Challenges, Considerations, and Opportunities for Exercise and Medical Accommodation Inside a Small Pressurized Rover

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Pressurized Rovers (PR) can enable crew to explore away from a lander or surface habitat at distances not possible on foot or even in unpressurized rovers. Sustaining crew for multiple days, they can rove for weeks, independent of other surface elements. Because these are essentially mobile habitats, it is critical that they provide sufficient volume to accommodate the exercise and medical systems to maintain human health in remote, low gravity environments such as the Moon and Mars. This is an area of extensive unknowns as requirements have not yet been developed for exercise or medical systems in pressurized rovers. Yet they must be considered in vehicle sizing studies as they are significant volume drivers, requiring allocation for stowed and deployed hardware inside the rover cabin. Previously flown spacecraft have allocated varying amounts of volume based on the expected crew mission and the state of the art in these systems. NASA-STD-3001 provides high-level requirements for standards of medical care and exercise capabilities. Crew injuries are possible both inside the cabin and on extravehicular activities (EVA), therefore requiring medical capability. Exercise countermeasures are needed to counteract the debilitating effects of lowered gravity. This may include both reconditioning following a lengthy microgravity transit as well as ongoing countermeasures against the effect of low surface gravity. The NASA reference concept for the PR dates back to the Constellation Program and prototypes have been extensively tested in NASA's Desert Research and Technology Studies (DRATS) program as well as at the NASA Johnson Space Center. The PR cabin is designed to accommodate two crewmembers and is subdivided into a forward cockpit area and a main body for crew habitation. EVAs are accomplished by transitioning through suit ports in the aft bulkhead into spacesuits. While no exercise devices have been developed for the PR, some have been prototyped and demonstrated in DRATS analog missions. A cycle ergometer performed reasonably well in DRATS testing as an aerobic exercise device and recent analysis work has theorized that a combination aerobic and resistive device could be packaged into a form factor similar to the DRATS ergometer. It is therefore suitable for use as an initial volumetric placeholder. No sensorimotor devices have been considered for the PR to aid in adaptation to surface gravity. However, there are commercially available treadmills that at minimum represent examples of the type of exercise system that could potentially be used for such a purpose. A combination of field test data, analysis, and CAD modeling will be used to perform a first pass assessment of whether these exercise devices can be stowed and deployed within the PR. Medical inventories from the International Space Station will be used as a

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volume placeholder for the PR medical system. A configuration will be discussed for medical deployment, including positioning of caregiver, patient, and medical equipment / supplies.

I. Nomenclature

AEC	=	Advance Exercise Concepts
CTB	=	Cargo Transfer Bag
DRATS	=	Desert Research and Technology Studies
DSH	=	Deep Space Habitat
EVA	=	Extravehicular Activities
ExMC	=	Exploration Medical Capability
HAL	=	Habitable Airlock
HLS	=	Human Landing System
HMS	=	Health Maintenance System
HMTA	=	Health and Medical Technical Authority
ISS	=	International Space Station
JSC	=	Johnson Space Center
LEO	=	Low Earth Orbit
LER	=	Lunar Electric Rover
MED-2	=	Miniature Exercise Device-2
MHR	=	Maximum Heart Rate
MMSEV	=	Multi-Mission Space Exploration Vehicle
NEA	=	Near-Earth Asteroid
NHV	=	Net Habitable Volume
PR	=	Pressurized Rover
SH	=	Surface Habitat
SPTM	=	Suit Port Transfer Module
T2	=	Second Treadmill
VO_2 Max	=	Maximal Oxygen Consumption
WCS	=	Waste Containment System

II. Introduction

In human spaceflight, countermeasures encompass physiological and nutritional health, physical fitness, and mission performance.[1] Countermeasures are specifically defined as, “any procedures, medications, devices, and other strategies designed to keep astronauts healthy and productive.” [2] Aboard the International Space Station (ISS) the large pressurized volume allows for extensive suites of equipment onboard the spacecraft to accomplish these goals, but smaller spacecraft are more limited in their options. It is well known that the absence of gravity is a key contributor to the need for countermeasures and it is not known if the one-sixth gravity of the Moon is sufficient to prevent the physical changes induced by the absence of gravity.

This paper will focus on accommodating volume intensive countermeasures in the Pressurized Rover. As such, the scope of countermeasures considered in this paper are those requiring significant quantities of stowed and deployed hardware or operator volume in the Pressurized Rover (PR) cabin. Exercise is the primary volume-driving countermeasures system and it is expected to be a significant volume driver inside the cabin.

Medical care is another significant human health system likely to impose substantial volume demands upon the PR. While medical autonomy is a major concern for human spaceflight, to an extent for missions to the Moon and even more so for missions to Mars, there is also a very practical question of what amount of medical hardware can physically be placed within a PR or be used by the crew in such a confined volume?

This topic is important as NASA and its partners work to define what type of PR should be used on the lunar surface, and the NASA Health and Medical Technical Authority begins the process of determining what exercise and medical requirements should be applied to the PR. Many key considerations have been captured in prior testing and several unknowns have been identified for future assessment. It is hoped that this data can help NASA planners to avoid either prescribing equipment that simply cannot be contained within the PR volume or declining to prescribe necessary systems out of a misplaced fear that such items are too large for the spacecraft. It should be noted that the

cabin volume is constrained by the PR's mission. Mass (indirectly related to volume) has a driving constraint on vehicle energy consumption, ultimately impacting both operating range and time of operation between recharges. (The rover is a battery powered, solar charged vehicle.) Thus, it is important to maximize performance within the available volume.

This paper will focus strictly on human factors and habitability considerations for exercise and medical systems – stowage, operational use, etc. It will not discuss the physiological effectiveness of exercise or medical systems nor the mechanical reliability of associated hardware, as those are out of scope of this assessment.

III. Exercise Countermeasures and the Pressurized Rover

NASA has been prototyping PR concepts since the mid-2000s and exercise countermeasures have always been a major functional design requirement for every version of the spacecraft, whether intended as a planetary surface rover, Habitable Airlock (HAL), lander or ascent vehicle, or any other PR-derived system. During the Constellation program, exercise systems were important as the PR could operate for up to two weeks away from the surface Outpost, but it was never further away than a 24-hour drive. But in the current Artemis mission concepts, it is possible for the PR to be the only habitable element on the surface, making the PR exercise system even more important.

Current Artemis mission manifests deliver the PR to the lunar surface prior to the Surface Habitat (SH) and it is conceivable that SH launch delays or other incidents could allow for a roughly 30-day lunar surface mission with only the PR present. Additionally, current Mars mission concepts include missions where short surface stay missions utilize a PR as the sole habitable element for a 30-day surface mission.

There is significant interest in identifying a common answer for exercise system for both the Moon and Mars. Questions are often raised (without clear answer) as to the effectiveness of surface extravehicular activities (EVAs) in a way to reduce needed exercise for crew. It is well known that long durations in microgravity will decondition the crew. This includes impacts to cardiovascular health, sensorimotor skills, bone loss, and physical strength.

IV. PR Reference Concept

Even with the earliest NASA PR concepts, exercise was always an important consideration. Vehicle designers wanted an exercise bike capability in the forward portion of the vehicle that would allow a crewmember to exercise as the rover traveled from site to site. A power recharging ergometer provides cardiovascular physical conditioning while generating a charging capability for the rover batteries, illustrated in Fig. 1. As the rover design evolved into the Lunar Electric Rover (LER) prototyped as the GEN 1A and GEN 1B vehicles, so did the exercise capability and location, with initial thoughts shown in Fig. 2.



Fig. 1 Early Concept Design of Using an Ergometer for Exercise and Battery Charging

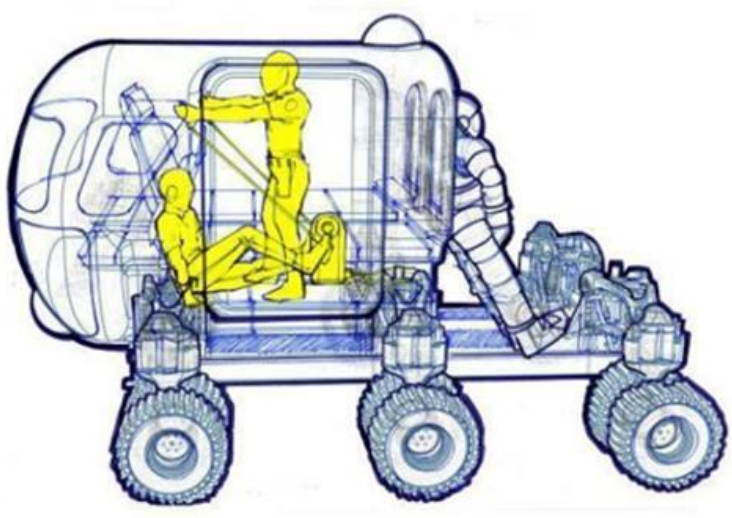


Fig. 2 Early GEN 1 Rover Exercise Designs

The LER prototypes constructed for field trials were considered medium fidelity functional vehicles. They provided a simulation of the actual spaceflight vehicle cabin's ability to provide a safe haven from the hazardous environment of the lunar surface, a living area for multi-day missions away from the lunar outpost, and a rapid EVA deployment system for scientific exploration of the surface. Using CAD of Cabin 1A's interior volume, the total pressurized volume is calculated at 10.8 m^3 (381.4 ft^3) with a net habitable volume (NHV) of approximately 8.6 m^3 (303.7 ft^3), resulting in about 79% functional volume. For Cabin 1B, the total pressurized volume is calculated at 11.9 m^3 (420.2 ft^3) with a NHV of approximately 9.7 m^3 (342.6 ft^3) resulting in about 85% functional volume. The difference between the two rover cabins is due to the extra 1.06 m^3 (37.4 ft^3) of volume from second side hatch which was a design modification for Cabin 1B after the 2008 field trials. [3] Net Habitable Volume is defined as the total remaining volume available to crew after accounting for the loss of volume due to equipment, stowage, and any other structural inefficiencies (nooks and crannies) which decrease functional volume. [4] Larger than the unpressurized Apollo rover, the LER is capable of multi-day sorties and was used as such in multi-day field tests during the Desert Research and Technology Studies (DRATS), shown in Fig. 3. Both rovers are broken into two basic task areas: the cockpit area that extends from the nose to the back of the seats; and the aft section, which extends from the back of the seat to the aft bulkhead. Differences between Cabin 1A and Cabin 1B are minor in structure but substantial with regard to suit port operations, interior stowage, docking aspects, cockpit layout, sleep station assembly and stowage, and aft enclosure operations.



