A Permanent Human Lunar Surface Presence Enabled By a CLV Class JUMP Lander

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There are compelling advantages of a human presence on the surface of the Moon, as evidenced partly by the preponderance of lunar surface architectures that have existed throughout NASA, industry, and academia since the Apollo program. This paper specifically advocates and illustrates an example of a permanent human lunar surface presence enabled by a commercial launch vehicle (CLV) class Joinable Undercarriage to Maximize Payload (JUMP) lunar lander. The paper will discuss purposes for such a surface presence, including SPD-1 fulfillment, global collaboration, US industry advancement, US government leadership in spaceflight, a Mars dress rehearsal, Mars collaborative exploration, and lunar village development. An architectural description will be presented, including site selection, primary elements, and surface configuration. Element and lander allocation to CLV and Space Launch System (SLS) rockets will be discussed in terms of launch vehicle selection philosophy and allocation to specific launch manifests. This will enable a presentation of a lunar campaign spanning the period from 2026 to 2056. In conclusion, various aspects of the architecture will be suggested for further study.

I. Nomenclature

AAMA	=	Active-Active Mating Adapter
ATHLETE	=	All-Terrain Hex-Legged ExtraTerrestrial Explorer
CLV	=	Commercial Launch Vehicle
ISRU	=	In-Situ Resource Utilization
JUMP	=	Joinable Undercarriage to Maximize Payload
kWe	=	Kilowatt electric
LOX	=	Liquid Oxygen
MMSEV	=	Multi-Mission Space Exploration Vehicle
PUP	=	Portable Utility Pallet
ROI	=	Return on Investment
SLS	=	Space Launch System
SPD	=	Space Policy Directive
SPR	=	Small Pressurized Rover

II. Introduction

The Moon has always captured the human imagination and since the Apollo program it has been evident that a human lunar surface presence offers unique value to the human experience. The Moon is the only location in the universe where a human presence can be directly visible to Earth societies, enabling people in two "worlds" to look upon on each other and (with the proper telescopes) see physical evidence of each other's existence. Additionally, the relatively short travel time between the Moon and Earth encourages routine transit, including short term visits as well as shipping of perishable items.

There have been architectures for lunar surface human development since the time of von Braun. These studies have varied from the barebones 1996 Human Lunar Return study with its open cockpit lander and small inflatable habitat [1] to the grandiose plans of the 90-Day Study in 1989 with its 12-person inflatable "igloo" habitat. [2]

This paper investigates an alternative to historic lunar surface architectures and numerous current lunar studies. The Joinable Undercarriage to Maximize Payload (JUMP) Lunar Lander [3] provides a lunar surface payload delivery capability that creates opportunities for high return on investment (ROI) lunar surface architectures.

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III. Purpose of the Permanent Human Lunar Surface Presence

A natural question is 'why should there be a permanent human lunar presence?' Fortunately, there are many reasons why such an endeavor is important. The first is simply a fulfillment of the Presidential direction carried in Space Policy Directive 1 (SPD-1).

SPD-1 issues direction to, *"Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations."*

This implies more than a simplistic Apollo "flags and footprints" return to the Moon. Innovative and sustainable drives at a desire to see a lunar program that does not look like what has been done before and can be executed within the current economic climate. Another key element is commercial and international partnership, suggesting NASA, industry, and other nations must all have significant roles. SPD-1 requires that this return to the lunar surface must be led by the United States. The phrase "long-term exploration and utilization" indicates a need for sufficient infrastructure to establish an ongoing presence with actual results of human activity on the Moon, including new knowledge and opportunities. Finally, SPD-1 indicates that this return is a prelude to human expansion throughout the solar system.

The vision of SPD-1 can be interpreted as expansive and inspiring, and there are three subsidiary rationales that directly follow SPD-1: global collaboration, US industry advancement, and US government leadership in spaceflight (human spaceflight in particular).

A permanent human lunar surface presence creates a powerful platform to collaborate with and engage the global community. This is inclusive of international crews, international provision of elements and subsystems, international payloads for both research and lunar resource utilization, and opportunities to engage students and the public worldwide.

