white paper

2023 Moon to Mars Architecture

Surface EVA Architectural Drivers

I. Introduction

Key elements of NASA's Moon to Mars Objectives for expanding humanity's presence beyond low-Earth orbit will require surface-based, partial-gravity extravehicular activities (EVAs). Surface EVA needs affect many aspects of the exploration architecture, including EVA suit subsystems, such as suit or pressure garment mobility, the portable life support system, and the informatics system; and external systems, such as habitation modules and surface mobility platforms.

Lunar surface missions take place in harsh environments with additional challenges, including limited resources/consumables resupply, communications delays, navigation, and lighting, depending on landing location and terrain. Suited activity on the Moon introduces multiple factors that drive the broader architecture, including dust intrusion, partial gravity, atmospheric pressures, logistics, pressurized volumes, site planning, contingencies, and human access to and from the lunar surface from various habitable elements. This paper highlights several key considerations related to lunar surface exploration EVAs that will be addressed in the Moon to Mars Architecture.

2. Dust (Regolith) Mitigation

An integrated strategy for lunar dust mitigation should include testing on Earth using simulants and the use of lunar experiments to characterize dust properties and build an understanding of polar regolith behavior. Dust in the polar region will be impacted by the unique natural environment: electrostatic charging can cause dust to adhere to surfaces, dust particles take longer to settle than on the Earth, and stirring/movement can remobilize dust particles.

Ground testing faces environmental limits. Convective flows typically dominate non-vacuum ground testing, making it difficult to replicate expected polar region electrostatic behaviors. Ground testing also typically requires multiple simulants, since no one simulant captures all the properties of lunar soil or the variety of soil compositions that astronauts might encounter.

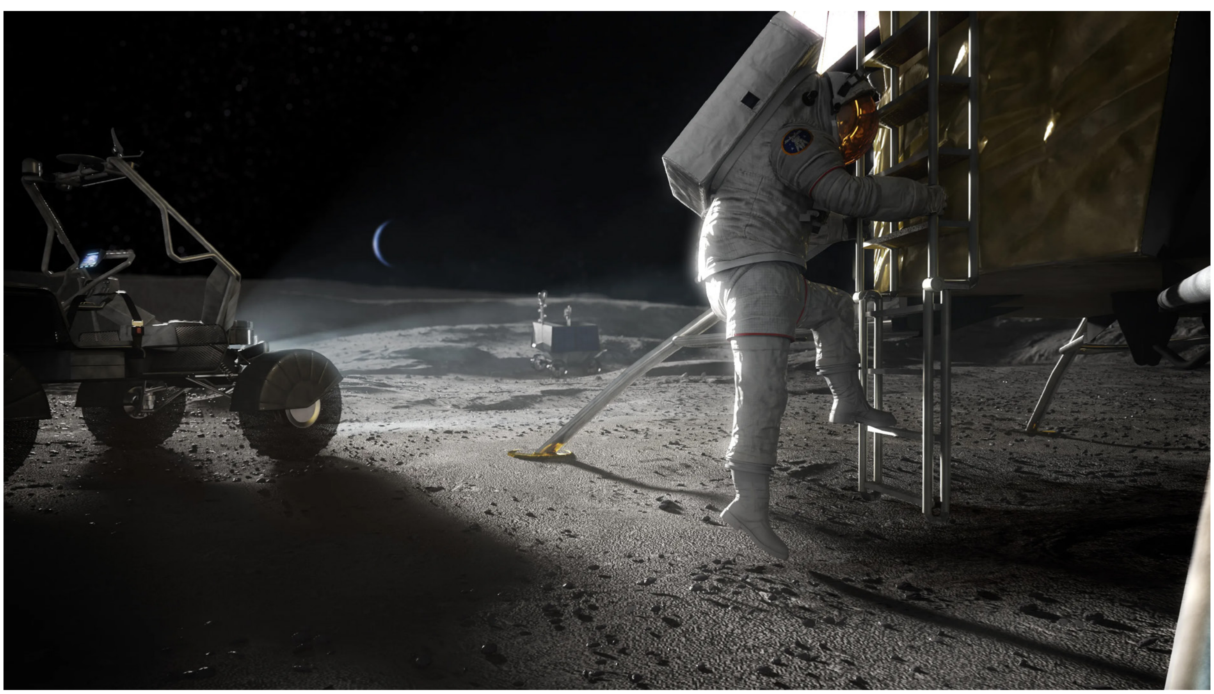

Figure 1. *Conceptual Rendering 1*

Most of the dust that poses a danger to system hardware and human health will also not be visible to the naked eye.