Fig. 3 LER Cabin 1A (foreground) and Cabin 1B (background) During Dual Operations at DRATS 2010

V. Exercise Device Reference Concepts for the LER

During the DRATS trials, two exercise devices were studied: 1) The Cycle Ergometer and 2) The Air Spring Rower, both of which are shown in Fig. 4. These devices were fully operational prototype devices and were used by the test crews during the DRATS field expeditions.



Fig. 4 Cycle Ergometer (left) and Air Spring (right).

At the time, there were very few requirements imposed on the design teams. The functional requirements imposed by the rover team for the exercise system were:

1. Device shall be stored in a single Cargo Transfer Bag (CTB) measuring 50cm x 42cm x 25cm (19.7 x 16.5 x 9.8) inches
2. Device setup shall take up to 5 minutes
3. Device shall bolt to a specific rover floor panel
4. Device should be simple to use for both aerobic and resistive exercise
5. Device shall produce TBD power to charge rover batteries
6. Device shall be disassembled in less than 5 minutes

A requirement for the Humans Systems Integration Requirement (MPCV 70024) document was added as well. Requirement HS6032 speaks to exercise capability for a crew and states: "*The system shall provide the capability for aerobic and resistive exercise training for 30 continuous minutes per day per crewmember for missions greater than 8 days.*" [5]. The rationale for the requirement was to be able to maintain the crew's cardiovascular fitness to aide in ambulation during gravity transitions and to minimize fatigue. Exercise would also maintain a crewmember's muscle mass and strength for recovering from strenuous tasks, confined postures and to be able to rehabilitate from minor muscles injuries.

A. The Cycle Ergometer

NASA Johnson Space Center's (JSC) Advanced Exercise Concepts (AEC) Project in collaboration with the contractor ZIN Technologies developed a ground prototype cycle, simply called the ergometer, based on current exercise technology. The ergometer, shown in Fig. 5, allowed field test crews to perform several adjustable loading modes of exercise as well as provide a means of power generation for the rover. There are three modes that the crew could select while using the ergometer: cycle mode, upper body resistive mode, and supplemental exercise mode [6].

In the cycle mode, the device provides the same basic aerobic workout as a commercial exercise bicycle. The user spins the pedals against a resistance that is created electronically and is controlled either by increasing or by decreasing

the resistive level (0-10) on the front panel of the ergometer, visible in Fig. 6. The resistance created is a function of the crewmember's speed and the load setting; thus, the faster one pedals, the harder it becomes at any given load.

During a workout, the crewmember can generate a maximum current load of 280 watts (W) of electrical output power. The upper body resistive mode gives concentric loading only for the upper body exercises. The load can be adjusted from 7.3 to 36.3 kg (16 to 80 pounds) with a maximum extension of 142 cm (56 inches). The user can attach handles to the strap protruding from the ergometer and adjust a knob on the front to vary the load. Exercises such as front squats or standing curls can be accomplished by the crewmember. Finally, the supplemental exercise mode consists of additional attachment points and elastic bands so that upper body exercises can be completed independently of cycling.

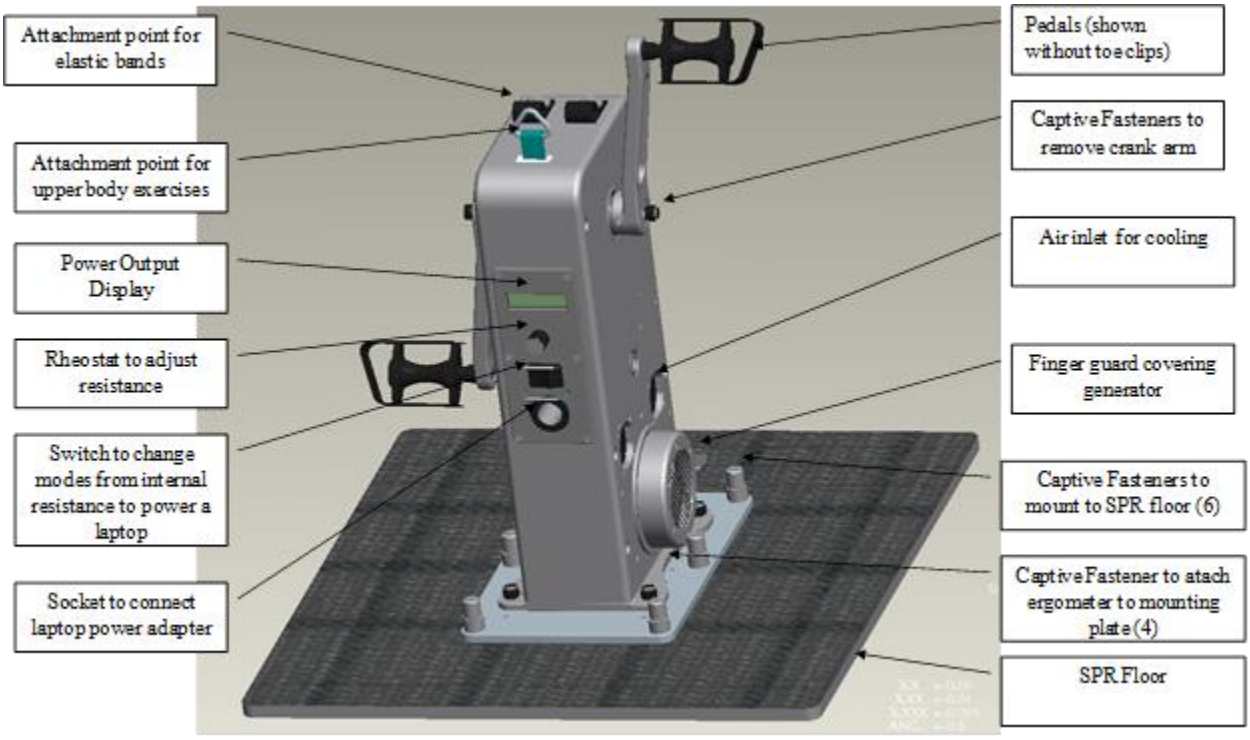


Fig .5 Ergometer Exercise Device Developed by NASA and ZIN Technologies.

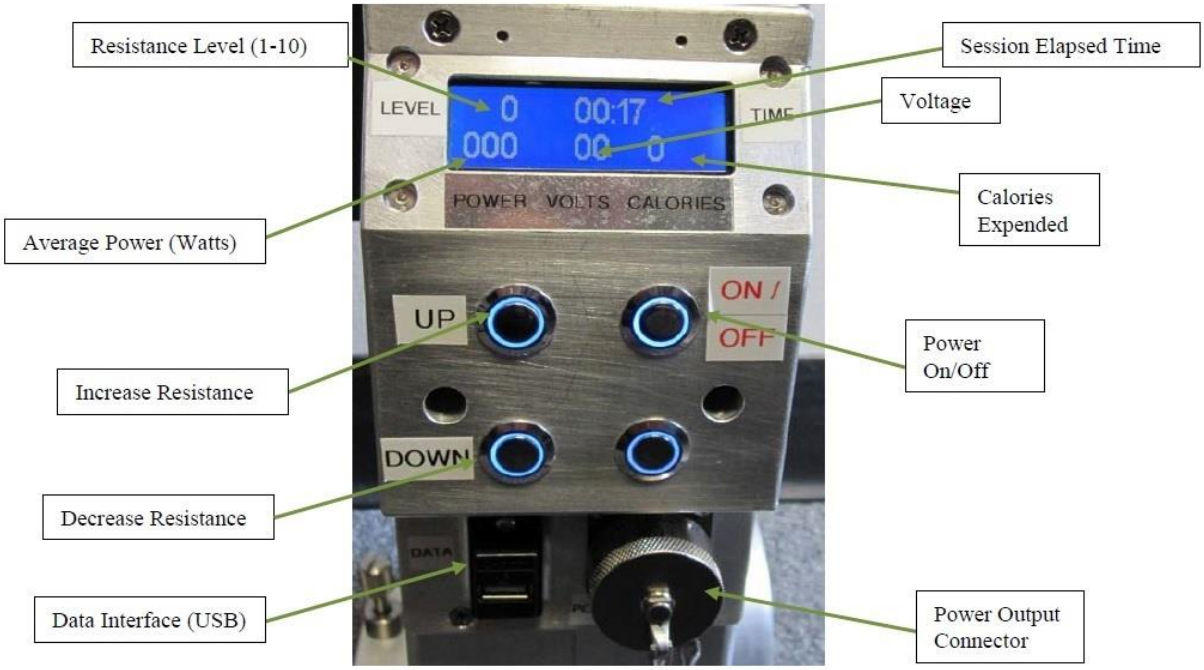


Fig. 6 Ergometer Display Facing the Operator.

B. The Air Spring Rower

Another AEC project, the Air Spring Rower, shown in Fig. 7, was originally developed as a ground prototype to meet the basic mass/volume/power requirements for the Crew Exploration Vehicle Constellation Program. When the Constellation Program was canceled, the LER team wanted to see if the small rower could be used in the rover as an alternative to the ergometer. The exercise device can provide a number of resistive exercises, such as squats, calf raises, dead lifts and upper arm curls, etc., from its single strap output position with a total stroke of 91.4 cm (36 inches) [7].



Fig. 7 Air-Spring Rowing Exercise Device Developed by NASA and ZIN Technologies.

VI. VII. Field Testing the Exercise Concept Devices in the LER

C. The Rover Setup and Exercise Protocol

During DRATS field trials, each LER cabin contained a single exercise device. The exercise device in each vehicle was set up for use on the floor in the 55-cm-wide (21.5-inch) aisle where a bolt pattern to hold the devices securely down to the rover floor was prepared. The seat for the devices was mounted directly above the WCS, attached to a platform spanning the aisle with Velcro strips holding it in place to the starboard and port benches. Fig. 8 indicates where the device and seat are placed for use. Fig. 9 and Fig. 10 show where exercise equipment was stored in Cabin 1A and Cabin 1B respectively. The under-floor stowage volume for the exercise system is roughly comparable to a mid-deck locker and contained enough space to store a single CTB. Two different types of seats were tested during DRATS 2010.



Fig. 8 GEN 1A Rover Location Where the Exercise Device was Located During Testing.

