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Desert Research and Technology Studies (DRATS) 2009: A 14-Day Evaluation of the Space Exploration Vehicle Prototype in a Lunar Analog Environment

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ACRONYMS & ABBREVIATIONS

1 G	Earth gravity
1/6 G	lunar gravity
AAMA	Active-Active Mating Adapter
AC	air conditioner
AFTP	JSC's Advanced Food Technology Project
BPLF	Black Point Lava Flow
C	Celsius
CAD	computer-aided design
CAPCOM	Capsule Communicator
CH	Cooper-Harper
CxAT_Lunar	Constellation Lunar Architecture Team
CxP	Constellation Program
D&C	displays and controls
DIO	Directorate Integration Office
DRATS	Desert Research and Technology Studies
EAMD	Exploration Analogs & Mission Development
EC5	Space Suit and Crew Survival Systems Branch
EPI	Exploration Productivity Index
EVA	extravehicular activity
F	Fahrenheit
ft^3	cubic feet
GPS	Global Positioning System
hh:mm:ss	hours:minutes:seconds
IFM	in-flight maintenance
ISS	International Space Station
ITCD	Information Technology and Communications Directorate
IVA	intravehicular activity
JSC	Johnson Space Center
kg	kilogram
kPa	kilopascal
KSC	Kennedy Space Center
L	liter
LAT	Lunar Architecture Team
lbs	pounds
LCNE	Lunar Communications and Network Emulator
LSS	Lunar Surface System
LW	Light Weight EVA Mockup Suit
m	meter(s)
M	mean
m^3	cubic meter
MMCC	Mobile Mission Control Center

MOD	Mission Operations Directorate
NASA	National Aeronautics and Space Administration
NE	northeast
NISN	NASA Integrated Services Network
Ops	operations
O_2	oxygen
PCT	Portable Communications Terminal
PLSS	Portable Life Support Subsystem
psi	pounds per square inch
PUP	Portable Utility Pallet
RMS	root mean square
RPM	revolutions per minute
SA	situational awareness
SEV	Space Exploration Vehicle
SPE	solar particle event
SPR	Small Pressurized Rover
SPTM	Suit Port Transfer Module
TBD	to be determined
TRI-ATHLETE	All-Terrain Hex-Legged Extra-terrestrial Explorer
UPR	unpressurized rover
UTAF	Usability Testing and Analysis Facility
W	watts
WCS	Waste Containment System
X-box	A controller usually used in video gaming

ABSTRACT

The Space Exploration Vehicle (SEV) concept is an integral part of NASA's plans for future human space exploration. Each SEV includes a small pressurized cabin to safely sustain two crewmembers for 14 to 28 days. Through suit ports, crewmembers may rapidly egress and ingress the cabin for extravehicular activities (EVAs). In addition to achieving a surface exploration range that is potentially orders of magnitude greater than was achievable during the Apollo Program, the SEV concept offers many other benefits, particularly with respect to the health, safety, and productivity of crewmembers during nominal and contingency operations.

The primary purpose of the 2009 Desert Research and Technology Studies (DRATS) test was to conduct a quantitative habitability and usability evaluation of the SEV 1B prototype during a high-fidelity simulation of a 14-day Constellation Program lunar mission. Although future exploration operations are expected to involve two SEVs, each with a two-person crew, the operations at DRATS 2009 focused primarily on operations by a single SEV with a two-person crew because only one mobile SEV prototype was available for testing. A two-person crew (Crew A) consisting of an astronaut and a field geologist remained within the SEV, day and night, for the entire 14-day mission, leaving the vehicle only through the suit ports to perform EVAs. Standard metrics were used to longitudinally quantify habitability and usability of all aspects of the SEV prototype throughout the 14-day mission. Vehicle and crewmember descriptive statistics were collected, including task times for EVA and intravehicular activity, distances traveled, scientific productivity, and egress and ingress durations. Multiple design modifications were identified, but the data indicated that the crewmembers found the overall SEV habitability and human factors to be acceptable for a 14-day mission. The SEV prototype was also found to be acceptable overall for 24 hours of habitation by four crewmembers, as assessed during a simulated crew rescue scenario on the final day of the 14-day mission.

The effect of degraded communications coverage on crew productivity was quantified by having Crew A perform the various mission tasks described above under different levels of communication coverage. Comparison of standard crew productivity metrics as well as other test-specific metrics at these different levels made it possible to quantitatively determine the extent to which degraded communications coverage affected crew productivity and performance. Results showed no practically significant difference in crew productivity when the crew was operating for extended periods without space-to-ground communications compared with continuous space-to-ground communications.

In achieving a secondary objective, it was found that 100-m (328-ft) root mean square (RMS) random error in navigational data did not adversely affect the ability of crewmembers to drive to specific targets. When 50-m (164-ft) and 100-m (328-ft) RMS noise was deliberately added to SEV navigational data, crewmembers were able to successfully and quickly navigate to exact rock sample locations using the traverse plan, photographs, and noisy vehicle position data.

1.0 INTRODUCTION

The Space Exploration Vehicle (SEV) concept is an integral part of NASA's plans for future human space exploration. The SEV offers numerous health and safety advantages that accrue from having a pressurized safe haven and radiation shelter in close proximity to the crew at all times. The SEV combines a comfortable shirtsleeve, sensor-augmented environment for gross translations and geological and mapping observations with the ability to rapidly place suited astronauts outside the vehicle using suit ports, to take full advantage of the unique human perception, judgment, and dexterity. Data from the 2008 Desert Research and Technology Studies (DRATS) field test[1] demonstrated that this combination of features and capabilities increases the productivity of suited crew time by an average of 370% during exploration, mapping, and geological operations with an SEV compared with using an unpressurized rover.

The primary objective of the 2009 DRATS test was to perform a quantitative habitability and usability evaluation of the SEV prototype during a high-fidelity simulation of a 14-day lunar mission. A two-person crew (Crew A) consisting of an astronaut and a field geologist remained inside the SEV, day and night, for the entire 14-day mission, leaving the vehicle only through the suit ports to perform extravehicular activities (EVAs). A detailed mission timeline was executed in which crewmembers performed a range of intravehicular activity (IVA) and EVA tasks consistent with the anticipated objectives of an early lunar mission. These tasks included teleoperations, docking, maintenance, repair, science and exploration activities, briefings, food preparation, personal hygiene, and exercise activities, and enabled quantitative evaluation of SEV habitability and usability in a variety of operational modes while also enabling validation of specific SEV functional requirements. Following the 2008 DRATS test, NASA built a new SEV prototype cabin – referred to as Cabin 1B. New features in the 2009 SEV that were quantitatively evaluated during the 14-day mission included a second side hatch, an Active-Active Mating Adapter (AAMA), an Aft Driving Station, Electromechanical Suit Ports, an Aft Suit Enclosure, a Portable Utility Pallet (PUP), and redesigned displays, controls, and interior stowage.

Standard metrics were used to longitudinally quantify habitability and usability of all aspects of the SEV prototype throughout the 14-day mission. Objective metrics were also used to evaluate the quality and quantity of crew sleep as well as crew performance. Vehicle and crewmember descriptive statistics were collected, including EVA and IVA task times, distances traveled, scientific productivity, and egress and ingress durations. Quantitative field test data pertaining to EVA frequency, task types, and traverse distances were combined with metabolic and suit kinematic data collected during previous 1/6-G pressurized EVA suit testing trials to yield improved estimates of consumables usage, suit cycles, and the physiological impact of EVA during future lunar missions. These data are important in ongoing trade studies, lunar campaign analyses, and Human Research Program studies of human adaptations and performance during future lunar missions.

In addition to the primary objective of evaluating SEV habitability and usability during a 14-day mission, the effect of degraded communications coverage on crew productivity was quantified by having Crew A perform the various mission tasks described above under different levels of communication coverage. Comparison of standard crew productivity metrics as well as other test-specific metrics at these different levels made it possible to quantitatively determine the extent to which degraded communications coverage affects crew productivity and performance.

Crewmembers performed a simulated contingency scenario during the final 24 hours of the 14-day mission wherein Crew A drove the SEV to rescue two other crewmembers whose mobility system had experienced a simulated failure. The two crewmembers being rescued ingressed the SEV via the suit ports, and all four crewmembers remained inside the SEV for 24 hours, except when EVAs were being performed.

This study was designed to test hypotheses involving a combination of objective and subjective productivity, performance, and human factors metrics, which are detailed in Section 2.4 of this protocol. Inferential statistics were not used in testing the SEV test hypotheses. Instead, for all test hypotheses involving the comparison of metrics under different conditions, practically significant differences in the relevant metrics were prospectively defined.

SEV operations at the 2009 DRATS field test enabled the quantitative evaluation of multiple SEV-related functional requirements while simultaneously achieving several other important test objectives relevant to ongoing development of Lunar Surface System (LSS) program architectures and systems. Although lunar operations are expected to involve two SEVs, each with a two-person crew, the operations at DRATS 2009 focused primarily on operations by a single SEV with a two-person crew because only one mobile SEV prototype was available for testing. A lower-fidelity static SEV prototype as well as an All-Terrain Hex-Legged Extra-terrestrial Explorer (TRI-ATHLETE) prototype were used in conjunction with the mobile SEV for docking operations.

1.1 Background and Significance

Fewer than 20 lunar EVAs were performed during the entire Apollo Program. Architectures considered by NASA's Constellation Lunar Architecture Team (CxAT_Lunar) involved as many as 30,000 hours of lunar exploration EVA time. As Figure 1 shows, 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, the need to extend exploration to potentially hundreds of kilometers from an outpost, and the increased decompression sickness risk and prebreathe requirements associated with 55 kPa (8 psi)/32% oxygen (O_2) cabin pressure compared to 34.5 kPa (5 psi)/100% O_2 in the Apollo Program.

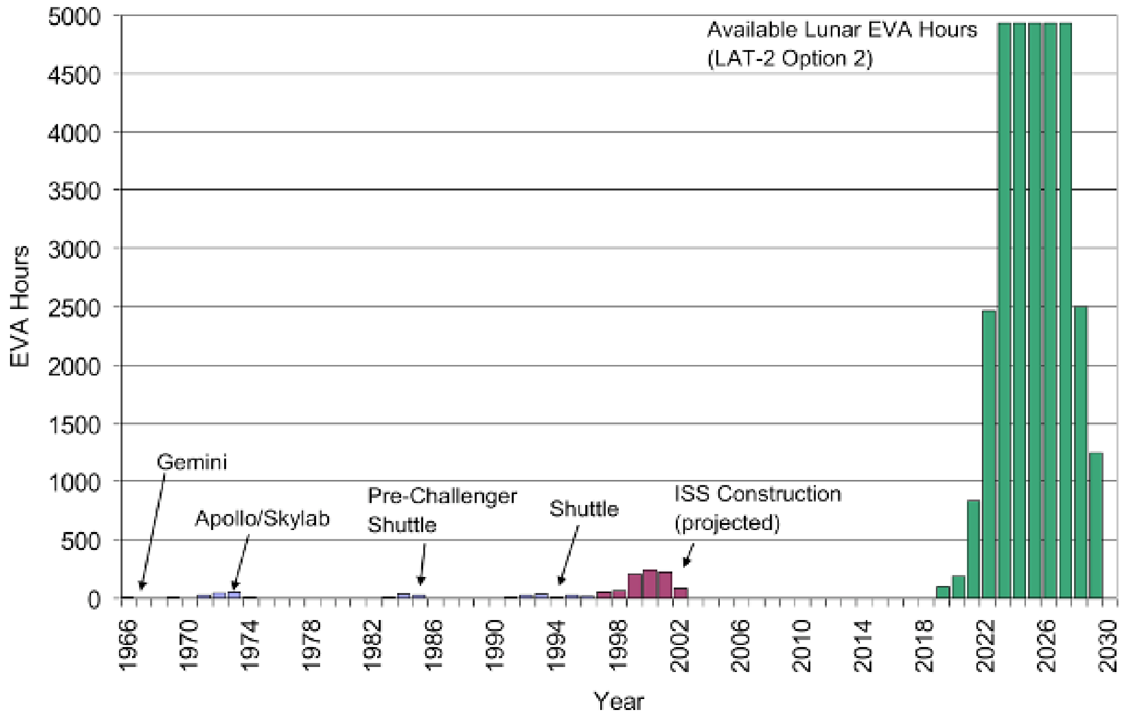


Figure 1. EVA estimates for Lunar Architecture Team (LAT)-2 Option 2 lunar mission architecture.

NASA is considering a novel approach to optimizing human safety and performance during future human exploration missions. The heart of the concept is a system of two SEVs, each of which nominally accommodates two astronauts in a shirtsleeve environment as they explore at a destination (Figure 2).

The SEVs are intended to optimize human safety and performance in planetary exploration by combining a comfortable shirtsleeve, 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 human perception, judgment, and dexterity. As illustrated in Figure 3, each SEV is slightly larger than the unpressurized Apollo rover. The front cabin of the SEV provides a pressurized shirtsleeve environment at the same pressure as the habitat or lander. Each SEV incorporates two suit ports that enable both rapid egress to the planetary surface and rapid ingress to the shelter of the SEV in response to SPEs, suit malfunctions, or medical emergencies. A side hatch that mates with the habitat, lander, or other SEVs enables transfer of personnel and equipment under pressure. This capability, along with the capability to quickly step into the suits and egress the vehicle, results in crewmembers actually "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. It also enables single-person EVA operations wherein one crewmember performs EVA tasks with in situ IVA support from a second crewmember that remains inside the SEV. The SEVs also incorporate an EVA driving station, and therefore can be operated with all the advantages of an unpressurized rover (UPR).