A successful mitigation strategy will both minimize dust intrusion and control dust at the interface with critical systems (including human dust exposure).[1] While human lungs are the most sensitive organs to dust exposure, dust can also have ocular and skin effects. NASA used research findings to derive a permissible exposure limit that defines acceptable lunar dust exposures and size fractions of physiological concern. Lunar dust adherence and transport into the habitable environment by EVA suits, tools, equipment, and payloads is difficult to predict. The amounts vary depending on the method of ingress/egress and mitigation methods/tools available to the crew.

Mechanical components of environmental control and life support systems, including vents, fans, intakes, and louvers, must be designed with dust intrusion in mind. Crew cabin systems and EVA systems adversely affected by dust include food preparation, medical implements, hygiene, filters, vacuum cleaners, seals, crew time, cameras, windows, lights, quick disconnects/connecters, switches, hatch seals, and more.

During the Apollo Program, the Lunar Module had direct crew access, with no intermediate airlock volume. Apollo crews complained of dust intrusion into the Lunar Module in almost all Apollo missions, and in some cases, dust was observed within the Command Module after on-orbit docking. The Artemis missions will develop operations to reduce dust intrusion, develop mitigation methods to reduce dust adherence and clean up/filter intruded dust, learn from the implementation of this development, and evolve as the missions progress.

3. Partial Gravity

Performing EVAs with differently sized crewmembers in partial gravity influences the design of the suits and accompanying architectures (especially sizing, mobility, and mass), science and logistics payloads that must be operated by crewmembers, and tools for performing geological/maintenance activities.[2] Some tasks will require the crew to navigate up and down slopes, traverse into and out of craters, and deploy surface payloads. Tasks beyond collecting geological samples could include vehicle maintenance, cargo/logistics transfer, and other physically demanding activities. Tasks to be performed by the EVA crew — such as riding in a rover, hammering, or climbing — drive specific interfaces and suit mobility features.

The suit architecture and interfaces with surface elements must accommodate a wide range of crewmember sizes. These requirements drive the design of the suit and attached hardware, vehicle interfaces, the types of crew actions and motions during EVAs, direct physical interactions with the lunar surface, and the total number of EVAs. Finally, systems will have to accommodate different prebreathe protocols than Apollo or microgravity prebreathe.[3]

4. Atmospheric Pressures

A fundamental limitation of human physiology when preparing for and conducting EVAs is the potential for acute and chronic injury from decompression sickness caused by pressure transitions. It is necessary to control the transition from the habitable volume's saturation atmosphere to the EVA suit's pressure, which is set lower to improve the crewmember's ability to operate and maneuver in the suit. This transition is managed in part by an oxygen prebreathe using a combination of the vehicle's atmosphere and the suit's pressure.

The amount of time necessary for this prebreathe is directly proportional to the difference between vehicle saturation and EVA pressures. While physiologically necessary, crew time spent engaged in prebreathe affects EVA operations and the risk of decompression sickness and can affect the duration of the EVA itself. Prebreathe studies help minimize prebreathe durations, allowing for increased utilization and completion of objectives performed by the crew during EVAs.

This choice of alternative atmospheric parameters in the vehicle (as opposed to relying on the suit and implementations thereof) may pose significant issues, including vehicle design challenges, such as reduced effectiveness for atmosphere-based avionics cooling, increased flammability, and more.[4] The suit and supporting architectures will also have the capability to perform decompression sickness treatment functions during the EVA if they are required for crew safety.

5. Commodities and Logistics

Elements that provide EVA capability include the architecture to recharge suit consumables (e.g., power, oxygen, water, CO2 removal) and the ability to reserve suit consumables while connected to the vehicle via umbilical during activities such as prebreathe, suit checkouts, and pre- and post-EVA. The interfaces between the suits and the vehicles/elements must use common hardware to ensure compatibility and reduce astronaut training time and vehicle reconfiguration time.

Given the constraints for landed surface mass, different exploration architecture solutions will have varied impacts on commodity usage (such as the amount of air required to repressurize the habitable volume, depending on the ingress/egress method), in addition to the quantities used in the EVAs themselves. Suit maintenance must take place in a habitable pressurized environment.