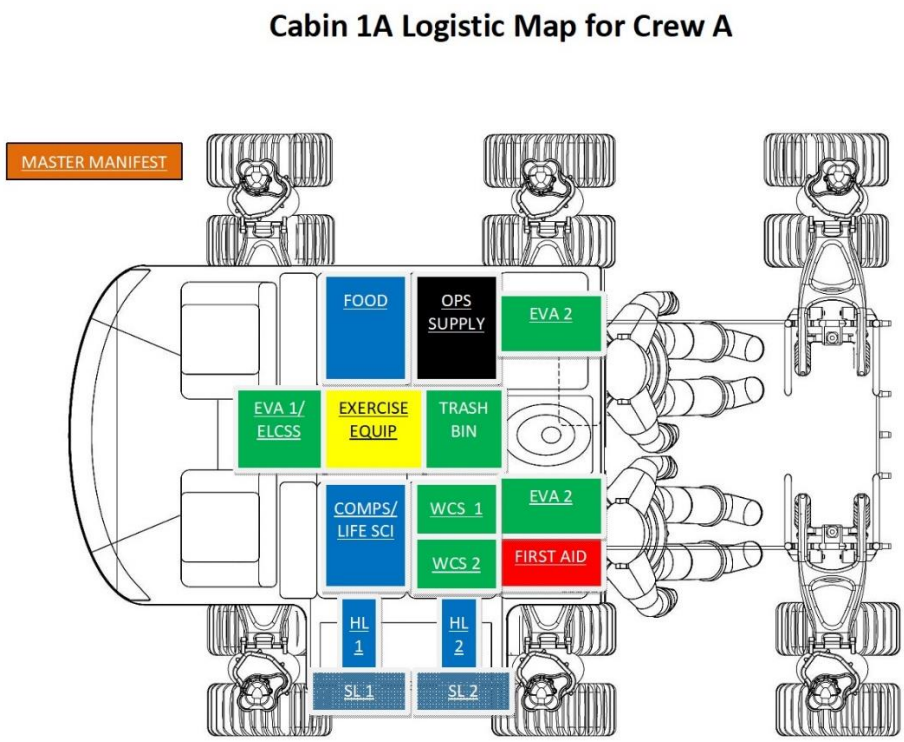


Fig. 9 The Cabin 1A Logistics Map Including Exercise Equipment.

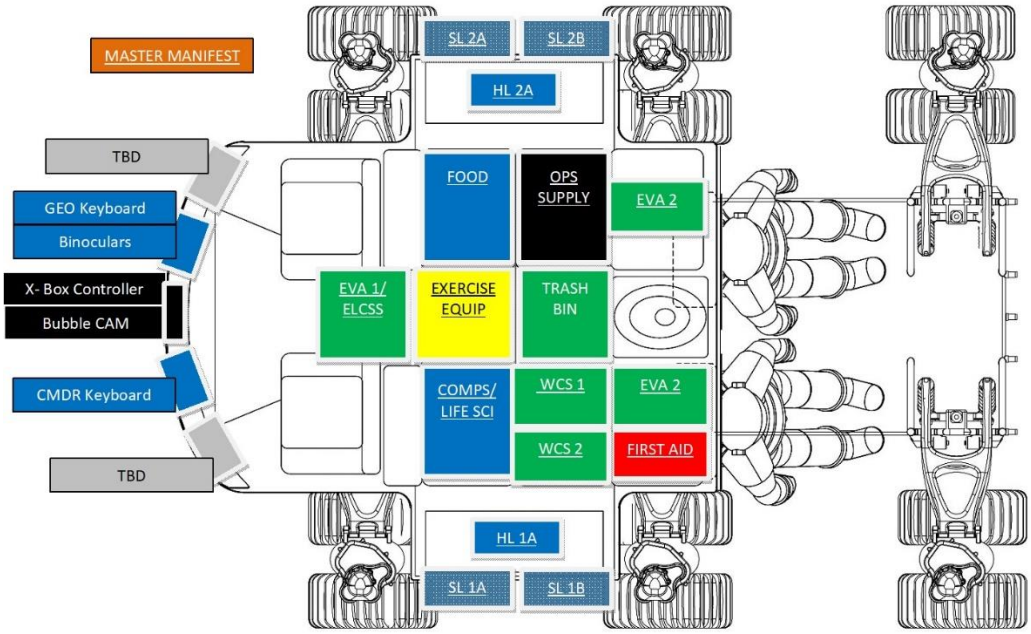


Fig. 10 The Cabin 1B Logistics Map Including Exercise Equipment.

A strict exercise protocol was used with all exercise devices in both rovers. The evaluation of the devices was scheduled in a detailed mission timeline that was part of the developed test plans. Durations for use of the devices was governed by standard test termination criteria from the NASA Institutional Review Board and the exercise community. The exercising crewmember had to wear a heart monitor so that their heart rate could be monitored so that testing could be terminated before the 75% of the subject's maximum heart rate was achieved. Crewmembers were to perform exercise every day. Subjects using the ergometer would pedal at approximately 75 rpm for up to 20 minutes in four stages lasting up to five minutes each. For the first exercise stage, the subject would pedal against a resistance set to up to 50W. For the second and third exercise stages, subjects would pedal against resistances set up to either 75W or 100W for females weighing less than 65 kg (143 pounds), or 100W and 150W for all males and females weighing more than 65kg. In the final exercise stage, subjects would continue to pedal the cycle ergometer for five minutes at less than 50W as an active cool-down. Subjects using the air-spring device would perform an equivalent protocol using rowing rather than cycling. With both exercise devices, subjects also performed pushing and pulling resistive exercises at low intensity with settings and durations equal to or less than those used when using the devices for aerobic exercise.

During the sessions, subjects' heart rate was monitored to ensure that it did not exceed 75% of the maximum heart rate (MHR) associated with their maximal oxygen consumption (VO_2 Max) peak test or 75% of their age predicted maximum heart rate if subjects have not had a VO_2 Max peak test within the last year. If subject heart rate exceeds 75% MHR, they would stop using the exercise device or, if possible, reduce the resistance to be no more than 50W for a five-minute cool down period.

VII. DRATS Field Testing from 2008 to 2010

Due to not being ready for field-testing in the 2008 test, the ergometer was only demonstrated in a limited capacity that year – after the official test period concluded and with only a single test subject. His task was to unstow the ergometer, use the technical manual for assembly, go through a random series of exercises (both aerobic and resistive), then disassemble and stow the equipment. The entire demonstration took approximately 30 to 45 minutes. Table 1 indicates the time used to set up and break down the equipment. The participant stated that the seat was simple to setup and was easily adjustable to his leg length. Moving the seat forward or aft by utilizing the Velcro, which held down the bench cushions, the participant was able to quickly adjust the seat and secure it. He also noted he could use a bench cushion as a backrest if needed. When asked if he could exercise while traveling, the participant stated there would be no problem. Figure 11 shows the participant performing cycling and resistive exercise using the ergometer.

Table 1. Exercise Equipment Time

Task	Approximate Time (h:mm:ss)
Unstow and Setup Time	0:10:00
Seat Cushion Reconfig Time	0:04:21
Breakdown and Stow Time	0:02:00



Fig. 11 Participant Demonstrating the Ergometer During Aerobic cycling and Resistive Exercise

The participant noted that another resistive outlet on the front of the device down near the base would be useful. Alignment guides on the base plate of the ergometer to assist in getting the machine into the correct position would be helpful. Other suggestions for redesign included: a bigger display in the front of the device, providing a straight bar for resistive exercising, and using a pulley system for resistive upper body exercises, such as illustrated in Fig. 12. [8] The participant suggested that exercise experts should evaluate the device while in the vehicle to create an exercise regimen for the field.

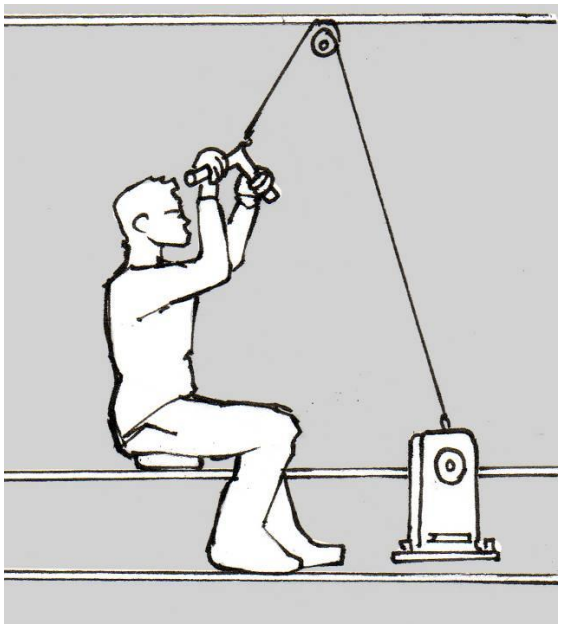


Fig. 12 Concept Drawing of Resistive Upper Body Exercise with a Bar and Pulley System

For the crew to maintain muscle mass, strength/endurance and to recover from strenuous tasks, confined postures, and minor muscle injuries, the LER is required to have the capability for the crew to have the volume for both aerobic

and resistive exercise for 30 continuous minutes each day. [5] During the 3-day field trial in 2008, only a demonstration of the exercise ergometer could be conducted. [9], [10] However, in the 14-day DRATS 2009 field trial, the crew was able to use the exercise ergometer, shown in Fig. 13, for twelve out of fourteen days at least an hour per crewmember per day.



Fig. 13 Crewmember Using the Ergometer During the 14-day Field Trial

With this is mind, human factors investigators examined sixteen factors of exercise within the PR, collecting data at certain times during the mission—Day 3, Day 6, Day 9, and Day 12. Of the sixteen factors, the crew rated ten of these as acceptable with only minor improvements desired. These included access to the exercise equipment within the PR, setup and stowage of the equipment, stability/adjustability of the seat, design of the ergometer for aerobic exercise, and volume to perform both resistive and aerobic exercise in the LER. [9] A camera photo of crew setting up the ergometer is shown in Fig. 14.



Fig. 14 Ergometer Setup During the 14-day Field Trial

The crew reported the overall ability to exercise in the LER was acceptable. They came up with several ways to exercise within the vehicle in conjunction with using the ergometer. The LER provided plenty of space using the resistive band exercises for upper body exercises, shown in Fig. 15. The interior volume of the LER was able to give the crew the ability to perform a variety of exercises and complaints of exercising during the 14-day field trial were non-existent. However, the crew did express some issues with the system where improvements were warranted. The ability of a crewmember to perform aerobic exercise while the vehicle was moving was a major concern. The crew reported it depended on the terrain in which the LER was traveling. If the terrain was flat and smooth, they did not

have an issue with exercising; however, if the terrain was bumpy and rough, exercise was not possible [9], [10]. Just walking from the aft cabin to the cockpit of the LER while on rough terrain was difficult according to the crew. The crew recommended that both aerobic and resistive exercise should probably be limited to when the vehicle is stationary to avoid injury.

This is a significant finding that demonstrates the value of the DRATS analog field testing. In 2008, the device was demonstrated, but only after the testing period had concluded. The vehicle was inert, in many ways equivalent to a laboratory test at JSC that only happened to take place in Arizona. During that demonstration, the test subject had concluded that the exercise device could be used while driving. However, in 2009, when the exercise device was incorporated into an actual field test that involved driving, the crew found it unsafe to use while the vehicle was in motion. Unfortunately, the imminent cancellation of the Constellation program would prevent the team from investigating the idea of exercise during vehicle motion further.