US industries are advanced by extending such partnerships to both existing and new commercial spaceflight providers. That engagement also creates opportunities with non-spaceflight companies (e.g. research, utilization) and even service industries. This US industry growth of course has significant economic impact in communities where those businesses are based.

A permanent human lunar surface presence helps to advance and maintain US government leadership in spaceflight in multiple ways. By definition such a lunar presence has a wide enough scope to include hands-on roles for in-house government developed space vehicles, thus advancing government spaceflight expertise and ensuring that technical proficiency continues to younger generations of government scientists and engineers. It also provides an experience base for the government to develop standards and regulations to apply to industry and international partners for safe human spaceflight. Finally, an active government leadership role positions the United States to define purposes for lunar activity and site locations.

An often-mentioned purpose for a human lunar presence is to conduct dress rehearsals for human Mars exploration. The crew size and mission timelines for Mars surface missions can be fully replicated on the Moon, enabling very similar simulations of Mars expeditions where they can potentially be supported by additional human and autonomous space systems and also within range of near real-time communications and relatively rapid evacuation in the case of the most serious contingencies. Even practicing and simulating contingency scenarios can reduce the risk of Mars exploration. While potentially complex to create, large lunar centrifuges could replicate Mars gravity, creating unique Mars simulation opportunities.

Mars collaborative exploration is also an important purpose for a permanent human lunar surface presence. Concurrent human operations on both the Moon and Mars can yield significant benefits. With parallel Moon and Mars human operations, responses to some Mars contingencies can even be practiced on the Moon before the Mars crew has to execute them. Also, science experiments performed at both destinations can use one world as a control for the other. Some payloads may even begin experiments in one destination and then be transported to another. With ISRU operations in progress at both destinations, there may even be instances of ISRU products developed on one world but used in the other, or ISRU products from both places being integrated together to form new products.

This suggests not a transient lunar presence that goes away after a few years, but one that continues indefinitely. NASA Administrator Jim Bridenstine said as much in a February 14, 2019, press conference, stating, "This time, when we go to the Moon, we're actually going to stay. We're not going to leave flags and footprints and then come home to not go back for another 50 years." The fulfillment of these goals may result in a lunar presence that matches the literal definition of permanent. Literal permanent human presence on the Moon pushes the human race into a multi-world species and creates a frame of reference that makes Mars more than an expedition, but instead an expansion. Further, if a lunar presence is permanent, it implies that a Mars presence would become permanent as well.

IV. Permanent Human Lunar Surface Presence Architectural Description

SPD-1 introduces a transformative view of humanity's role beyond Low Earth Orbit, but due to limitations in Earth launch capability it is arguable how fully this vision can be realized. The Space Launch System is a few years from being operational, with some of the first SLS rockets already in production, but the launch rate will be limited to one or two launches per year, with no expectation that the annual launch rate could ever exceed three. While at least one commercial launch vehicle of equal or superior capability is in development, other commercial rockets have significantly lesser launch mass capability. However, the JUMP lander concept is predicted to be able to enable delivery of significant mass to the lunar surface despite launch vehicle limitations. [3]

This research centers on a permanent human lunar surface presence at a South Pole location such as Shackleton Crater or Malapert Mountain. The two locations are within pressurized rover traverse range of each other and thus the entire region is of potential site interest. Terrain features may also provide benefits for radiation protection – such as if a habitat can be placed against the side of a cliff wall or inside a canyon or crater.

A set of lunar surface elements are assumed to scope a permanent human lunar surface presence and characterize the transportation needs associated with delivery of such a capability. Listed in Table 1 and described in subsequent paragraphs, the sixteen surface elements in the JUMP-enabled architecture are: ATHLETE, Small Pressurized Rover, Common Habitat, External Airlock, Kilopower, Power Cable Spool, Communications, External Thermal, PUP, Logistics Module, ISRU, Lander Tunnel, 4x4 AAMA, 5x6 AAMA, 4x6 AAMA, and Ascent Module.

