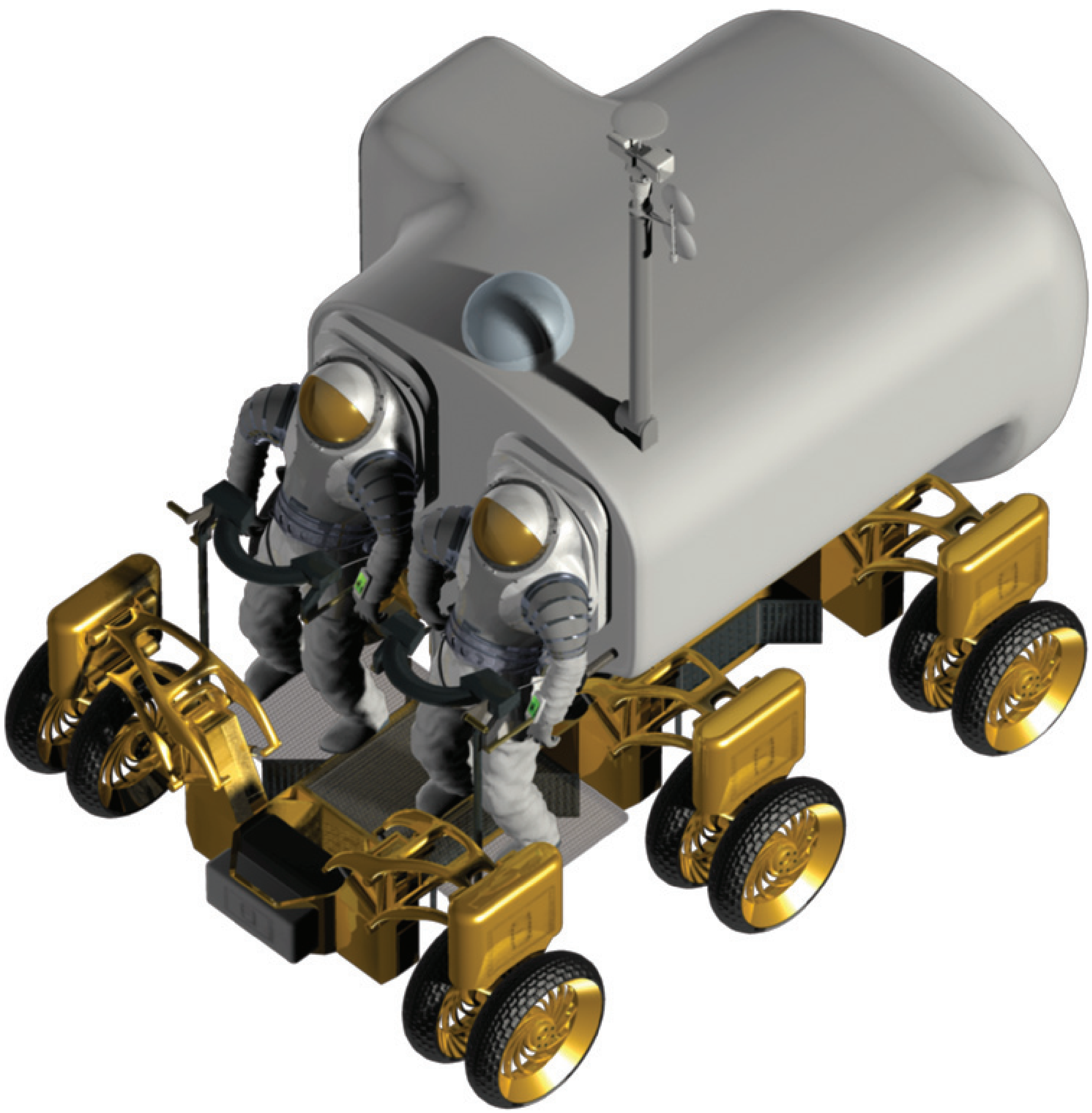
Preliminary Report of the Small Pressurized Rover (SPR)



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Executive Summary

A fundamentally novel approach to optimizing astronaut safety and performance during exploration of a planetary surface was developed as part of a study focused on optimizing the balance of humans and technology commissioned by NASA, led by the Institute for Human and Machine Cognition (IHMC), and drawing upon the expertise of selected personnel from academia, NASA, and the private sector.

The heart of the concept is a system of two Small Pressurized Rovers (SPRs), which nominally accommodate two astronauts each, in a shirt sleeve environment as they explore the planetary surface. These SPRs incorporate “step in” space suits enabling both rapid egress to the planetary surface and rapid ingress to the shelter of the rover in response to solar particle events (SPE), suit malfunctions or medical emergencies. The SPRs are capable of an extended exploration range at least an order of magnitude greater than the Apollo rovers and perhaps up to 1000 km. Each SPR is a backup to the other, and capable of supporting four crew members in a contingency return to the base or Lander, thus providing greater range capability than a single larger pressurized rover.

As explained in detail in this report, the linchpin technologies of the recommended approach are focused on optimizing human safety and performance in planetary exploration by combining a comfortable shirt sleeve, sensor augmented environment for gross translations and geological observations with the ability to rapidly place suited astronauts on the planetary surface to take full advantage of the unique human perception, judgment and dexterity. This combination of features should increase the productivity of suited crew time and, because the SPRs are capable of multi-day or week-long sortie durations, eliminate the overhead of returning to the outpost or lander at the end of each day. The SPRs also incorporate an EVA driving station, and therefore can be operated with all the advantages of an unpressurized rover (UPR). The SPR is envisioned as relatively simple device combining elements of the suits’ life support systems, with additional consumables tankage, cabin circulation fans, passive radiators, and an ice block heat sink for removal of cabin avionics and crew metabolic heat loads that also doubles as radiation protection. As a consequence of the relative simplicity and low cost, the SPR and all the associated safety and operational advantages could be available much earlier in the exploration architecture than some of the more complex mobility options that have been previously considered.

This report presents the SPR concept and is not intended to provide detailed engineering or design analysis. The functional requirements of SPR are given in Section II, a detailed description of the concept in Section III, the health and safety advantages of SPR rovers in Section IV, the exploration advantages of the concept in Section V, its operational and engineering advantages in Section VI, and its architectural advantages in Section VII. In Section VIII the implications of the SPR for public engagement and support are considered. Finally, a brief summary appears in Section IX.

I. Introduction and Background

Realization of the US space exploration policy for the Moon and beyond will require the development of new approaches to planetary surface exploration by astronauts. The Apollo program will always be recognized as a remarkable human achievement; however, there are many new challenges associated with returning to the Moon and subsequently exploring Mars.

This report contains the results of a study conducted under the sponsorship of NASA's Exploration Systems Mission Directorate (ESMD). Additional science and technology (S&T) funding support was provided by the Office of Naval Research (Code 30). The purpose of the study was to explore new approaches for human exploration of planetary surfaces, aiming in particular at approaches that enhance the surface area that can be explored and the safety with which the astronauts carry out their tasks. Toward this end, the Florida Institute for Human and Machine Cognition (IHMC) assembled a multi-disciplinary team of scientists and engineers drawn from among the best and most creative individuals in the academic community, NASA, and industry. The participants are listed in Appendix-1. Additionally, this work was closely coordinated with NASA's Lunar Architecture Team Phase II (LAT-2) study to assure that insights from each effort informed the other. The participants worked together to find innovative solutions to the new challenges posed by extended duration human exploration of the lunar surface. The result is an approach to human planetary surface exploration that employs a new class of EVA surface support vehicle: Small Pressurized Rovers (SPRs).

Fewer than 20 Lunar Extravehicular Activities (EVAs) were performed during the entire Apollo program. Current architectures under consideration by NASA's Lunar Architecture Team Phase 2 could involve as many as 30,000 hours of Lunar exploration EVA time. As Figure 1 demonstrates, these plans represent an enormous increase in EVA hours in an extreme and challenging environment. No previous astronaut or spacesuit has performed more than three Lunar EVAs, yet future astronauts and their EVA suits must be capable of performing as many as 76 Lunar EVAs during a 6-month mission. Damage to suit components and considerable dust contamination occurred during Apollo after only three EVAs; suit-induced trauma of astronauts in current EVA suits often occurs during a single EVA. Other challenges include the risk and consequences of a significant Solar Particle Event (SPE); Galactic Cosmic Rays (GCR); the need to extend exploration to potentially hundreds of kilometers from an outpost; and the increased Decompression Sickness (DCS) risk and prebreathe requirements associated with 8 psi/32% O_2 cabin pressure versus Apollo with 5 psi/100% O_2.

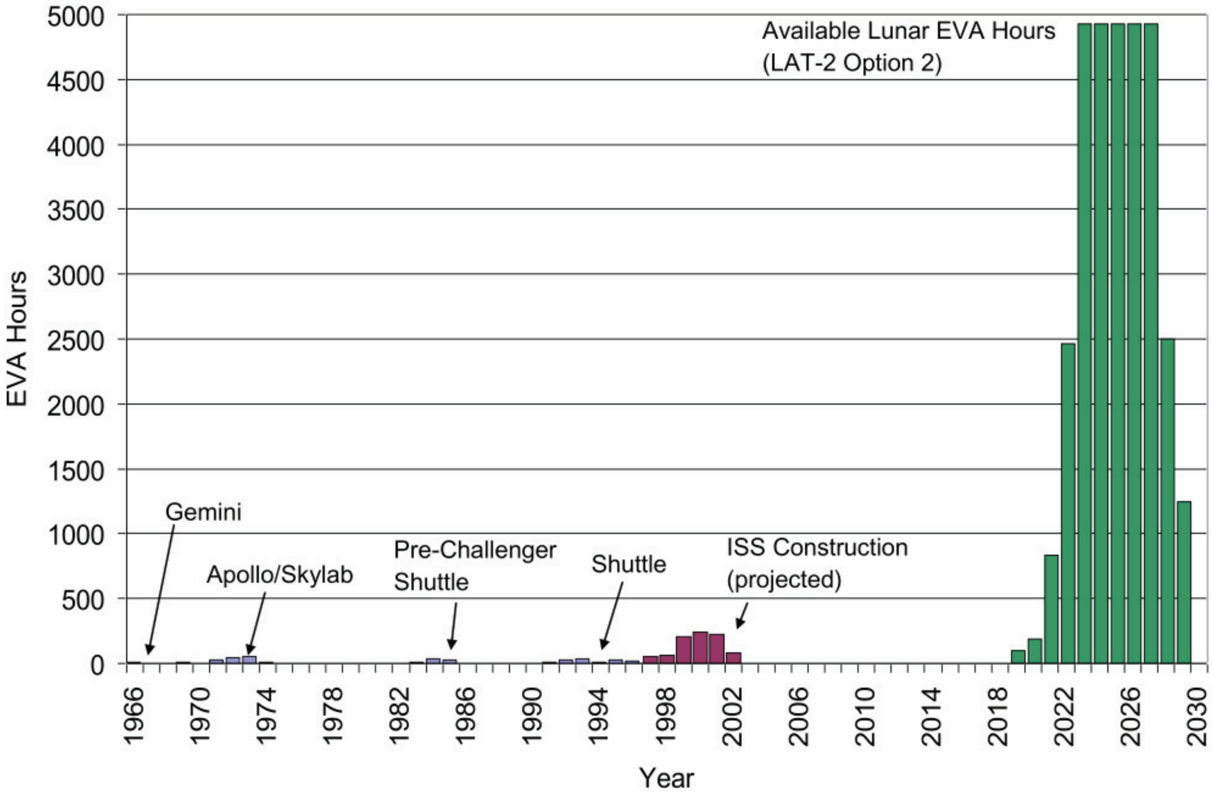


Figure 1: EVA Estimates for Current Lunar Architecture

As illustrated in Figure 2, the SPR is only slightly larger than the unpressurized Apollo rover. The front cabin of the rover provides a pressurized shirt-sleeve environment at the same pressure as the habitat or Lander. Two EVA suits attach to the vehicle with a rear entry hatch outside the pressurized volume in the lunar vacuum environment. A side hatch that mates with the habitat, Lander or other SPRs enables transfers of personnel and equipment under pressure. This capability, along with the capability to quickly step into the suits and perform surface operations, results in crewmembers going EVA for only the limited portions of an EVA sortie that require the superior perception, judgment and dexterity of an astronaut in an EVA suit. The SPR concept significantly reduces EVA time by eliminating all EVA overhead associated with long translations between sites and contextual observations. It also significantly extends exploration range, allowing multi-day sorties rather than the range limited (8 hour) EVA activities achievable with an unpressurized rover.

Section II briefly describes the enabling designs and technologies identified during the LAT-2 study. The functional requirements of this new class of vehicle are described in Section III. The remaining sections of this report describe the implications of SPRs in terms of improved crew health and safety (Section IV), exploration capabilities (Section V), operational and engineering considerations (Section VI), architectural-level mass and crew time benefits (Section VII), public engagement advantages (Section VIII), and a brief summary (Section IX).