The 2009 test did prove that the exercise device – as implemented – was unsafe to use while the vehicle is in motion. But it did not prove that exercising is fundamentally unsafe while the vehicle is in motion. As previously mentioned, very few requirements had been imposed on the exercise device itself and essentially none had been imposed on the exercise seat.

With respect to aerobic exercise using the ergometer, the seat was only attached to the cabin structure with Velcro and thus it would never have been able to accommodate the loads associated with dynamic driving. This was likely the fundamental weakness in the aerobic system and could be accommodated with a seat redesign and relatively minor modifications to the rover cabin structure. Given that the ergometer is already in line with vehicle motion it is very likely that ergometer exercise could be designed in a manner to be safe, even when performed over very rough terrain and should be substantially safer than terrestrial bicycling.

For the case of resistive exercise, it is not clear that the air spring rower could be made compatible with a user accommodation compatible with vehicle motion over rough terrain. However, with rough terrain driving as a design input it may be possible to design a resistive exercise system that also provides user restraints. Unlike with aerobic exercise, there are no terrestrial analogs to resistive exercise while in dynamic motion so it is not as certain that a design solution can be found. Should resistive exercise during vehicle motion become important from a crew timeline perspective it may be worth pursuing research in this direction, presumably to develop a different resistive device and user restraint system conceived specifically with this capability in mind.



Fig. 15 Crewmember Using Ergometer and Resistive Band Simultaneously

Access to other stations within the vehicle by the non-exercising crewmember while a crewmember was performing either aerobic or resistive exercise was also challenging. The ergometer setup consumed a lot of aisle space and blocked access to the aft section of the cabin. Because of this, the crew indicated they tried to make sure certain items were stationed up in the cockpit area and some stowage was accessible from the front section of the vehicle before initiating exercise, resulting in the cabin configuration shown in Fig. 16.



Fig. 16 One Crew Member in Cockpit Area with Snacks and Small Table while Other Crewmember Exercises in Aft Section on the Bench

Exercise seat comfort was also reported as uncomfortable with no back support. They reported the absence of any type of back support and they would add several bench cushions, shown in Fig. 17, to get comfortable. They suggested to redesign the seat for improved back support. With respect to the design of the ergometer itself, the crew reported several concerns with the weight, pedals, and displays. They noticed that for such a heavy piece of gear, the ergometer seemed fragile when it was being used by the crew. Pedals were also an annoyance to the crew. They reported the pedal attach/detach design was too difficult to remove. One of the biggest observations on the pedal design was the fact the pedals, once locked on the device, were so tight the crew almost injured themselves taking them off. In fact, the crew stated they would leave them on just so they would not have to take the pedals on and off. The suggested recommendation was to design a better attach/detach method for the pedals to make it easier and faster so the crew can avoid any injury.

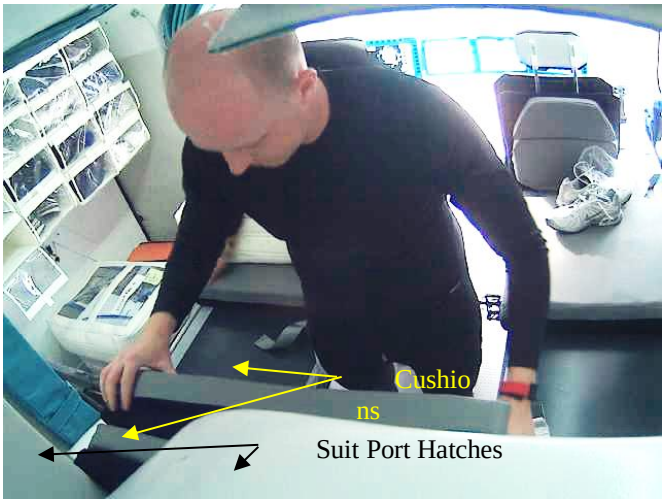


Fig. 17 Crewmember Setting Up LER Bench Cushions Between the Suit Port Hatches as a Seat Back for the Ergometer

During the 2010 field trial, Cabin 1A tested a new exercise device called the air spring rower, which was originally developed for the Orion capsule. Four crews of two test subjects each lived and worked in the two rovers for two 7-day periods. Crew 1A and 1B lived in Cabin 1A and 1B respectively during the first 7 days, and Crew 2A and 2B lived in Cabin 1A and 1B respectively during the second 7 days.

Cabin 1B crews used the Glenn Research Center's ergometer with some modifications from data collected last year and a new system for resistive exercise. During the 14-day mission, of the total hours the crews could have exercised (28 hours) they only exercised about 50% of the time during the mission (14 hours recorded via questionnaires). The reasoning the crew provided for their decision not to exercise as much as in the previous years of testing was the more rugged and physically demanding EVA terrain.

With this in mind, investigators examined nine general elements of exercise across the vehicles with two special elements for the Cabin 1A device and five special elements for the Cabin 1B device. Of the nine general exercise elements, the crews deemed access to the exercise equipment and the overall ability to exercise in the rovers as acceptable. Generally, all the crews agreed the location for stowing the exercise equipment under the floor was good and that the interior volume of the vehicles offered a crewmember enough room to perform both aerobic and resistive exercise with the device tested. However, all the crews indicated it was somewhat awkward to access the equipment from the floor stowage compartment and the weight of the equipment made lifting the equipment out of the floor a little difficult.

General exercise elements that were considered borderline by some or all of the crews included the setup of the exercise equipment, the volume for one crew member to perform resistive or aerobic exercise within the vehicle, accessibility of the non-exercising crew member to other vehicle stations during resistive or aerobic exercise, stowing of the equipment, and the amount of stowage volume for the equipment.

Crews 1A and 2A deemed the setup of the air spring rower as borderline. Both crews reported that no technical manual was provided to instruct them on how to setup the device. Another issue the A crews faced was how to charge the gas cylinder to achieve a desired amount of resistance. Fig. 18 shows a crew member setting up the rower.

Cabin 1A crews also reported borderline ratings with stowing the rower and with the volume of that stowage space. They stated the long length of handle for the rower made it difficult to stow in the CTB. The handle usually ended up being stowed separately under the floor, much like the exercise seat.

With respect to the rower itself, design of the device to perform resistive exercise and design of the device to perform aerobic exercise were scored by the crews. Crew 1A rated both of these elements as acceptable, but Crew 2A rated both of these elements as borderline. They stated the device was designed more for resistive exercise than aerobic. Issues reported by the crew included difficulties setting up the device and the absence of a clear procedure for charging the gas cylinder and changing the resistance to the user's preference. Both crews indicated a cue card for setting up the device and dialing it in was badly needed.



Fig. 18 Crew Member Setting up (left) and Using (right) the Air Spring Rower in Cabin 1A

As for the ergometer in Cabin 1B, shown in Fig. 19, both B crews indicated the device could be setup within a minute or so and they liked this device much better than the ergometers on Shuttle and the ISS. The cue card, which accompanied both the devices, aided the crews in stowing the equipment back into the CTB; however, the crews did suggest another cue card for assembling the equipment.



Fig. 19 Ergometer Setup (left) and Use (center, right) in Cabin 1B

The crews using the ergometer in Cabin 1B deemed four of the five specialty elements as acceptable. These included stability of the seat, adjustability of the seat, design of the ergometer to perform resistive exercise and design of the ergometer to perform aerobic exercise. Seat comfort was considered by Crew 1B as borderline with improvements warranted while Crew 2B deemed it acceptable with minor improvement desired. As for the stability of the exercise seat, both crews indicated it was stable; however, there was concern from Crew 1B that a shorter stature person could have some trouble reaching the pedals even with the seat full forward. Crew 2B noted when the ergometer was bolted to the vehicle's floor panel, the panel tended to move up and down when they pedaled harder. They also stated the noise of the device was annoying and the seat tended to move back and forth slightly during exercise. Both crews reported the adjustability range of the seat was limited but workable. Crew 1B commented it was somewhat difficult to reposition the seat due to the Velcro used to hold it in place. Both crews also indicated they wanted straps to ensure the back of the seat remains straight. Ergometer design for both resistive and aerobic exercise was considered by the crew as providing a "good solid workout." They thought the adjustability of the resistive levels was good and combining aerobic and resistive was a solid way to exercise most of the body. Crews liked the fact the device needed no power, no tools were required for setup, both setup and take down were quick, and using the bungee straps with ceiling strap in the vehicle's ceiling made for an effective resistive workout. The crews also liked the variety in the accessory kit provided for the ergometer. Improvements needed for the ergometer included relocating the device's display so the crew can reach the controls without having to stop exercising – as stopping meant the exercise session had to be reset. They suggested adding a remote/cable controller to the device so that it could be placed next to the user. Stowing the ergometer in Cabin 1B posed no issues according to both of the B crews.

Vehicle access for the non-exercising crewmember during aerobic and resistive exercise was considered borderline by three out of four crews. Vehicle volume for exercise according to both crews was limited and crews in both vehicles reported the non-exercising crewmember was limited to the cockpit area while the other exercised in the aft section. Crews in the Cabin 1A vehicle performed limited aerobic exercise with the rower while crews in Cabin 1B noted the volume between the benches was adequate for pedaling the ergometer but seat distance from the pedals was long. One crewmember stated that this distance would be difficult for a person who was shorter that 1.78 m (5 foot 10 inches). All crews stated that as long as the exercising crewmember remained in the aft section while the non-exercising crewmember remained in the cockpit, exercise of any type could be accomplished.

Despite the presence of numerous areas of improvement, the crews were generally pleased with the overall ability to exercise in the vehicles and were impressed with how the vehicle, interior, worked together and how designers were able to use such a small space with a tight fit to give the crews the ability to get a good workout. They stated the designers did such a great job using the volume, that any type of exercise could be accomplished in the rovers.

VIII. Post-Constellation Exercise Device Testing

The Constellation Program was canceled in 2010 and the lunar mission was replaced by a mission to a Near-Earth Asteroid (NEA). The PR was quickly repurposed to become the Multi-Mission Space Exploration Vehicle (MMSEV). Essentially, the mobility chassis was replaced with a propulsion and service module. The MMSEV would become the spacecraft to explore the asteroid while the Deep Space Habitat (DSH) provided transit and served as the primary

outpost during the roughly 400-day mission. The second-generation rover prototype (GEN 2A) cabin had begun construction with the intent to place it on a mobility platform for desert testing but was instead completed and placed on an air-bearing platform for use in a NASA high bay. Two three-day studies and two five-day studies were conducted during the 2011-2012 period at JSC. In the MMSEV studies, crewmembers used the same ergometer that had been previously used in the first-generation lunar rover prototypes (Cabin 1A and 1B). The vehicle structural design was changed significantly from the early rover designs, but the interior volume had roughly the same configuration, as can be seen in Fig. 20. The stowage location for the exercise device was moved to a side bench location instead of the floor, shown in Fig. 21, due to the new pressure vessel design, which eliminated all floor storage.