Lunar Elements	Qty	Estimated Unit Mass (kg)
ATHLETE	2	2500
Small Pressurized Rover	2	6000
Common Habitat	1	30000
External Airlock	1	6920
Kilopower Unit	6	1500
Power Cable Spool	10	100
Communications	1	500
External Thermal	1	5000
PUP	4	1000
Logistics Module	3	12000
ISRU	3	12000
Lander Tunnel	1	250
4x4 AAMA	1	150
5x6 AAMA	1	200
4x6 AAMA	3	250
Ascent Module	1	9000

Table 1. Assumed Elements in Permanent Human Lunar Surface Presence

ATHLETE

The ATHLETE is a six-legged `cargo handling robot developed by the Jet Propulsion Laboratory. It is used to offload cargo from landers and to transport large modules across the lunar surface. It can split into two three-legged subunits when performing these tasks. The ATHLETE can also manipulate various tools for earth moving or construction tasks. A half scale prototype for the Constellation program's ATHLETE was tested in the desert, shown in figure 1. For the JUMP architecture, each leg segment will need to be increased by one meter beyond that of the Constellation flight version, giving the ATHLETE sufficient vertical clearance to offload cargo from the JUMP landers. [3]

Fig. 1 Half-Scale ATHLETE Prototype Carrying Mockup Habitat Module

Small Pressurized Rover

The two rovers are the Small Pressurized Rover (SPR) variant of the Multi-Mission Space Exploration Vehicle (MMSEV) under development primarily at the NASA Johnson Space Center. The first generation variants of this vehicle were featured extensively in NASA desert field testing, as shown in figure 2. When operating as a two vehicle-unit, the rovers can have a range of up to approximately 200 km from the habitat. Similar to the ATHLETE, the SPR can also attach earth moving tools to itself for outpost buildup tasks.

Fig. 2 First Generation Prototypes of SPR

Common Habitat

The habitat is a monolithic habitat based on the Skylab II concept, where a propellant tank of the SLS is used as the pressure vessel of the habitat, just like the original Skylab space station used a propellant tank of the Saturn S-IV stage as its pressure vessel. In particular, the habitat uses an SLS core stage liquid oxygen (LOX) tank. Note that this is a "dry tank" concept, meaning an additional tank is manufactured as a habitat and launched as a payload. (A "wet tank" concept is where the rocket's actual propellant tank is used as a propellant tank, carried into orbit, and then repurposed into a habitat. The dry tank approach shares the same structural testing and production line with the rocket, but does not attempt the more complex orbital repurposing.) It is a common habitat with a similar design used for lunar surface, Mars transit, and Mars surface habitation. [4] A parallel study to the JUMP lander study is investigating the Common Habitat as a potential option for long duration human spaceflight and is trading four variants of the concept, involving vertical and horizontal configurations as well as four and eight crew. A notional configuration developed by University of Houston students is shown in Figure 3. One of the larger long duration habitats, the variant shown has a vertical orientation with habitable compartments in both the upper and lower domes as well as four decks in the cylindrical section and provides long duration living and working space for a crew of eight. This is larger than the current NASA baseline and represents an upper end in the exploration trade space.

Fig. 3 SLS LOX Tank Skylab II Common Habitat

External Airlock

The airlock notionally selected for this study is a derivative of the MMSEV cabin and the shuttle airlock. While there are literally dozens of possible airlock options, a notional airlock suggested for this study consists of a system lock (inner chamber) that is a three-port version of the MMSEV cabin with two suit ports. The nose port docks to the habitat. The two side hatches each are mated to a shuttle airlock, each of which serves as separate crew lock (outer chamber).

Kilopower

The Mars Integration Group has baselined a modular nuclear fission system for surface power that can be piloted on the lunar surface. These kilopower units are 10 kWe, 1500 kg modules that are inert until activated after landing. [5], [6] Six kilopower units are baselined as fixed elements to provide power for the surface outpost.

Power Cable Spool

Each fixed or mobile power system will be accompanied by a 1 km power cable spool. The spool includes a small robotic rover/manipulator to self-deploy the cable to connect with the power system and powered elements.

Communications

A self-erecting tower serves as the communications hub for the outpost. The system includes local and long-range radio frequency and laser communications systems. The tower can support parallel communication between Earth (via relays when line of sight is not available), Gateway, other flight vehicles, and numerous surface assets including EVA crew members and robotic assistants.

