access. The concept of operations outlined in this document assumes the use of the Gateway. Modifications to this con ops will be necessary to adequately describe an architectural approach that does not use Gateway, however many of the flight rules outlined in this document will apply regardless of the overall mission design solution.

General Concept of Operations for Lunar Landing Missions

The nominal HLS mission will be to pick up 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. The crew will be flown to the Gateway in an Orion spacecraft, where the Gateway will be used to support the transfer of crew and supplies into the HLS. Figure 1 provides a generic concept of operations diagram for the initial mission capability, outlining the various waypoints in the HLS mission. While Figure 1 shows a three-element architecture, that is for reference only, and is one of many possible design solutions.

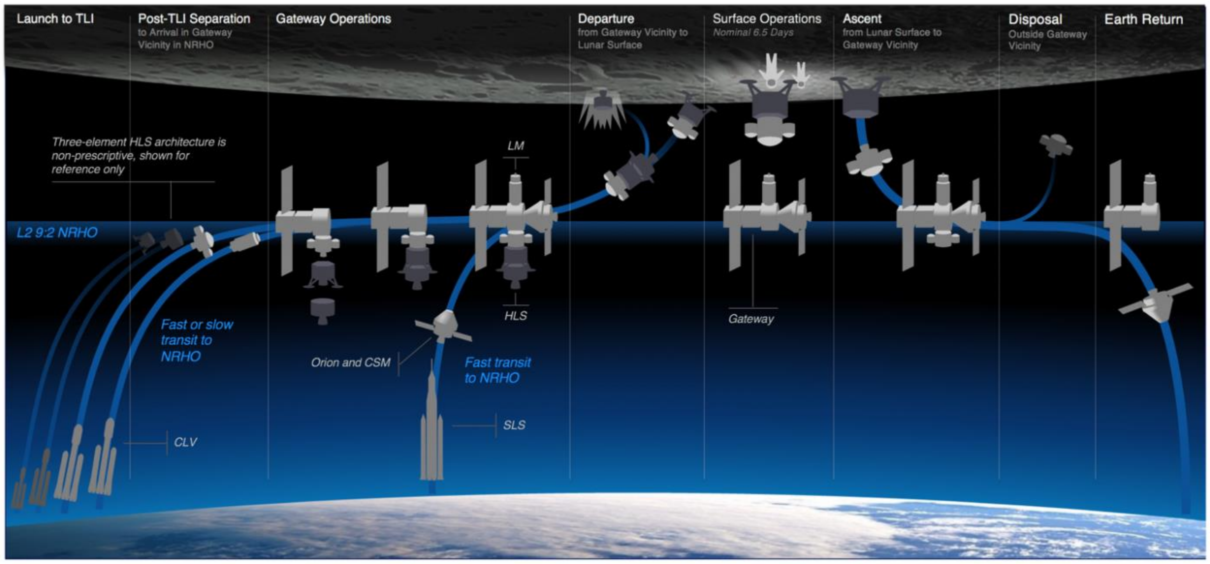

Figure 1 - Generic Concept of Operations for the initial mission capability. The three-element architecture is for reference only and represents one possible approach, hence two of the three elements are shown in grey.

While reuse may be a fundamental part of a sustainable lunar presence, the initial HLS mission capability for 2024 does not require vehicle reuse.

Assumptions for Initial Mission Capability in 2024

- Two astronauts land on the Lunar South Pole
- Astronauts live and work out of the HLS during their surface stay
- Crew transfer into the HLS may be achieved either by docking directly to Orion or through the use of the Gateway.
- Pre-deployed surface assets are not required
- Hardware reuse is not required

Assumptions for Sustainable Missions

- Four crew land on the Lunar Surface
- Pre-deployed surface assets are available
- The Gateway will be used to facilitate crew and cargo transfers to HLS
- Some or all of the HLS is reusable, depending on sustainability analysis to be performed
- Refueling element enables reuse of elements if required for sustainability and to address disposal of elements for multiple missions.

Operational Mission Phases

Launch-to-Trans Lunar Injection

The offeror will ensure delivery of the HLS to the proximity of the Gateway using commercial launch vehicle(s).

Post-TLI Separation to Arrival in Gateway Vicinity in NRHO

The crew will be transported to the Gateway in its Near Rectilinear Halo Orbit (NRHO) by an Orion/SLS. The HLS can be launched as separate elements on multiple launch vehicles, if required by the architecture, with the Gateway available as a rendezvous, aggregation, staging and logistics point. The Gateway provides the HLS the option to take advantage of flexible launch opportunities, by providing an operational hub in which the element(s) may loiter and/or dock at the Gateway.