Cabin 2A only provided only two positions on the floor to mount the ergometer and this caused some crew to hit their heel on the front panel of the WCS as shown in Fig. 22. The crew wanted more adjustability to better position the ergometer. As with the previous field trials, there was a need for more back support when using the WCS as an exercise seat for exercising. The seat used in the DRATS testing was not used in Cabin 2A and crewmembers would instead stack seat cushions between the suitport hatches for back support, shown in Fig. 23. Pedal attachment, even with a new key design, was still difficult, especially when removing them for stowage. Resistive bands, shown in Fig. 24, 25, and 26, were used for resistive exercise while the crewmember was using the ergometer.

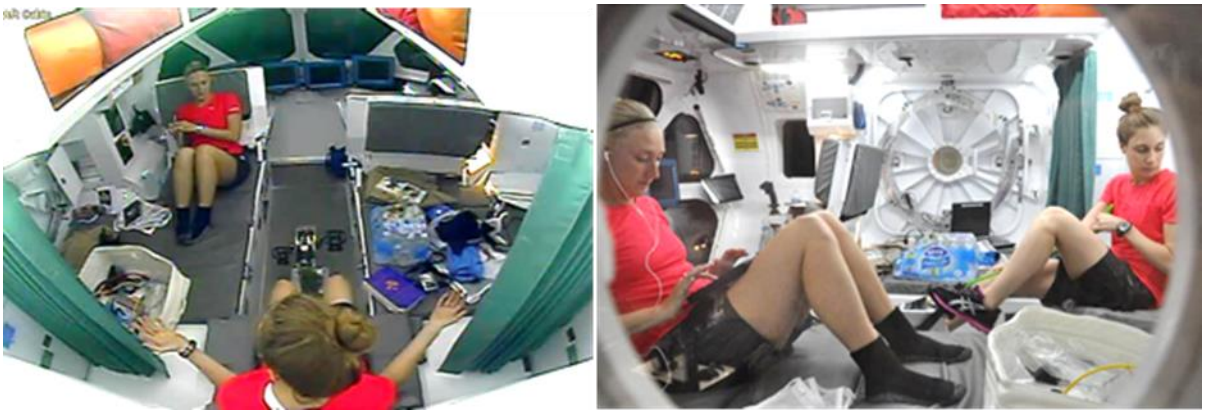


Fig. 20 Interior Volume of the GEN 2A MMSEV During Crew Exercise

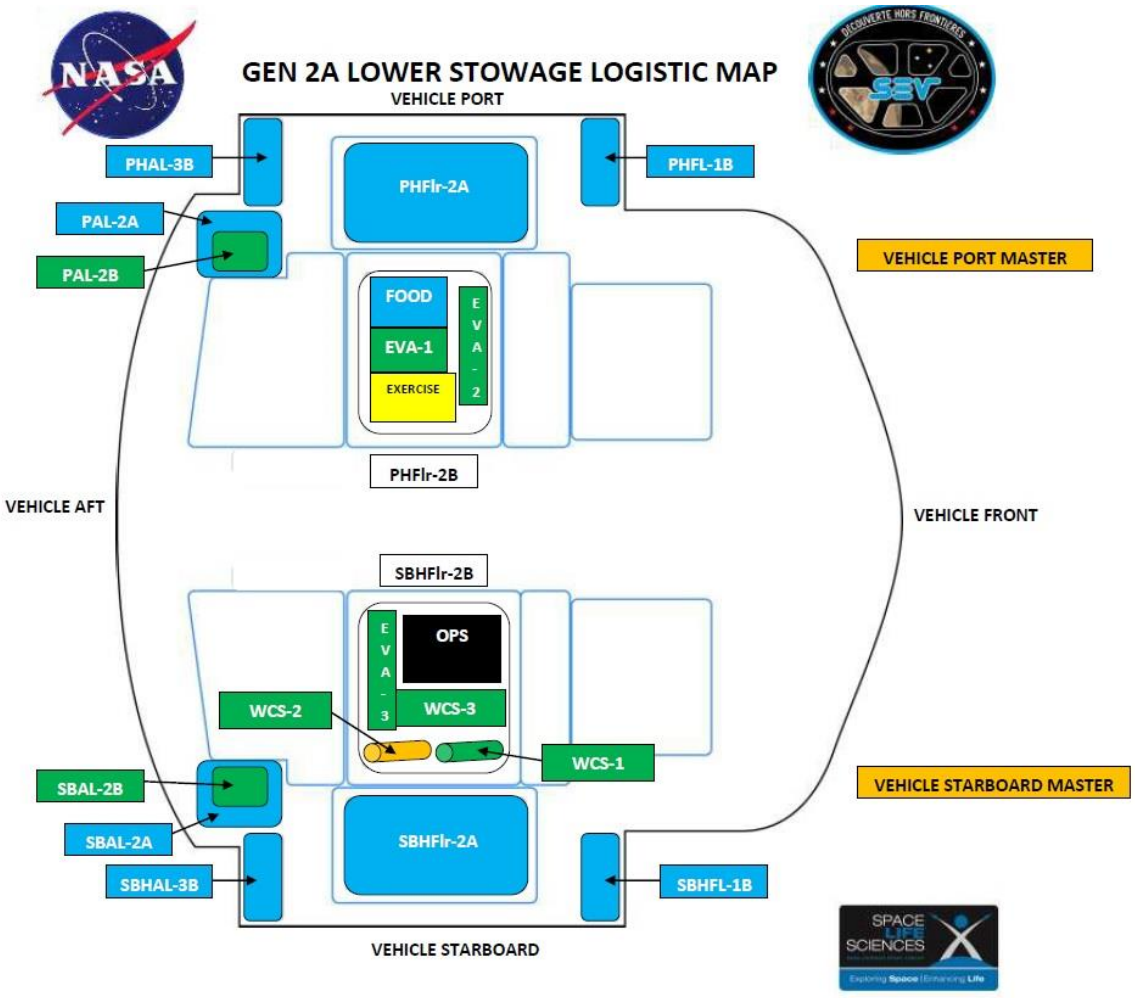


Fig. 21 GEN 2A MMSEV Logistic Map with Exercise Device in Bench Stowage



Fig. 22 Heel Collision with Front Panel of WCS During Exercise



Fig. 23 Bench Cushions Used as Back Support During Exercise

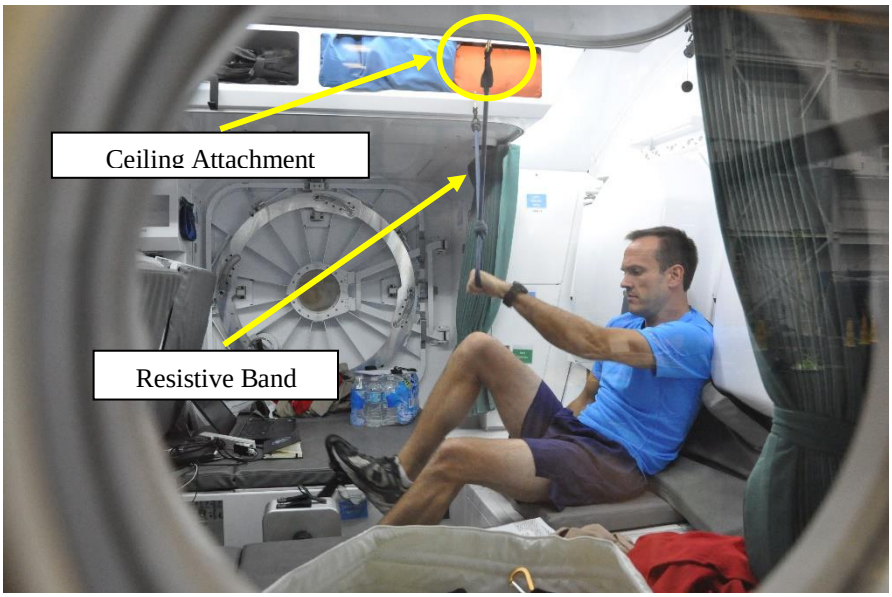


Fig. 24 Crewmember Using the Ceiling Attachment Point

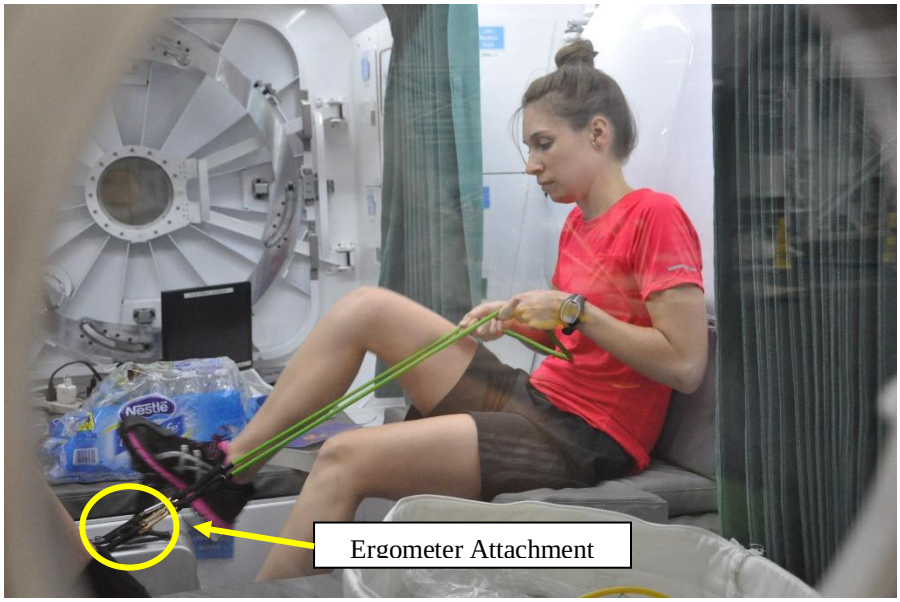


Fig. 25 Crewmember Using the Ergometer Attachment Point



Fig. 26 Crewmember Using the Suit Port Attachment Point.