External Thermal

An external radiator system provides heat rejection for the Common Habitat and other powered elements of the surface infrastructure. Forward work can determine the specific working fluid, whether the radiators are fixed or articulating, and specific heat rejection capability.

PUP

The Portable Utility Pallet (PUP) is a modular power and consumables device proposed during the Constellation program as an augment to the SPR variant of the MMSEV. [7] The purpose is to enable extended range excursions away from an outpost. The PUP carries communications systems and additional gases, fluids, and power generation capability. Constellation PUPs used solar power, but nuclear options are possible. The SPR can carry a PUP and deploy it as a remote recharging station and/or communications relay, allowing excursions radially away from the PUP, returning periodically to recharge.

Logistics Module

The logistics modules used for purposes of this study are assumed to be dimensionally similar to the Gateway International Habitat, approximately 4.2 meters in diameter with a barrel length of 5 meters and 0.6 meter end cones. At least one logistics module is docked to the habitat at any given time.

ISRU

The In-Situ Resource Utilization (ISRU) lunar capability is presumed to focus on three primary activities: extraction of gaseous oxygen from lunar regolith, harvesting of water from lunar cold traps, and production of liquid oxygen and liquid hydrogen from harvested water. Each activity is assumed to be contained within a distinct, uncrewed ISRU element that contains removable processed material containers that can be transported by ATHLETEs.

Lander Tunnel

A pressurized tunnel allows shirt-sleeve crew and equipment transfer between the Ascent Module cabin and a docked element. This element is typically a pressurized rover, but in theory any of the surface pressurized elements could be connected to the tunnel. In this study, the tunnel is assumed to be delivered with the JUMP descent stage, pre-integrated with the Ascent Module. The lower end enables docking with surface assets. This study conservatively assumes the tunnel is not reused, though further refinement may identify solutions to reuse or repurpose the tunnel.

4x4 AAMA

This study features three variants of the Active-Active Mating Adapter (AAMA). The AAMA was developed during the Constellation program to facilitate docking between pressurized rovers and other assets while also reducing the unit masses of component vehicles and reducing the impact of docking system failures. [8] The AAMA is a pressurized tunnel that contains Marmon actuators similar to those on the MMSEV suit ports. These actuators clamp against a metal flange that surrounds the docking hatch of a target vessel (rover, habitat, etc.) The 4x4 AAMA is sized to connect to a 40” x 40” square hatch on both ends. This AAMA is intended to allow pressurized rovers to dock to each other.

5x6 AAMA

The 5x6 AAMA is identical in function to the 4x4, but is designed to accommodate a different set of hatch sizes. One end accommodates the 50” x 50” square hatch common to ISS and the Common Berthing Mechanism (CBM). The other end connects to a 40” x 60” rectangular hatch recommended by Constellation-era human-in-the-loop studies for surface outposts. This AAMA is intended to allow ISS-derived logistics vehicles to retain their large hatch sizes in order to deliver bulk logistics items such as M-bags to the lunar surface.

4x6 AAMA

Like the 5x6, the 4x6 AAMA allows vehicles with dissimilar hatch sizes to dock to one another. This AAMA accommodates a 40” x 40” square hatch on one end and a 40” x 60” rectangular hatch on the other. This AAMA allows pressurized rovers to dock to the Common Habitat. (Note that a 6x6 AAMA is not featured in this study, but would be present in an expanded lunar surface architecture where multiple Common Habitats are present, allowing increased surface populations. It would of course link multiple 40” x 60” hatches together.)

Ascent Module

The Ascent Module is the portion of the lunar lander that returns to orbit. It consists of a pressurized cabin and a propulsion system. This study assumes that the ascent cabin is another variant of the MMSEV, retaining the MMSEV's traditional 40" x 40" side hatches. The precise configuration of the ascent cabin is the subject of other NASA studies and is beyond the scope of this paper. The Ascent Module is delivered to the lunar surface by the Descent Module and remains on top of the Descent Module until it lifts off to return the crew to Gateway.