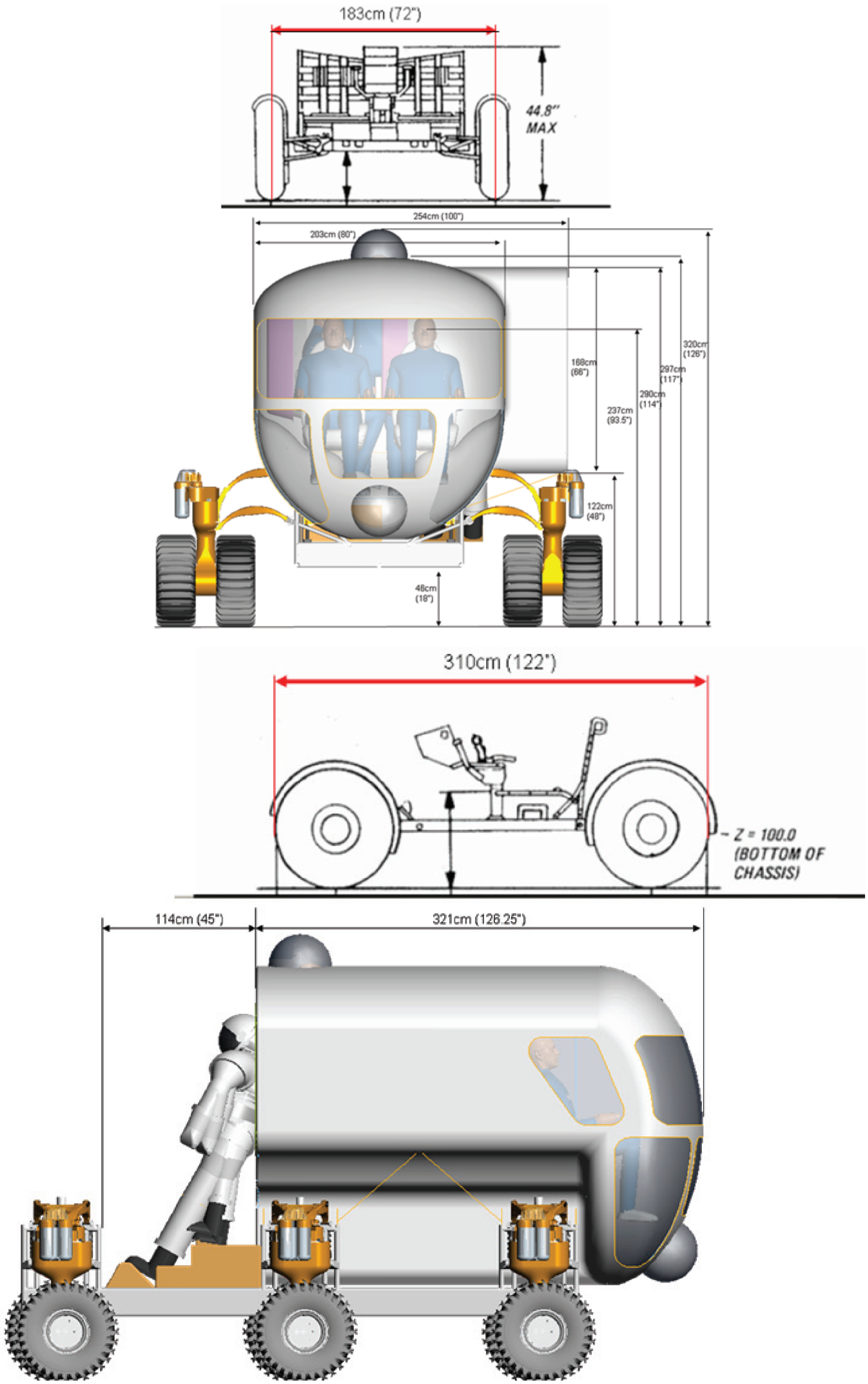


Figure 2: SPR vs. Apollo Rover Size Comparison

II. Description of Small Pressurized Rovers (SPRs)

The important design characteristics of the SPRs are summarized in Figure 3 and are described in detail below.

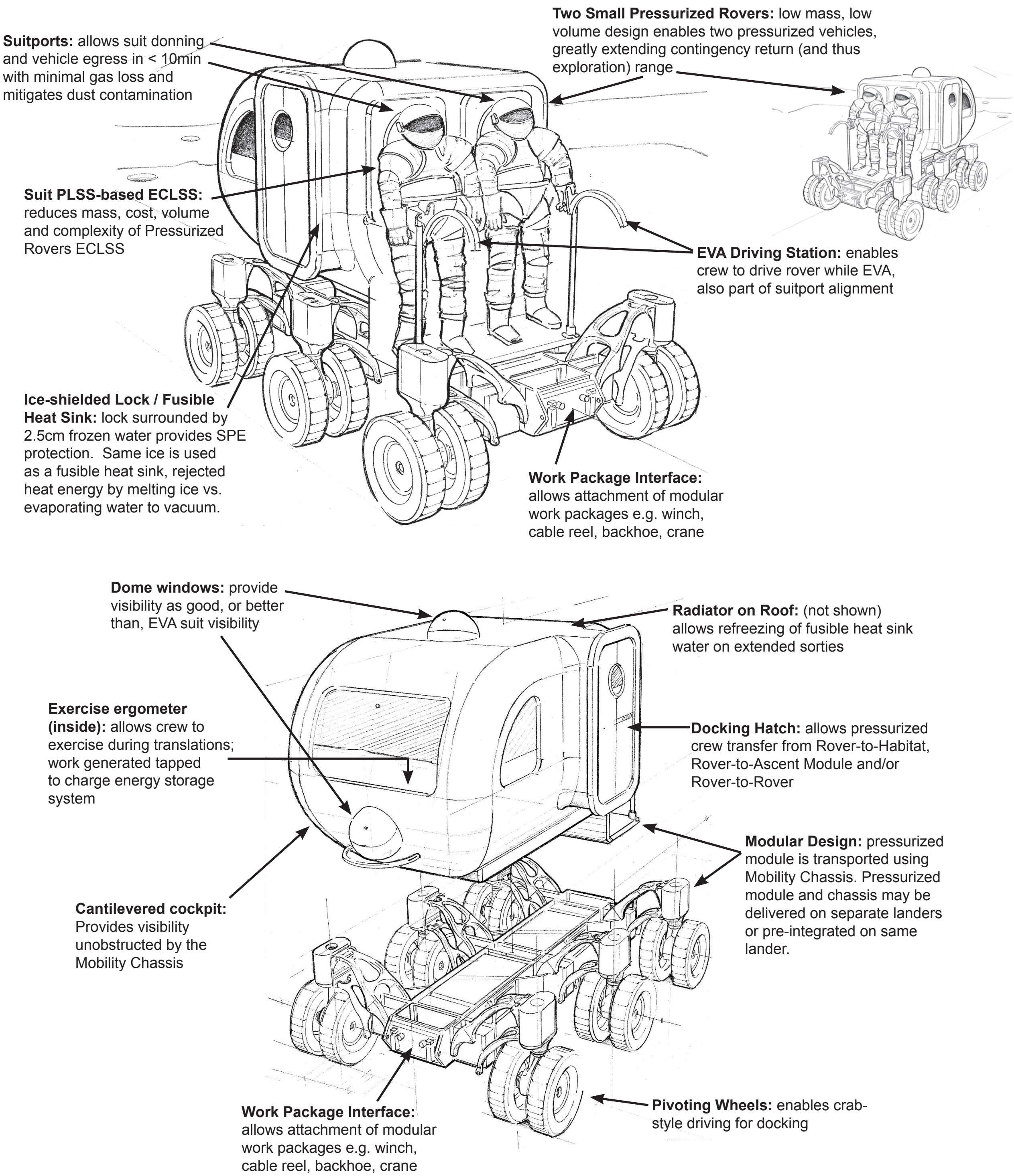


Figure 3: Summary of SPRs Design Characteristics

Two Small Pressurized Rovers

Because a single SPR is less than half the mass of a conventional Large Pressurized Rover (LPR) design, two SPRs can be delivered to the planetary surface rather than a single LPR, offering advantages and mission augmentation as described in later sections of this report. SPRs are small (habitable volume ~8m^3 per SPR) and designed to be nominally operated by two crewmembers per SPR with the ability to accommodate up to four crewmembers for contingency events.

The total mass of two SPR modules (2 x 2998kg), including two Mobility Chassis (MCs) (2 x 1309kg), is 700kg less than the combined mass of an LPR (8006kg) and an unpressurized rover (UPR) (1309kg). A single LPR cannot operate beyond walk back range (10km) without a UPR available for contingency return. The LPR mass estimate breakdown from Lunar Architecture Team Phase I (LAT-1) and the SPR module mass estimate breakdown (excluding MC) from LAT Phase II, including the basis of estimates, are included in Appendix 3.

The design and geometry of the cabins shown in this report should be considered preliminary and have not yet been rigorously evaluated. Preliminary stress analysis results for one cabin geometry included in this report are shown in Figure 4. The current configuration was developed based on the human factors and functionality considerations detailed in Section III while also adapting to certain constraints associated with the existing Chassis C design. Designing of the pressure vessel to fit suitably between the suspension elements of the Chassis C while also keeping the crew as close as possible to the surface, resulted in a cabin with a toadstool-shaped cross-section. Interestingly, this shape is actually representative of an ideal habitable volume for the necessary tasks required of the crew of this vehicle.

The narrowing of the lower half of the volume creates a natural walkway facilitating crew translation through the vehicle. The geometry creates natural benches, in this case desirable for stowage, seating, sleeping platforms and entry into suitports. Perhaps most importantly, this cabin geometry contains features that promote a larger perceived volume, which is in turn beneficial for crew productivity and general wellbeing. The cabin's longitudinal orientation and longitudinal architectural lines, with smooth sweeping rounds leading into the ceiling, create the illusion of a larger interior volume. Also the smaller volume at foot level in opposition to the larger volume at standing height increases the perceived volume of this small space.

Ongoing human factors evaluations in low-fidelity mockups, performed by the Habitability and Environmental Factors Division at Johnson Space Center, suggest many potential benefits of the current cabin geometry. However, continuing development of the SPR concept at Johnson Space Center, Langley Research Center, and Ames Research Center includes evaluation of every aspect of the cabin design and geometry including the optimal size and locations of windows, integration with the Mobility Chassis, center-of-gravity considerations, interior layout, and suitport human factors.

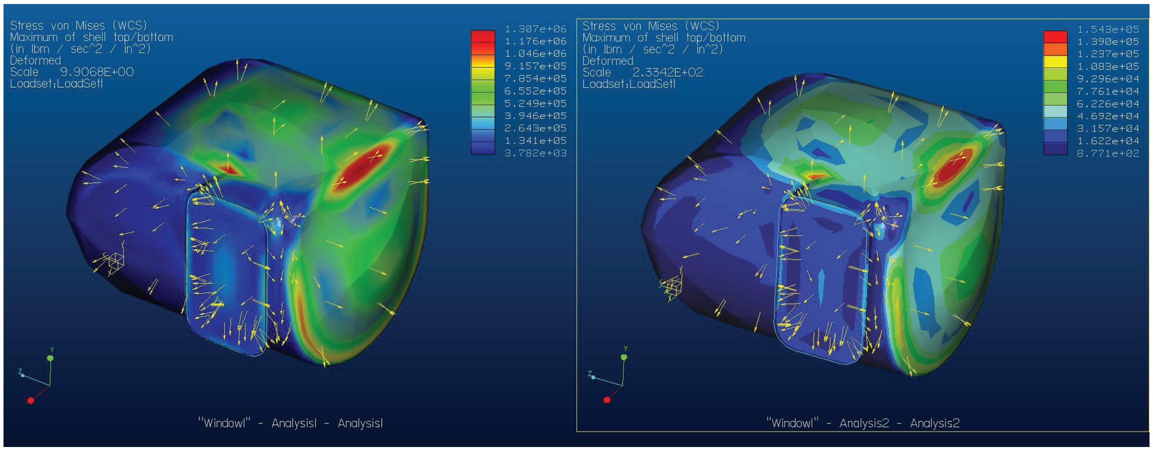


Figure 4: Preliminary Stress Analysis Results for Possible Cabin Geometry

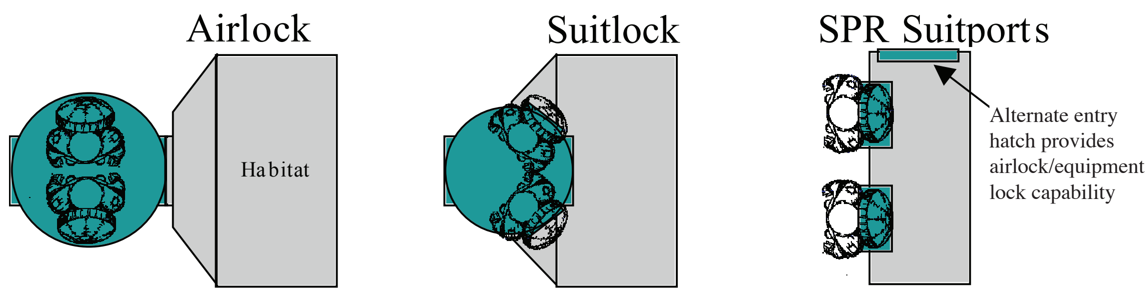
Suitports

Each SPR incorporates two suitports with a Lunar EVA suit attached to each. The configuration and operation of a pair of suitports compared with an airlock and suitlock is shown in Figure 5. During traverse to exploration or assembly sites, astronauts drive in shirt-sleeves from the pressurized cockpit.

When desired, one or both astronauts can quickly get into the EVA suits via the suitport, closing the suitport hatch and detaching from the rover, in order to begin performing boots-on-surface untethered EVA exploration within 10 minutes of deciding to go EVA. Upon completion of EVA tasks in that location, astronauts reenter SPR via the suitport before returning to the habitat or translating to the next EVA location.