By 2017, the NEA mission had been cancelled, and Gateway was in formulation. The rover cabin design was again changed, with both a design maturity update to the GEN 2B cabin and a repurposing in mission to become a HAL. Instead of a surface rover or microgravity free flyer, the HAL is an airlock with a habitable crew cabin that could be docked to Gateway. This would allow the Gateway to operate at a cabin pressure that is not optimal for EVA but is more favorable for cabin activity, such as 14.7 psi. During time periods designated for EVA (e.g. spacecraft assembly or repair tasks – a repair could conceivably require 2-3 EVAs spread over several days), the EVA crew can ingress HAL, close the hatch, and lower the HAL cabin pressure to 8.2 psi. The EVA crew could live in the HAL at this lower pressure and conduct the EVAs needed to accomplish the objective while non-EVA crew continue their higher cabin pressure activities without being impacted. Cabin 2B had a more circular cross-section (as compared with the elliptical cross section of 2A), which allowed room to regain under-floor stowage, visible in Fig. 27.

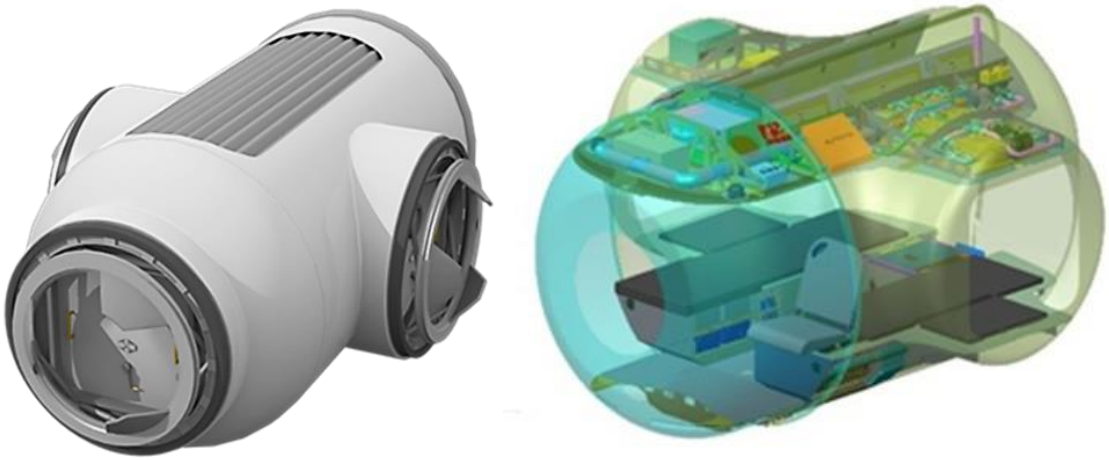


Fig. 27 HAL Vehicle Design

In 2017, during a 1-day study using the Cabin 2B HAL prototype, a crew of two tested both the ergometer and a new device called the Miniature Exercise Device 2 (MED-2). The MED-2, shown in Fig. 28, was designed by JSC engineering in response to a call for small exercise devices for use in Orion. It is a compact motorized resistive and aerobic rowing device that went through several iterations. MED-2 was flown as an ISS technology demonstration to evaluate its usefulness and effectiveness for exploration missions. MED-2 consists of a series of electric motors

controlling a pulley which tensions an exercise cable to provide resistance as the user pulls against the cable. As an aerobic device, the MED-2 software simulates a variety of rowing conditions that can simulate boat drag and weight.



Fig. 28 MED-2 Installed on a Floor Panel in the HAL

Testing indicated that in both individual and consensus acceptability ratings, the HAL interior volume was considered acceptable for both devices. Setup and breakdown of the exercise equipment indicated the ergometer, shown in use in Fig. 29, was very acceptable with no improvements necessary. However, MED-2 device setup, use, and stowage was considered acceptable with some minor improvements desired. Crew exercise with MED-2 is shown in Fig. 30, but the crew stated that while performing the MED-2 exercises (i.e. upright rows) in the HAL, a taller (173-cm or 68-inch stature) person could hit their elbows against the overhead panels as shown in Fig. 31. Additionally, in a 1-g environment, the weight of the MED-2 device required two crewmembers to stow the unit. This would not be an issue in the lunar environment. When asked if there would be a need for two exercise devices in the vehicle, the crew indicated this would save time by enabling both crewmembers to exercise together, thereby cutting the time allocated to exercise in half.



Fig. 29 Crewmember Using the Ergometer While Another is Working on an Experiment



Fig. 30 Crewmember Using the MED-2 Device in the HAL



Fig. 31 Crewmember Elbow can Hit Overhead Panel with Upright Rows

The Artemis program has returned the cabin to its original role and it now serves as the NASA reference configuration for the Pressurized Rover. But there are possible considerations that were not present in the original Constellation iteration of the vehicle. The PR may be the sole habitable element on Mars, with crew landing in the rover after a 300-400-day outbound trip from Earth. In preparation for Mars missions, lunar crews may spend progressively longer periods of time in microgravity before landing on the Moon.

In both cases, this will result in deconditioned crew landings on the surface. The operational concepts for such missions are still in development but it is not clear if it will be safe for the crew to perform EVAs during the first few days on the surface. Presumably, on the Moon the burden will be on the Human Landing System (HLS) to recondition the crew, but there is a mass impact in doing so – every day that the crew spends in recovery imposes habitation and

exercise requirements on the HLS that might otherwise not be part of the vehicle design. It could save significant mass if this responsibility were offloaded to a surface element. On Mars, the crew will land in the PR. The PR is also the only pressurized habitable asset on the surface and it will be responsible for reconditioning the crew.

Neurovestibular symptoms have been observed in returning space shuttle and ISS crews immediately after landing [11], [12] and will likely be experienced by Moon and Mars crews. These symptoms are still being researched and it is not clear yet what the proper recovery should be. However, it is conceivable that having a treadmill in the cabin for astronauts might accelerate recovery time by allowing the crew to walk in a safer manner than might otherwise be possible.

Clearly a treadmill comparable to the ISS Second Treadmill (T2), which is a modified commercial Woodway treadmill, would be far too large and too massive to be used inside the PR cabin. The limited dimensions of the PR cabin impose severe requirements on the use of any treadmill within its confines. The only place in the cabin where a treadmill could even be considered is the aisle.

The aisle of the GEN 3 cabin is 73.44 inches in length, 22.61 inches in width, and 74.26 inches in height. If the floor panels are removed and the under-floor stowage compartment is included, the aisle takes on a height of 82.57 inches. Three models of the commercial WalkingPad folding treadmill have a width of 21.5 inches, and when folded have a lengths ranging from 32.5 inches to 33.66 inches and heights ranging from 5 inches to 5.73 inches. Deployed for use, the length extends to 56.38 inches to 57.05 inches. The walking platform height ranges from 2.24 inches to 2.72 inches. Thus, the WalkingPad treadmills can be deployed in the aisle at the bottom of the stowage compartments with an available clearance of 79.85 to 80.33 inches for the crew member, depending on the specific treadmill selected. The maximum crew member stature is 76.6 inches, or 78.9 inches when including spinal elongation. (Because rehabilitation will begin immediately after landing it is possible that some degree of elongation from microgravity exposure will still be present.) While it is a very tight fit, it is theoretically possible to position a treadmill in the rover aisle to support gravity adaptation exercise protocols. Human-in-the-loop testing would be needed to determine the acceptability of such a protocol or the possible need for safety headgear or padding in the cabin ceiling.

It is worth noting that using a treadmill in the aisle under-floor stowage in such a way would require removing equipment normally stowed in these locations, the floor panels, and the dividers that normally break the aisle under-floor storage into separate compartments. All of this would presumably be temporarily stowed on the bench of the exercising crew member. And as previously noted in DRATS field trials, everything aft of the cockpit would be inaccessible to the non-exercising crew member.

Such a treadmill would only need to be used for a few days at the beginning of a surface mission and would need to be stored out of the way when not in use. Several options exist. Perhaps the most intuitive option is to leave the treadmill permanently installed in the aisle under-floor stowage. But this would consume a primary stowage volume for CTB-sized equipment, including exercise devices comparable to the ergometer or MED-2. A second option is to stow the treadmill within one of the benches, though this is also a valuable stowage volume for relatively large items. A third option is to stow the treadmill on mounting clips in the ceiling or on the aisle floor, though this could reduce the aisle height to very uncomfortable heights for taller crew. A fourth option would be to store the treadmill outside of the cabin, in a Suit Port Transfer Module (SPTM). A variety of SPTM sizes were tested with low fidelity mockups at Johnson Space Center, shown in Fig. 32, and a functional prototype roughly the size of two Portable Life Support Subystem backpacks was tested at DRATS, as shown in Fig. 33. The suit port hatch and all of the tested SPTM sizes are large enough to accommodate a treadmill close in size to the commercial WalkingPad example. Operationally, the PR could be launched (in both the Moon and Mars cases) with the treadmill secured to the aisle floor. When the crew arrives, they can use the treadmill for gravity adaptation and once cleared for EVA they can use a SPTM to remove it from the cabin and stow it externally, since it will not be needed for the remainder of their surface mission. During the final surface EVA, it can be a crew task to retrieve the treadmill from the SPTM and position it in the cabin to await the next crew.



Fig. 32 SPTM Concept Test Conducted at JSC in 2009.



Fig. 33 SPTM Unit Field-Tested During DRATS 2009.

IX. In-Space Medical Care

The medical challenges expected in Moon and Mars surface missions are unlike any prior human spaceflight experience. The roughly 33-day Artemis lunar surface missions move well beyond the Apollo surface experience. Thus, it is critical to both draw lessons from prior human spaceflight programs and to recognize the limitations of the associated experience. [13]

Most medical systems used in prior human spaceflight programs were developed for low Earth orbit (LEO) mission architectures where the crew was supported by real-time ground communication with surgeons and other medical support staff. Most long-duration missions enjoyed consumable resupply and had identified mission abort windows. And other than the relatively short Apollo missions, anytime medical evacuation was always an option. In addition to the loss of much of this supporting infratructure, exploration of the Moon and Mars introduces new hazards that impact onboard crew health care capabilities. These hazards include those created by the terrain of lunar or planetary surfaces, the effects of gravity transitions, and low-gravity environments. Each challenge has associated medical implications and medical requirements and technologies to ensure safety and success. [1] As with exercise, this paper will focus on those aspects of medical care that have driving impacts on rover volume and layout, with the goal to elevate medical capability within the constraints imposed by the vehicle architecture.

During an exploration mission, there are several possible ways crew could be injured. Injury to crew could happen during an off nominal but survivable landing on the surface. Another possibly for injury is during the adaptation phase of flight from a microgravity environment to a surface gravity environment. The crew could be injured during a normal intravehicular activity (i.e. exercise, maintenance, habitation, etc.) or from a vehicle fault or malfunction. Injury can occur if a crew member attempts to move about the cabin while the vehicle is in motion. Injuries can occur during surface EVA. Many other events can trigger a crew need for immediate medical care.

X. Pressurized Rover (PR) Medical Kits and Testing

Unfortunately, no testing of medical capabilities or determination of medical stowage needs was conducted during DRATS field trials. Thus, unlike for exercise, there is no baseline data on how medical systems can be integrated with the PR cabin. The GEN 1 cabins were equipped with commercial first aid kits, but there was no correlation between these kits and medical outfitting needed for lunar missions.