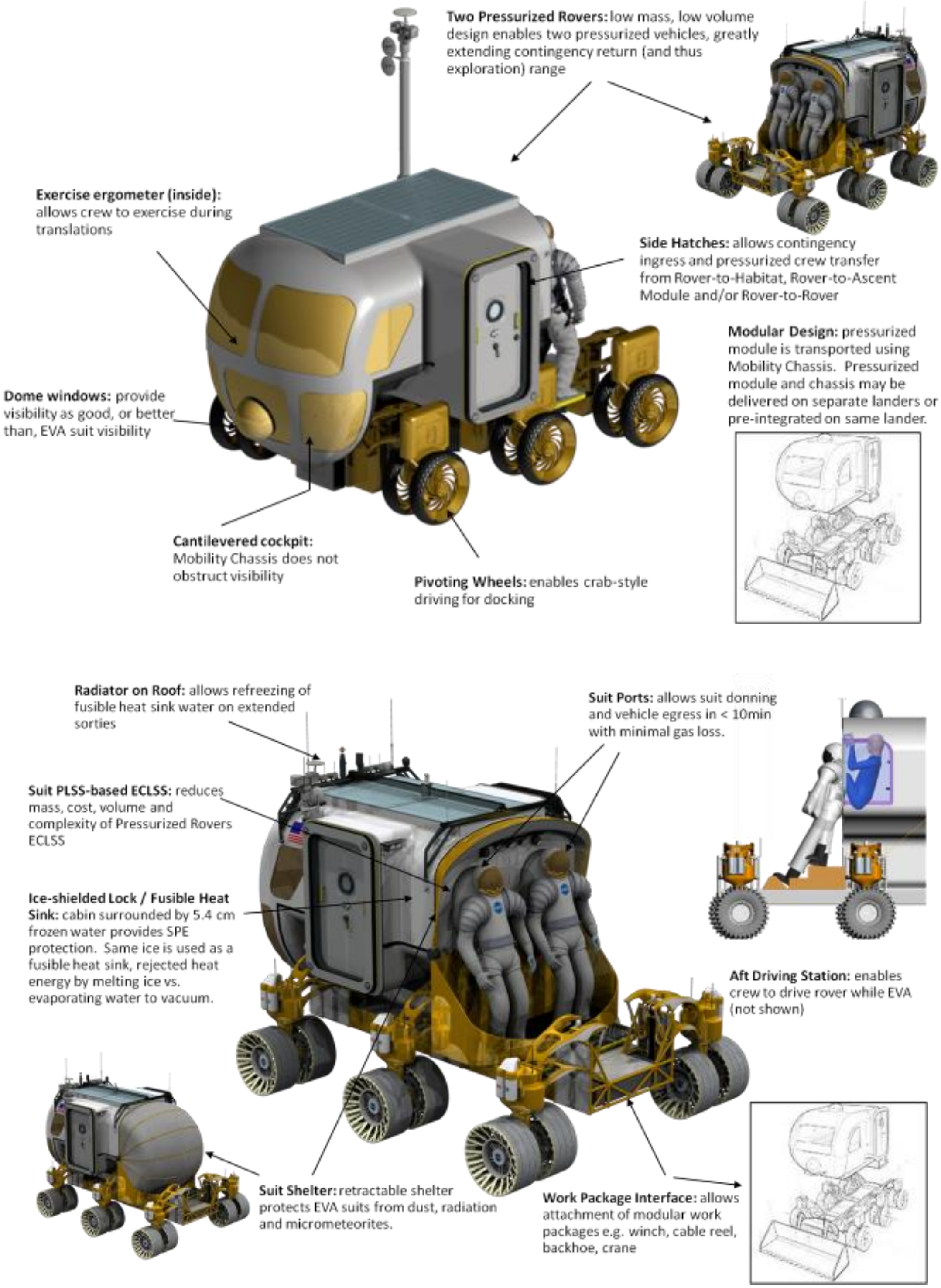


Figure 2. SEV features.

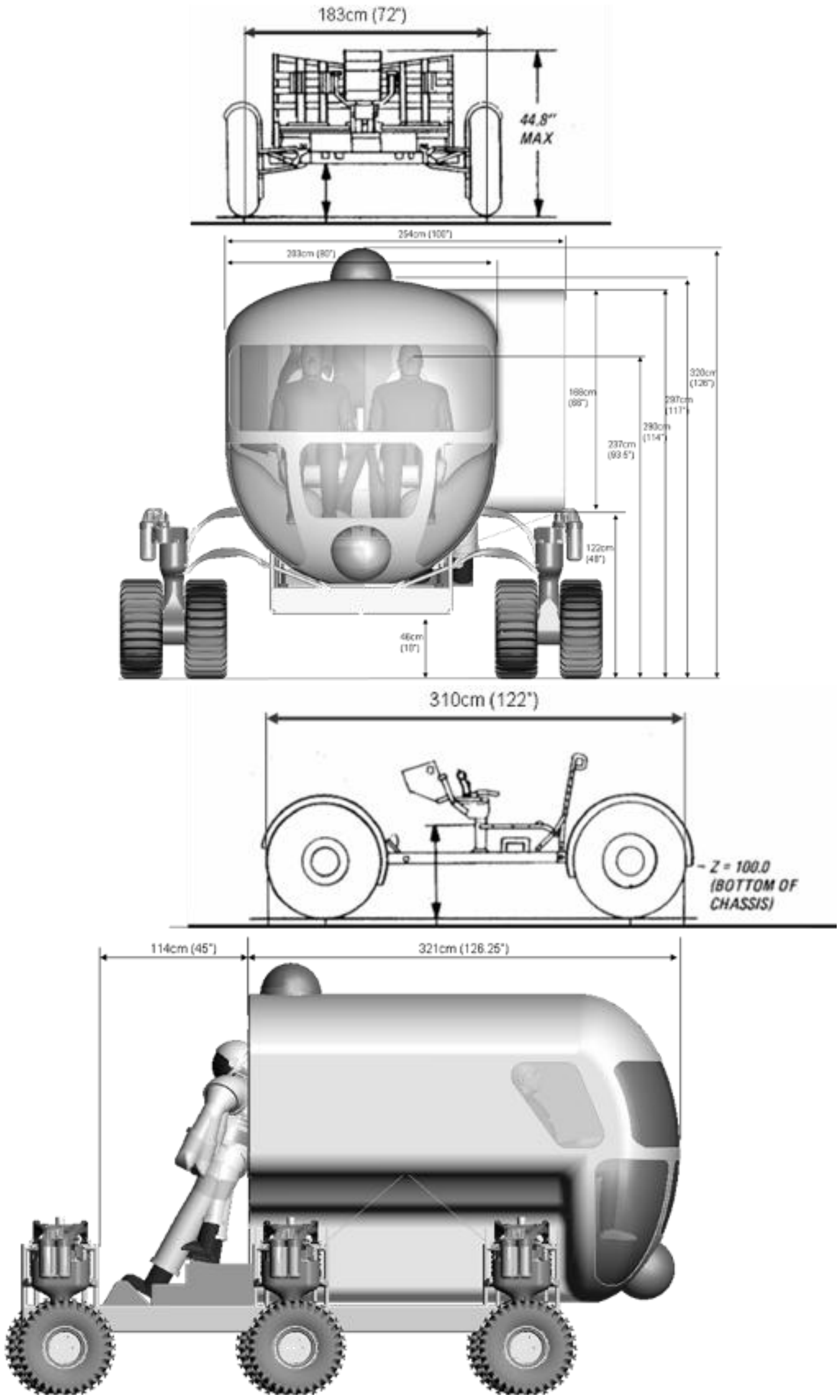


Figure 3. SEV vs. Apollo Rover size comparison.

Because the SEVs are capable of multi-day or weeklong sortie durations rather than the range-limited (8-hour) EVA activities achievable with a UPR, the overhead of returning to the outpost or lander at the end of each day will be avoided and exploration range may be significantly increased compared with UPR operations. Furthermore, because each SEV is a backup to the other, and is capable of supporting four crewmembers in a contingency return to the base or lander, the system of two SEVs provides greater range capability than a single larger pressurized rover. Data from the 2008 DRATS field test demonstrated that this combination of features and capabilities increases the productivity of suited crew time in an SEV by an average of 370% during exploration/mapping/geological operations compared with productivity in a UPR (Figure 4).

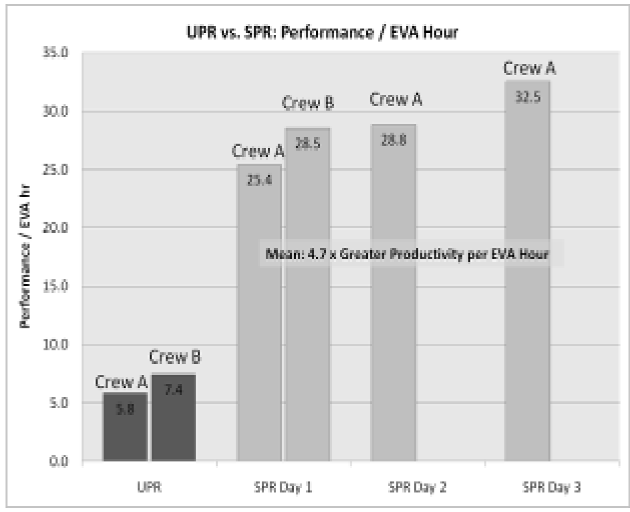


Figure 4. UPR vs. SPR: Performance per EVA hour.

The SEVs are designed to support 3-day traverses away from an outpost or other power and consumables resupply location. To enable longer range traverses lasting up to 14 days, each SEV can carry a deployable PUP, which incorporates a solar array, additional energy storage, gas and water consumables, and communications equipment (Figure 5). PUPs have the functional requirement of being mechanically attached to and detached from SEVs within 15 minutes without the need for EVA, although EVA support is required to connect gas and fluid lines. Thus, traverses up to 14 days are achievable with SEV and PUP combinations, but the adequacy of the crew accommodations in each SEV to satisfactorily support two crewmembers for a 14-day traverse has not been demonstrated. If greater volume and mass are required for achievement of the desired SEV functional requirements, then this will significantly affect ongoing lunar architecture analyses. The primary purpose of the test reported here was to determine whether the SEV human factors and crew accommodations are adequate to support a 14-day mission.

This test also addressed a need to verify the feasibility and operational characteristics of the SEV concept and to refine mass, volume, dimension, range, consumables usage, communications, and cost estimates and requirements not only for the SEVs but also for the EVA suits and other vehicles and systems with which the SEVs will interact. Estimates of performance metrics such as drive time, distance driven, range achieved, stationary time, and EVA time and frequency during exploration/mapping/geological traverses are necessary inputs to surface mobility power and energy storage models. Objective data on the effects of degraded communications coverage on productivity and performance are needed to help


Figure 5. SEV and PUP concepts.

inform decisions regarding how many lunar relay satellites – if any – are necessary to support future lunar exploration architectures. Additionally, EVA frequency and duration estimates are sought by the Human Research Program for use in models of physiological adaptations during long-duration lunar missions.

Evaluation of the SEV in this test was accomplished by planning and executing a 14-day traverse with the prototype SEV on the Black Point Lava Flow (BPLF) near Flagstaff, Arizona. The study design and metrics used to quantify productivity, human factors, and performance are detailed in Section 1.0. The rationale for the use of BPLF to conduct the test is described in Appendix A.

1.2 Hypotheses and Test Objectives

The hypotheses for this study are detailed below. The statistical analysis and the specific metrics associated with each hypothesis are detailed in Section 2.4.

Hypotheses:

1. The habitability and human factors of the SEV during a 14-day mission will be acceptable as assessed by established human factors metrics.
2. Crew productivity during SEV mission tasks (EVA and IVA science operations and vehicle maintenance tasks) will not significantly vary between two different communications scenarios:
    a. Continuous real-time communications (baseline)
    b. Limited communications (66% coverage, 34% no coverage – based on single relay satellite in highly elliptical orbit with apogee above the lunar south pole)
3. Human interfaces of the redesigned SEV prototype aft deck (suit ports, alignment guides, aft enclosure, and aft driving station) will be acceptable as assessed by established human factors metrics.
4. A prototype PUP will meet the functional requirement that it can successfully dock with (≤ 5 min) and undock from (≤ 5 min) the SEV.
5. A prototype AAMA will enable docking (≤ 5 min) and undocking (≤ 5 min) between two SEVs on representative terrain.
6. The habitability and human factors of the SEV will be acceptable to support a 24-hour contingency scenario.

Secondary Objective:

- Assess the effect of increasing navigational uncertainty (± 50 m, ± 100 m [± 164 ft. ± 328 ft]) on the ability to return to previously identified traverse locations.

1.3 ARCHITECTURAL TRACEABILITY MATRIX

Table 1. Architectural Traceability Matrix

	Objective	DIO Architectural Traceability
1	The habitability and human factors of the SEV during a 14-day mission will be acceptable as assessed by established human factors metrics.	#8 Small Press. Rover
2	Crew productivity during SEV mission tasks (EVA and IVA science operations and vehicle maintenance tasks) will not significantly vary between two different communications scenarios: a). continuous real-time communications (baseline); b). limited communications (66% coverage, 34% no coverage – based on single relay satellite in highly elliptical orbit with apogee above the lunar south pole).	#2,3,4: Traverses; #5: Power, #6: Comm. #8 Small Press. Rover; #18: Ops Scen.; #19: Observations; #21: Geo. Sampling; #23: Data Flow
3	Human interfaces to the SEV 1B prototype aft deck (suit ports, alignment guides, aft enclosure, and aft driving station) will be acceptable as assessed by established human factors metrics.	#8 Small Press. Rover; #11: EVA
4	A prototype PUP will meet the functional requirement that it can successfully dock (≤ 5 min) and undock (≤ 5 min) from the SEV.	#5: Power, #6: Comm.; #13: Logistics
5	A prototype AAMA will enable docking (≤ 5 min) and undocking (≤ 5 min) between an SEV and Habitat in representative terrain.	#2,3,4: Traverses; #8 Small Press. Rover
6	The habitability and human factors of the SEV will be acceptable to support a 24-hour contingency scenario.	#8 Small Press. Rover
	Secondary Objective	**DIO Architectural Traceability**
1	Assess the effect of increasing navigational uncertainty (± 50 m, ± 100 m [± 164 ft, ± 328 ft]) on the ability to return to previously identified traverse locations.	#6B: Nav

Note: Each of the hypotheses and objectives tested at DRATS 2009 mapped to one or more key architectural questions as defined by NASA's Directorate Integration Office (DIO).

2.0 METHODS

2.1 PROTOCOL DESIGN

2.1.1 FOURTEEN-DAY SPACE EXPLORATION VEHICLE TRAVERSE

The hypotheses described in Section 1.2 were evaluated during a 14-day simulated lunar traverse by an SEV. Mission Operations Directorate (MOD) personnel developed a high-fidelity flight-like 14-day traverse timeline by using flight rules and assumptions consistent with the current lunar mission architecture. Flight controllers at the test site served as capsule communicator (CAPCOM)/test directors to ensure that all SEV test operations were executed in a consistent and flight-like manner.

Hypotheses 1, 3, 4, 5, and 6 involved the quantitative evaluation of crew accommodations, aft deck, dust protection, PUP, and AAMA, respectively. These evaluations were conducted on an ongoing basis throughout the 14-day traverse using a rating system (Section 2.4) that was successfully developed and used during the 2008 DRATS field test. Although only one mobile SEV was available at the test site, a second SEV cabin on a static chassis was available for performing docking operations using the AAMA.

2.1.2 VARIED COMMUNICATIONS CONDITIONS

SEV crewmembers were able to communicate with the test safety support personnel and with each other during all test operations. However, the effects of degraded communications on crew productivity and performance were evaluated by intentionally varying the communications capabilities between the SEV and the support team in the Mobile Mission Control Center (MMCC).

Hypothesis 2 was evaluated by using measures of crew performance and productivity that were previously used during DRATS 2008 and Pavilion Lake Research Program field tests. Metrics were collected during operations that were performed under at least two different communication conditions. The first 6 days of the 14-day SEV traverse were conducted with continuous real-time communications available between the SEV and the test director/CAPCOM and Science Team personnel in the MMCC.

Activities during the first 6 days included geological/mapping/exploration activities as well as in-flight maintenance (IFM) tasks, vehicle inspections and checkout, suit port transfer module operations, and PUP transfer activities. The next 4 days of the 14-day traverse consisted of similar activities, but the communication infrastructure was intentionally modified so that every 8 hours of communications between the SEV and MMCC were interrupted by 4 hours of loss of signal. This communication mode of 8 hours of real-time communication followed by 4 hours without communication represents the anticipated ground coverage footprint of the lunar south pole region from a single communications relay satellite in highly elliptical orbit with orbital apogee above the lunar south pole (Figure 6). Crew performance and productivity under these varied communication conditions were quantified and compared using the metrics described in Section 2.4.