There are multiple trajectory options for rendezvous with the Gateway at NRHO. Ballistic trajectories, which may range up to 120 days or longer, reduce the energy required for NRHO insertion. Fast transits can reach the Gateway in a few days, but may require a lunar flyby followed by a higher energy direct insertion to NRHO.

Communications During Launch and Cruise

The HLS may use the DSN during this phase or may propose the use of other networks in whole or in part. For the direct to Earth (DTE) link, both uplink and downlink encryption is mandatory, and the choice of band and protocols are not prescribed.

The HLS may use the DTE link to provide for command uplink, telemetry downlink, and radiometric tracking/ranging (needed by GN&C) while enroute from Earth to the Moon. Additional data bandwidth may be needed, for example, for video.

Gateway Operations

The Gateway serves as a staging and aggregation point, as well as a crew, logistics and sample transfer conduit. Figure 2 shows the Gateway configuration for the initial phase. The initial phase mini-hab is planned to have two radial passive docking ports. The initial phase Gateway will accommodate docking the HLS, Orion and a logistics module, simultaneously. If an Active-Active Docking Adapter is part of the HLS solution for docking with Gateway, it will be launched with HLS elements. The Gateway will provide power and data interfaces to the HLS through an IDSS-compliant connection. The initial Gateway capability will not support fluid transfer (propellant and thermal fluids) aross the docking port to HLS.

Gateway will be in a 9:2 Near Rectilinear Halo Orbit (NRHO). While the initial capability mission will focus on a polar landing, any point on the lunar surface may be reached by the HLS in future missions however, energy required to achieve this global surface access varies depending on mission profile selected and surface sites targeted.

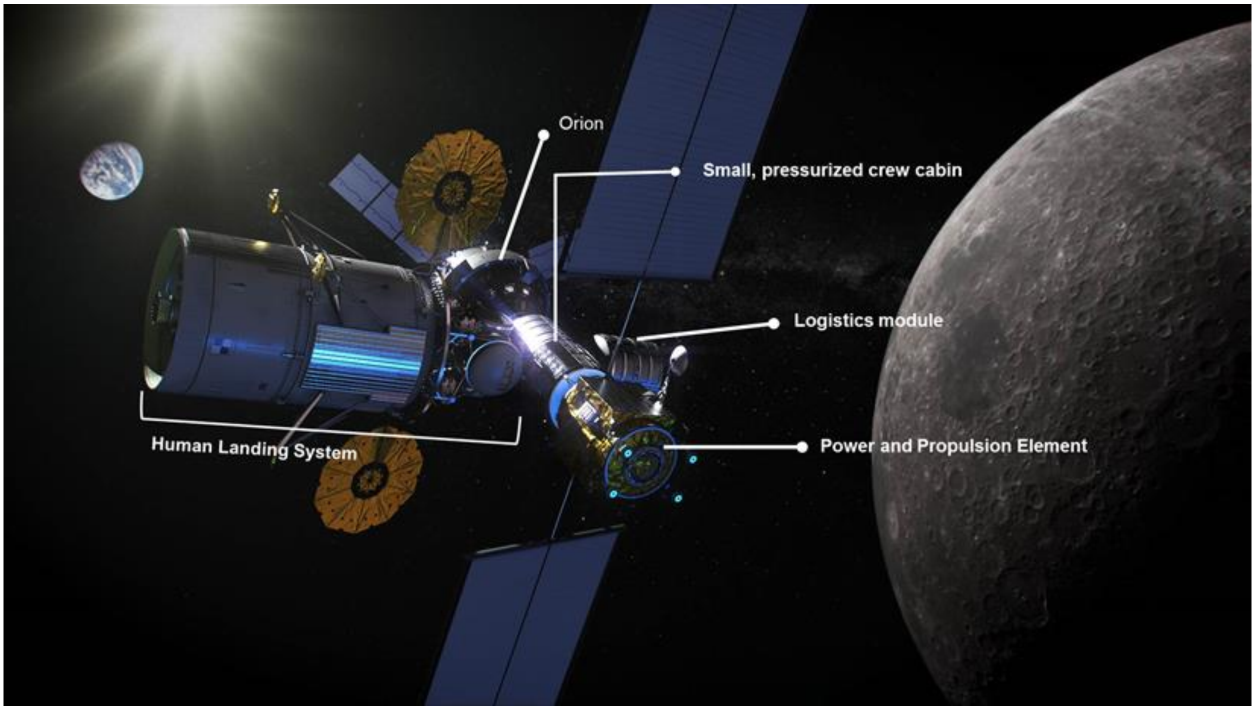

Figure 2 - The Initial Phase Gateway with Orion, an HLS and a logistics module docked.