It was not until the HAL testing in 2017 that the team started to examine medical activity, and even there in only a very limited capacity. It must be noted this testing, shown in Fig. 34, only examined a crewmember tasked with a medical experiment, not a medical procedure. It is interesting to note the unexpressed implications for the crew member being examined in this experiment. Because this test was for the HAL iteration of the cabin, it must be considered to be a simulation of a microgravity mission – and that is the only reason why this test is somewhat realistic. The position of the caregiver in the photo is a conceivable body posture but note that only an arm mannequin is being used to represent the crew member being examined. Had the rest of the body been present, the only way to fit the body in this experiment would be for the body to float vertically against the starboard wall. This would be possible in a HAL scenario, but not in a lunar surface or Mars surface PR. In any gravity environment, the body would not fit inside the spacecraft, given the caregiver posture and position.

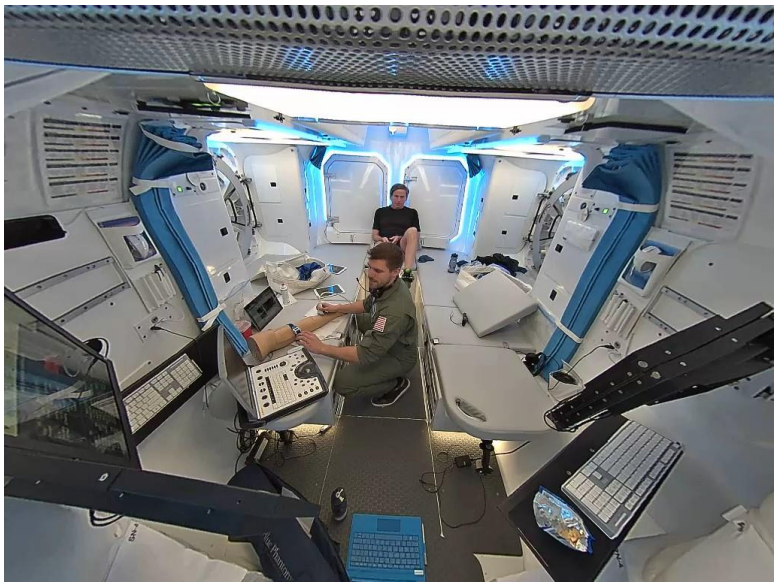


Fig. 34 Crew Medical Experiment During 2017 HAL Test

Individual acceptability rating scores collected during this test indicated the medical workstation used in the HAL was acceptable, though it is likely these scores only considered acceptability from the perspective of the caregiver, not the patient – whose body (had this been a lunar or Mars case) literally could not have been contained inside the vehicle given the way this experiment was conducted. No consensus or simulation quality data was recorded. However, consensus data on the capability indicated the capabilities of the medical workstation were moderately enhancing meaning the capability is likely to moderately enhance one or more aspects of the mission and, on rare occasions, significantly enhance the mission. Lessons learned included: there was a lack of privacy for a private medical conference; combining all the needed tools and devices into one collocated area would improve both efficiency and volume used; and location of the station was important. The medical experiment was planned during the commander's exercise event. The crewmember noted a lot of vibration for the exercising that affected their ability to perform the medical experiment during that time. It was suggested to cease all activities that could cause vibrations when a dexterous activity is needed.

XI. Medical Levels of Care

NASA-STD-3001 provides standards that help to define an exploration medical system. The standard defines five levels of medical care, listed in Table 2, that must be considered when developing spacecraft medical capabilities. NASA-STD-3001 contains additional requirements that guide the design of spacecraft exercise systems. These standards ensure spatial accommodation, equipment usability, treatment restraints, waste and disposal, and deceased crew considerations. [14]

Table 2. Medical Care Capabilities [13]

Level of Care	Space Environment	Mission Duration	Capability
I	LEO	<8 days	Space Motion Sickness, Basic Life Support, First Aid, Private Audio, Anaphylaxis Response
II	LEO	<30 days	Level I + Clinical Diagnostics, Ambulatory Care, Private Video, Private Telemedicine
III	Beyond LEO	<30 days	Level II + Limited Advanced Life Support, Trauma Care, Limited Dental Care
IV	Lunar	>30 days	Level III + Medical Imaging, Sustainable Advanced Life Support, Limited Surgical, Dental Care
V	Mars Expedition		Level IV + Autonomous Advanced Life Support and Ambulatory Care, Basic Surgical Care

It is not initially clear what this means for the PR medical system and as previously noted, medical care has not been explored in any of the pressurized rover human-in-the-loop testing to date. Assumptions for the Artemis lunar exploration missions include the PR as the first habitable element on the lunar surface with surface missions of approximately 33 days in duration. Nominally, there will also be a Surface Habitat present, but there are concepts where a surface mission is conducted with only the PR on the surface. The current initial human Mars mission assumes a surface infrastructure of one PR for a 30-day surface mission with no surface habitat.

Human factors engineers held an initial discussion with representatives of the NASA Exploration Medical Capability (ExMC) Team to gain their impressions surrounding the applicable level of care, given the prior assumptions, for the PR in both Moon and Mars surface architectures. These experts indicated that while the Health and Medical Technical Authority (HMTA) has not yet developed the applicable requirements, each vehicle can be expected to be subject to different levels of care and that the level of care assignment is likely to be influenced in part by the mission descriptions in the ConOps and how crew will be expected to move between different vehicles.

Given the assumptions, the ExMC experts suspect that the PR may be held to a Level of Care III, with the caveat that the surface mission is roughly 30 days or less. Given that HMTA is presently focused on lunar missions prior to PR delivery and has not yet considered PR missions, this can only be treated as an expert suspicion, not a requirement. HMTA may make a different determination once the appropriate analyses have been completed. As described in NASA-STD-3001, Vol 2, a Level of Care III indicates: [14]

> *"A moderate to high level of risk exists that personnel may experience medical problems during training of that portion of the mission. Preventive strategies shall be used to a greater degree to reduce the overall risk. Intervention strategies shall be used to reduce the risk to an acceptable level, including an increased level of advanced care in the form of medications or equipment to include limited advance*

life support, trauma care and limited dental care. The ability to sustain a critically ill or injured patient for any length of time is limited by consumables, training and vehicle constraints."

These experts also indicated that the medical capability on ISS is presently a hybrid between Level of Care III and IV and it would represent a good starting point to estimate the mass and volume of a PR medical system. They suggested that individual items would likely swap in and out, given that the ISS microgravity environment and the PR lunar surface environment are different, but that it is a good first order approximation to use in a sizing exercise.

XII. ISS Medical Kit Application to the Pressurized Rover

The ISS Health Maintenance System (HMS) consists of medical kits or packs and support hardware available to the crew pertinent to both emergent and non-emergent on-orbit medical scenarios. The HMS was originally launched to the ISS in June 2011. The HMS medical packs and kits are organized according to types of medications, supplies, and functions [15] and are stowed in the Crew Health Care System Resupply Stowage Rack. The HMS stowage bags are colored either red denoting emergency or blue signifying non-emergency. The packs, kits, and other support hardware include the following:

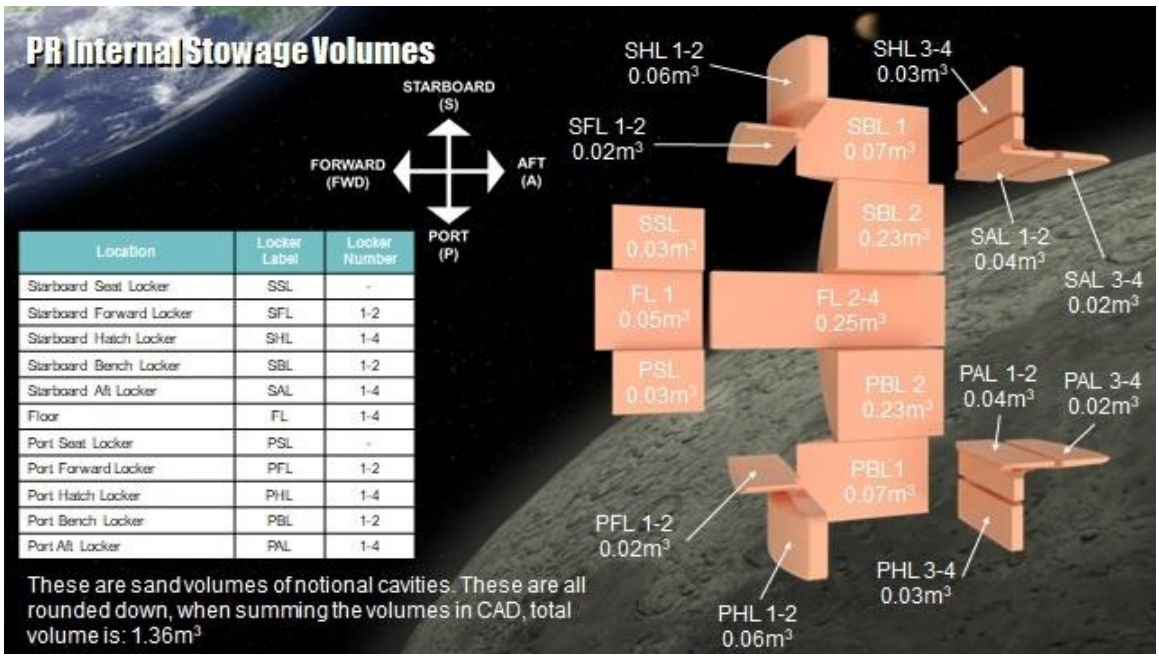
1. Convenience Medication Pack
2. Emergency Medical Treatment Pack
3. Medical Diagnostic Pack
4. Medical Supply Pack
5. Minor Treatment Pack
6. Oral Medication Pack
7. Physician Equipment Pack
8. Respiratory Support Pack
9. Topical and Injectable Medication Pack
10. Crew Contamination Protection Kit
11. ISS Medical Accessory Kit
12. Blood Pressure/Electrocardiograph Kit
13. Heart Rate Monitor 2 Kit
14. Crew Medical Restraint System
15. Automated External Defibrillator

Figure 35 shows some examples of the HMS medical kits. The current ISS medical capability is essentially a hybrid between a Level of Care III and a Level of Care IV.