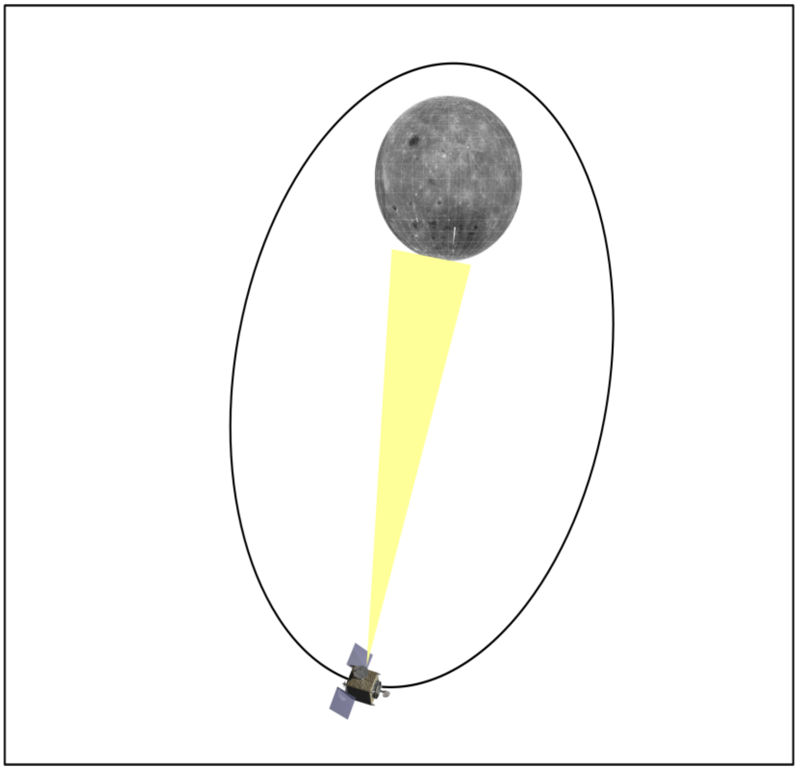


Figure 6. SEV traverse days 7-10 simulated communications at the lunar south pole obtained through the use of a single Lunar Relay Satellite orbiting the moon.

The communication mode for the remaining 4 days of the 14-day traverse was intentionally unspecified to allow flexibility during test operations to either collect additional data for comparing the two communication modes described above or test a different communication mode that had a 20-minute delay in communication between the SEV and the MMCC, simulating a Mars mission.

2.1.3 Twenty-Four-Hour Contingency Scenario

Hypothesis 7 required that a 24-hour contingency scenario be simulated. This occurred during the final 24 hours of the 14-day SEV traverse. An immobilized SEV scenario was simulated in which two crewmembers in an immobilized SEV (the SEV Cabin 1A on static chassis) were transferred into the SEV Cabin 1B alongside the two crewmembers already inside the SEV Cabin 1B. All four crewmembers then remained inside the single SEV for 24 hours. At the end of that time, the 14-day SEV traverse was completed.

2.1.4 Navigational Accuracy Scenario

Objective 1 required that Crew A navigate to a series of traverse locations, previously visited by Crew B, using position information incorporating different levels of uncertainty. A software program intentionally introduced known levels of random noise to SEV position data derived from the Global Positioning System (GPS) so that the position of the SEV was known to within ± 20, 40, or 80 m (± 66, 131, or 262 ft). A total of nine different waypoints were identified. Crew A navigated to three waypoints using navigational accuracy of ± 20 m (±66 ft), three waypoints using navigational accuracy of ± 40 m (± 131 ft), and three waypoints using navigational accuracy of ± 80 m (± 262 ft). Crew B navigated to all nine waypoints using navigational accuracy of ± 20 m (± 66 ft). The mean time and distance traveled for each crew to navigate to each of the nine waypoints were then compared to determine whether the decreased navigational accuracy resulted in the crew taking more time and traveling farther to navigate to the specified traverse locations.

2.2 Procedures, Mission Rules, and Extravehicular Activity Tools

A controlled and meaningful evaluation of the SEV, as well as safety of crewmembers and protection of equipment, requires consistency in the way different tasks are performed by all crewmembers. Taking Apollo and comparable Space Shuttle and International Space Station (ISS) procedures as a starting point, procedures and mission rules are being developed, tested, and revised for SEV-based EVA operations. Apollo-era EVA geological sample collection procedures (rock sample, soil sample, trenching sample, drive tube sample) were modified, documented, and used during the Moses Lake field test in 2008. Apollo-style EVA tools were also used during sampling tasks. As a result of lessons learned during Moses Lake testing (i.e., excessive time was spent on photo-documentation, the second EVA crewmember was used inefficiently during sampling tasks, information available to the science CAPCOM and backroom was inadequate), modified procedures, EVA tools, and camera equipment were developed and were subsequently used during the 2008 DRATS field test.[1] These procedures were refined, updated, and used during this test.

2.2.1 Traverse Planning and Timeline Development

The 14-day traverse plans and detailed timeline developed were consistent with defined capabilities, constraints, and assumptions. The functional requirements of the SEV, as described in the Preliminary Report of the Small Pressurized Rover,[2] are listed below.

2.2.2 Space Exploration Vehicle Functional Requirements

- Contingency return capability always available
- Nominal two-person crew per SEV, four-person crew in contingency
- Power-up and check-out including suit/ Portable Life Support System (PLSS) power-up and check-out: ≤ 1 hr
- Dock/undock from habitat or lander:
  - ≤ 10 min
  - ≤ 0.03 kg gas loss per person
  - Capable of several (to be determined [TBD]) dock/undock cycles per day
  - Robust to dust contamination
- Nominal velocity: 10 kph (~6 mph)
- Driving naked-eye visibility should be comparable to walking in an EVA suit; i.e., eyes at same level, similar field of view
  - Augmented by multispectral cameras and instruments
- Visual accessibility to geological targets comparable to EVA observations; i.e., naked eyes ≤ 1 m (≤ 3 ft) from targets
  - Possibility of magnification optics providing superior capability over EVA observations
- Suit don and ingress/egress
  - ≤ 10 min

  - ≤ 0.03 kg gas loss per person
  - Capable of several (TBD) dock/undock cycles per day
  - ≥ 2 independent methods of ingress and egress
  - Robust to dust contamination
- Vehicle mass (excluding mobility chassis) ≤ 2400 kg (5291 lbs)
- Habitable volume: approximately 10 m^3 (353 ft^3)
- 12 two-person EVA hours at 200-km (124-mile) range on batteries and nominal consumable load
- Ability to augment power and consumables range and duration to achieve ≥ 1000 km (621 miles)
- PLSS recharge time ≤ 30 min
- Crewmembers ≤ 20 min from ice-shielded lock radiation protection (including translation to SEVs and ingress)
- Heat and humidity rejection provided by airflow through ice-shielded lock and condensing heat exchanger

In addition to the IFM and hardware evaluation tasks that were performed during the 14-day traverse, detailed geological/mapping/exploration traverse plans were developed and performed. The Science Team identified and prioritized specific sites of scientific interest in the test site region using remote sensing data with resolution equivalent to that of the remote sensing expected before a crewed lunar mission not preceded by robotic or crewed missions to that site. A traverse plan was then developed for the 14-day SEV traverse based on the assumptions, constraints, and capabilities associated with the vehicle.

Traverse plans included detailed timelines and traverse stations, each having specific tasks associated with the science objectives at those stations (Figure 7). "Get-ahead" tasks also were included in traverse plans; these were secondary tasks that were to be accomplished if the nominal tasks were completed and the crewmembers were ahead of the timeline by a predefined amount of time.

Detailed timelines for each traverse day were developed consistent with current lunar architecture EVA/surface operations assumptions and with guidance from the Johnson Space Center (JSC) MOD.

The preliminary Science Traceability Matrix developed by the Science Team (Appendix B), including prioritized science stations, was derived from preliminary interpretation of a U.S. Geological Survey aerial photomosaic of the test area. On the basis of this preliminary interpretation, the Science Team identified the geologic units and associated objectives listed in Sections 2.2.3, 2.2.4, and 2.2.5.

2.2.3 GEOLOGIC UNITS

- *Volcanics*
  - BPLF or "The Flow"
  - Lava flows – undifferentiated
  - Cinder cones
  - Dissected layered unit and lava flow cap rock?
- *Undetermined (Sedimentary? Igneous?)*

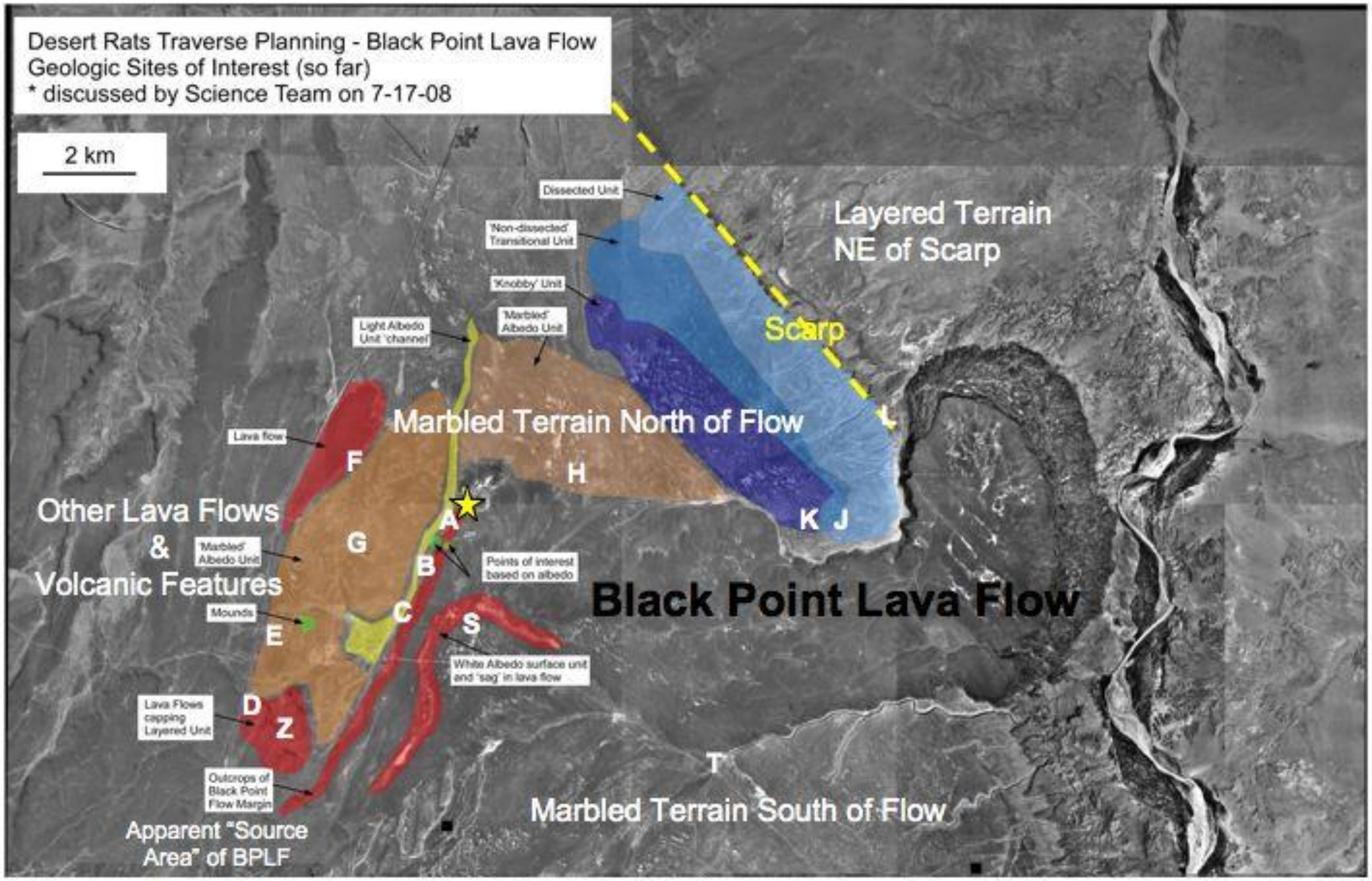
  - Marbled terrain north of flow (includes marbled albedo unit, dissected unit, non-dissected transitional unit, and “knobby” unit)
  - Marbled terrain south of flow
  - Layered terrain northeast of (“below”) scarp
  - More layered terrain – undifferentiated
  - Layered topologic highs
  - Chaotic terrain
  - Dissected layered unit and valley
- *Other*
  - High-albedo units
  - Fluvial channel

2.2.4 OVERARCHING SCIENCE OBJECTIVES

1) Determine the origin and the nature of the geologic units represented at the site.
2) Understand age relationships and reconstruct the geologic evolution of the site.

2.2.5 SPECIFIC SCIENCE OBJECTIVES

1) Understand the geology of the BPLF, in particular its morphology, structure, petrology, mineralogy, chemistry, age, and any spatial and temporal variations of these characteristics.
2) Understand the geology of other lava flows and volcanic features in the area and their relation to the BPLF in space and time.
3) Understand the origin and nature of other geologic units and features in the area and their relation to the BPLF in space and time.



Tentative EVA Stations as of 24 Jul 2008: A, B, C, D, E, F, G, H, J, K, L, S, T, Z
Refer to Science Traceability Matrix Table for Science Plan Details.

Figure 7. Annotated map of BPLF showing tentative EVA stations.

2.2.6 TECHNICAL CONTINGENCY PLANS

In the event of technical contingencies during the field test, the validity of the 14-day SEV habitability evaluation was preserved by ensuring strict adherence to simulation rules, which state:

i) SEV crewmembers may not leave the SEV cabin except on simulated EVAs using lightweight suits or EVA backpacks.

ii) No more than four people, including the two SEV crewmembers, may simultaneously occupy the SEV cabin.

The operations concept for the SEV-based lunar missions involves frequent interaction among the four crewmembers and transfers between SEVs. Thus, the SEV crewmembers during the 14-day mission continually operated under conditions that are consistent with the four-person, dual-SEV lunar mission scenario being simulated. Adherence to these simulation rules during technical contingencies was ensured by the strict application of the Technical Contingency Plans listed below.

EVENT & TECHNICAL CONTINGENCY PLAN #1:

Technical issues arise that require the SEV crew to leave the SEV Cabin 1B.

TECHNICAL CONTINGENCY PLAN:

Depending on time of day and duration of anticipated technical resolution, the SEV crew will perform EVA tasks and/or transfer into SEV Cabin 1A until the Cabin 1B technical issues have been resolved. Transfer between Cabins 1A and 1B may be achieved either through suit ports or by transferring under pressure through the side hatches.

EVENT:

Technical issues require that engineers enter the SEV cabin while one or both SEV crewmembers are in the cabin.