Transferring logistics and consumables from logistics landers to habitable elements also presents a major challenge. The presence or absence of existing lunar

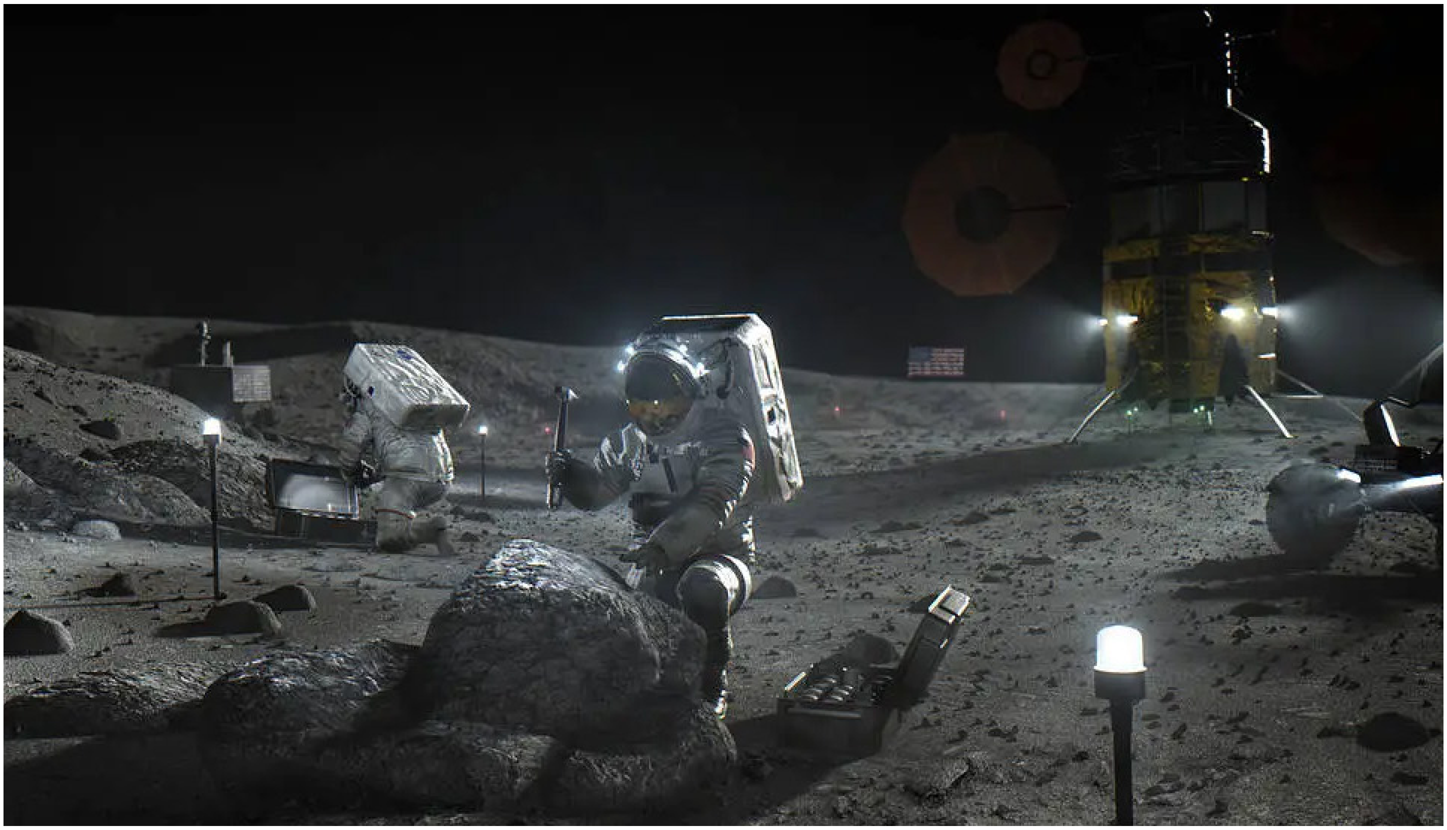

Figure 2. *Conceptual Rendering 2*

surface infrastructure, such as hardware for logistics transfer, is also an architecture driver since the EVA system may have to make up for any shortcomings in existing assets. The goal is to minimize logistics transfer in EVA timelines and maintain utilization objectives during EVAs.

6. Habitation and Pressurized Volumes

For both mobile and permanently emplaced surface habitation, layout and volume are important factors in the acceptability of the cabin interior. Crewmembers will require adequate internal size, in terms of both volume and surface area, to perform mission tasks safely and efficiently. This includes sufficient space to allow crewmembers to don/doff the suits in parallel, perform maintenance, volume for spares/logistics, and gather items needed to perform the EVA objectives.

For example, rear-entry suits require volume above the helmet to allow crewmembers to climb into their suits. Once suited, acceptable volume will be needed for EVA airlock hatches to swing open and closed, creating keep-out zones. Both mobile and permanently emplaced elements must also be designed for EVA compatibility. This includes access to any worksites, hatch sizes, sharp edges, thermal touch temperatures, and other factors.