V. Launch Manifests and Lunar Surface Buildup

This paper develops a launch manifest assigning these elements and associated landers and crew missions to individual SLS and CLV flights. A preliminary manifest for the JUMP landers is in table 2. As a general rule, crew will be exclusively launched in the Orion capsule atop the SLS rocket. The habitat will be launched by a cargo SLS flight. JUMP landers will be launched by CLVs. The Gateway will be the staging point in Cislunar space for all lunar surface missions. The manifest begins after the 2024 human lunar landing (the 2024 lander is not a JUMP capable vehicle) and will manifest a lunar surface program that supports human lunar landings in even numbered years only up through 2036. This lunar manifest could cease in 2036 with a subsequent transition to human Mars exploration, or (if a permanent lunar presence is to be realized) lunar landings could accelerate in parallel with Mars exploration. In the latter scenario, an extended campaign beyond the scope of this paper could develop lunar infrastructure in the direction of continued permanent settlement and the first lunar village.

Table 2. JUMP Lander Flight Manifest 2025 – 2036 (preliminary)

Year	Lander Payload (Assume ~30,000 kg JUMP Lander Payload Capacity [3])
2025	JUMP Lander 1 (Cargo): ATHLETE 1, SPR 1 & 2, Kilopower 1 & 2, Power Cable Spools 1-5, Communications, External Thermal, PUPs 1-3, 4x4 AAMA, 4x6 AAMAs 1 & 2 [Total mass: 27,400 kg; remaining capacity: 2,600 kg]
2026	JUMP Lander 2 (Crew/Cargo): Ascent Module with Crew, JUMP Lander Tunnel, Logistics Module [Total mass: 21,250 kg; remaining capacity: 8,750 kg] 14-day mission
2027	JUMP Lander 3 (Cargo): ATHLETE 2, External Airlock, Kilopower 3-6, Power Cable Spools 6-10, PUP 4, Logistics Module, 5x6 AAMA, 4x6 AAMA 3 [Total mass: 29,620 kg; remaining capacity: 300 kg]
2028	JUMP Lander 4 (Crew/Cargo): Ascent Module with Crew, JUMP Lander Tunnel, Logistics Module [Total mass: 21,250 kg; remaining capacity: 8,750 kg] 14-day mission
2029	JUMP Lander 5 (Cargo): Common Habitat [Total mass: 30,000 kg; remaining capacity: 0 kg]
2030	JUMP Lander 6 (Crew/Cargo): Ascent Module with Crew, JUMP Lander Tunnel, Logistics Module [Total mass: 21,250 kg; remaining capacity: 8,750 kg] 182-day mission
2031	JUMP Lander 7 (Cargo): Logistics Module, ISRU Element 1 [Total mass: 24,000 kg; remaining capacity: 6,000 kg]
2032	JUMP Lander 8 (Crew/Cargo): Ascent Module with Crew, JUMP Lander Tunnel, Logistics Module [Total mass: 21,250 kg; remaining capacity: 8,750 kg] 378-day mission
2033	JUMP Lander 9 (Cargo): ISRU Element 2 & 3 [Total mass: 24,000 kg; remaining capacity: 6,000 kg]
2034	JUMP Lander 10 (Crew/Cargo): Ascent Module with Crew, JUMP Lander Tunnel, Logistics Module [Total mass: 21,250 kg; remaining capacity: 8,750 kg] 735-day mission
2035	JUMP Lander 11 (Cargo): Logistics Modules x 2 [Total mass: 24,000 kg; remaining capacity: 6,000 kg]
2036	JUMP Lander 12 (Crew/Cargo): Ascent Module with Crew, JUMP Lander Tunnel, Logistics Module [Total mass: 21,250 kg; remaining capacity: 8,750 kg] 735-day mission

This buildup places initial emphasis on mobility and resources to manipulate heavy payloads on the lunar surface. The Common Habitat is not delivered until Lander 5, when sufficient infrastructure is present on the Moon to support its operation. However, this by no means deprioritizes habitation. By delaying the habitat until the infrastructure is ready to support it, the crews can immediately jump into long duration missions, rapidly building up to 2-year expeditions. Additionally, with the installation of additional subsystem hardware, an emptied Logistics Module could refurbished as a short duration habitat and be carried by an ATHLETE to support an extended SPR excursion away from the outpost, perhaps as long as 90 days in duration.