The space between the suitport hatch and the suit hatch contains a vented volume of approximately 0.0354 m^3 (1.25 ft^3) while the vented volume of a 2-person suitlock cylinder is approximately 5.4 m^3 (191 ft^3). Even if a reclaim pump salvages 90% of the gas in a suitlock (or similar sized airlock), the volume of vented gas is still more than 7 times greater than with the two single-person suitports. Furthermore, approximately 50 minutes is required to reclaim 90% of suitlock or airlock gasses before egress, compared with 2 minutes for a suitport. Also, suitports provide protection against dust contamination because the dust-covered exterior of the EVA suits are not brought inside the pressurized volume of the SPR after an EVA, as would be the case with an airlock. It will be very important operationally to keep dust out of the inhabited volumes and away from internal equipment. This is especially true, since the equipment will be employed for long periods of time in the lunar environment. It may be found that the health of the astronauts could be impaired if exposed to too much lunar dust as well. There are similar concerns regarding Mars dust, where little is known of its hazards to human health. Therefore, gaining experience in isolating the crew from dust at the moon will be valuable in preparing for missions to Mars.

An inner hatch and appropriate procedural controls ensure that the use of suitports carry no greater risk of rover depressurization than an airlock or suitlock. Suits are pressure/leak checked at 8 psi with both the suit hatch and suitport hatches closed. After a successful pressure/leak check, the suitport hatch and suit hatches are opened and the astronaut steps into the rear-entry suit as shown in Figure 6. If only one astronaut is going EVA at a time, the second astronaut may remain in the forward cockpit. In the event that a catastrophic suit leak occurred during donning while the suitport and suit hatches were open, an interior hatch provides protection against depressurization of the forward cockpit.



Suitlock:
- Reclaim pump drops pressure to ~2psi in ~40mins (lose last 2psi to vacuum)
- Standard submarine hatch for exit to lunar surface
- Suitlock provides dust isolation and mitigation countermeasures
- Interior hatch allows suits to be brought into the habitat
- Outer hatch provides protection against hab depress through major suit **and** suit hatch leak
- Option to add suitport feature to suitlock (requires donning suits at 8psi with relaxed man-loads)

Suitport:
- Suits are pressure/leak checked with both hatches closed, minimizing likelihood of catastrophic suit failure during donning
- Interior hatch provides protection against depressurization of habitat/ forward SPR cockpit

Figure 5: Comparison of Airlock, Suitlock and Suitport Configurations

At the cost of adding mass, operational complexity, and longer ingress/egress times, reclaim pumps could depress the central lock from 8 to 6 psi, eliminating the need to pressurize the suits to 8psi during donning. As the reclaim pumps would be operating on the high end of the exponential depress curve, the 2 psi pressure drop could be achieved in reasonable time, with no gas losses. In a suitlock or airlock the entire lock volume would need to be pumped from the lock into the forward cabin, which would take much longer operating across the full range of the exponential depress curve. That approach would also require dumping the last 2 psi of gas overboard and require a higher pressure structural design for the forward cockpit.

To simplify return to the SPR pressurized compartment, EVA suited astronauts would employ suit alignment guides that would align the EVA suits with the suitport to dock with and ingress the SPR. The example illustrated in Figure 7 uses an interface ring attached to the front of the waist ring on the suit. The astronaut then pivots about the support stem until the guide pins of the interface ring are engaged by the suitport guide cones. The astronaut then translates backward until the suit and suitport hatches are aligned. Alternative alignment methods are currently being developed and tested.

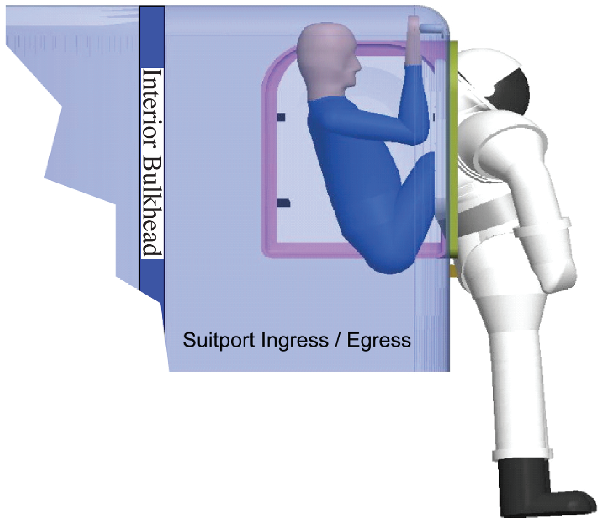


Figure 6: Suitport Ingress/Egress

If an astronaut is incapacitated during an EVA, the second astronaut may bring him or her back inside SPR either by using the suitport or by depressurizing the central lock and transferring while both astronauts are still in their EVA suits. In this way, suits may also be brought inside the SPRs for maintenance, although using the habitat suitlock modules would be preferable for suit maintenance in order to minimize potential dust contamination inside the SPR. The SPR could incorporate a dual use suitlock design that nominally operates as a suitport but with the capability to pressurize an outer lock for suit maintenance, contingency ingress, and environmental protection of the suits.

Suitports are a central feature of the SPRs concept. The many advantages of suitports are described in terms of exploration, operational, engineering, and architectural implications in Sections V, VI, and VII.

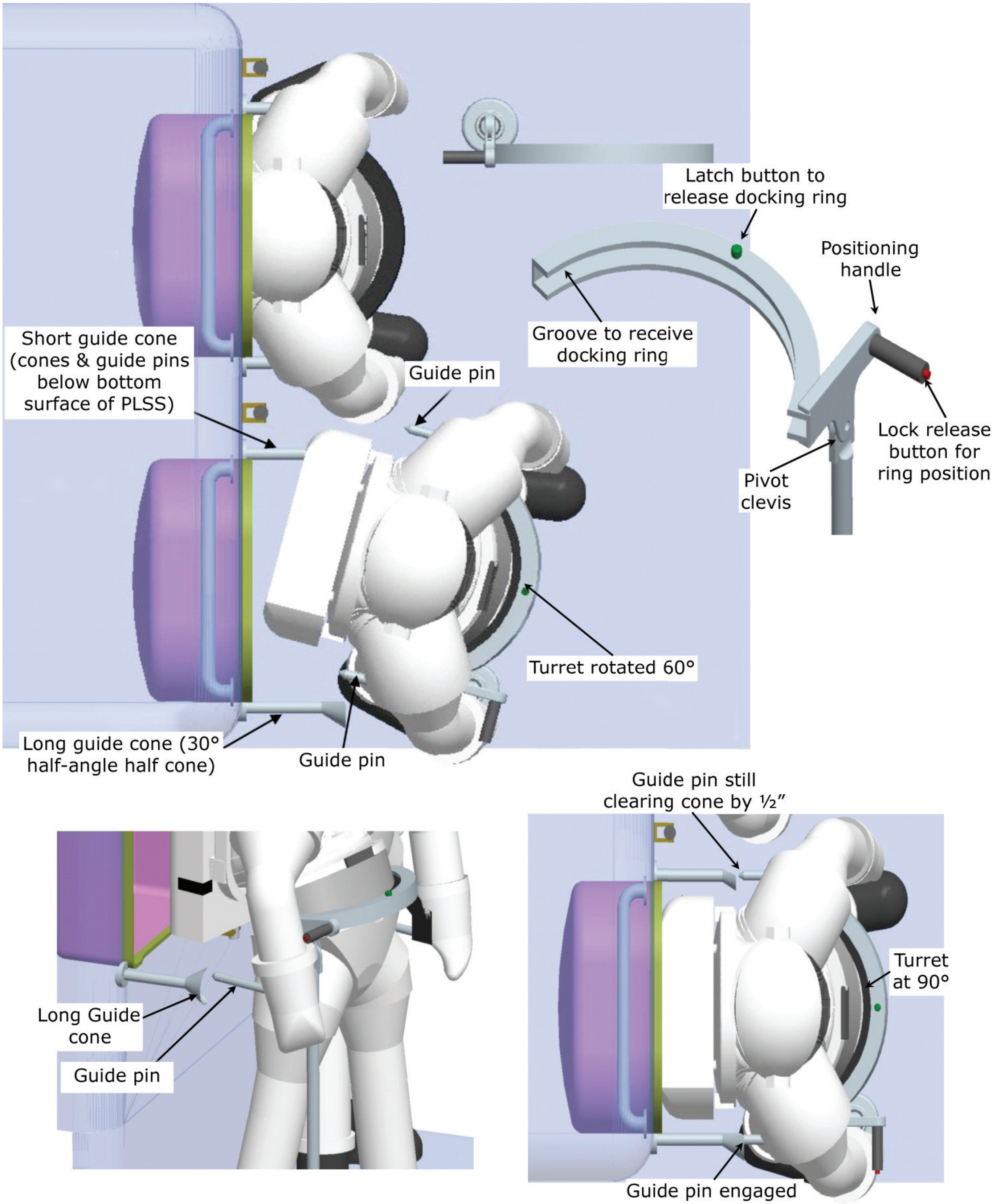


Figure 7: Alignment of EVA Suit with Suitport

Suit PLSS-based ECLSS (Environmental Control & Life Support System)

Instead of using a dedicated life support system, SPRs use the EVA-suit PLSS (Portable Life Support System) for oxygen make up and $C0_2$ removal. A 100W cabin fan provides airflow through a fusible heat sink and a condensing heat exchanger to remove heat and humidity. Nitrogen make up tanks, supply and waste water tanks, and a top-mounted radiator for freezing the water in the central lock complete the life support system of SPR. Each SPR includes a third suit PLSS for redundancy. The schematics for the SPR ECLSS and suit PLSS are shown in Figures 8 and 9. The operational, engineering, and architectural benefits of a suit-PLSS based ECLSS are discussed in Sections VI and VII.