TECHNICAL CONTINGENCY PLAN:

Up to two engineers will be allowed to enter the cabin with the two SEV crewmembers, or three engineers if only one SEV crewmember is in the cabin. Thus, no more than four crewmembers will simultaneously occupy the cabin, consistent with the lunar architecture. SEV crewmembers will sit in the cockpit area while the side hatch door is open.

EVENT:

Technical or other unforeseen issues necessitate the transfer of materiel into the SEV cabin.

TECHNICAL CONTINGENCY PLAN:

Where possible, the Suit Port Transfer Modules will be used to transfer materiel in and out of the SEV. An inventory of any materiel transferred into the cabin will be kept and added to the pre-mission inventory to ensure that mass and volume assumptions are documented throughout the mission. Otherwise, materiel will be transferred under pressure from Cabin 1A to 1B through the side hatch or transferred into the vehicle through the side hatch while crewmembers sit in the cockpit area.

2.2.7 Crews and Crew Training

Test subjects ("crewmembers") were identified before they were deployed into the field. The two-person crew consisted of one astronaut and one field geologist. Crewmembers were briefed on the objectives and methods of the study and participated in a comprehensive training program that included review and practice of the following:

- Study hypotheses
- Metrics and data-collection procedures
- Mission rules
- SEV procedures
- Mock-up MkIII spacesuit fit check and familiarization
- Suit port ingress/egress procedures
- SEV driving
- EVA geological sampling tasks
- Geological briefings
- Communications protocols

Upon deployment to the field test site, all crewmembers completed a brief refresher course. The pretest training and the refresher course were combined to ensure the safety of the crewmembers and protection of the equipment, and to prevent confounding of results due to time-varying crewmember learning effects.

2.3 Test Hardware

2.3.1 Space Exploration Vehicle

The SEV Cabin 1B used in this study was developed as a collaborative effort of JSC, Langley Research Center, Ames Research Center, and Glenn Research Center. The cabin is not pressurized but incorporates functional electromechanical suit ports including alignment guides and clamping mechanisms, includes all necessary crew accommodations to support a 14-day traverse, and is fully integrated with the Chariot chassis, consistent with the lunar architecture assumptions (Figure 8). The SEV cabin also incorporates interior cameras and microphones that were used by the JSC Usability, Testing and Analysis Facility (UTAF) in the collection of human factors data throughout the study.

Figure 8. Space Exploration Vehicle Cabin 1B integrated with Chariot chassis.

2.3.2 Suit Port Mock-up

The electromechanical suit ports on SEV Cabin 1B are the elements of the SEV through which crewmembers nominally egress and ingress to perform EVAs. The suit port mock-ups are located on the aft bulkhead of the SEV cabin structure. They include interior aids for suit donning and doffing as well as electromechanically adjustable exterior platforms to accommodate different crewmember heights.

Human factors evaluation of the suit ports began at JSC in the Building 9 Space Vehicle Mockup Facility and during testing at the JSC Rock Yard facility. This testing continued throughout the 2009 DRATS field test, when crewmembers repeatedly used the suit ports during the 14-day SEV traverse.

The human factors evaluation of the suit port mock-up (at JSC and during the field test) focused on the following specific features and functions of the suit port:

Suit don and doff capabilities and features of the suit port architecture

- location and usability of interior handholds for suit don/doff
- usability of an “ottoman” as an interior booster seat for suit don/doff
- usability of exterior handrails for alignment guides and positioning during suited ingress operations
- leg angle positioning for suit don/doff operations
- adequacy of adjustable exterior platform heights for various crewmembers

Suit undocking from and docking to the suit port hatch interface area

- usability of actuator to unlock/lock inner hatch
- usability of actuator to close/open inner hatch

- method of closing and opening PLSS to suit
- usability of actuator to unlock/lock closure mechanism attaching suit to the suit port entry hatch
- ability of suited test subject to detach the suit from the suit port and reattach it
- alignment guides and exterior platform height and adjustability
- external umbilical access and functional operation characteristics

It is important to note that a) the suit port does not pressurize (a pressurized engineering unit is currently being fabricated), b) the mock-up suits are unpressurized and were not specifically designed for use with suit ports, c) all of the testing will be performed in a 1-G environment, and d) the mock-up suits and suit ports do not incorporate the additional complexities associated with an actual PLSS and the data, power, gas, and fluid connections between the suits and the SEV. Testing in a 1-G environment using unpressurized suits that are not specifically designed for use with suit ports is likely to increase the time and difficulty associated with suit port egress and ingress tasks, and the reduced complexity of the suit port mock-up compared with a fully functioning pressurized version means that EVA overhead and technical challenges associated with this complexity will not be identified during this study.

Results of the suit port evaluation are presented and interpreted in the context of these limitations.

2.3.3 LIGHTWEIGHT SPACESUITS AND SHIRTSLEEVE BACKPACKS

The Space Suit and Crew Survival Systems Branch (EC5) of the Crew and Thermal Systems Division at JSC developed two "lightweight suits" and two "shirtsleeve backpacks" as part of the fiscal year 2009 SEV project.

The lightweight suits (Figure 9) were used with the electromechanical suit ports and SEV aft deck systems. They are unpressurized and have an open-air helmet. The major components are the interface plate to the suit port (with brackets to make the bottom of the plate sit about 9 degrees off of the person, alignment guide pins for suit port docking, shoulder and waist harnesses, and neck ring with half of a representative helmet bubble), a PLSS shell that includes a removable electronics package, and a lightweight garment that includes representative gloves and boots. The lightweight garment is made of Ortho-Fabric and Spandex, and is modular. For subject comfort, the arms can be removed at the shoulders, the lower torso can be removed at the waist, and the front panel can be unzipped, leaving behind a "vest" that allows more airflow for thermal comfort. These suits have integrated audio systems (speakers and microphones). The total suit weight is approximately 34 kg (~75 lbs), which is about 9 kg (~20 lbs) lighter than the Mark III mock-up suits used in 2008.

Figure 9. Lightweight EVA suit mock-ups.

Shirtsleeve backpacks (Figure 10) were used as backups to the lightweight suits and also to house opportunistic technology demonstrations. The audio system is a headset with in-line volume control and mute. The total system weight is approximately 14 kg (~30 lbs).

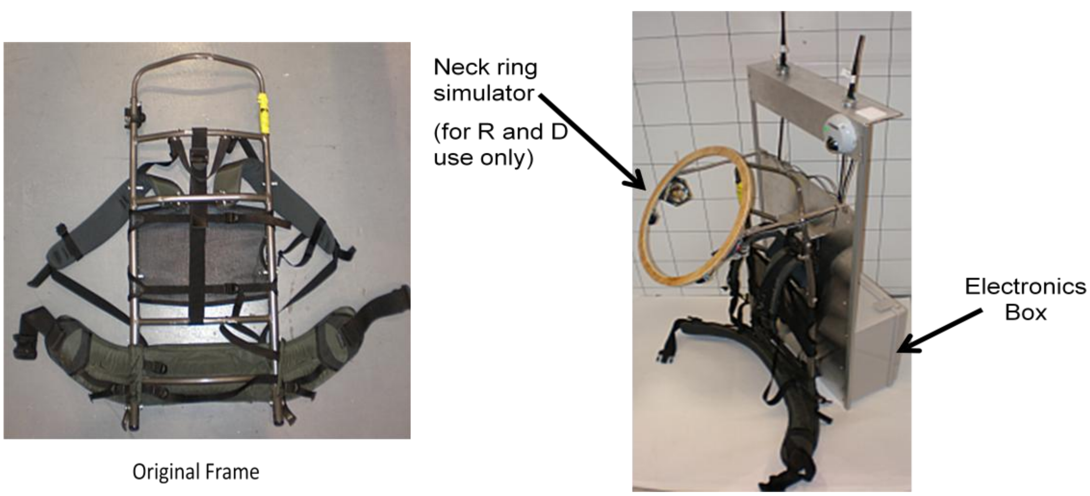


Figure 10. Shirtsleeve backpacks.

The electronics system in both the lightweight suits and shirtsleeve backpacks includes the power system, network system, computer, voice communication system, GPS, video camera, and helmet lights.

2.3.4 COMMUNICATIONS, NETWORKING, AND NAVIGATION INFRASTRUCTURE

The Information Technology and Communications Directorate (ITCD) at Kennedy Space Center (KSC) was responsible for engineering, implementing, testing, and deploying operationally a diverse communications and networking infrastructure to support test operations. This infrastructure is known as a Lunar Communications and Network Emulator (LCNE). The system was deployed to model the architecture of a lunar command network to evaluate the architecture and identify gaps in planning.

The LCNE was configured for DRATS 2009 to emulate many aspects of the Constellation LSS Scenario 12 architecture. Figure 11 shows the emulated communications and networking architecture. A mast system was statically deployed to emulate the communications and networking function of a deployed Portable Communications Terminal (PCT)/PUP combination, in a location that has solid link visibility to "Earth." At the test site, Earth is a low-inclination mountain top 52 km (32 miles) from the test site, where LCNE router and communications equipment is deployed to provide secure connectivity back to the NASA Integrated Services Network (NISN). This simulated PCT aggregated all surface element traffic for uplink to Earth and the MMCC, and provided surface links to a second, mobile PCT/TRI-ATHLETE simulator (modeled with a mobile off-road truck with 20-m [66-ft] mast). The PCT/ATHLETE simulator moved to locations that served traffic between the SEVs, and it provided linkage to the static PCT and therefore to the MMCC when terrain between the elements was favorable.

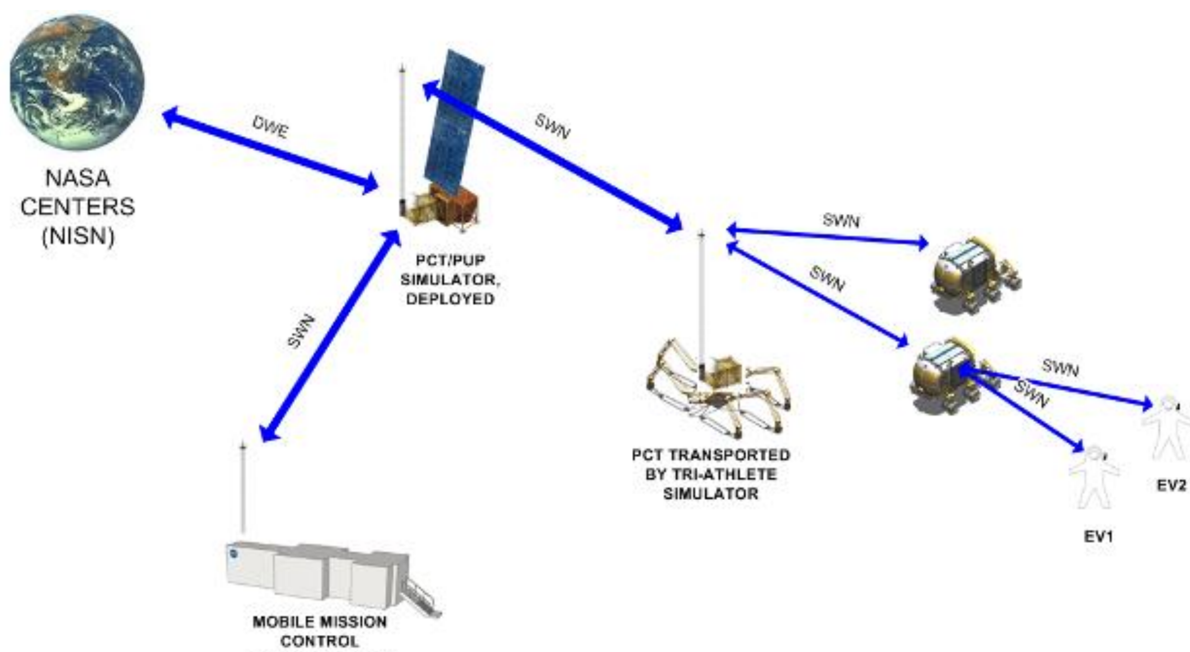


Figure 11. DRATS 2009 communications and networking architecture, implementing the Scenario 12 functional architecture.

The KSC ITCD team provided the following major areas of support:

- Install communication and networking assets on nearby Mount Elden to serve as aggregate broadband network bandwidth to the field test from a commercial Internet service provider, and provide multiple networks at the test site for a variety of operational and experimental functions
- Secure the network from Internet attacks, and tunnel test site traffic back to NASA's networks
- Measure network utilization and performance useful for future lunar data requirements planning
- Engineer and deploy a duplicate network tunnel from a JSC location to NISN to allow engineers to test their field configuration before the outing during dry-run operations
- Engineer, fabricate, test, and deploy a static PCT simulator and a mobile PCT simulator.
- Provide Spectrum Management leadership for the entire DRATS test team
- Engineer, fabricate, test, and deploy pan/tilt/zoom cameras that were remotely controlled by MMCC personnel throughout the field test
- Engineer and field on-suit EVA megapixel science cameras and associated science CAPCOM image and video stream data display system
- Assist with design and testing of SEV full-duplex audio and radio system

Navigation and asset tracking and recording for the SEVs at the field test was facilitated through the use of the U.S. GPS. GPS data were adjusted in the SEV to resemble the accuracy of a proposed lunar navigation system. Other lunar surface navigation technology demonstrations were also performed. Future tests will involve the use of navigation techniques that more accurately model the lunar navigation architecture.

2.3.5 Mobile Mission Control Center

In addition to the communications and networking infrastructure described above, the ITCD at KSC provided an MMCC, which accommodated test support personnel including the Science Backroom Team, CAPCOM/test director, and data collection personnel. The MMCC is shown in Figure 12 and Figure 13.

Figure 12. Interior of MMCC.

Figure 13. Exterior of MMCC.

2.3.6 SPACE EXPLORATION VEHICLE EXERCISE ERGOMETER

The SEV incorporates a fully functional exercise ergometer, the use of which was included in the 14-day SEV traverse timeline. The exercise device can be used as both a cycle ergometer and a resistive exercise device. The device and its integration into the SEV were included in the human factors evaluation of the SEV crew accommodations. The evaluation of the SEV exercise device was scheduled in the detailed timelines developed as part of the test plan or conducted ad hoc as time permitted during the field testing.

An annotated computer-aided design (CAD) model of the device is shown in Figure 14, and an overview of the exercise device's mechanical system is given in Figure 15. Photographs showing the setup and use of the exercise device are presented in Figure 16, and the location of the exercise device in the SEV cabin is shown in Figure 17.