7. Variations in Architectural Solutions for Ingress/Egress

An airlock could provide a separate volume from the main cabin to facilitate surface access. As such, airlocks provide a significant opportunity to control or propagate backward and forward contamination.[4,5] While other ingress/egress architecture solutions could help with dust intrusion, consumables, and other drivers listed in this paper, they also pose significant challenges to vehicles and suit architectures such as mass and volume.[6]

8. Enabling Suited Crew Decision-Making

Distributing work functions among Earth-based assets and mission assets, enabling an Earth-independent architecture, will be a profound architectural driver. Earth independence starts by giving crew members, particularly during EVA, the capacity to make informed decisions by interacting with and acting upon locally sourced information. Achieving this feat will not only be a technological accomplishment that advances suit capabilities but would also establish a fundamentally new medium of communication and information exchange between mission assets and Earth-based support.[7,8,9]

Earth-independent crew decision-making currently faces multiple challenges, such as establishing a highly integrated network of data-sharing among mission assets (from different vendors); rendering a variety of data in meaningful and contextually useful ways for crew consumption, interaction, and understanding; and aligning the broader flight operations structure (across NASA and service vendors) with the appropriate function allocation.[10,11]

9. Communications, Navigation, and Lighting

Communications between EVA crewmembers may be limited by distance and/or line of sight to each other and other surface assets during certain periods of initial surface missions because of architecture constraints and the potential for contingencies/walk-back scenarios. Surface mobility assets and other surface elements with Earth communications capabilities will allow the crew to explore further from the landing site, increasing utilization destination options.

Early missions will mainly utilize orienteering for navigation. Guidance and navigation systems, displayed via informatics and mobility assets, will help crew members get to destinations and back, guiding them to targets specifically designated by the science team.

The crew will experience persistent long shadows near the lunar South Pole, while also having the Sun directly in their field of view. To traverse safely and effectively across lunar terrain and slopes and into shadowed regions, the crew will use lighting sources (e.g., helmet lights and lights strapped/mounted to a crewmember or placed near the worksite), which can drive power needs. Thermal control performance in dark shadows will also affect EVA duration.

10. Site Planning

While missions to the lunar South Pole are being planned, design reference missions also include the capability to perform missions globally. Performing multiple missions to the South Pole and different regions of interest within range of each other will require strategic site planning. Several factors, such as ability to navigate difficult terrain while in a spacesuit, interactions required between surface elements, and safety will affect the integrated arrangement and configuration of surface elements to accomplish mission objectives. Mission designs will also need to address environmental factors (e.g., terrain, illumination, distance, plume) in concert with surface asset capabilities (e.g., rovers, habitats, landers, driving range, charging) and EVA capabilities (e.g., walk-back distance, vision), all while protecting the EVA crew.

Lunar surface selection of the site location of the surface elements must, of course, accommodate EVAs to perform science and utilization, maintenance, logistics, observations, and traversing during short-term missions, long-term stays, and sustained operations. This requires monitoring surface operations effects and management of habitation.

EVA ranges must be considered when planning distances between stationary elements to provide the crew access to a pressurized safe haven within the limits of emergency consumables in the event of a suit failure or medical event. Along with other considerations (i.e., landing accuracy, plume/surface interaction), distances the mobility elements can be driven or teleoperated before requiring charging affects the mission's mass requirements and must be balanced with operational needs such as EVA preparation, EVA duration, crew time, and crew sleep.

11. Contingencies and Operations

Ensuring crew safety is the most important aspect of planning human space missions. Risks such as system complexity, suit exposure, dust intrusion, EVA overhead times, vehicle failures, distance from a safe haven, and more can factor into the possible loss of crew or mission and must be considered in capability assessments. A vehicle/suit failure could result in scenarios where crew must walk back to a safe haven.

Hardware and human failures can lead to contingencies or incapacitation on the lunar surface, ultimately requiring assistance during EVA. Incapacitation requiring continuous full assistance is a risk that may need additional loading, transport, and lift capabilities, all of which affect suit design.

12. Conclusions

Surface EVA exploration has a significant number of architectural drivers that differ from microgravity. These differences include dust, the challenge of operating in partial gravity, mobility and habitation architecture, site planning, and contingency scenarios. Architectural challenges for surface EVAs result from limitations to mass, power, volume, the environment, and physical operations that occur on the Moon and, to even greater extent, on Mars.

Figure 3. *Conceptual Rendering 3*

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