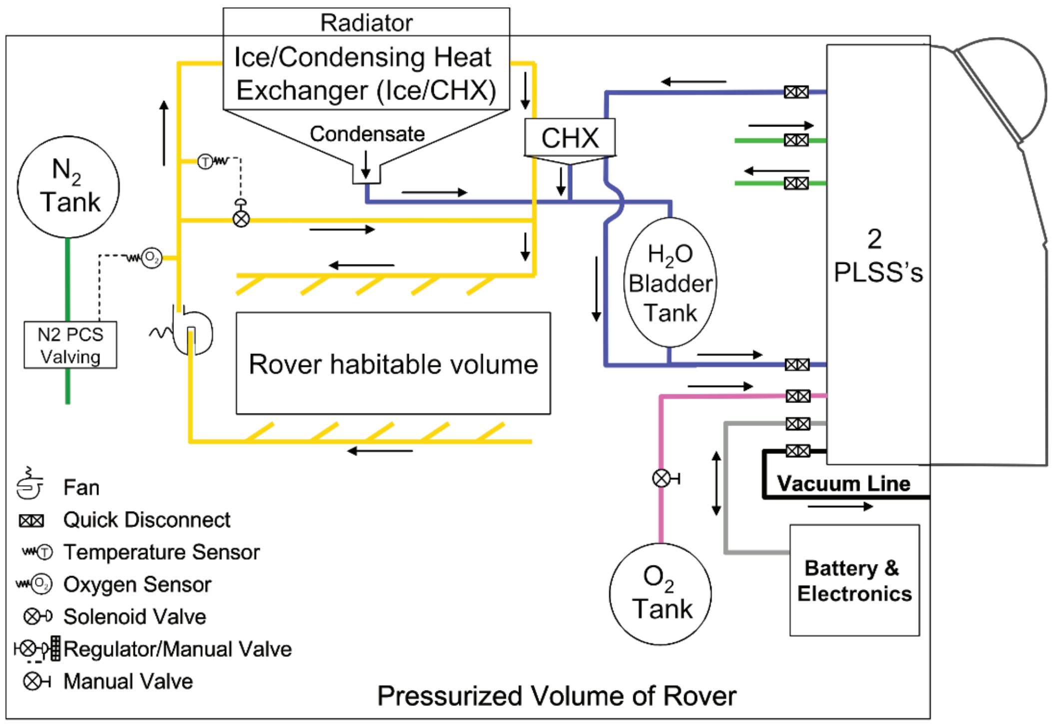


Figure 8: SPR ECLSS Schematic

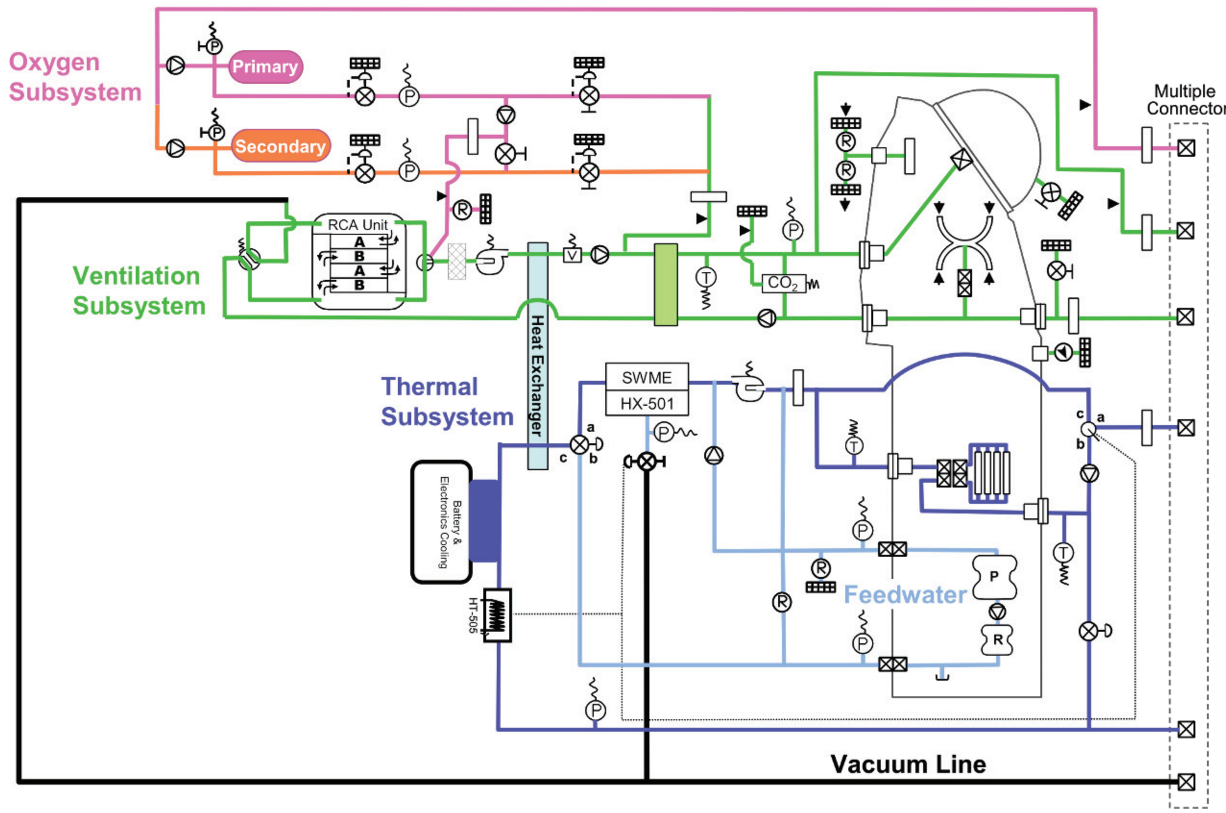


Figure 9: SPR PLSS schematic

Ice-Shielded Lock / Fusible Heat Sink

The central lock of each SPR is surrounded by a layer of sub-cooled water ice with a mass of approximately 225 kg (500 lb). A preliminary analysis performed by the JSC Space Radiation Group indicates that the required thickness of the ice shielding will vary from 1.3cm to 5.3 cm (0.5” to 2.4”) with less shielding needed in areas where the central lock is also shielded by the rest of the SPR structure. The analysis is based on reducing the effective dose (organ averaged) below 10cSv (rem) for the historically largest Solar Particle Events (SPEs). Polyethylene shielding will be used for surfaces where the use of water shielding would be complicated by other structures such as the suitport hatches. This SPE safe haven in the SPRs should eliminate the need for dedicated SPE shielding in either the habitats.

Water will be a precious, limited resource in Lunar exploration. Therefore, rather than evaporating water and rejecting it to vacuum for thermal management, the SPR ECLSS will use the SPE shielding ice as a fusible, phase change heat sink. Cabin heat energy transferred from the air to the fusible heat sink will warm and eventually melt the ice. The roof-mounted radiator will reject the latent heat in the ice/water, thereby cooling and re-freezing the water in the fusible heat sink.

The net rate of heat energy flow depends on the tasks being performed by the SPR and the astronauts (e.g. driving vs. sleeping vs. EVA), the amount of solar illumination, and the size and efficiency of the radiator. SPR sorties would be planned to allow adequate time to refreeze the water in the fusible heat sink. However, in the event that all of the ice in the fusible heat sink melted completely, the water could then be evaporated to vacuum to reject heat. Because the specific latent heat of vaporization is more than six times greater than the specific latent heat of fusion, the vaporization of the fusible heat sink provides enormous safety margin with respect to heat rejection.

The implications of the Ice-Shielded Lock and Fusible Heat Sink in terms of mass savings and astronaut health and safety are discussed in Section IV.

Modular Design

Each SPR consists of a Mobility Chassis (MC) and an SPR module, which may be delivered to the Lunar surface as a pre-integrated unit or as separate elements. These two components are shown in Figure 10 and an initial implementation of the Mobility Chassis in Figure 11. The Mobility Chassis is the core surface mobility vehicle in the LAT-2 mission architectures, with most architectures including up to four such chassis over the duration of the architecture.

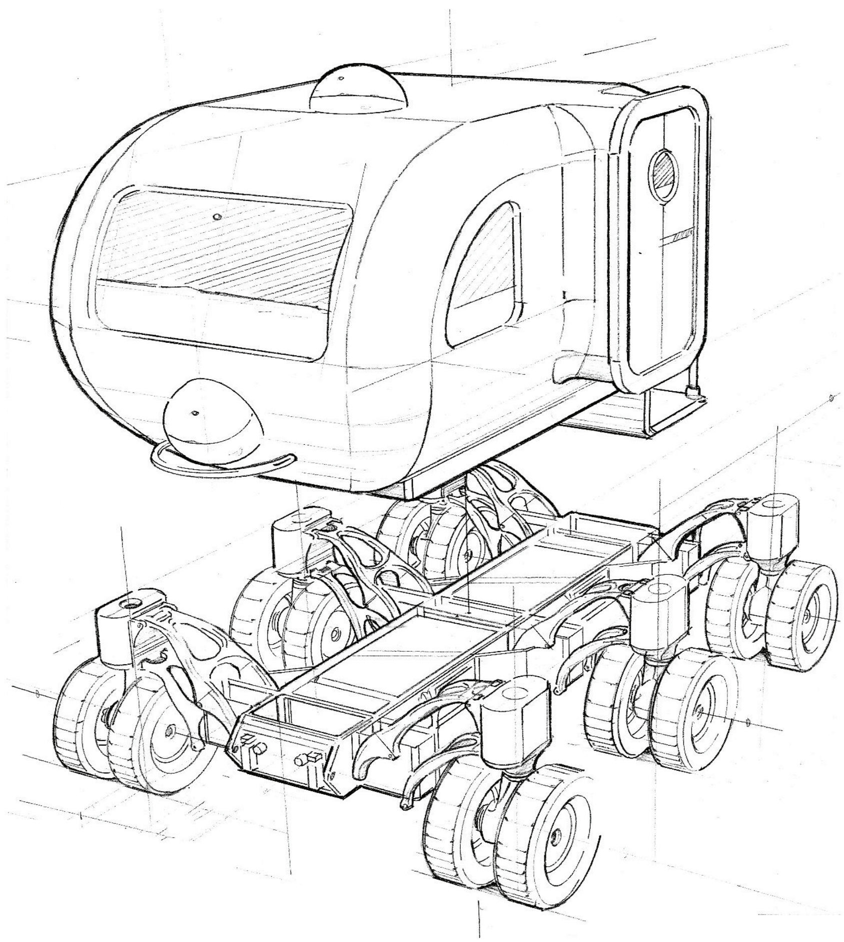


Figure 10: SPR Mobility Chassis and Module

These MC may be used with or without an SPR module attached. Indeed, the deployment of some types of habitat, logistics, power, and energy storage elements require MCs without attached SPR modules. If SPR modules are not delivered attached to MCs, they will be unloaded from their Lander onto MCs upon their arrival using the same methods used for the unloading of other payloads. In the event that an SPR module must be removed from its MC for any reason, the SPR module will rest on deployable jack-stands and the MC will lower itself down from underneath the SPR module in the same way that it drives out from under other payloads when deploying them. The chassis can then be used as a powered platform, either driven using the Aft-Driving Station (by an EVA astronaut), remotely controlled (from the habitat or earth), or linked to another SPR to provide increased payload capacity. The modular design of the SPR has exploration, operational, engineering, and architectural benefits as described in Sections V, VI, and VII.

Figure 11: Photos of Mobility Chassis Prototype

Work Package Interface

Each Mobility Chassis incorporates a common, self aligning, modular interface to which various work packages such as bulldozer blades, front loader buckets, drilling rigs, backhoes, winches, cable spools, cherry-pickers, manipulators, and cranes may be attached as shown in Figure 12. Attachment of work packages will not require EVA support.

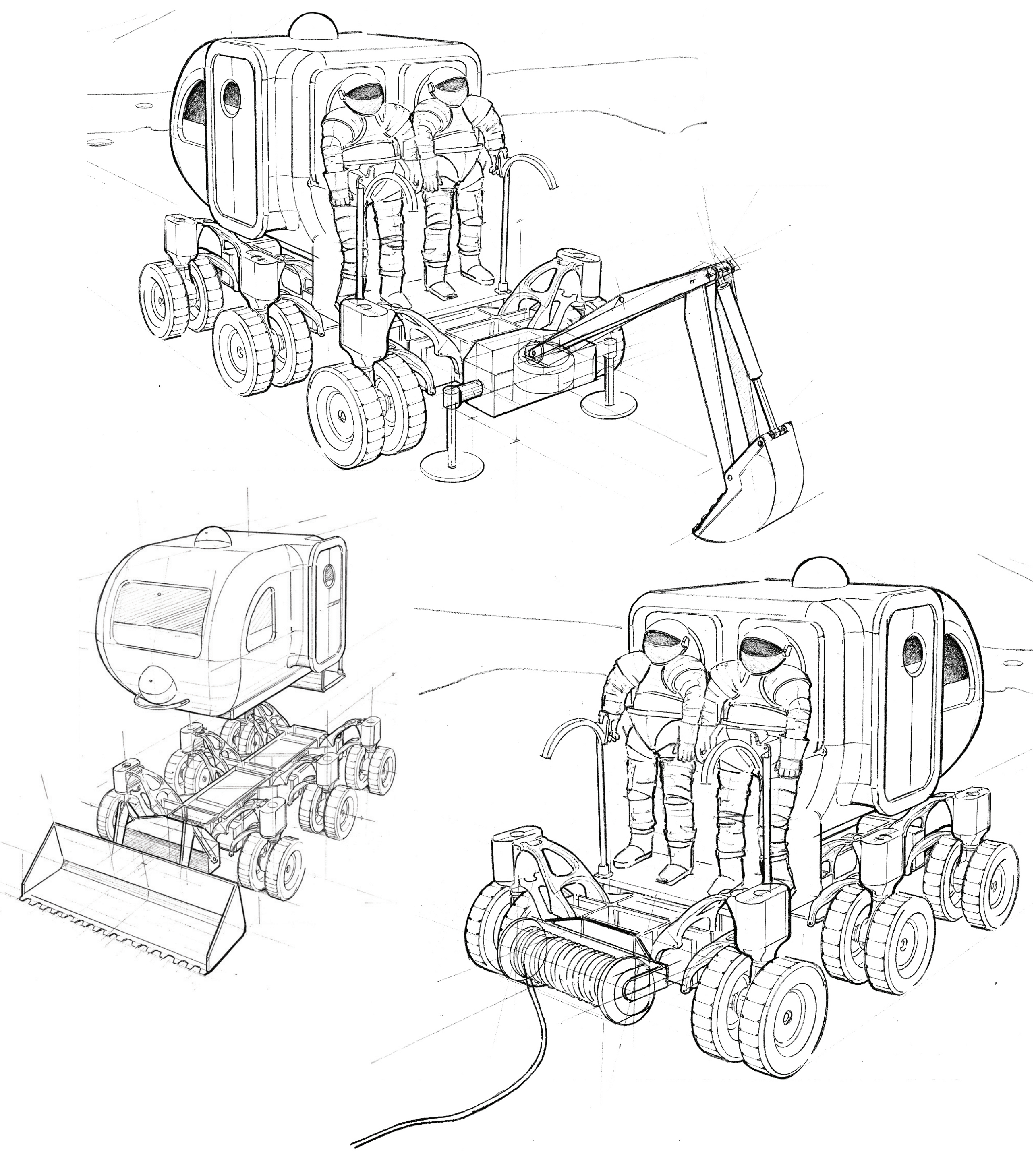


Figure 12: Work Packages on Mobility Chassis

EVA Driving Station

Mobility Chassis without attached SPR modules can operate as unpressurized rovers (UPR) where suited EVA astronauts can secure themselves to the MC and drive using an EVA Driving Station. Astronauts could also use the driving station with an SPR module attached to control the rover during suited EVA. This capability would support assembly and localized science/exploration tasks where short translations are required between EVA tasks. When using the EVA Driving Station, astronauts will be secured to the vehicle by either the suitports or possibly a dedicated support structure.

Docking Hatch

A docking hatch on the side of SPR enables astronauts to transfer under pressure into and out of the SPRs while attached to habitat modules (Figure 13), other SPRs, and possibly the ascent module. This hatch should be capable of docking or undocking in 10 minutes or less, must be capable of performing multiple dock/undock cycles every day, and must be resistant/tolerant of dust contamination.