Before launching the crew on a fast trajectory to the Gateway, the operational intent is to verify HLS readiness to receive the crew and perform the lunar surface mission. Depending on the HLS design, this may include system checkouts, HLS stacking, and docking at Gateway. The operational readiness criteria for crew launch will be developed by the flight team and will be documented as mission rules. The checkout and readiness verifications will be developed by the flight team as procedures.

Orion will dock to the Gateway with four crew members. 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. Sustainable phase missions are expected to have four crew members traveling to and from the surface. Mission logistics may be transferred from Gateway to the HLS. Some portion of mission logistics (GFE or other) may be launched on a logistics module that would arrive at Gateway before the crew. If in initial missions, HLS bypasses Gateway to dock directly to Orion, all logistics must be launched with HLS.

The Gateway operates for extended periods without crew. During un-crewed operations both Gateway and any HLS element operating docked or in the vicinity of Gateway operate using ground-based command and control and/or a combination of automation and/or autonomy.

The crew will be transported to Gateway on Orion. While Orion is docked, the Gateway will be in an Orion Tail to Sun orientation (Figure 2).

The total crew time in space, from Orion launch to landing, is expected to fall within 25-34 days, based on vehicle performance and launch opportunities. Gateway is responsible for providing consumables while HLS is docked at Gateway with hatch open, while HLS provides consumables for two crew for the lunar sortie, including transport to and from the surface. A mission time of longer than 30 days may have additional crew medical requirements and constraints.

Atmosphere

For each of the missions, after the HLS crew transfer element docks, prior to crew opening of the HLS hatch, the HLS will have to modulate its cabin pressure to a pressure compatible with Gateway shared atmosphere standards. The HLS will provide a hatch opening for ingress and egress. When docked to the Gateway, when the HLS hatch is open, the Gateway will be responsible for providing atmosphere and maintaining atmospheric circulation. A joint strategy between HLS and Gateway will be used to mitigate lunar dust levels in the combined habitable volume.

Communications at Gateway

Within 440 km of the Gateway, the HLS will utilize an S-Band Transponder to communicate (command uplink and telemetry downlink) with the Gateway, and to provide/determine radiometric ranging. This S-Band Link is known as the Visiting Vehicle/Prox-Ops Link. This S-Band link will be concurrent with a DTE Link. Note that for this S-Band Visiting Vehicle/Prox-Ops Link, only one HLS element can communicate with the Gateway at a time (Gateway limitation). The HLS may opt to send simultaneous high definition real-time video to Earth as per mission plans.

Within 1km TBR of Gateway, the HLS may have the option to concurrently utilize dual-band Wi-Fi for non-critical voice, data, and video. While the S-Band visiting vehicle link operates between the Gateway and one visiting vehicle at a time, the Wi-Fi has the capability for simultaneous comm between multiple vehicles for non-critical operations.

When docked to Gateway, the S-Band Visiting Vehicle Link will cease, and communication may take place over hardline Ethernet and/or Wi-Fi. While docked, the DTE link can also be available.

Communication Latency

The HLS may opt to use the DSN for DTE, or may propose the use of other communications networks. For any network, the round-trip communication latency must be considered in the design of operational command and control and any decision loops that include ground-based calls or decisions. For the DSN, the expected round-trip latency varies with data rates and channel priorities. For critical mission phases, such as descent and landing, where we expect the HLS to have the highest DSN priority, we can plan for best-case round trip latencies of slightly under six seconds for voice communications and for low-data rate critical telemetry. For non-critical mission phases and /or higher data rates, latency may be higher.

This means, for example, from a ground-based decision perspective, that a telemetry alarm would be seen on the ground within 2.5 - 3 seconds of the alarm on board. Following a decision time on the ground to make a call, the voice uplink of that decision would take another 2.5 - 3 seconds to reach the crew.