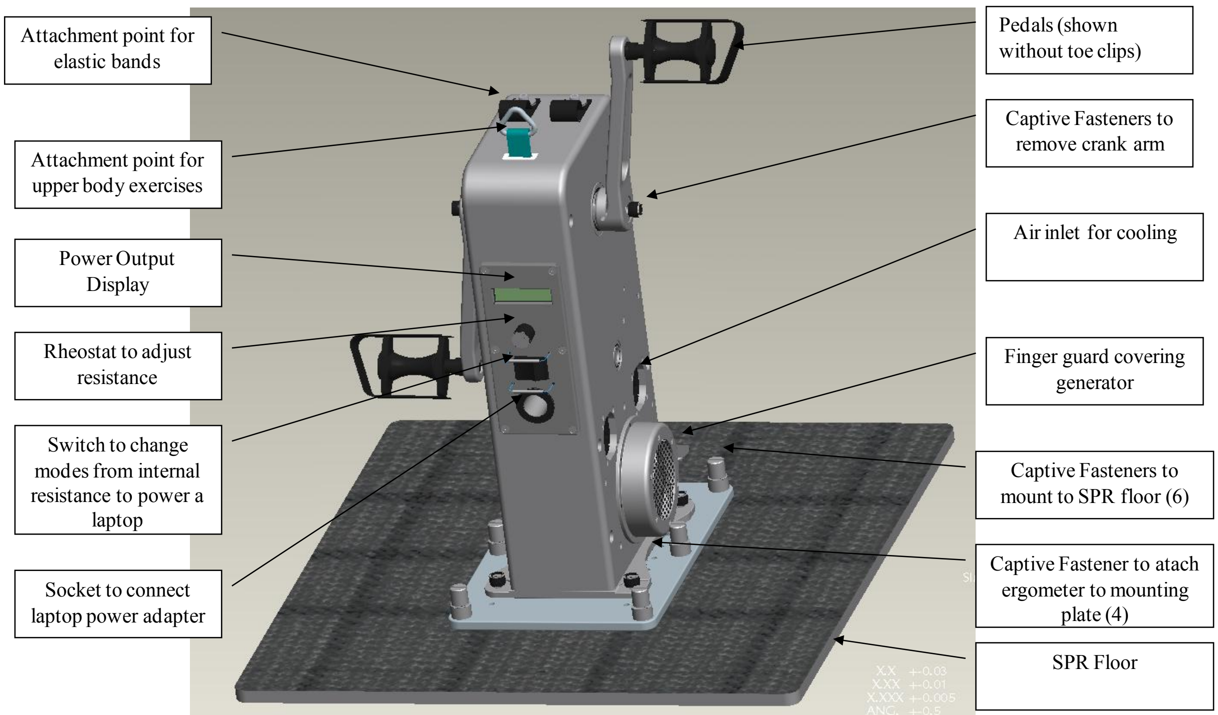


Figure 14. Annotated CAD model of SPR exercise device.

- The user pedals at a comfortable speed approximately 60 RPM (must be between 25 and 83 RPM)
- Internal gearing steps up the speed to the generator by 36 times
- The generator power is delivered to either the custom adjustable internal load or to a power supply which adapts to laptop computers through a front electrical connector
- The electrical resistance created is used to create mechanical resistance turning the pedals

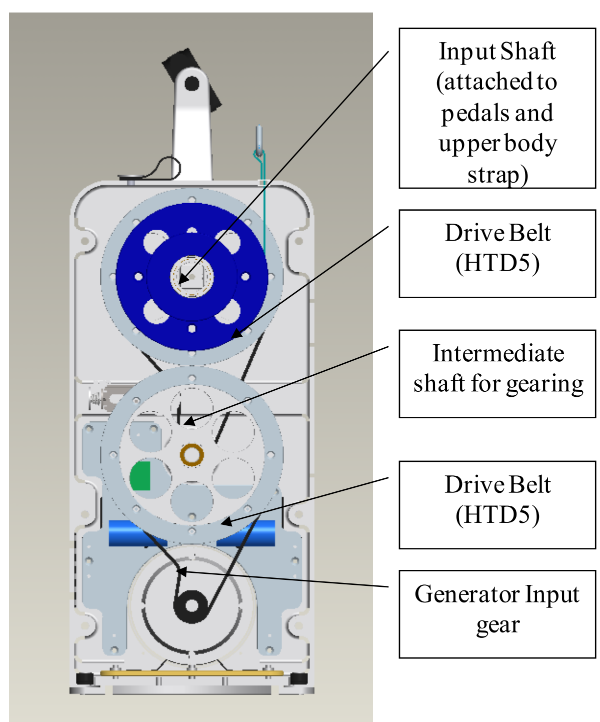


Figure 15. Mechanical overview of SEV exercise device.

Figure 16. Photographs demonstrating the setup and use of the SEV exercise device. Clockwise, from top left: attaching pedals; placing seat across aisle; cycling; using resistive exercise handle attachments.

Figure 17. Location of exercise device in SEV cabin.

The JSC Committee for the Protection of Human Subject approved a detailed protocol for the human factors evaluation of the SEV exercise device. During the 14-day traverse timelines at BPLF, subjects performed up to one exercise session per day during which they pedaled the cycle ergometer at about 75 revolutions per minute (RPM) for up to 20 minutes in four stages lasting up to 5 minutes each. For the first exercise stage, the subject pedaled against a resistance set to up to 50 watts (W). For the second and third exercise stages, subjects pedaled against resistances set up to either 75 W and 100 W (for women weighing less than 65 kg [143 lbs]) or 100 W and 150 W (for women weighing more than 65 kg [143 lbs] and all men). In the final exercise stage, subjects continued to pedal the cycle ergometer for 5 minutes at less than 50 W as an active cool-down. Subjects also used the resistive exercise device to perform pushing and pulling exercises at low intensity with settings and durations equal to or less than those used when using the device as a cycle ergometer.

2.4 Metrics and Hypothesis Testing

The specific metrics used to test each of the study hypotheses are described in this section. For comparative hypotheses, the difference value for each metric that was considered practically significant was prospectively defined and the rationale explained. For non-comparative hypotheses, the absolute value of each metric that accepts or rejects each hypothesis was prospectively defined and the rationale explained. Table 2 provides an overview of the study metrics and their associated method of data collection (GPS-derived or data sheet).

Table 2. Productivity, Performance, Human Factors, and Subjective Crew Health Metrics

METHOD		METRIC	
DATA SHEET	GPS		
		Productivity	
x		Pavilion Lake Research Program Observation Quality Scale	
x		Pavilion Lake Research Program Data Quality Scale	
x		Exploration Productivity Index	
		Performance	
X	X	EVA suit time (max, mean)	
	X	Range (max, plot vs. time)	
X	X	Vehicle traverse duration	
	X	Vehicle distance driven	
	X	Vehicle terrain factor (distance driven / range)	
	X	SEV time spent moving – both crew IVA	
X	X	Vehicle distance driven – one or both crew EVA	
	X	Vehicle speed while moving (max, mean incl. stops, mean excl. stops)	
X		Vehicle time spent stationary, navigating	
X		Vehicle time spent stationary, making contextual observations	
X		Vehicle time spent stationary, resting/eating/other	
X	X	Number of EVAs	Work Efficiency Index
X		EVA overhead time	
X	X	EVA boots-on-surface time (total, mean per EVA, plot vs. range)	
X		Task completion times (max, min, mean, sd)	
	X	EVA distance walked (total, mean per EVA)	
X		Post-dropout communications efficiency	
		Human Factors	
X		Cooper-Harper	
X		Gravity Compensation & Performance Scale	
X		Human factors questionnaires	
other		Sleep duration	
X		Sleep quality	
		Subjective Crew Health Metrics	
X		Bedford Thermal Scale	
X		Corlett and Bishop Discomfort Scale (Figure 23)	
X		Borg Rating of Perceived Exertion	

Descriptive statistics were used to characterize the performance, productivity, and human factors metrics under all test conditions. Inferential statistics were not used to test the study hypotheses because statistical power was low. Instead, practically significant differences in specific metrics were prospectively defined for testing the study hypotheses. This process was used during previous Constellation Program EVA suit testing protocols conducted by the EVA Physiology, Systems and Performance Project in which small sample sizes precluded the use of inferential statistics.

2.4.1 HYPOTHESIS 1: SPACE EXPLORATION VEHICLE HABITABILITY AND HUMAN FACTORS DURING A 14-DAY TRAVERSE

Hypothesis 1: The habitability and human factors of the SEV during a 14-day mission will be acceptable as assessed by established human factors metrics.

The JSC UTAF used a combination of existing human factors metrics and customized questionnaires to evaluate the acceptability of the SEV human factors. The task types, metrics, and data collection frequencies for the 14-day SEV traverse are shown in Table 3. Data collection intervals were incorporated into the detailed EVA timelines. Data were collected primarily using electronic data sheets, but data from built-in video cameras and microphones inside the SEV were also analyzed to yield additional usability information.

In addition to the UTAF human factors evaluation, data were collected during the 14-day SEV traverse to quantitatively assess the duration and quantity of sleep achieved by each crewmember. Negative effects of sleep deprivation include vigilance decrements, increased lapses of attention, lengthening reaction time, cognitive slowing and errors, fixation on ineffective solutions, rapid and involuntary sleep onsets, and increased compensatory effort. Measurement of sleep duration and quality was limited to the two crewmembers participating in the 14-day SEV traverse, but provided an initial assessment of the acceptability of the crew accommodations for sleeping.

Table 3. Summary of Human Factors Metrics for 14-day SEV Traverse

Area for Human Factors Study	Measures for Data Collection	Data Type	Frequency
Driving	Cooper-Harper	Subjective	Per task
	Real-time human factors questionnaire	Subjective	Mealtime
	Post-evaluation questionnaire	Subjective	End of duty day
Daily Ops	Real-time human factors questionnaire	Subjective	Mealtime
	Post evaluation questionnaire	Subjective	End of duty day
Exercise/Medical	Real-time human factors questionnaire	Subjective	Mealtime
	Post-evaluation questionnaire	Subjective	End of duty day
EVA	Real-time human factors questionnaire	Subjective	Mealtime
	Post-evaluation questionnaire	Subjective	End of duty day
Sleep	Actiwatch light and activity log	Objective	Continuous
	Subjective sleep log	Subjective	Post-sleep
Time (drive time, EVA time, task time)	Field-recorded time stamps and post (hh:mm:ss)	Objective	Per task
	Post video analysis		
Crew Interference	Post video analysis (frequency)	Objective	Per task

METRIC: COOPER-HARPER RATING OF VEHICLE HANDLING QUALITIES

The Cooper-Harper rating of vehicle handling qualities is shown in Figure 18 and was used in evaluating the SEV handling qualities.

HYPOTHESIS ACCEPT-REJECT CRITERIA AND RATIONALE

The study hypotheses required that the acceptability of human factors be assessed. For this purpose, a Cooper-Harper rating of ≤ 3 was considered acceptable. A Cooper-Harper rating of 3 corresponds to "Satisfactory without improvements" with "minimal compensation required for desired performance."

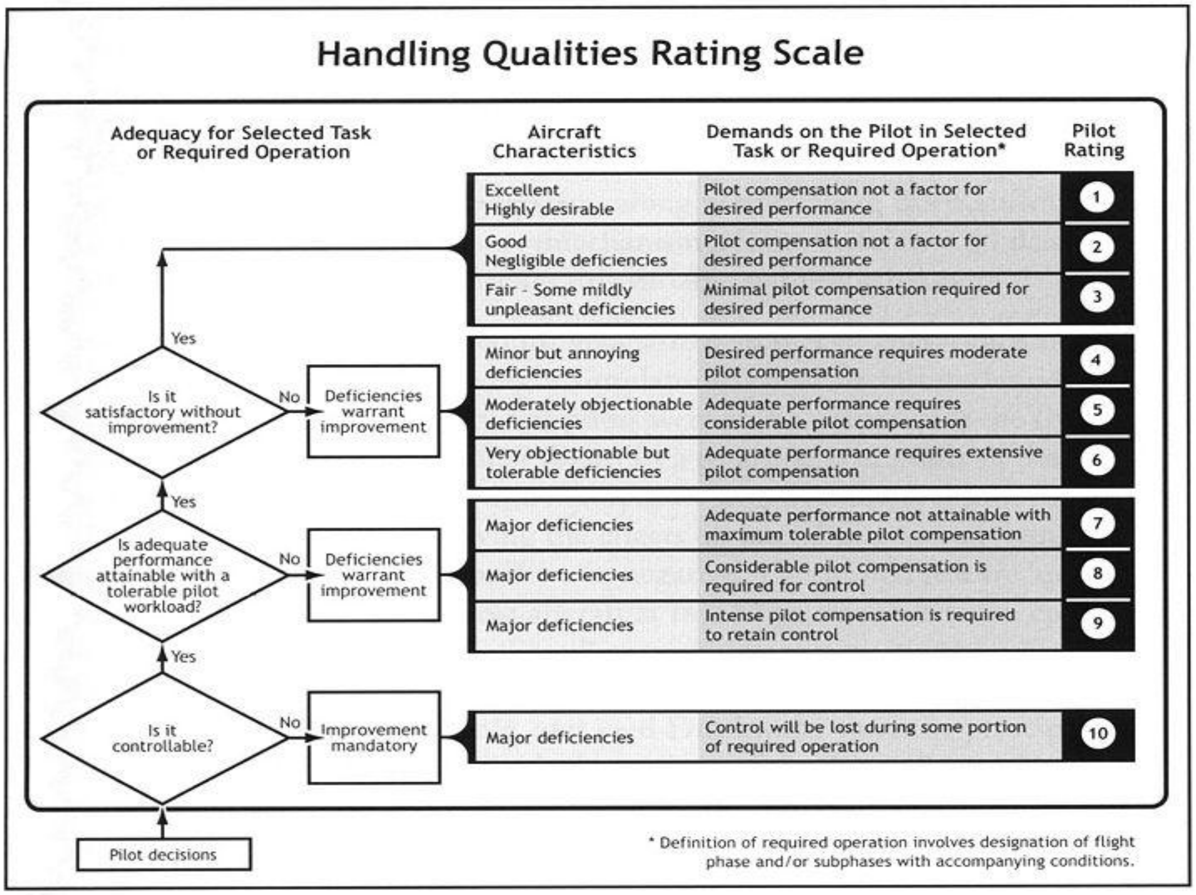


Figure 18. Cooper-Harper rating for vehicle handling qualities.

METRIC: FATIGUE RATING

The Likert scale in Figure 19 was defined to measure fatigue during the 14-day traverse.

No Fatigue: performance not compromised		Minor Fatigue: performance not compromised		Moderate Fatigue: performance will likely be compromised if continued		Significant Fatigue: performance is compromised		Extreme Fatigue: unable to continue with adequate performance	
1	2	3	4	5	6	7	8	9	10

Figure 19. 10-point Likert Fatigue Scale used to measure daily mission fatigue.

The fatigue scale measures the level of underlying fatigue that a crewmember feels while resting. Fatigue was measured at the beginning and end of each traverse day.

HYPOTHESIS ACCEPT-REJECT CRITERIA AND RATIONALE

By definition, ratings of ≤ 4 indicate that subjects are not fatigued to an extent that would compromise performance. A rating of > 4 would indicate unacceptable fatigue, which might indicate inadequate human factors or crew accommodations or an overly demanding traverse timeline.

METRIC: WORKLOAD RATING

The Likert scale in Figure 20 was defined as a derivative of the Bedford Workload Scale to measure workload during the 14-day traverse.

Insignificant Workload: significant spare capacity remaining		Light Workload: desirable spare capacity remaining		Moderate Workload: enough spare capacity remaining		Significant Workload: very little spare capacity remaining		Maximum Workload: no spare capacity remaining	
1	2	3	4	5	6	7	8	9	10

Figure 20. 10-point Likert Workload Scale used to measure daily mission workload.