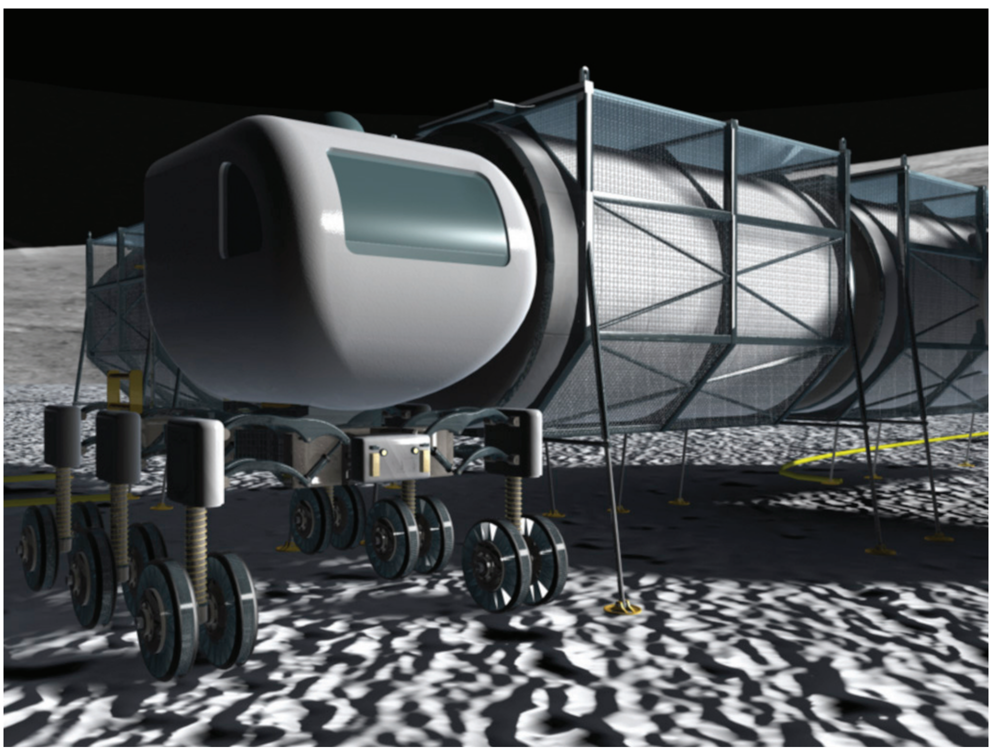


Figure 13: SPR Docked to Habitat

Dome Windows and Cantilevered Cockpit

The size and number of windows on the initial SPR concepts has been reduced due to thermal concerns. However, dome windows on the roof and at the front of the cockpit ensure that visibility from inside the SPR is at least equivalent to the visibility available to astronauts when standing in the EVA suit. The forward cockpit is cantilevered to ensure that the front of the Mobility Chassis does not interfere with visibility.

Pivoting Wheels

The design and capabilities of the Mobility Chassis are not detailed extensively in this report. However, it is important to note that the ability of the Chassis' wheels to pivot allow it to drive in any direction, which will facilitate docking of the SPRs with the habitat modules and with each other.

Exercise Ergometer

A power recharging exercise ergometer in the forward cabin recovers useful work from the cardiovascular and resistance training each astronaut performs. This ergometer in the SPR mitigates the need for an ergometer in the habitat, thus saving space and mass in the habitat and allowing the crew to exercise during unproductive traverse times.

III. SPR Functional Requirements

- Contingency return capability always available
- Nominal 2-person crew per SPR, 4-person crew in contingency
- Power-up and Check-out including suit/PLSS (Portable Life Support System) power up and check-out: ≤1hr
- Dock/un-dock from Hab/Lander:
    - ≤ 10mins
    - ≤ 0.03kg gas losses
    - Capable of several (TBD) dock/undock cycles per day
    - Robust to dust contamination
- Nominal velocity: 10kph
- Driving naked-eye visibility should be comparable to walking in suit i.e. eyes at same level, similar Field-of-View
    - Augmented by multi-spectral cameras/instruments
- Visual accessibility to geological targets comparable to EVA observations i.e. naked eyes ≤ 1m of targets
    - Possibility of magnification optics providing superior observation capability
- Suit don and Ingress/Egress
    - ≤ 10mins
    - ≤ 0.03kg gas losses per person
    - Capable of several (TBD) dock/undock cycles per day
    - ≥ 2 independent methods of ingress/egress
    - Robust to dust contamination
- Vehicle Mass (excl. mobility chassis) ≤ 2400kg
- Habitable volume: ~ < 10m^3
- 12 two-person EVA hours at 200km range on batteries and nominal consumable load
- Ability to augment power and consumables range and duration to achieve ≥ 1000km
- PLSS recharge time ≤ 30mins
- Crewmembers ≤ 20mins from ice-shielded lock radiation protection (incl. translation to Small Pressurized Rovers and ingress)
- Heat and humidity rejection provided by airflow through ice-shielded lock and condensing heat exchanger

IV. Health and Safety Advantages of SPRs

Radiation Protection

When astronaut explorers are performing EVAs, they are subject to acute radiation exposure if a significant solar particle event (SPE) occurs. The more energetic the SPE, the more important it is for the astronauts to find shelter quickly. When an SPE occurs, astronauts will always be within 20 minutes of the SPE protection provided by the mobile ice-shielded central locks on each SPR where they can remain until the SPE event has passed. The ability of an SPR to autonomously return to the habitat would also allow the crew to return in safety in the event of an extended SPE. The capability to quickly ingress the vehicle is of particular importance in this scenario. The water ice would also provide some degree of protection from harmful Galactic Cosmic Rays (GCR).

Pressurized Safe Haven for Treatment of Injuries or Decompression Sickness

In addition to providing SPE protection, the SPRs ensure that crewmembers are always within 20 minutes of a pressurized safe haven, enabling treatment for decompression sickness and expedited on-site treatment/medication of injured crewmembers. SPR will carry an expeditionary medical kit, which will provide for the needs of the crews in the event of health events from foreign objects in a crewmember's eyes to more serious medical challenges. The medical capabilities of SPR will match the standards of care mandated by NASA requirements based on the duration of the expedition and the distance from the outpost.

Reduced Suit-Induced Trauma

The SPRs are designed to provide crewmembers, while inside the SPR, the ability to make geological contextual observations comparable to walking in an EVA suit while inside the SPRs, with the visual field augmented by cameras and other instruments. Allied with the fact that the SPRs allow astronauts to perform long translations in the comfort of a pressurized cabin, the amount of time crewmembers spend inside their EVA suits may be decreased by more than 50% while enabling the same or greater "boots-on-surface" EVA time at sites of scientific interest.

For example, a 2 hour outbound drive on a UPR would allow a maximum of 4 hours "boots-on-surface" EVA time at the destination, assuming the inbound drive was also 2 hours and the maximum EVA time is 8 hours. By comparison, if the driving was performed from inside SPRs then the astronauts would have up to 8 hours of "boots-on-surface" EVA time at the destination. Alternatively, the astronauts using SPRs could spend 4 hours "boots-on-surface" EVA time and achieve the same or greater scientific and exploration productivity for 50% of the total EVA time thereby increasing the life of the EVA-suits and reducing suit-induced trauma among crewmembers.

Reduced Decompression Stress

The exploration benefits of suitports enabling fast and repeated vehicle egress and ingress are discussed in Section V. Another indirect but potentially significant benefit of the SPR operations concept relates to specific physiological effects of performing multiple short EVAs as opposed to a conventional 6-8 hour EVA. The intermittent recompressions between SPR cabin pressure (8 psi) and EVA suit pressure (4.3 psi) will reduce decompression stress with the effect that some EVAs may be performed at reduced suit pressures, increasing mobility and potentially further reducing suit-induced trauma.

Improved Nutrition, Hydration and Waste Management Options

The ability to quickly ingress the SPRs means that nutrition, hydration, and waste management functions need not necessarily be incorporated into the EVA suits. These needs can be met in greater comfort and with potentially lower EVA overhead by using the SPRs. Each SPR will contain a small heater, where standard outpost meals can be prepared. A small toilet will be available with the capability to remove most solids and other contaminants from the urine, providing a source of recycled water that can be used for other purposes within the rover. In addition, moist towelettes can be heated in the food warmer to allow crews to wash.

Exercise Capability

The exercise ergometer capability provided in the cab portion of the SPR will allow astronauts the opportunity to exercise as the SPRs travel from site to site. This exercise will supplement the exercise obtained during EVAs and may also be used to provide partial charge of the batteries of the rover.

V. Exploration Advantages of SPRs

The SPR architecture represents a fundamental change in the manner in which we perform exploration compared to Apollo-era methods. During Apollo missions the crew members were in EVA suits at all times while performing exploration functions away from the Lander. For safety reasons, the exploration forays and suits were designed so that the astronauts were always able to walk back to their pressurized Lander in the event of an emergency. Even while using the Lunar Rover to extend their range, they were always constrained by a walk-back distance from the nearest pressurized asset. Since the Rover was not pressurized, the nearest asset was the Lander. This constraint dominated the design of the exploration forays, and limited the range of exploration activities that the astronauts could perform.

Increased Exploration Range and Surface Area

Exploration range is limited by a) contingency return range, b) available consumables, or c) human factors.

By definition, the substantial mass of the various proposed Large Pressurized Rover (LPR) designs means that only one such vehicle is likely to be delivered to the Lunar surface and per current planning would not be delivered until other more critical payloads have been delivered. Indeed, in the original Lunar Architecture Team (LAT) baseline architecture the first and only pressurized rover was not to be delivered until the 17th flight of the 21 flight architecture.

Without a pressurized rover of any sort, exploration range is limited by the maximum amount of time that crewmembers can nominally spend inside the EVA suits. Assuming a maximum EVA duration of 8 hours, and a UPR average speed of 10kph, the maximum range achievable with two or more UPRs is less than 40km from the habitat. For example, to perform a 4 hour “boots-on-surface" EVA at a site of interest using UPRs, a total of not more than 4 hours is available for driving. Without any safety margin and assuming a constant 10kph driving velocity, this corresponds to a maximum range of only 20km.

With a single pressurized rover of any size, an adequately equipped UPR is required to provide contingency return to the habitat in the event of a malfunction (unless the pressurized rover operates only within walkback range). Assuming that a) the contingency UPR had adequate energy storage, b) the suit PLSSs could be recharged while onboard the UPRs, and c) the crew could drive non-stop for 24 hours at 10kph, then the maximum possible contingency return range for a single pressurized rover of any sort, even with infinite consumables, is not more than 240 km. Two or more pressurized rovers are required if exploration range is to be increased beyond 240km.

Because of the SPRs' small, lightweight and modular design and because the outpost assembly and unpressurized surface exploration tasks will require the support of multiple MCs, less than 2700kg of dedicated payload need be delivered to the lunar surface in order to achieve an exploration range of 240km. The SPRs are conceived such that their batteries and life support systems will nominally support a 3-day sortie of almost 200km. However, SPRs could extend their range by carrying additional logistics, tanks, batteries, or even Solar Power Units (SPUs) and Mobile Power Units (MPUs) as specified by the LAT-2 architecture. Extending the SPRs range in this way would not incur any additional delivered mass penalty to the lunar surface as the additional consumables would be required to support the crew at the habitat over the same time-period, and the extra MCs will already be on the lunar surface.

Figure 14: SPU/MPU Towed by SPR

Delivery of a second SPR module and towed deployable SPU/MPUs could potentially extend the range to almost 1000km based on a maximum sortie duration of 14 days. SPUs generate power that is stored by the MPU regenerative fuel cells, thereby providing the additional energy necessary to traverse beyond the distances enabled by the SPRs' batteries alone. SPU/MPUs could be towed (Figure 14) or carried on an additional Mobility Chassis. A maximum duration of 14 days would ensure that an entire sortie could be performed during one lunar day. Ongoing analysis of power systems being performed as part of the Constellation Lunar Architecture Team (CxAT_Lunar) project indicates that deployable SPU/MPUs might enable sorties lasting 43 days or more provided adequate availability of logistics. The possibility of operating SPRs with either a Mobile Habitat (depicted in Figure 15) or a low mass, low power Logistics Vehicle that would enable extended range and extended duration traverses is also being evaluated.

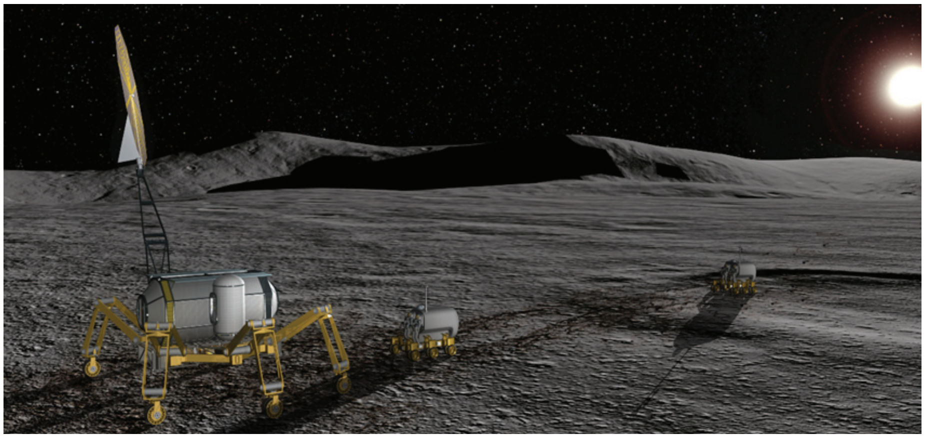


Figure 15: SPRs Operating with a Mobile Habitat

It is important to recognize that a long traverse will not be driven in a straight line. Indeed, it is likely that the effect of terrain along with margin added for safety will greatly reduce the range that can be achieved such that a driven distance of 1000km may only achieve a range of 500km or 250km from the lander. It is therefore imperative that the capabilities of surface mobility systems be maximized to afford exploration ranges significantly greater than those accomplished during Apollo.