Proximity Operations & Loiter

The HLS, or an HLS element, may conduct proximity operations (prox ops) and may also loiter in the vicinity of the Gateway. Proximity operations (prox ops) is an active operational state in the near vicinity (as defined by mission rules and system capabilities) of a target spacecraft, terminating in the achievement of a mission objective, usually docking or departure. Loiter is differentiated from prox ops by distance, duration, and operational state. Loiter is a semi-passive operational state that is stable over time. When a vehicle loiters relative to another vehicle or element, the relative motion between the two will not cause closure to a conjunction condition over a set period of time.

In practical operational terms, the HLS would be in prox ops relative to the Gateway, or another HLS element, during operations such as stacking and docking. An HLS element might loiter in the vicinity of the Gateway while awaiting crew arrival before stacking and docking or, in the sustainable phase, between missions. The element loiter must not only take Gateway into consideration, but also other visiting vehicles (e.g. Orion, logistics module) RPOD trajectories. Mission rules and procedures will govern prox ops and loiter.

The Gateway provides an operational hub where the HLS may loiter or dock. The capability for long term docking of HLS elements to the Gateway provides an option to simplify ground-based flight operations by flying a docked stack instead of an active multi-element swarm.

Docking and Berthing

For crewed operations, current mission rules at ISS require docking, not berthing. This is because of the possibility of berthing arm failure stranding the crew. A crewed vehicle operating autonomously or remotely, without crew, may dock or berth. Mission rules have not been written for HLS. For autonomous berthing, free-flyer capture technology would be required. This does not currently exist and would have to be developed to enable fully autonomous berthing at the Gateway.

Assuming a docking requirement for a crewed vehicle, that would require the HLS to dock to Gateway on return from the lunar surface or anytime it is crewed, but would allow for docking or berthing for the HLS on arrival at Gateway without a crew.

The design of operational scenarios must consider communications latency when the ground is in the operational command and control and/or decision loop. This does not imply any requirements on ground based control vs. autonomous operations or crew control.

For un-crewed Gateway operations, docking or berthing is an option. The Gateway is not planned to have a robotic arm during the initial capability phase. An arm may be available for the sustainable operations phase.

Preparation for the Surface

For the initial capability phase, one docking port will be available for HLS, to facilitate crew and material transfers, as well as power, data and atmosphere exchange.

If there is a need to transfer suits from the Gateway to the HLS, the crew will transfer the unpressurized xEMU suits from the Gateway to the HLS. In the initial capability phase the Gateway configuration will not have suit servicing hardware, so suit checkout will be done in the HLS, while still docked to Gateway, thus providing access to Gateway suit spares and tooling if needed. In this capacity the HLS will have to provide volume to assemble the suits and support pre-form fit and pressure checks prior to descent. The single suit architecture requires that the xEMU have the capability to be pressurized via umbilical, without the portable life support system (PLSS) backpack. In the sustainable phase, suit fitting and checks may be done on the Gateway.

Crew time at Gateway to prepare for the surface mission is constrained by vehicle architecture and landing location. The time between crew arrival to Gateway and commencement of the Lunar Surface

Mission is a function of flight mechanics and orbit phasing between the Gateway, the desired landing location, the selected Orion transit and approach trajectory, and the performance capabilities of the vehicle.

Departure from Gateway Vicinity to Lunar Surface

Departure Preparations

The crew must begin their pre-breathe operations prior to departing for the lunar surface, with a total of 36 hours of prebreathe required prior to the first EVA. Prior to crew ingress of the HLS for descent to the surface, the integrated inhabited space's pressure is reduced to 10.2 psi for a predetermined period of time. Once the hatch is closed, the HLS cabin pressure will be reduced to 8.2 psi. After a successful checkout, HLS cabin saturation operations will begin as part of the prebreathe. Based on current operational planning, the period between final crew ingress and touchdown on the surface is expected to be more than a day. As such, the crew will require sleep, and other activities such as meals and biological waste elimination. Go/no-go calls and vehicle checkout(s) from the ground and/or performed by the crew will be determined in mission planning.

NRHO to Phasing Orbit

Upon a go call for Gateway departure, based on mission criteria to be established in mission rules, the HLS will separate from the Gateway and begin its journey to the lunar surface. It is anticipated that a phasing orbit of some kind will be necessary to update navigation systems to support the powered descent and landing phase of the missions. Transits from NRHO to this phasing orbit vary in both duration and energy required, however a propulsive maneuver will be required to leave NRHO and to insert into this phasing orbit. A loiter in low lunar orbit (LLO), up to three revolutions, will likely be needed either for crew preparation for descent and/or navigation state updates to reduce error after the LOI burn. A nominal transit of 12 hours from NRHO to a 100 km circular LLO is anticipated, but trip time can vary based on final mission designs.