The workload scale measures the level of mental spare capacity that a crewmember feels while performing a task. Crewmembers were prompted at intervals of not more than 30 minutes during all traverses to give subjective ratings on workload during that period. Measures of spare capacity offer a means of evaluating user workload, although indirectly.

HYPOTHESIS ACCEPT-REJECT CRITERIA AND RATIONALE

By definition, ratings of ≤ 4 indicate the workload was acceptable. However, even where median values were ≤ 4, the reasons for any outlying data points > 4 were recorded to inform the redesign of any system to reduce workload in the SEV.

METRIC: HUMAN FACTORS QUESTIONNAIRES

The Likert scale in Figure 21 was developed to evaluate the acceptability of the SEV's 212 operational elements including vehicle driving, displays and controls, visibility, daily habitation operations, exercise, sleep, food packaging, and seating.

Totally Acceptable: No improvements necessary		Acceptable: Minor improvements desired		Borderline: Improvements warranted		Unacceptable: Improvements required		Totally Unacceptable: Major improvements required	
1	2	3	4	5	6	7	8	9	10

Figure 21. 10-point Likert Acceptability Scale used for the post-traverse human factors questionnaires.

HYPOTHESIS ACCEPT-REJECT CRITERIA AND RATIONALE

Testing the study hypotheses required that the acceptability of human factors be assessed. For this purpose, ratings of ≤ 4 indicated acceptable human factors. However, even where mean values were ≤ 4, the reasons for any outlying data points > 4 (that is, unacceptable human factors) were recorded to inform the redesign of the vehicle.

2.4.2 HYPOTHESIS 2: EFFECT OF INTERMITTENT COMMUNICATIONS ON CREW PRODUCTIVITY

Hypothesis 2: Crew productivity during SEV mission tasks (EVA and IVA science operations and vehicle maintenance tasks) will not significantly vary between two different communications scenarios: a. continuous real-time communications (baseline); b. limited communications (66% coverage, 34% no coverage – based on single relay satellite in highly elliptical orbit with apogee above the lunar south pole).

Three methods of quantifying traverse productivity were used and compared during this study: the Exploration Analogs & Mission Development (EAMD) Observation Quality Scale, the EAMD Data Quality Scale, and the Exploration Productivity Index.

METRIC: EXPLORATION ANALOGS & MISSION DEVELOPMENT OBSERVATIONAL QUALITY SCALE

The EAMD project used a system of rating submersible research traverses during the Pavilion Lake Research Project. The quality of observations by scientist pilots during the performance of each traverse objective was rated using the scale in Table 4.

Table 4. EAMD Development Traverse Observational Quality Scale

METRIC	DESCRIPTOR	DEFINITION
1	Poor	Observations acquired by observer are poor in quality; limited in scale and context.
2	Fair	Observations acquired by observer are fair in quality; adequate scales and context.
3	Good	Observations acquired by observer are good in quality; sufficient scales and context.
4	Very Good	Observations acquired by observer are very good in quality; very good spectrum of relevant scales and context.
5	Excellent	Observations acquired by observer are excellent in quality; maximum of relevant scales and context.

HYPOTHESIS ACCEPT-REJECT CRITERIA AND RATIONALE

Observation quality during the performance of each science-related traverse objective was rated using the EAMD Observational Quality scale during and after the execution of each objective. By definition, any change in category on the scale represents a qualitatively significant difference in the metric.

METRIC: EXPLORATION ANALOGS & MISSION DEVELOPMENT DATA QUALITY SCALE

The EAMD Data Quality Scale is a metric used to quantify the quality of data collected during sorties performed by submersibles equipped with video cameras and manipulators. The scale is shown in Table 5.

Table 5. EAMD Development Data Quality Scale

METRIC	DESCRIPTOR	DEFINITION
0	No data	No data collection or other relevant observations were achieved.
1	Limited	Video and navigation did not support scientific observations and other relevant data was of limited use.
2	Adequate	Quantitative data adequate for general documentation of findings. Provides useful context and enables efficient return.
3	Significant	Quantitative data adequate to support specific documentation of scientific findings.
4	Exceptional	High-quality video, navigation, and other quantitative data that supports and enhances scientific findings.

HYPOTHESIS ACCEPT-REJECT CRITERIA AND RATIONALE

The quality of data collected during each traverse was rated using the EAMD Data Quality Scale before and after the traverse was performed. By definition, any change in category on the scale represents a qualitatively significant difference in the metric.

METRIC: EXPLORATION PRODUCTIVITY INDEX

The Exploration Productivity Index (EPI) metric enables absolute comparison of the productivity of different traverses in the same region. The metric is based on the EAMD Scales of Science Merit and Data Quality, but is applied to individual traverse objectives rather than a traverse as a whole.

$$\text{Exploration Productivity Index} = \sum \text{VTO (n)} \times \text{DQ (n)}$$

where

VTO (n): value of traverse objective *n*, on a 1-3 scale

1 = low anticipated scientific importance

2 = moderate anticipated scientific importance

3 = high anticipated scientific importance

DQ (n): Quality of data collected at traverse waypoint objective *n*, on a 0-4 scale (Table 5).

HYPOTHESIS ACCEPT-REJECT CRITERIA AND RATIONALE

The mean value for traverse activities under each communication condition with each vehicle was to be compared. A difference in EPI of 9 points would reflect completion of one high-priority science objective with high-quality data and was considered a practically significant difference in productivity for the purposes of this test.

METRIC: EXTRAVEHICULAR ACTIVITY SUIT TIME

Time spent inside the EVA suit increases suit-induced trauma and increases consumables usage due to the evaporative cooling process. Data from DRATS 2008 confirmed that the ability to make contextual geologic observations from inside the SEV means that less EVA suit time is required to achieve equal or greater productivity during SEV traverses than during UPR traverses. EVA suit time was inferred from suit GPS data and also recorded on data sheets. The maximum and mean EVA suit time for each vehicle was calculated for each day of the 14-day SEV traverse.

HYPOTHESIS ACCEPT-REJECT CRITERIA AND RATIONALE

A difference in mean or maximum suit time of ≥ 10% was prospectively defined as practically significant. Although the relationship between EVA suit time and suit trauma is variable and difficult to quantify, the relationship between EVA suit time and consumables usage is better defined. Measured differences in EVA suit time may therefore be related to expected savings in mass of consumables based on lunar architecture consumables usage rates, mission durations, and tankage mass assumptions.

METRICS: EXTRAVEHICULAR ACTIVITY BOOTS-ON-SURFACE SUIT TIME

EVA boots-on-surface suit time is generally the time during which most scientific productivity is being achieved. Time spent inside the EVA suit during vehicle ingress and egress is nonproductive EVA time. Comparing EVA suit time to EVA boots-on-surface suit time allows the efficiency with which EVA suit time is used to be quantified. Physiological modeling of the ameliorating effects of EVA exercise on bone and muscle atrophy also requires estimates of EVA boots-on-surface suit time.

HYPOTHESIS ACCEPT-REJECT CRITERIA AND RATIONALE

A difference in mean or maximum boots-on-surface EVA suit time of ≥ 10% was prospectively defined as practically significant.

METRICS: NUMBER OF EXTRAVEHICULAR ACTIVITIES

The number of EVAs performed during traverses affects the consumables lost during ingress and egress operations, the energy required to operate gas reclaim pumps (with airlock), and the number of cycles on suit ports or the Mobile Habitat airlock. Although it was anticipated that having suit ports will mean that EVAs from an SEV are typically shorter and more frequent, this has not been verified during operations. It is possible that the terrain and distribution of traverse stations will make even the rapid SEV egress and ingress an inefficient use of time.

HYPOTHESIS ACCEPT-REJECT CRITERIA AND RATIONALE

Because multiple EVAs in a single day have not previously been performed, a difference in mean number of EVAs of ≥ 1 per day was prospectively defined as practically significant.

METRICS: EXTRAVEHICULAR ACTIVITY DISTANCE WALKED

Physiological modeling of the ameliorating effects of EVA exercise on bone and muscle atrophy requires estimates of typical EVA walking distances. These data are also valuable in estimating the number of cycles on EVA suit components.

HYPOTHESIS ACCEPT-REJECT CRITERIA AND RATIONALE

For the purposes of this study, a difference in mean or maximum EVA distance walked of ≥ 10% was prospectively defined as practically significant.

METRIC: TASK COMPLETION TIMES

Crewmembers verbally communicate to the CAPCOM the times when tasks started and finished. Times were recorded using data sheets, and the duration of each task was calculated. Consistent with the procedures used during the Moses Lake test, reasons for large deviations from normal completion times (defined as about 25% or more deviation from normal task completion times) were documented. Additionally, any instances in which EVA crewmembers were aided by spotters was communicated by crewmembers and recorded on task completion time data sheets. Where communications between the SEV and the MMCC were unavailable, task completion times were recorded by a data collector in a chase vehicle.

HYPOTHESIS ACCEPT-REJECT CRITERIA AND RATIONALE

A sustained increase of at least 10% in any crewmember's average completion time for a series of EVA tasks was prospectively defined as practically significant and a non-negligible decrement in crew performance.

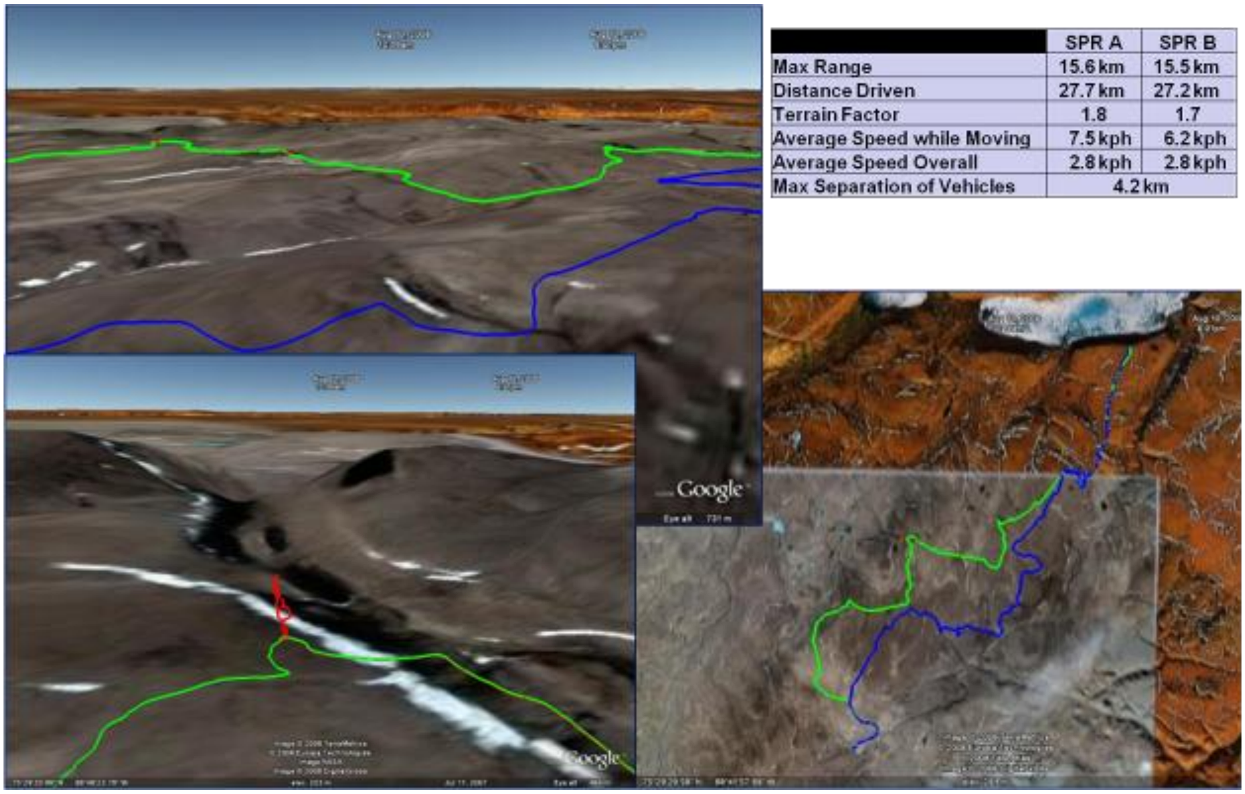
METRICS: RANGE, DISTANCE DRIVEN, TERRAIN FACTOR, SPEED

Quantifying the range achieved and distances driven during multi-day exploration/mapping/geological traverses in a lunar-like environment enabled improved estimation of exploration range from a fixed lunar outpost and the development of a Global Coverage Map. The model used to size the solar arrays and energy storage systems on lunar surface mobility systems requires estimates of these metrics. Current model inputs are speculative and were compared with field test data from this study.

For descriptive purposes only, the range, distance driven, and speed (average and maximum) of each traverse day were measured using GPS. The mean of the maximum range for each traverse day was calculated and range was also plotted for each traverse as a function of traverse duration.

HYPOTHESIS ACCEPT-REJECT CRITERIA AND RATIONALE

A difference in mean or maximum range or distance driven of ≥ 10% was prospectively defined as practically significant.



	SPR A	SPR B
Max Range	15.6 km	15.5 km
Distance Driven	27.7 km	27.2 km
Terrain Factor	1.8	1.7
Average Speed while Moving	7.5 kph	6.2 kph
Average Speed Overall	2.8 kph	2.8 kph
Max Separation of Vehicles	4.2 km	

Figure 22. Example of GPS-derived performance data collected during Haughton-Mars Project-2008 field test.

2.4.3 HYPOTHESIS 3: HUMAN INTERFACES OF SPACE EXPLORATION VEHICLE AFT DECK

Hypothesis 3: Human interfaces of the redesigned SEV prototype aft deck (suit ports, alignment guides, aft enclosure, and aft driving station) will be acceptable as assessed by established human factors metrics.

METRIC: SUBJECTIVE RATINGS OF SUIT PORT HUMAN FACTORS

The Likert scale for acceptability (Figure 21) that was used to evaluate vehicle acceptability was also used to evaluate the acceptability of the SEV aft deck and suit ports. Crewmembers were asked to evaluate the suit port operations and aft deck operations during the 14-day field trial.

HYPOTHESIS ACCEPT-REJECT CRITERIA AND RATIONALE

To test the hypothesis, mean values of the human factors metrics for all suit port, alignment guide, and aft deck tasks during the 14-day mission were calculated. By definition, ratings of ≤ 4 indicated acceptable human factors. However, even where mean values were ≤ 4, the reasons for any outlying data points > 4 (that is, unacceptable human factors) were recorded to inform the design of the Generation 2 suit ports and alignment guides.