Fig. 35 NASA Medical Technician Surrounded by the ISS Medical Kits

Based on the ExMC recommendation to use ISS as a starting point, an initial PR stowage plan incorporated the ISS HMS as a volume and mass placeholder. The medical kits have a total stowage volume of 0.256 m³ (0.84 ft³) and a mass of 98.7 kg (217.6 pounds). The PR has a total stowage capacity of 1.36 m³ (4.46 ft³), not including external stowage contained within SPTMs. Taking the total stowage capacity into account, the medical kits take up approximately 18.8% of the stowage capacity in the PR. To put this into perspective, the food is the largest consumer of PR stowage volume at 34 %, while exercise comes in third at 8%. The GEN 3 PR cabin has defined stowage compartments under the floors, in the benches, adjacent to hatches, and in the aft bulkhead, as shown in Fig. 36. The ISS HMS was included when developing the PR logistics map shown in Fig. 37, placing medical stowage in the six under-floor stowage compartments. It should be noted from the exercise discussion, that stowage compartments FL-2, FL-3, and at least portions of FL-4 must be temporarily emptied in order to set up the treadmill.



Location	Locker Label	Locker Number
Starboard Seat Locker	SSL	-
Starboard Forward Locker	SFL	1-2
Starboard Hatch Locker	SHL	1-4
Starboard Bench Locker	SBL	1-2
Starboard Aft Locker	SAL	1-4
Floor	FL	1-4
Port Seat Locker	PSL	-
Port Forward Locker	PFL	1-2
Port Hatch Locker	PHL	1-4
Port Bench Locker	PBL	1-2
Port Aft Locker	PAL	1-4

Fig. 36 GEN 3 PR Stowage Volumes

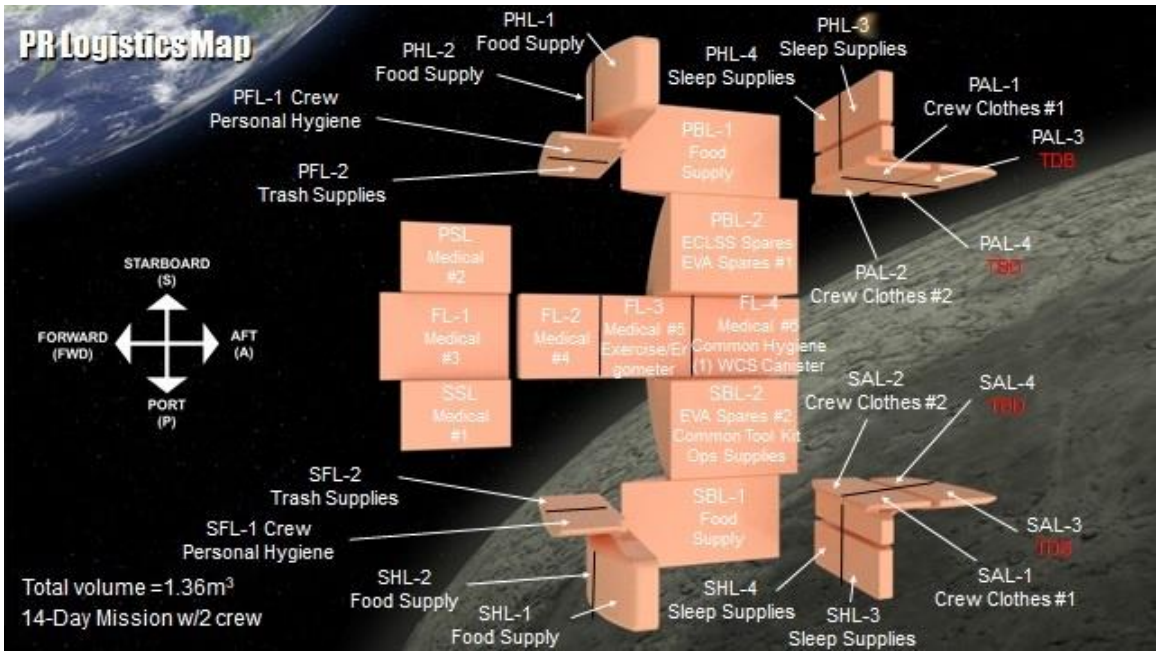


Fig. 37 Proposed Medical Kit Stowage Inside the PR

Orientation of caregiver and patient still needs to be addressed. The HAL test represented in Fig. 34 is likely correct in that the caregiver will need to be in the aisle. That is probably the most effective placement to give access to the patient. The patient, however, should likely be placed perpendicular to the aisle, using a PR variant of the ISS Crew Medical Restraint System to span the aisle at bunk height, shown in Fig. 38. Finally, deployment of medical equipment should be considered. It should be quick to deploy and place medical equipment within easy reach of the caregiver.

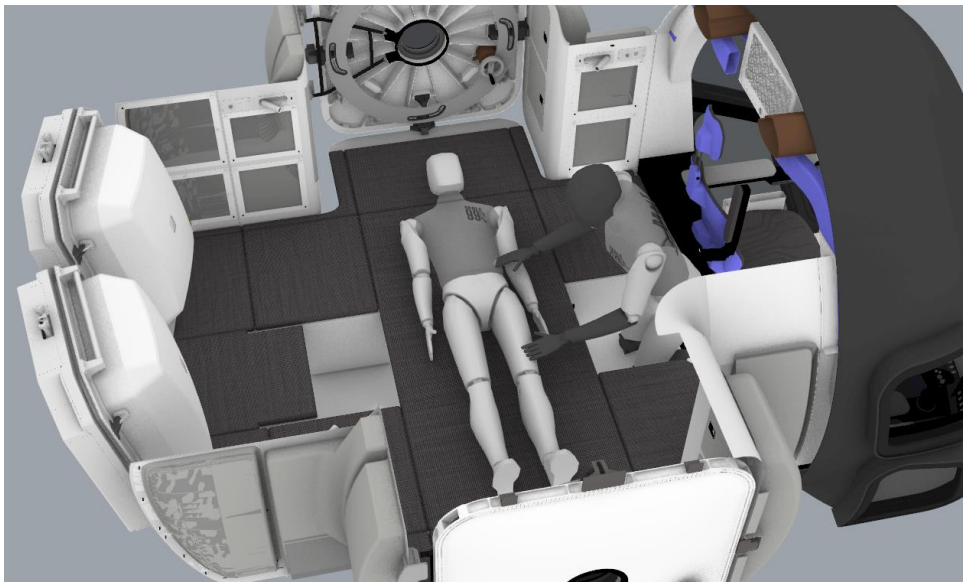


Fig. 38 Placement of Incapacitated Crew Member for Medical Treatment

It is clear from Fig. 38 that the caregiver does not have a wide range of motion, thus the placement of medical equipment will be limited. However, an innovation used with Cabin 1B could serve as a point of inspiration here. The first-generation rovers were originally designed for a 3-day mission and when their duration was expanded to 14 days in the Constellation program, additional stowage volume was needed. Designers took advantage of the side hatch volume in Cabin 1B to add rails to the side hatch ceiling to support ceiling-mounted soft lockers, visible on the left side of the image in Fig. 14 and Fig. 15. A rigid version of this system could be developed to enable rapid removal of medical lockers from the under-floor stowage and placement on the ceiling, potentially with a configuration similar to that notionally shown in Fig. 39. Human-in-the-loop testing would be useful (using level of care interpretations provided by HMTA [13] to identify tasks) to determine the acceptability of this configuration. Forward work should also include exploration of lifting aids to assist with incapacitated crew member extraction form the suit port.

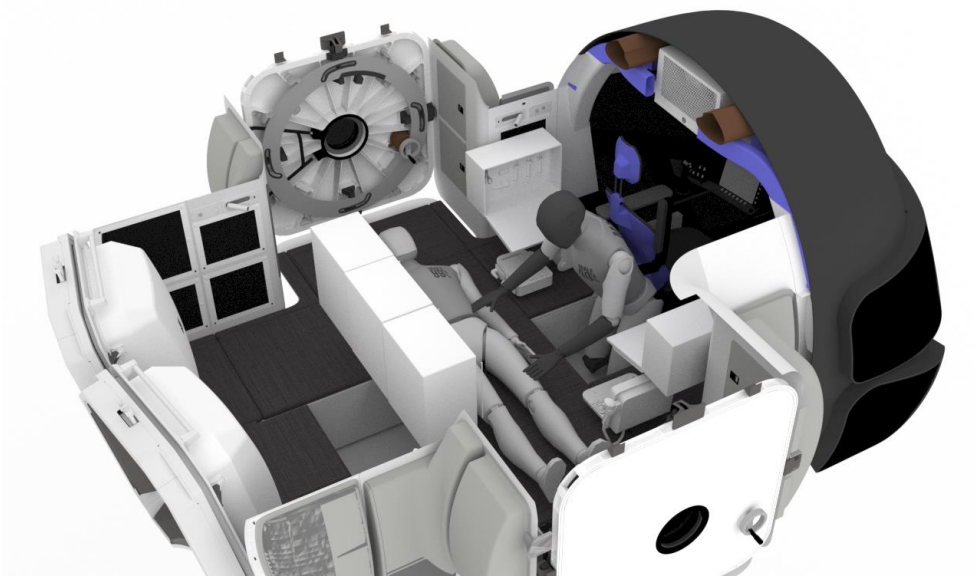


Fig. 39 Ceiling-Mounted Medical Equipment Placed Within Caregiver Reach

XIII. Conclusion

As of this writing, medical and exercise personnel are just now beginning to examine implications of Pressurized Rover activity on the surfaces of the Moon and Mars. While it will be some time before NASA has actionable requirements from HMTA, this analysis indicates a robust capability within the NASA reference PR design to accommodate systems to ensure crew health and well-being.

Both the exercise and medical systems may potentially benefit from consideration during vehicle structural design as incorporating load points into the pressure vessel can aid in optimizing placement of equipment to maximize vehicle habitability and system usability. This will enable placement of pulleys and cabling to support resistive exercise and increase the stability of deployed medical equipment. It may also reduce setup time for both exercise and medical systems.

An area of perhaps understated importance raised in this paper is the neurovestibular deconditioning astronauts will experience when landing on the Moon or Mars after extended periods in microgravity. The current Mars architecture is the driving case as it forces this recovery to occur in the PR. Because of this, it is recommended that the lunar PR should at minimum practice Mars recovery protocols, whether the lunar PR or HLS has prime responsibility for recovery in the actual Artemis sustained mission phase

While this work in no way attempts to prescribe requirements or rules for exercise or medical systems – it may still be a year or more before such requirements exist – it has combined past test data, expert opinion, and volumetric analysis to identify possible options that could be implemented, if required, within the general profile of the current NASA reference configuration. This can inform future discussions, either to identify those areas where requirements for more extensive systems might create volume/layout challenges or where requirements for less capable systems might create volume/layout opportunities for any other crew or vehicle functionality.

Acknowledgments

This paper includes work funded under the Artemis Lunar Surface Human Mobility Systems Project, Constellation Lunar Surface Systems Project, Desert Research and Testing Studies, Advanced Engineering Systems Program, and Gateway Program.

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