Human factors considerations may limit the maximum acceptable sortie duration and may necessitate more frequent EVAs during longer sorties due to the relatively small habitable volume of the SPRs. Shorter more frequent EVAs may be enabled by the anticipated rapid egress/ingress to and from a SPR EVA suit. Also, the ability to easily don and doff the EVA suit should facilitate planning of single EVA astronaut tasks to be conducted in coordination with the second crewmember that remains in the pressurized volume.

Each SPR would nominally seat two crewmembers and could accommodate up to four in a contingency situation. Allowing the crews to operate in pairs, within 240 km of each other, means that different sites within the same region could be explored simultaneously such that the overall surface area explored is greater than would be possible using a single Large Pressurized Rover.

If the surface operations concept required that one or two crewmembers remain within close proximity of the ascent module at all times, the two SPRs could be crewed by as few as one person per SPR. In this scenario, the two SPRs would remain in immediate proximity to each other in order that the astronauts could always render assistance to each other within 10 minutes. In the event that one crewmember became incapacitated inside their SPR, the second SPR could dock with the first SPR allowing IVA transfer within 10 minutes. If the incapacitated crewmember was EVA, the second astronaut could egress the suitport and provide assistance as quickly as in the single-person EVA scenario described above. Alternatively, both astronauts could remain within the same SPR while the second SPR was remotely controlled so as to provide contingency return capability and possibly to perform limited scouting functions. During sleep periods, the two SPRs could be docked together providing additional habitable volume. Benefits of using fewer than four crewmembers during SPR sorties include the reduced consumables that must be carried by the SPRs and the increased habitable volume per crewmember.

Increased Exploration Flexibility

SPRs offer the possibility of performing EVAs every day. LAT-1 operational rules limited astronauts to three 8-hour EVAs per week during extended lunar missions. Because of the low overhead associated with EVAs from SPRs, there is very little extra overhead associated with performing multiple short EVAs versus a single 8 hour EVA. As such, it is possible that flight rules will allow up to 24 hours of EVA per crewmember per week rather than three 8-hour EVAs. The time spent in the suit would be dedicated to EVA mission objectives rather than predominantly spent strapped onto an unpressurized rover during traverses between sites. The versatility of the SPR/EVA combination provides the most optimal use of the EVA hours available.

Pressurized Exploration Capability Redundancy

In addition to greatly increasing the exploration range and surface area as described above, the second SPR provides redundancy that is not available with a single Large Pressurized Rover. If a Large Pressurized Rover malfunctions, exploration is limited to the range that can be covered during an 8hr EVA on a UPR (~15km). In the event that one SPR malfunctions, one SPR is still available for exploration within the UPR contingency return range (~240km). The SPR architecture provides additional redundancy because the modules can mate with any of the multiple Mobility Chassis already on the Lunar surface versus the single integrated mobility capability with the Large Pressurized Rover designs. Deployable SPU/MPUs, described above, also serve to increase contingency return range by providing recharge capability for an SPR en route back the lander.

Mixed Suit and Shirtsleeve Environments

The SPRs provide a large direct visual field augmented by cameras and other instruments to provide the ability to make geological observations in context, comparable to walking in an EVA suit but while remaining in the relatively safer environment inside the rover. Furthermore, the ability to quickly ingress and egress the SPRs will empower the crew to choose the most effective work environment for performing a task. While some in-situ science tasks will require a boots-on-the-ground EVA, many other activities would benefit from access to the small laboratory analysis tools carried in SPR and operated in a shirtsleeve environment (e.g., initial sample analysis). Activities requiring fine manipulation and unfettered visual access are best performed without the confines of an EVA suit.

Increased Availability of Scientific Sensors and Instrumentation

Designing instruments to be used by gloved astronauts from an unpressurized rover is difficult and expensive; transporting instrumentation in a mobile pressurized volume facilitates the use of standard, space-rated, scientific sensors and instruments at the work site. The availability of a shirtsleeve work environment in-situ, makes the design and selection of terrestrial field science equipment analogs relatively easy. Laboratory analysis equipment at the field site may improve the science and also reduce the mass of samples that would otherwise require transport back to the outpost. As the range of SPR sorties from the outpost increases, this mass would have increasing impact on range. Local analysis allows the astronauts to assess samples in the field, and only collect and return high value samples. Reducing the returned sample mass has implications for overall mission architecture, as sample return capability is often a strong architectural driver.

Increased Access to Difficult Terrain

The small, lightweight design of the SPRs and the capabilities of the Mobility Chassis will likely offer greater access to uneven terrain than a Large Pressurized Rover (penalized by greater mass, volume, wheelbase, etc.).

VI. Operational / Engineering Advantages of SPRs

Increased Redundancy, Reduced Mass and Development Cost

By using existing Mobility Chassis, the SPR architecture exploits surface assets delivered to the surface for assembly tasks, avoiding the cost and mass of developing and delivering a dedicated MC designed specifically for the SPRs while also providing redundancy in the event of MC failures. Using the suit PLSS as the basis of the SPR ECLSS yields similar benefits in terms of redundancy, cost, and mass savings.

Increased Suit Life, Decreased Suit Complexity and EVA Overhead

Because crewmembers are inside the SPRs during most surface translations, the overall number of in-suit EVA hours to achieve the same (or greater) science/exploration return is reduced. The possibility of performing single-person EVAs with a second crewmember inside SPR would further reduce total EVA hours during the lunar architecture to the same order of magnitude as during ISS construction. As a result, the number of cycles on the EVA suits would be decreased, thereby increasing the life of each EVA suit. However, even if maximizing productivity was preferred and total EVA hours were not reduced, there are other ways in which the SPRs may enable simplification of EVA suit design:

- Because the SPR will be providing nutrition, hydration, waste management and medical treatment capabilities, the suit system will not need to provide these functions to the same degree as would be required with an unpressurized rover.
- Use of an SPR will allow shorter EVA sorties, providing options for reducing suit weight and complexity.
- Because the need for walkback is removed by two SPRs, walkback-related design requirements could be significantly reduced or eliminated.

Although not shown in the drawings it is anticipated that the SPR would have an environmental shelter to protect the suits from the lunar enviroment when not in use.

Increased Crew Productivity during Translations

The ability to perform translations in a pressurized vehicle rather than in an EVA suit on an unpressurized rover means that better use can be made of this time: astronauts may exercise, perform limited sample analysis, conduct EVA debriefs and planning sessions for future EVAs, engage with the public, and/or write to or talk with family members on earth.

Dust Mitigation

The use of suitports (or suitlocks) should reduce the problem of dust contamination inside pressurized rovers and habitats. Although the possibility exists of bringing the suits inside the SPRs through the side hatch, suit maintenance would nominally be performed using the suitlock on the habitat to mitigate dust contamination inside the SPRs. As described in Section III, the SPR rover could incorporate suitlocks that are operated as suitports except in contingency or suit maintenance scenarios.

Mobile Airlock Capability

Each SPR also includes an exterior hatch which will mate with a habitat or with another SPR. By using this mating hatch for ingress/egress, the SPR may also be used as a mobile airlock for suit maintenance and/or contingency scenarios such as an incapacitated crewmember or a malfunctioning suitport.

Depending on Lander design, the SPR could also provide the capability to transfer under pressure to and from the ascent module. This would permit the crew to leave the suit PLSSs in the controlled environment of an SPR for reuse on later missions instead of discarding them after performing a final EVA to the ascent vehicle at the end of each mission. More importantly, this capability prevents a mission abort in the event of a single suit failure—without an airlock such as SPR, if any of the four suits is not functional on the initial post-landing check out, the Lander cannot be depressurized for EVA to the habitat.

Mars Forward

The SPR concept and its constituent technologies are highly applicable to future Mars missions. Indeed, many of the benefits described in this report are of even greater significance on Mars and the primary technology development needs for the SPRs are highly relevant to future Mars missions. The experience on the moon will help to shape and optimize operational approaches. Experience in isolating the crew from the external dust environment could be enabling for Mars missions. All of the functions envisioned for the SPR/EVA combination will be needed at Mars and can be perfected at the moon well before those missions are flown.

VII. Architectural Advantages of SPRs

NASA's Lunar Architecture Team Phase II (LAT-2) study included quantitative and qualitative evaluation of several different Lunar architectures. Several potentially enormous benefits of SPRs became apparent when quantitatively evaluated over the duration of entire Lunar architectures.

Direct Mass Savings

Four of the five architectures evaluated during the LAT-2 study include multiple Mobility Chassis, which serve as unpressurized rovers as well as surface mobility carriers for payloads. The total estimated mass of two SPR modules is 5314 kg, which is 2692kg less than the estimated mass of a single LAT-1 Large Pressurized Rover. Even if the Mobility Chassis for each SPR were included in the mass estimate, the total estimated mass for two SPR modules plus two Mobility Chassis is still 74kg less than the estimated mass of a proposed Large Pressurized Rover (LPR). The LPR mass estimate breakdown from LAT-1 and the SPR module mass estimate breakdown (excluding MC) from LAT-2 are included in Appendix 3.

Initial architectures in the LAT-2 study included two suitlock modules as part of the habitat. Because each SPR incorporates two suitports, they provide adequate redundancy so that the second habitat suitlock was deemed unnecessary. The effect of this is to either decrease the mass of the habitat or to increase the habitable volume available for other purposes. Another benefit of the SPRs docking with the habitat between excursions is that each SPR adds approximately $8m^3$ of valuable partitioned living space to the habitat when docked.

Because the LAT-2 Lander ascent module does not include an airlock (an additional 1000kg in mass), the crew would discard suit PLSSs with functional life expectancies at the end of each mission and a single suit failure could cause a full-mission abort. Crew transfers under pressure to and from the ascent module may also be feasible using an SPR, which would eliminate the need for a dedicated airlock and/or suit components and supporting hardware on each Lander. Crew could transfer under pressure from the Lander to an SPR and then from the SPR to the habitat, thus removing the requirement to bring PLSS's down on every flight, as they could be stored in the habitat.

Calculated Cumulative Mass and Time Savings

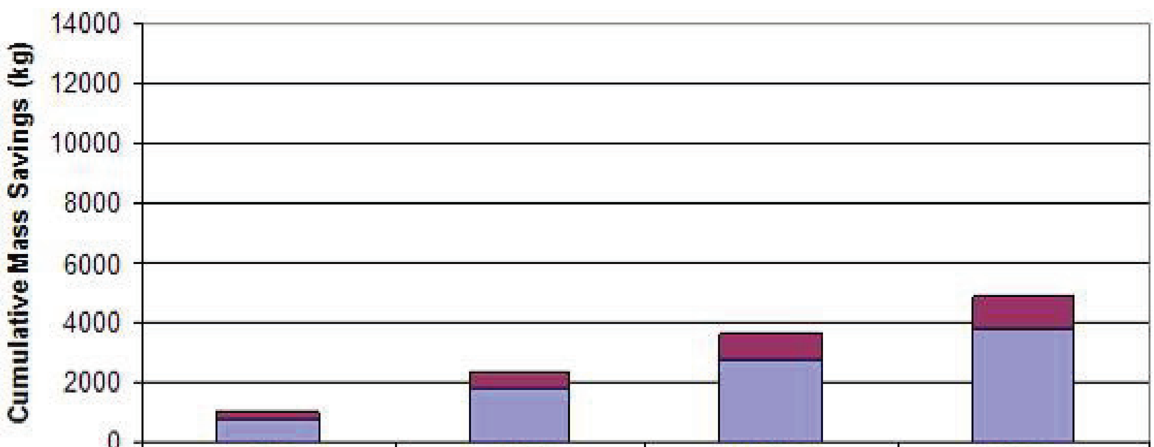
As part of the LAT-2 EVA & Surface Operations Focus Element analysis, astronauts and Mission Operations Directorate (MOD) personnel at Johnson Space Center used standard EVA planning methodology to identify and plan the EVA timelines for every assembly, maintenance and science/exploration EVA task that would be performed during the LAT-2 architecture. Based on this, and the estimates of the differences in crew time and consumables associated with suitports and fusible heat sink (described earlier in this report), estimates of the cumulative savings in terms of crew time and consumables were calculated.

By using a suitport as an alternative to a suitlock or an airlock, egress at the beginning of an EVA requires only 2 minutes from an SPR compared with approximately 40 minutes from a 2-person suitlock or airlock. When this time difference is accumulated over the 1998 projected assembly, maintenance and science/exploration EVAs in the LAT-2 Option 2 architecture, the suitports on the

SPRs provide a reduction of more than 1300kg in gas losses and a reduction in cumulative depress time of over 100 days. As described earlier, an inner hatch and appropriate procedural controls would ensure no increased risk of rover depressurization.

In addition to the several hundred kilograms of polyethylene radiation shielding that it replaces, the ice-shielded lock/fusible heat sink also offers potentially enormous consumables mass savings over the course of the LAT-2 lunar architectures. Every hour that each astronaut spends away from the habitat without a fusible heat sink incurs a cost, on average, of approximately 0.329 kg of H_2O. The LAT-2 Option 2 architecture included up to 1998 two-person EVAs over the course of the architecture, which corresponds to more than 10,000kg of water consumed by vaporizing to space for thermal management. More than 7000kg of H_2O mass could be saved, however, by melting and later refreezing ice in the fusible heat sink while the crewmembers are inside SPR instead of evaporating water and rejecting it to vacuum. If a fusible heat sink rather than an evaporator were also used in the suit PLSS, further overall mass savings would be possible. Data from EVA suit tests suggest that the extra mass of water required for a EVA suit fusible heat sink may actually improve human performance in lunar gravity because of the stabilizing benefit of increased ground reaction forces with control of center of gravity position.