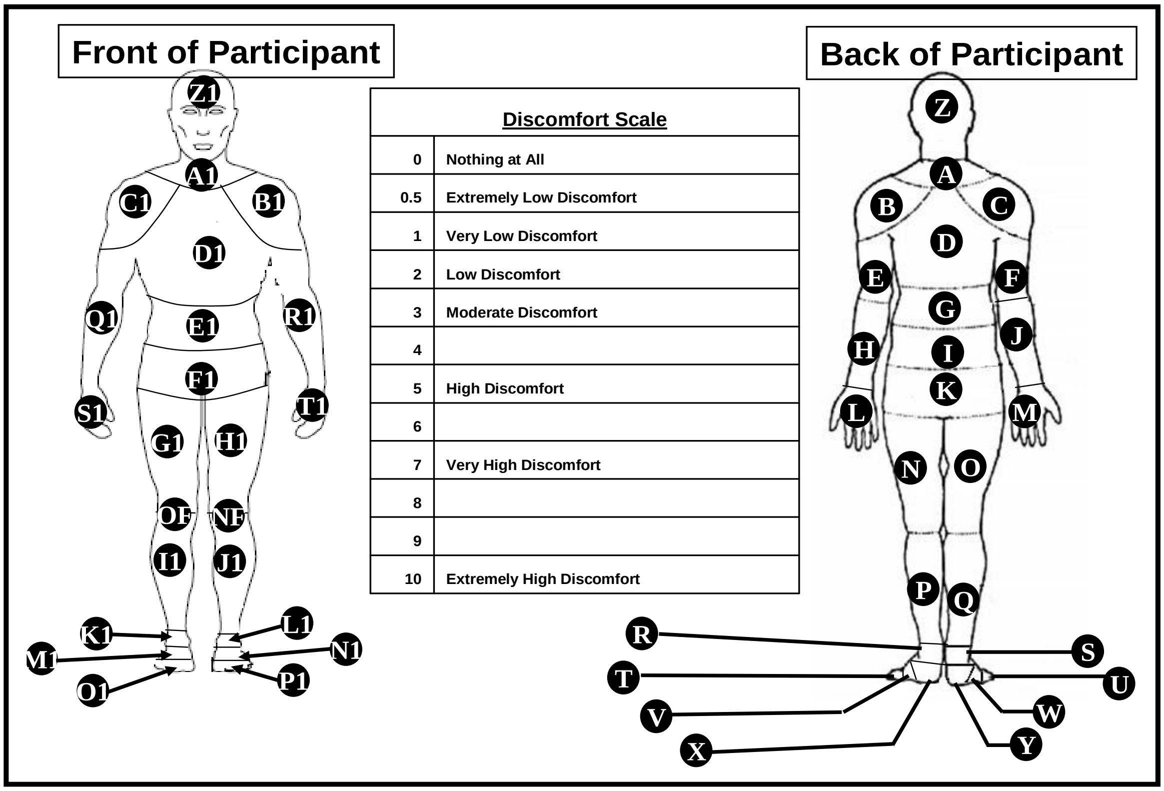
Crewmembers were prompted at intervals of not more than 30 minutes during all traverses for subjective ratings on each of the following scales: a) Perceived Exertion Scale[3]; b) Discomfort Scale[4]; and c) Thermal Comfort Scale.[5] Because of the limitations of the 1-G test environment and the mock-up MkIII suits, the data will not be used in a comparative sense; the data were used to ensure the health and safety of the crewmembers throughout the field test and may also be used to identify deficiencies in test equipment. The scales are shown below in Table 6 and Table 7.

Table 6. Borg Rating of Perceived Exertion Scale

METRIC	DEFINITION
6	No exertion at all
7	Extremely light
8	
9	Very light (easy walking slowly at a comfortable pace)
10	
11	Light
12	
13	Somewhat hard (quite an effort; you feel tired but can continue)
14	
15	Hard (heavy)
16	
17	Very hard (very strenuous, and you are very fatigued)
18	
19	Extremely hard (you cannot continue for long at this pace)
20	Maximal exertion

Table 7. Bedford Thermal Comfort Scale

METRIC	DEFINITION
-3	Much too cool
-2	Too cool
-1	Comfortably cool
0	Comfortable
1	Comfortably warm
2	Too warm
3	Much too warm



Discomfort Scale

0	Nothing at All
0.5	Extremely Low Discomfort
1	Very Low Discomfort
2	Low Discomfort
3	Moderate Discomfort
4	
5	High Discomfort
6	
7	Very High Discomfort
8	
9	
10	Extremely High Discomfort

Figure 23. Corlett and Bishop Discomfort Scale.

METRIC: FATIGUE RATING

The Fatigue Likert Scale shown in Figure 19 was used to measure fatigue during the 14-day traverse. Unlike Borg's Rating of Perceived Exertion scale, which measures acute exertion during a particular activity, the fatigue scale measures the level of underlying fatigue that a crewmember feels while resting. Fatigue was measured at the beginning and end of each EVA during the 14-day mission.

HYPOTHESIS ACCEPT-REJECT CRITERIA AND RATIONALE

By definition, ratings of ≤ 4 indicate that subjects were not fatigued to an extent that would compromise performance. A rating of > 4 would indicate unacceptable fatigue, which might indicate inadequate human factors or crew accommodations or an overly demanding traverse timeline.

2.4.4 HYPOTHESIS 4: PORTABLE UTILITY PALLET DOCK AND UNDOCK PERFORMANCE

Hypothesis 4: A prototype PUP will meet the functional requirement that it can successfully dock with (≤ 5 min) and undock from (≤ 5 min) the SEV.

The PUP is a prototype logistics support element of the SEV that can mate or de-mate with the vehicle to provide EVA support (gas and fluid lines), be a sample depository, and support Suit Port Transfer Module (SPTM) operations. The PUP will be an integral part of the LSS architecture.

METRIC: SUBJECTIVE RATINGS FOR PORTABLE UTILITY PALLET HUMAN FACTORS

The Likert scale for acceptability (Figure 21) that was used to evaluate vehicle acceptability was also used to evaluate the acceptability of SEV-PUP mating and de-mating operations. Crewmembers were asked to evaluate the PUP operations during the 14-day field test. Along with the subjective ratings, timing data were also collected.

HYPOTHESIS ACCEPT-REJECT CRITERIA AND RATIONALE

Mean values of the human factors metrics for all PUP operations during the 14-day mission were calculated to test the hypothesis. By definition, ratings of ≤ 4 indicated acceptable human factors. However, even where mean values were ≤ 4, the reasons for any outlying data points > 4 (that is, unacceptable human factors) were recorded to help inform the design of the Generation 2 PUP. Timing criteria for successful attachment and detachment had to be accomplished within ≤ 5 minutes.

2.4.5 HYPOTHESIS 5: ACTIVE-ACTIVE MATING ADAPTER DOCK AND UNDOCK PERFORMANCE

Hypothesis 5: A prototype AAMA will enable docking (≤ 5 min) and undocking (≤ 5 min) between two SEVs on representative terrain.

As a pressurized passageway between two SEVs or a habitat and an SEV, the AAMA is a prototype design that was developed to meet the functional requirements for the current lunar architecture.

METRIC: SUBJECTIVE RATINGS FOR ACTIVE-ACTIVE MATING ADAPTER HUMAN FACTORS

The Likert scale for acceptability (Figure 21) that was used to evaluate vehicle acceptability was also used to evaluate the acceptability of SEV AAMA docking and undocking operations. Crewmembers were asked to evaluate the AAMA operations during the 14-day field test. Along with the subjective ratings, timing data were also collected.

HYPOTHESIS ACCEPT-REJECT CRITERIA AND RATIONALE

Mean values of the human factors metrics for all AAMA operations during the 14-day mission were calculated to test the hypothesis. By definition, ratings of ≤ 4 indicated acceptable human factors. However, even where mean values were ≤ 4, the reasons for any outlying data points > 4 (that is, unacceptable human factors) were recorded to help inform the design of the Generation 2 AAMA. Timing criteria for successful attachment and detachment had to be accomplished within ≤ 5 minutes.

2.4.6 HYPOTHESIS 6: 24-HOUR CREW RESCUE SCENARIO

Hypothesis 6: The habitability and human factors of the SEV will be acceptable to support a 24-hour contingency scenario.

One of the primary questions investigated during the 14-day field test was whether it was feasible to perform a crew rescue between two SEVs. Two crews tested 21 different factors for this scenario on day 13 of the 14-day mission.

METRIC: SUBJECTIVE RATINGS FOR ACTIVE-ACTIVE MATING ADAPTER HUMAN FACTORS

The Likert scale for acceptability (Figure 21) that was used to evaluate vehicle acceptability was also used to evaluate the acceptability of SEV contingency operations. Both crews were asked to evaluate the rescue operations.

Hypothesis Accept-Reject Criteria and Rationale

Mean values of the human factors metrics for the contingency operation were calculated to test the hypothesis. By definition, ratings of ≤ 4 indicated acceptable human factors. However, even where mean values were ≤ 4, the reasons for any outlying data points > 4 (that is, unacceptable human factors) were recorded to help inform the design of the Generation 2 vehicle.

3.0 Results and Discussion

Results of the field test are presented and discussed in the following pages. Results are presented in order according to the hypotheses and test objectives described in Section 1.2.

3.1 Hypothesis 1: Space Exploration Vehicle Habitability and Human Factors during a 14-Day Traverse

Hypothesis 1: The habitability and human factors of the SEV during a 14-day mission will be acceptable as assessed by established human factors metrics.

A combination of existing human factors metrics and customized questionnaires were used to evaluate the acceptability of the SEV human factors.

3.1.1 Overall Human Performance for 14 Days

During the 14-day field test, the crew recorded 316 hours and 15 minutes in total mission time. Mission time officially started at 9:59:00 on 31 August 2009 and ended at 15:00:00 on 13 September 2009. A breakdown of time data by element (SEV driving [driving, driving traverse time, contextual observations while driving], EVA [EVA setup, stowage, EVA setup and cleanup, EVA translation, EVA SEV translation, sampling, contextual observations], on-duty time [all drive time, daily briefs, IVA maintenance, meals, Waste Containment System (WCS) operations, contextual observations, rescue time], off-duty time [meals, exercise, WCS operations, daily operations, sleep, entertainment, surveys], rescue [time began when CAPCOM announced emergency to when rescue crew egressed Cabin 1B from suit ports], and total habitat [all on- and off-duty time combined minus EVA time]) was conducted to understand crew productivity (Table 8).

Table 8. Field Time for the SEV 14-day Mission

Element	Time (hh:mm:ss)
ON-DUTY TIME	
SEV Driving	23:27:00
EVA	7:18:00
Rescue	23:26:00
Other	83:55:00
Total On-Duty	137:56:00
Off-Duty	178:59:00
Total Habitat	316:15:00

With this in mind, investigators realized the importance of crew consumables over the 14-day field test. With this mission being the first to test all types of consumables that may be needed for a lunar mission, obtaining mass data was extremely important, not just for the SEV but also for future exploration missions. The consumables data collected from the crew were the mass of clothing and supplies, food and packaging, water, and trash, and food calories consumed before and after flight. Table 9 shows the data collected for the 14-day field test. Trash transferred out of the vehicle for a crew of two over 14 days had a total mass of 52.62 kg (125 lbs). It was calculated that a crew of two generated 5.26 kg (12 lbs) of trash per day. This equals 2.63 kg (6 lbs) of trash per crewmember per day. See Appendix C for a complete 14-day SEV manifest.

Table 9. Comparison of SEV 14-day Consumables with LSS Baseline Assumptions

Consumable	DRATS 2009	LSS Baseline	DRATS-modified Baseline
	kg per person per day	*kg per person per day*	*kg per person per day*
Water, food preparation	0.57	0.5	0.57
Water, EVA	0.86	1.71	0.86
Water, hygiene	0.12	0.4	0.12
Water, flush	0	0.5	0
Food/packaging	0.47	2.06	0.47
Clothing/supplies	0.86	1.10	0.86
Water, drinking*	9.45	2.0	2.0
Total without drinking water	2.88	6.27	2.88
Total with drinking water	12.33	8.27	4.88

**Note: Drinking water was not added to the total calculation. Explanation of this omission is discussed in the paragraph below.*

The results of comparing these data with LSS baseline assumption data indicate that a significant mass savings in food could be realized by reducing packaging waste. The silver-impregnated clothing that was used by the crew during the 14-day mission could also represent a reduction in clothing mass. In fact, the field test data indicate that about 53% reduction in total mass could be achieved. As for the drinking water, it should be noted that this figure is extremely high. This is due to very high consumption by the crew as a result of interior environment failure issues with the air conditioner (AC) unit, heavy EVA suits in 1 G, and the summer desert weather.

The amount of food consumption during this 14-day mission was collected in an attempt to understand what would be a realistic value for the amount of food needed for a lunar mission. Subjects were given a predetermined menu that included packaged meals and snacks provided by the JSC Advanced Food Technology Project and a commercial provider of freeze-dried meals. A preflight menu was created to provide a calculated per-day caloric intake of 3,001 (total of 42,016). However, because the crew was dissatisfied with the thermostabilized food, their caloric intake was much lower than expected. Each crewmember was asked to keep a daily food log of all meals and snacks consumed throughout the day. For subject 137, only 10 out of 14 days were recorded, for a caloric intake of 1,785 per day (total intake recorded was 17,846). Subject 27 recorded his food consumption for 12 out of 14 days, with his caloric intake being 1,734 per day (total intake recorded was 20,813). Other factors possibly related to the low food consumption could be fatigue caused by the AC failure in the vehicle for several days and the lack of cool drinking water.

Interior vehicle temperature became a major issue with the crew during the 14-day field test. For the first time, human factors personnel were interested in understanding the vehicle's interior environment and installed three temperature sensors in Cabin 1B. One sensor was placed in the cockpit area, one at the cabin's midpoint, and one between the suit ports in the aft end of the cabin. The sensors were set up to sample the interior temperature of the cabin every 5 minutes during the test. When investigators went to retrieve the sensors from Cabin 1B the aft sensor was missing; thus, the data collected from this sensor were lost. However, the cockpit and mid-cabin sensors did collect valuable interior temperature data, which revealed a very warm environment for the crew even with the front and side windows being covered with a film that reduced ultraviolet light by 75% and contained a thermal filter.

The highest interior temperature recorded in the cockpit was 106°F on day 4 of the test. The reason this temperature was so high is unknown; however, investigators know the AC unit inside the vehicle had been troublesome for several days and the crew had the unit's thermostat turned up to around 80°F so the unit would not freeze. From 13:15:00, when the temperature was first recorded at 100°F, until 15:20:00, when 98°F was recorded, 2 hours and 5 minutes had elapsed with the cockpit at or above 100°F. Investigators believe this was one of the major factors for some fatigue data being high, as the crew reported having trouble sleeping at night due to the heat being retained in the cabin and the lack of cool air. The mid-cabin sensor also recorded 100°F but for a much shorter period. On three more test days the temperature in the cockpit ranged from 100°F to 104°F for about 45 minutes to an hour (Figure 24).