Common Habitat research is currently trading benefits of 4 vs. 8 person crew sizes [4], and it is worth noting that the crew lander missions have significant excess cargo capacity, suggesting multiple paths to reach an 8 person crew. A larger lander cabin could allow all 8 to be delivered together. Alternately, overlapping crews could arrive midway through the others' missions, similar to how ISS expedition crews rotate today.

It should be noted from table 2 that continuous occupancy is achieved in the 2036 mission, where the crew of Lander 12 will arrive prior to the departure of the crew of Lander 10. It is at this point that the infrastructure for permanent lunar surface human presence has been achieved.

This JUMP-enabled architecture places 2058 days (8232 crew days) on the lunar surface between 2025-2036. Without the JUMP lander, and assuming annual crew flights, the nominal 5-9 mt lander capacity would likely max out with a Gateway-derived surface habitat and 30-day missions, resulting in less than 350 days (less than 1400 crew days) on the lunar surface during this same time period. The JUMP architecture delivers approximately 360,000 kg to the lunar surface in twelve missions (requiring 48 CLVs), while the nominal 9 mt lander capacity may deliver on the order of 216,000 kg, assuming the same number of CLV launches. Clearly, the increase in lunar exploration enabled by a JUMP capability is staggering.

A notional Phase Two campaign could be constructed for the years 2037-2058 with annual landings representing a delivery capability of approximately 630,000 kg. Of course, if the launch rate were to enable both crew and dedicated cargo missions in the same year, this capacity would double. There is no practical way to reach Phase Two with the nominal 9 mt lunar lander cargo delivery capacity. Without greater Earth launch systems, an augmentation along the lines of the JUMP lander is necessary to enable substantial lunar infrastructure development.

Research can show how this delivery capability can enable construction of a lunar village. It should be noted that the term lunar village has been used in popular culture and even the aerospace industry with widely differing meanings. The Census Bureau notes that different states in the United States vary significantly in the population requirements to constitute a village. [9] ESA Director General Jan Woerner spoke of a lunar village but made the specific disclaimer that he did not mean a village on the Moon, but Jeff Bezos is quoted as saying he wants to put a city on the Moon. [10] In the context of this paper, a lunar village is intended to imply an actual village of sorts, with a population of 250 identified as a semi-notional target to constitute a village.

A 10-meter diameter variant of the Common Habitat has been shown to be able to house habitation facilities for as many as 48 people. [11] Six of those, along with other ISRU, mobility, robotic, power/thermal, and habitable facilities for working, subsystems, and logistics, could be delivered and outfitted during this 21-year period, to form such a village.

VI. Conclusion and Forward Work

A CLV class JUMP lander enables lunar development on par with early Constellation outpost concepts and Mars field station conceptual designs, even with Earth launch capability reduced (from Ares V class rockets) to primarily Falcon-Heavy class CLVs. This capability prevents a human lunar presence from being only slightly more than flags and footprints and enables orders of magnitude greater crew time and mission productivity.

Continued JUMP lander research is an obvious priority. The payload capacity of the JUMP lander has a transformative effect on the resulting lunar architecture and all aspects of the JUMP system, including Earth launch vehicle availability and manufacturing chains deserve focused attention.

Forward work also includes refinement of all of the estimated masses used in this paper. Many of the elements are proposed in other concept studies or Agency programs and mass values are constantly changing as systems are better defined. Additional Operational Concepts research can identify specific outpost needs such as landing site constraints, science and ISRU zones, options for addressing used lander descent stages and logistics modules, etc.

An area of significant interest for future research is to delve into the Phase Two lunar campaign suggested by this paper. Artist concepts have shown lunar cities since the dawn of the space program, but few serious studies have developed a credible path to transition from Apollo sortie missions, to Constellation-type outposts, to these notional cities. Identification of a technical path could enable companion economic and political studies to develop the rationale and means for such development.

Additional forward work can examine the interaction between parallel human Moon and Mars programs. The Phase Two suggested in this paper would occur at the same time as the human Mars missions proposed by NASA's Mars Integration Group. To what extent can lunar ISRU be utilized by the Mars missions? Could a parallel (as opposed to precursor) lunar outpost play any role in crew training, contingency response, planetary protection? What additional benefits are provided by concurrent human missions to both destinations?

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