Descent to the Surface

For descent, the crew will wear the xEMU (on umbilicals, without the PLSS). The descent from the phasing orbit to the lunar surface will typically consist of four distinct phases. A Descent Orbit Insertion (DOI) burn will place the HLS in an orbit with a perilune sufficiently low to perform Powered Descent Initiation (PDI). The Powered Descent Initiation (PDI) and Braking phase will slow the HLS into a surface-intercepting trajectory and arrest the HLS to a sufficiently low altitude to begin the approach phase. The Approach Phase typically consists of a pitch maneuver to allow for crew viewing of the landing site. The Terminal Descent and Touchdown Phase consists of the final vertical descent to the surface achieving the desired velocity/attitude state for touchdown. The duration and profile of these phases will vary with descent trajectory design. The HLS will perform precision navigation to achieve a safe landing within a specified distance of a target site. HLS landing capabilities are expected to include automated landing, as well as the capability for the crew to land the vehicle, with the nominal use of these capabilities to be defined as part of operationally pre-determined flight scenarios governed by mission rules.

Descent Abort

In the event of a problem during descent that, according to pre-determined mission rules and abort region definitions determined by the NASA/industry team, requires an aborted landing, the HLS will safely return the crew to the Gateway. These are the only options, as neither the Gateway nor Orion systems have an LLO rescue capability.

Descent Communications

When the HLS departs the Gateway for the lunar surface, it will maintain simultaneous S-Band Visiting Vehicle Link with Gateway (when within 440 km of the Gateway) and the DTE link.

As the HLS moves outside of the 440 km from Gateway, the S-Band visiting vehicle link will transition to the lunar system link (on either S- or Ka-Band), so that a near-continuous connection to the Gateway is maintained. HLS will concurrently maintain a DTE link. During descent, the HLS may send High-Rate, High-Def video of the landing, either back to Gateway (then acting as a Comm Relay), or back DTE, or both.

Surface Operations

For the initial missions, two crew will descend to the surface, and two will remain at Gateway/Orion. For sustainable phase missions, we expect up to four crew members on the surface. The HLS must support the crew during surface operations, including life support, consumables, power and communications and must enable surface access and EVA. The intial mission(s) should not exceed 6.5 days of surface stay. Sustained missions may be of longer surface stay duration.

Immediately following lunar surface touchdown, the HLS transitions to a safe surface mode. This mode will require little maintenance by the crew while ensuring that the ascent portion of the HLS will remain capable of performing ascent operations at the end of the surface stay. At this time, the crew will perform any cabin reconfiguration required for surface operations.

EVA

The surface mission operational intent is to perform EVA's. Preparation for EVA's begins before the crew opens the hatch to egress the HLS landed element. EVA preparation time is driven by vehicle atmospheres, oxygen saturation levels, and pre-breath protocols. Donning the EVA suit is currently anticipated to take approximately one-hour. Based on current analysis, once the crew has donned their suits, the half-hour EVA pre-breathe begins, followed by the cabin or airlock depressurization process. Once pressures have equalized, the crew will open the exterior hatch and proceed to the surface.

Initial EVA ingress/egress capability can only be achieved through an airlock-style option (could be main cabin or separate isolated volume). Lander Systems with an isolated EVA ingress/egress volume will not require entire cabin depress for each EVA cycle. However, Lander Systems without an isolated EVA ingress/egress volume will require complete cabin depress for each EVA cycle. The EVA System and Lander System will share responsibility for maintaining dust exposure within the permissible exposure limits. Operationally, the crew will perform post-EVA dust mitigation activities external and internal to the lander. The exact activities are still being developed but likely include coarse cleaning with EVA System-provided tools prior to ingress and then stowing the suit in a container inside the lander when not in use to minimize loose dust in the vehicle.

There is a possibility that sustainable phase surface suits will utilize a suitport or suitlock interface for EVA egress/ingress on the lunar surface. While these options would help minimize nominal dust transfer into the vehicle it would not eliminate the possibility. Another benefit would be potentially reducing required consumables per EVA.