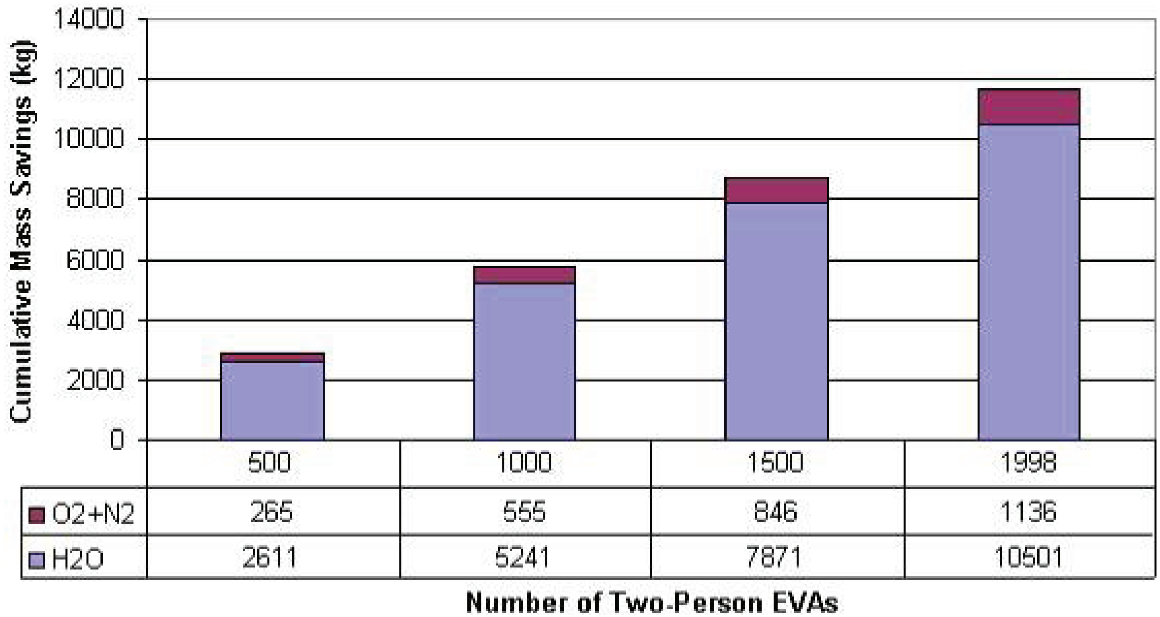
Figures 16 and 17 show the anticipated cumulative mass savings achieved through the use of suitports and fusible heat sinks in the SPR and EVA suit PLSS. The estimated savings (compared with a two-person suitlock and a conventional evaporator heat sink) depend on the number of two-person EVAs performed over the mission architecture. The maximum number of two-person EVAs (including assembly, maintenance, and science/exploration) available in the LAT-2 Option 2 architecture is 1998. The total mass savings shown in Figures 16 and 17 are calculated based on the same total number of assembly and maintenance EVAs being performed (approximately 152) but with the total number of science/exploration EVAs varying between 348 (500 total) and 1846 (1998 total).



	500	1000	1500	1998
O2+N2	265	555	846	1136
H2O	788	1779	2770	3761

Number of Two-Person EVAs

Fig. 16: LAT-2 Option 2 Cumulative Mass Savings: Suitports+SPR Fusible Heat Sink



	500	1000	1500	1998
O2+N2	265	555	846	1136
H2O	2611	5241	7871	10501

Fig. 17: LAT-2 Option 2 Cumulative Mass Savings: Suitports+SPR Fusible Heat Sink+PLSS Fusible Heat Sink

VIII. Public Engagement Advantages of SPRs

The SPR concept should significantly expand opportunities for public engagement and interaction with astronauts on the lunar surface. The SPRs will enable early exploration and discovery with high quality capabilities early in the lunar campaign. This will excite stakeholders with valued results and virtual experience. The range of distances that can be traversed will offer many opportunities to view inspiring lunar features. Views of the Earth above the lunar horizon are in sight much of the time in the Polar Regions providing many opportunities to reflect on the magnificence of our own planet.

The SPR concept will often be used in pairs. The cameras on each vehicle will provide unique views of the other vehicle and of astronauts in EVA suits in the context of their surroundings. An example of this type of image is shown in Figure 18.

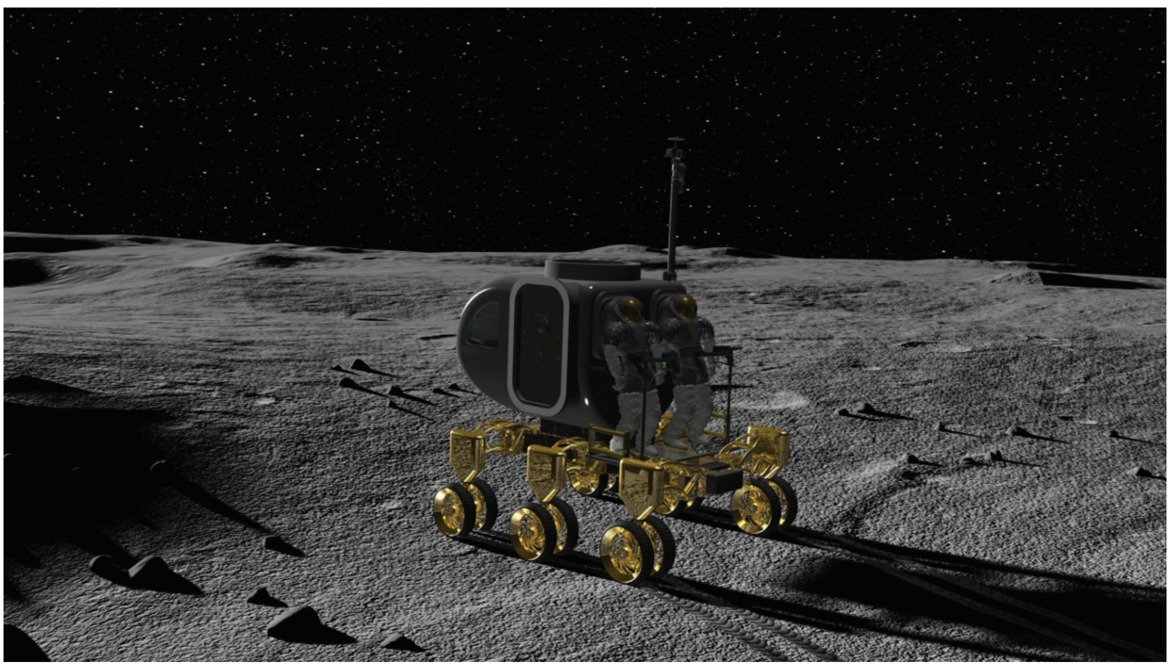


Figure 18: Viewing an SPR from the Second SPR

Additionally, the cabin's shirtsleeve environment will allow public observation of the astronauts' activities in a way not possible when the astronauts are in EVA suits. The astronauts' personal reactions to unexpected discoveries and potential problems will provide a degree of human connection, interest, and drama not present in any previous NASA exploration activities.

The SPR concept, with its on-board analysis capability should create scientific interest in people all ages. Watching astronauts perform in-situ analysis is very different than awaiting results announced at a later time. The deliberation with the science community on Earth about the significance and meaning of individual rock samples selected by the astronauts provides a much more engaging and realistic view of scientific inquiry than a press conference announcing even the most important findings. It is hoped that this engaging process will attract young minds to seriously consider careers in science and engineering.

The American public expects innovation in design and engineering from NASA. The SPR will captivate the public and be appreciated as a large step forward in exploration vehicles and operational concepts.

IX. Summary

The Small Pressurized Rover concept represents a significant advance in the way in which human planetary surface exploration can be conducted. This is accomplished by taking an integrated view of crew, EVA, and mobility capabilities. The operational approach envisioned will provide the most efficient and effective use of EVA time and resources. This approach maximizes mission return, while reducing wear and tear on crews and space suits. The SPR concept will minimize EVA prep time and crew exposure to lunar dust. As has been explained in detail in this report, creative use of SPRs in lunar surface exploration offers a broad range of health and safety advantages for the astronauts, including radiation protection during SPEs, reduced suit-induced trauma, and a pressurized safe haven for treatment of injury or illness. The SPRs also provide exploration advantages such as increased exploration range, the flexibility of both shirtsleeve and EVA suit environments, and increased availability of scientific instruments. Additional operational, engineering and architectural advantages include increased system redundancy, reduced mass of assets to be transported from Earth to the planetary surface, and astronaut productivity (e.g., exercise, planning) during transit from one exploration to another.

A number of these advantages are portrayed in Appendix-4 through “day-in-the-life” scenarios that might take place as a result of this unique approach to lunar and planetary surface exploration.

X. Appendices

Appendix-1: Blue Sky Participants

1. Alessandro Acquisti, CMU
2. Dave Akin, University of Maryland
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4. Dave Blakely, IDEO
5. Amy Bolton, Strategic Analysis
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8. Larry Cheng, IDEO
9. Bill Clancey, IHMC/NASA
10. Doug Cooke, NASA
11. Ken Ford, IHMC
12. Michael Gernhardt, NASA
13. Michael Goodrich, BYU
14. John Grunsfeld, NASA
15. Peter Hancock, UCF
16. Jack Hansen, IHMC
17. Butler Hine, NASA
18. Robert Hoffman, IHMC
19. Joseph Kosmo, NASA
20. Dava Newman, MIT
21. Anil Raj, IHMC
22. Leah Reeves, Potomac Institute
23. Dylan Schmorrow, ONR
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Study Support Staff

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- Alexander Moore

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Constellation Office
- Dean Eppler

EVA Systems Project Office
- R M (Mike) Hembree

Appendix-3: SPR and LPR Mass Estimates

Master Equipment List for Small Pressurized Rover

Updated: 2/07/08

Description	Mass (kg)	Inside/Outside	Basis of Estimate
Structure	846		
FRED Pressure Vessel	411		Dorsey Mass Analysis
Suit Port Inner Hatches	55	Inside	Estimate needs verification
Side Hatch	55		Scaling shuttle hatch
Mating adapter	90	Outside	Estimate needs verification
Equipment/Sample Lock	135	Inside	Estimate needs verification
Windows with visors	100	Outside	1" thick Lexan w/ 3" x 2" structural frame
ECLSS (inc. WCS)	1160.3		Analysis (See Charts)
PLSS x2	90	Inside	
Battery	500	Outside	Analysis-Lithium Ion Battery
Pressure Control System	36.2		
Nitrogen Solenoid Valve	1.34	Inside	ISS
Nitrogen Step-Down Reg x2	0.9	Inside	ISS
Nitrogen Introduction Valve	1.34	Inside	ISS
N2 Relief Valves x2	10.8	Inside	ISS
N2 Pressure Transducer	0.14	Inside	ISS
PCS Panel	11.2	Inside	ISS
CO2 sensor	0.78	Inside	
O2 sensor	1.82	Inside	
Total Pressure Sensor	0.14	Inside	
Positive Pressure Relief Valve	3.2	Inside	
Equalization Valve	4.5	Inside (on central hatch)	
Thermal Control and Ventilation	87.3		
Ice/Condensing Heat Exchanger	34.02	Outside (in water jacket)	
Water Loop CHX	11.7	Outside (in water jacket)	
Radiator	36.01	Outside	
Solenoid Valve CHX bypass	1.34	Inside	
Ventilation Fan x2	4.2	Inside	
Solid Waste System	17.6		
Toilet seat interface	3.4	Inside	CEV 605 ECLSS MEL
Canister, Covers, and Supplies	4.2	Inside	Shuttle EDO Potty from Jim Broyan's CEV Consumables Planning
Odor & Bacteria Filter	3.2	Inside	Use cabin fan to duct through
Ventilation Fan	6.8	Inside	CEV 605 ECLSS MEL
Urine Collection & Venting	12.3		
Urinal	4.55	Inside	ESDM, simpler than CEV
Collection Tank	4.3	Inside	Scaled down CEV 605 ECLSS MEL (2 CM, 1 vent/half day)
Urine Vent Kit (Line & Htr)	0.4	Inside	CEV 605 ECLSS MEL
Vacuum Isolation Valve x2	3	Inside	Liquid Solenoid
Potable Water	19.8		
Water Dispensing Unit	18	Inside	CEV 605 Crew Systems MEL
Hot Water Heater	1.8	Inside	CEV 605 Crew Systems MEL
Fluid Tanks	46.9		
Potable Water Tanks	16.59	Inside	
Cooling Water Tanks	15	Inside	
O2 Tanks	14.2	Outside	
N2 Tanks	1.1	Outside	
Fluids, Gases & Ice	305.3		Analysis (See Charts)
Potable & PLSS Water	33.2	Inside	5 kg comes back as condensate during 3 day mission
Rover Cooling Water	30.0	Inside	
O2	14.2	Outside	
N2	1.1	Outside	
Ice	226.8	Outside	
ECLSS Spares	45		Analysis (Extra PLSS)

Master Equipment List for Small Pressurized Rover (contd)

Updated: 2/07/08

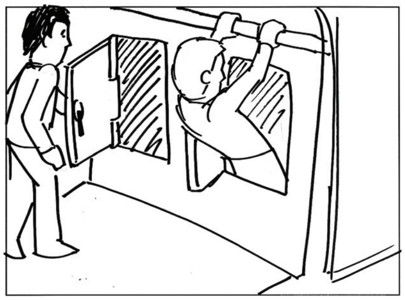
Description	Mass (kg)	Inside/Outside	Basis of Estimate
IV Equipment	182.3		
Food Locker	3.4	Inside	COTS analogy
Trash Receptacle		Inside	
Clothes Locker	3.4	Inside	Estimate needs verification
Chairs/Benches	27.2	Inside	Estimate needs verification
Power Conditioning	68	Inside	Estimate needs verification
Fire Extinguisher	2.3	Inside	COTS analogy
Science Kit	5	Inside	
Small Tools	2.3	Inside	Estimate needs verification
Medical Kit (lightweight trauma module)	tbd	Inside	
Cameras x2	2	Inside	
Privacy Curtains	0.7	Inside	Estimate needs verification
Internal Lights	3	Inside	Estimate needs verification
Plumbing & Servicing Panel	45	Inside	Estimate needs verification
Ergometer Charger	20	Inside	Estimate needs verification
Avionics:	101.3		
S-Band 802.16 Xcvr	3.6	Inside	Kevin Somervill
S-Band Xponder	3.6	Inside	Kevin Somervill
EVA Airlock Interface Panel	4.1	Inside	Kevin Somervill
Workstation Displays x 2	18	Inside	Kevin Somervill
Workstation Keyboards x 2	2.7	Inside	Kevin Somervill
Hand Controller x 2	4.5	Inside	Kevin Somervill
Trans Contoller x 2	4.5	Inside	Kevin Somervill
Operational Computer x 2	15.4	Inside	Kevin Somervill
Operational Computer (1) x 2	10.6	Inside	Kevin Somervill
Video Recorder	4.1	Inside	Kevin Somervill
Data Recorder	6.5	Inside	Kevin Somervill
External Camera x 2	3.5	Outside	Kevin Somervill
Buses and Cabling (25%)	20.3	Inside	Kevin Somervill
External Masses:	86.8		
External Lights	9.1	Outside	Estimate needs verification
Tool Rack	6.8	Outside	Estimate needs verification
Unpressurized Stowage	15.9	Outside	Estimate needs verification
Aft Cabana (unpressurized)	55	Outside	Estimate needs verification
Margin (30%)	621.4		
Total w/o Margin	2377		Kg
TOTAL (inc. 30% Margin)	2998		Kg

Large Pressurized Rover Mass Breakdown (LAT-1)

Description		Mass (kg)
1.0	Structures	2169
2.0	Protection	500
3.0	Propulsion	0
4.0	Power	1150
5.0	Control/CC&DH	63
6.0	Avionics	14
7.0	Environment	2500
8.0	Other	195
9.0	Growth	1415
Dry Mass		
10.0	Non-Cargo	0
11.0	Cargo	0
Inert Mass		
12.0	Non-Propellant	0
13.0	Propellant	0
Total Mass		8006

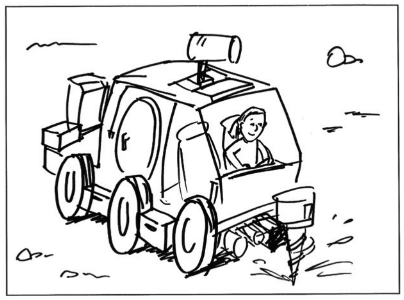
Appendix-4: Day-in-the-life Scenarios for SPR Architecture

Description of SPR: A Modular System



The SPR system consists of modular components for the vehicle as well as the science and exploration tool packages.

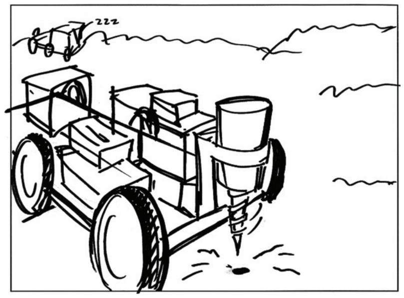
One module is a cockpit/ suit-port/ suit-lock/EVA suit



The SPR system consists of modular components for the vehicle as well as the science and exploration tool packages.

One module is a powered chassis.

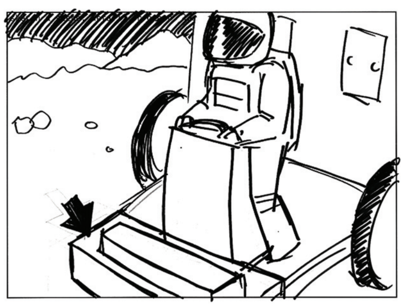
One module is an interchangeable tool package



Reconfiguration for the chassis and tool packages will not require special tooling or dedicated EVA support.

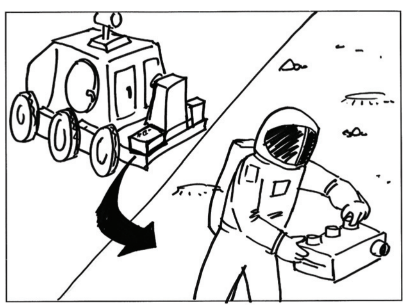
Ideally, the connections and interfaces will be self-guiding and hermaphroditic with broad tolerance for initial misalignment.

The chassis can detach from the crew compartment and lock, so that the chassis can be used as powered platform.



The SPR system consists of modular components for the vehicle as well as the science and exploration tool packages.

One module is a rear control station, so that astronauts can drive the rover during EVA.



With the mobility implied by the SPR architecture, emergency shelter and support can be less than an hour away, even for challenging terrain.

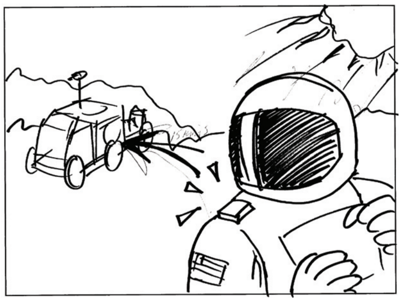
This enables a far greater range of terrain access, which leads to much more productive science return.

The on-board analysis capability should create scientific interest in all ages.

Watching astronauts do on-site analysis is very different than awaiting results announced at a later time.

The deliberation with the science community on Earth provides a more engaging and realistic view of scientific inquiry than a press conference.

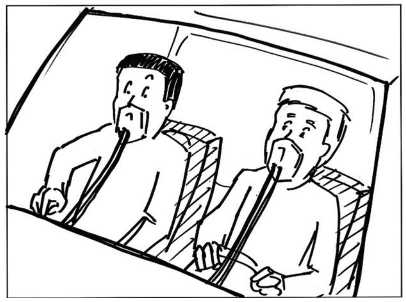
Health & Safety Advantages of SPR



The greatest risk to human explorers on the lunar surface is the risk posed by unanticipated solar particle events.

With a heavily shielded suit lock area, SPR provides a handy “storm shelter” for the exploring crewmembers.

In addition the ability of SPR to autonomously return to the Outpost can allow the crew to return in safety in the event of an extended SPE.



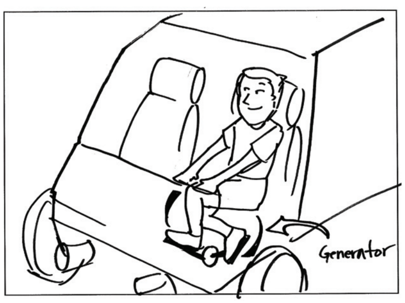
The atmosphere of SPR will be optimized to allow EVA’s without the need for prebreathe.

The combination of a low cabin pressure (8 psi) with an enhanced oxygen partial pressure will allow for EVA as soon as the rear hatch is closed and leak checks are completed.

SPR will provide aspects of habitability that were not available to the Apollo astronauts, even in the Lunar Module.

The SPR will contain a small heater, where Meals-Ready to Eat can be prepared for the explorers

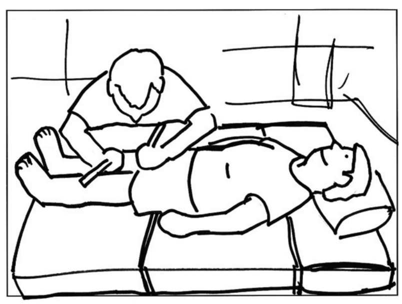
In addition, moist towelettes can be heated in the food warmer to allow crews to wash up after a long day exploring



An exercise bike capability will be provided in the cab portion of the SPR to allow astronauts to exercise as the rover travels from site to site.

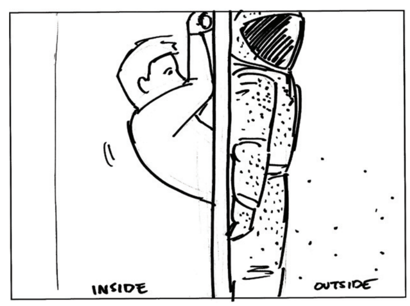
A power recharging ergometer recovers useful work from the cardiovascular and resistance physical conditioning each astronaut must perform.

This exercise will supplement the exercise obtained during EVAs, and could be used to charge the batteries of the rover.



SPR will also carry an expeditionary medical kit, which will provide for the needs of the crews in the event of health events from foreign objects in a crewmember’s eyes to more serious challenges.

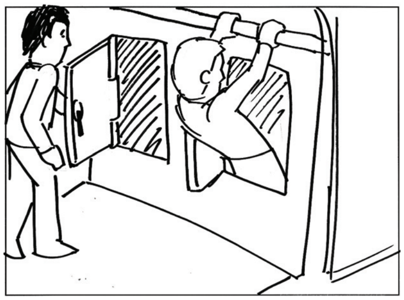
The medical capabilities of SPR will match the standards of care mandated by NASA requirements based on duration of the expedition and the distance from the outpost.



The crew lock will minimize the loss of consumables when it is depressurized for EVA, extending duration of an SPR sortie.

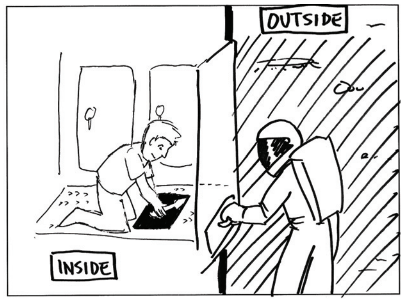
The crew-lock will also allow the crew to enter and exit the EVA suit while never having to bring the majority of the suit inside, keeping the internal space mostly free of dust.

Exploration advantages of SPR



The SPR vehicle is pressurized and contains life support systems, which can sustain the crew for multiple days.

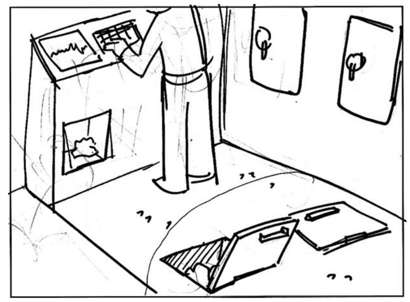
SPR allows a nearby-pressurized resource with rapid EVA ingress-egress cycle times during exploration activities, or emergencies



SPR allows mixed EVA and shirtsleeve environment: the crew is able to choose the most effective work environment for performing a task.

There are many activities, such as initial sample analysis, which can best be performed in a shirtsleeve environment with small laboratory analysis tools.

Activities requiring fine manipulation and unfettered visual access are best performed without the confines of an EVA suit.

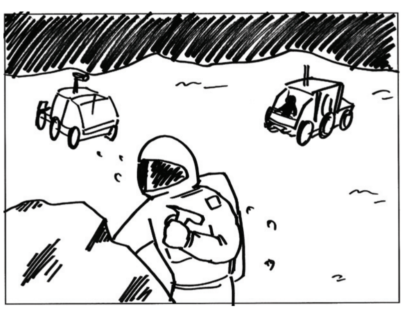


SPR allows the availability of small laboratory analysis tools at the work site.

A shirtsleeve work environment makes such tools relatively easy to design following that of terrestrial field science equipment.

Local analysis allows the astronauts to assess samples in the field, and only collect and return high value samples.

Public Engagement Advantages of SPR

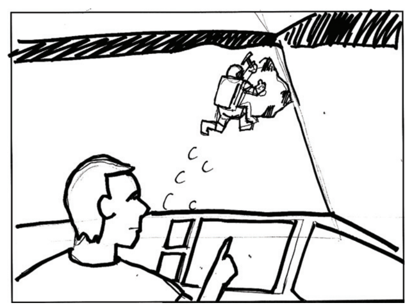


The design of the vehicle and its use in pairs and in coordination with the habitat and other exploration assets is dramatically different from Apollo missions, or any other human exploration activities in extreme environments on Earth to date.

Public interest in this new mode of human exploration will be very high.

That the astronauts will be in a shirtsleeve environment will allow public observation of their activities in a way not possible when they are in EVA suits.

Such human reactions as to unexpected discoveries and potential problems will provide a degree of human connection, interest and drama not present in any previous NASA exploration activities.



An advantage of the SPR concept is the fact that the vehicle will often be used in pairs.

This will allow the cameras on each vehicle to provide unique views of the other vehicle and of astronauts in EVA suits in context.

Such views of human activity should generate a substantial level of public interest and engagement.