Between EVA's, the suits will have access to HLS resources for maintenance and recharge, including power for batteries, O_2, water for cooling, waste water removal and vacuum.

Science EVA plans are in formulation and will grow with capability. They are expected to include general scouting, surveying, sampling including rocks, volatiles, and subsurface drilling. Other possible science objectives include identification and marking of the highest local terrain.

Surface Communications

On the surface, the crew will need to talk from inside the HLS landed element to the ground, and to the crew on the Gateway. For EVA crew on the surface, they can communicate to Gateway and/or Earth through the HLS landed element. There is no direct communication link from an EVA crew member to the Gateway or Earth. Crew members inside the HLS will need to communicate with the Gateway and Earth both suited and in shirt sleeves. During sustainable operations, if there are two crewmembers in the HLS while the other two conduct an EVA, the EVA crew will need to talk to their two surface companions in the HLS. EVA crew members may talk directly to each other in their xEMU's.

During Lunar Surface Operations, the HLS landed elements will support EVA operations via Wi-Fi and UHF Space-Suit communications. Other options may be possible in the sustainable mission phase, such as 5G or LTE. Crew communications during EVA will have Wi-Fi as well as UHF for EVA astronaut voice and data. An acquisition of signal (AOS) state from the EVA crew to the HLS is presumed to be the operational state for EVA, however, mission rules will have to determine if any loss of signal (LOS) time during EVA, caused by distance or blockage, is allowable. EVA distance limitations for communication are under discussion.

For the surface mission, the HLS may communicate DTE, and concurrently on the Gateway Lunar Systems Link (S-Band and/or Ka-Band). During EVAs, the HLS will have a direct UHF and Wi-Fi comm link from the suits to the HLS landed element to enable the crew to communicate with the HLS, and by extension, with the Gateway crew and Earth. Because HLS will be concurrently communicating with both Gateway and Earth, it means the HLS EVA Suits will be able to communicate with both Earth & Gateway.

DTE communications from lunar polar locations are subject to multi-path issues and blockages, due to the low angle of Earth over the horizon. DTE communications requires line of site from the HLS landed element to Earth. This condition is highly variable at the lunar poles, with DTE loss of signal (LOS) periods being a dynamic condition. Communications coverage from Gateway will therefore be crucial for providing adequate AOS communication time for the EVA crew. It is possible that lunar communications assets may be available to mitigate these conditions but those are TBD as of now.

Surface Abort

In the event of a problem on the surface that, according to pre-defined mission rules determined by the NASA/industry team, requires an aborted surface mission, the options are for the HLS to return the crew to the Gateway. A surface abort may require the crew to shelter in place until the Gateway is in the correct orbital position for an ascent.

Ascent Preparations

For ascent, the crew will wear the xEMU (on umbilicals, without the PLSS). If possible the PLSS will be returned to the Gateway. If necessary the PLSS may be left on the surface. These, and any other items that are to be left behind, must be moved to their disposal locations. The crew will perform any required vehicle reconfiguration and the vehicle systems will be checked out prior to ascent. Vehicle checkout may be initiated onboard or from the ground, depending on vehicle design, mission planning and flight rules.

Ascent from Lunar Surface to Gateway Vicinity

Upon completion of the surface mission, the crew will use the HLS to ascend to the Gateway. This phase will include a powered ascent phase, similar to a launch to orbit on Earth, a loiter period in a phasing orbit to target a return to Gateway in NRHO, a cruise phase from phasing orbit to NRHO, and a rendezvous and docking phase to connect to Gateway. Duration and propulsive maneuver will vary with ascent profile design. The procedure for docking with Gateway will be similar to those outlined in the Gateway Operations sub-section above.

Disposal Outside Gateway Vicinity

Element reuse is not required for the initial capability phase. For disposal, planetary protection and orbital debris regulations must be observed.

Element Reuse

In the sustainable phase, some HLS elements may be reused. Which elements are reused will depend on the HLS design and sustainability analysis. Element recycling through repurposing is also a possibility.

Crew Return

Once docked with Gateway, the crew will use Gateway to prepare the HLS for post-mission operations (either disposal for the early missions or reuse for later missions) and to transfer crew and cargo into Orion for return to Earth. This includes transfer of any samples or science instruments that are to be returned with the crew. The crew will return to Earth in Orion using a standard Earth-return mission profile.

For initial phase capability missions, reuse is not required. HLS removal from the Gateway and vicinity is assumed.