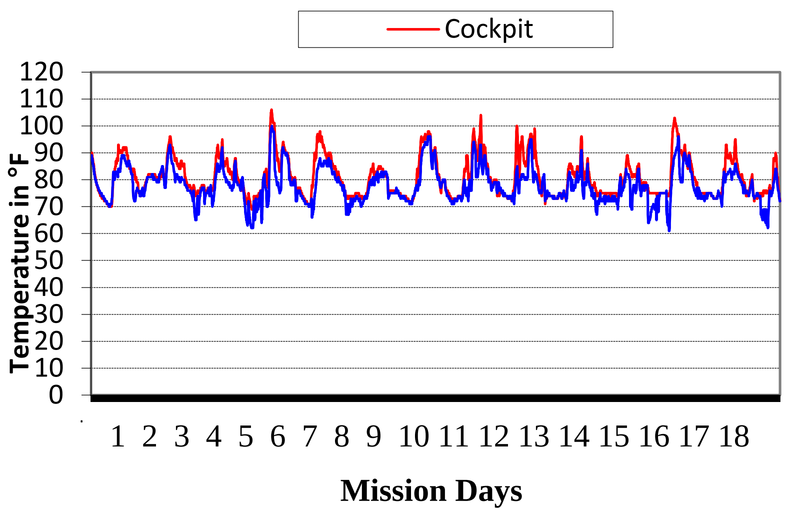


Figure 24. Combined temperature data from the SEV cockpit and mid-cabin section.

Fatigue is defined as a physical or mental weariness resulting from exertion or tiring effort. With that in mind, two sets of data on fatigue were collected by the investigators. Once the mission duty day began, human factors personnel gathered crew fatigue data every 30 to 45 minutes during the 14-day mission. Collection of these data cut across the subtask work elements during the crew's duty day to give investigators a first look at how crewmembers were feeling during various times of the day. Nine major categories of work task elements were defined after the data were analyzed (Figure 25). An overall mean of the fatigue ratings was calculated across the 14 days per element. (The overall fatigue ranged from 2.0 to 3.3 over the entire mission, indicating that crew fatigue within elements ranged from no fatigue to minor fatigue with performance.) Operations with the PUP and AAMA were rated among the highest in fatigue according to the crew. The reason for this was mainly frustration from toggling between procedure screens on the computer to accomplish the task, external camera failure, or delay affecting crew situational awareness of the task, and vehicle maneuverability. Cooper-Harper scores and subjective ratings also reflected these issues.

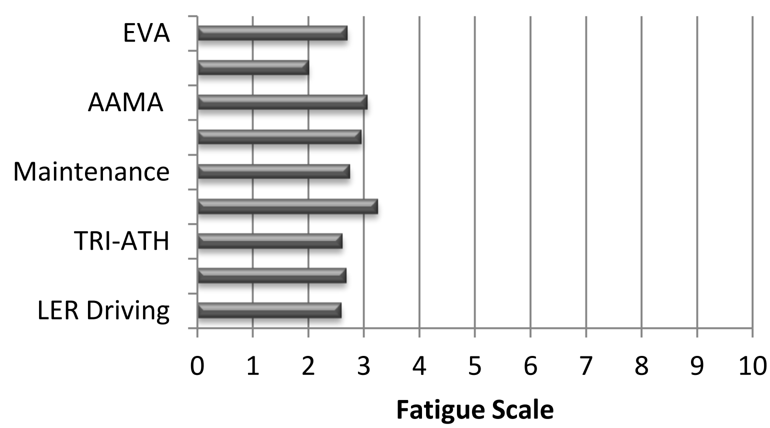


Figure 25. Mean fatigue during different work tasks.

The second fatigue data set collected consisted of crew fatigue ratings obtained in the morning before the mission duty day began (AM) and in the evening after the mission duty day ended (PM) for the entire mission (Figure 26). The typical duty day for the crew during the field test was 8 hours. For AM data, a spike rating of 4.0 was observed on days 2 and 4. According to field notes, the crew reported that their fatigue numbers were high because the AC unit inside the vehicle iced up and was not working properly. Temperatures in the cabin started to rise and the crew reported they got little sleep due to the cabin getting hot; however, the temperature was within the Human Systems Integration Requirements limits. As expected, PM fatigue ratings were typically higher than AM ratings. However, on day 2 the PM crew fatigue spiked to a rating of 5.0, indicating “moderate fatigue; performance will likely be compromised if continued.” Field notes indicate the crew worked with an icing AC unit most of the morning until the vehicle engineers determined that the temperature setting on the AC unit needed to be raised to 80°F to keep the unit from freezing. This made the cabin temperature hover around the mid to upper 90s for most of the afternoon. Frustration with the procedural screens, vehicle maneuverability, and display toggling from two different docking operations compounded the crew’s overall fatigue for this particular day. The spike on day 10 was due mainly to the display issues during PUP operations, according to the crew. With this in mind, the crew’s overall mission fatigue level was within the level of minor fatigue where performance was not compromised.

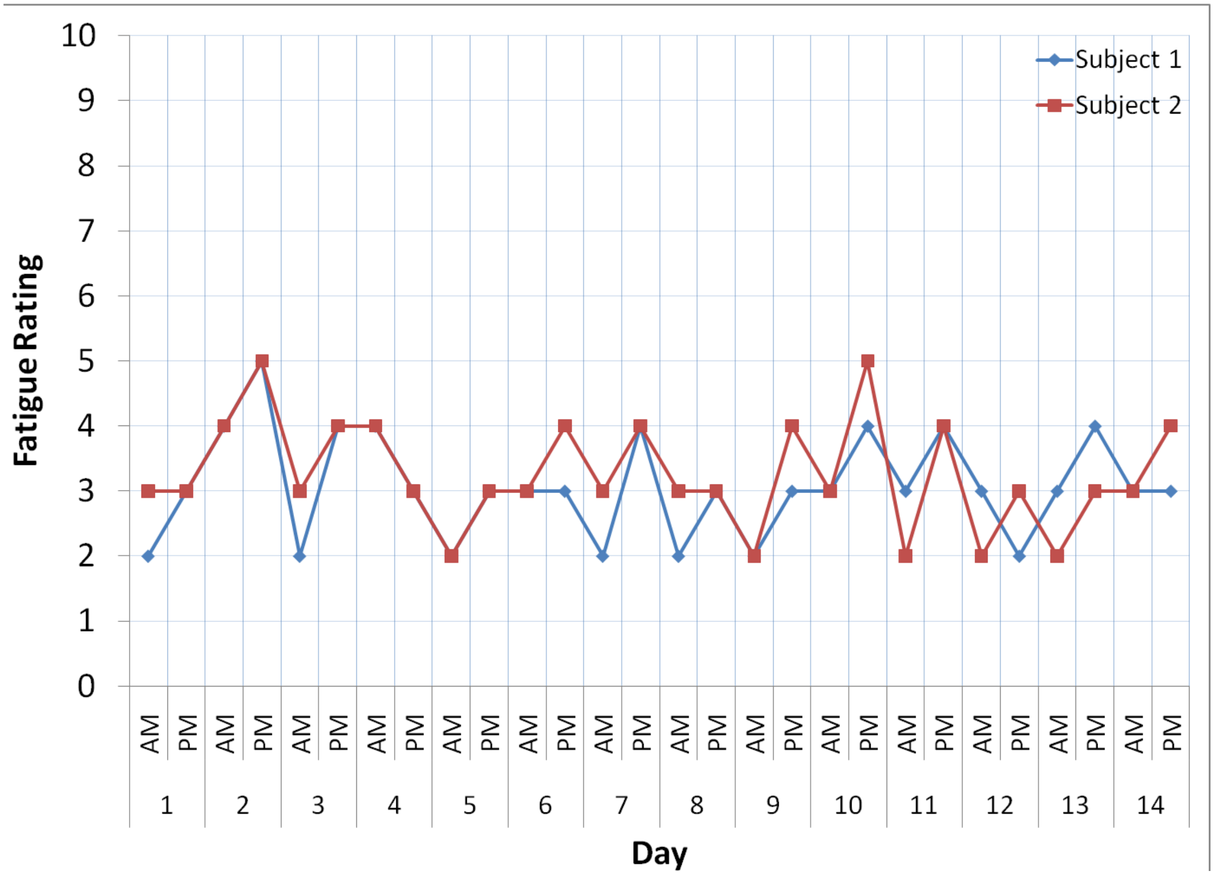


Figure 26. Daily fatigue means for two subjects during the 14-day mission.

Gartner and Murphy[6] defined workload as a set of task demands, which are goals to be achieved, through effort, activity, or accomplishment. Measures of spare capacity offer a means of evaluating user workload, although indirectly. By pretest definition, ratings of ≤ 4 indicate the workload was acceptable. For this section of the report, only the major vehicle workload task elements will be discussed with regard to the full mission. EVA workload will be discussed in Section 3.3.1.

The workload ratings of eight separate tasks inside the SEV during the 14-day field test were examined. The crew was asked to give a rating about every 30 to 45 minutes. Taking the overall mean (*M*) of the crew's workload ratings across all 14 days for each work task element, a trend can be seen as to which work element caused the most mental effort for the crew. The workload ratings ranged from 2.1 to 3.8 over the 14-day field test. As with crew fatigue, PUP (*M* = 3.7) and AAMA (*M* = 3.8) operations tended to have the highest workload ratings. Though these two workload task elements are considered light workload with light mental effort and desirable spare capacity remaining, the crew did report frustration and fatigue while doing these tasks, particularly on days 2 and 11. Failure of the target camera, target alignment issues, procedural issues, toggling between multiple displays during critical subtasks, uncommanded vehicle control issues, side joystick failure, and lack of training on the X-box controller were all causes for the high workload rating reported by the crew on these operations. Even with these difficulties, the overall workload task elements performed by the crew over a 14-day period in the SEV were still considered light.

The final overall aspect examined was the acceptability of the SEV in terms of habitability, functionality, and human factors during the 14-day field test. These data were collected at the end of the duty day. This was the overall crew rating for all elements, interfaces, and systems in the SEV over the last 24-hour period. Spikes in the ratings are shown on days 2, 6, 7, and 10. On days 2, 6, and 10, PUP and AAMA operations were being attempted, and as reflected in the fatigue and workload ratings previously, the crew rated the vehicle acceptability higher as well (Figure 27). The spike for day 7 was due to vehicle power loss issues. The crew worked feverishly to conserve vehicle power and was consistently working on power-saving calculations to get the vehicle to the next recharging station. With this in mind, the overall vehicle acceptability was within the defined acceptability range.

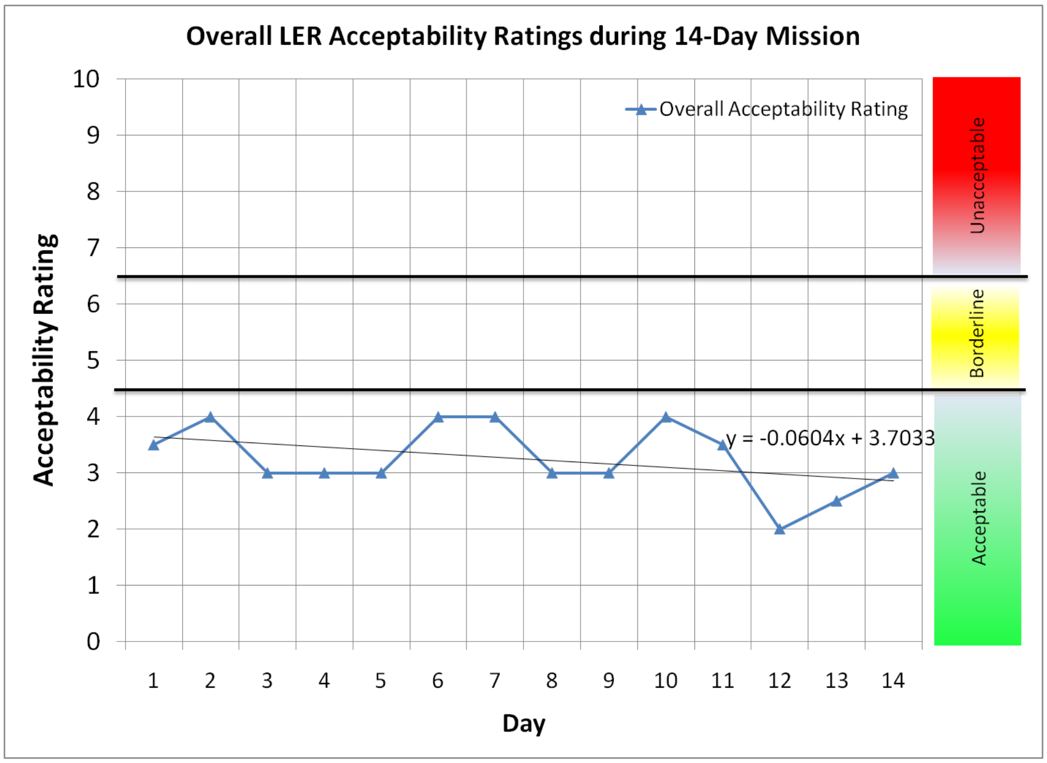


Figure 27. Daily means of overall vehicle acceptability over the 14-day test.

The results of the SEV human factors evaluation are described in greater detail in the following subsections.

3.1.2 Habitability of Crew Accommodations

The following sections will discuss the crew ratings of the 14-day field test on crew habitation. Seventy-four habitation factors were examined. Subjective habitation data were collected on day 3, day 6, day 9, and day 12. Because the number of habitation factors examined was so large, this section is broken into six smaller discussion segments to make it easier for the reader to understand the complexity of daily living during a simulated 14-day lunar mission.

Habitability of Crew Accommodations: Meal Preparation, Waste Containment System, and Cleaning

This first section discusses 14 habitation elements. Of the 14 elements studied, the crew rated volume to limit cross-contamination, WCS privacy, frequency of trash/waste removal using the SPTM, accessibility of the water dispenser, housecleaning, and volume for preparing and eating a meal in the vehicle as acceptable. According to the SEV Concept of Operations, trash was to be taken out every third day. The crew reported this worked well, noting that trash tended to build up quickly over a 3-day period and the odor started to become unpleasant.

Table 10. Acceptability Ratings for Internal Daily Food, Hygiene, and WCS Operations

Element	Day 3	Day 6	Day 9	Day 12	Mean (*M*)
Access to food stowage	5.0	4.0	4.0	4.5	4.4
Volume for meal prep and eating	3.5	2.5	2.5	2.5	2.8
Accessibility of water dispenser	4.5	3.0	3.0	3.0	3.4
Volume to deploy and stow WCS	5.5	5.5	4.5	4.5	5.0
Access to hygiene shower	4.5	4.5	5.5	5.5	5.0
Ability to use WCS during sleeping hours without disrupting others	6.5	6.0	6.0	4.5	5.8
Adequacy of WCS privacy	3.5	4.0	4.5	3.5	3.9
Volume for waste/trash stowage	6.0	6.5	6.5	4.5	5.9
Odor of waste/trash	8.0	8.0	9.0	9.0	8.5
Ease of using vacuum for waste/trash compacting	5.0	5.5	4.5	4.5	4.9
Effectiveness of space bags for waste/trash compacting	5.0	4.0	4.5	6.0	4.9
Frequency of waste/trash removal using sptm	3.0	4.0	4.0	4.0	3.8
Volume to limit cross-contamination	4.5	4.0	4.5	4.5	4.4
Volume for housecleaning	3.5	3.0	3.0	3.0	3.1

N = 2

Seven elements were considered borderline by the crew and one – odor of waste/trash stowage –was considered totally unacceptable (Table 10). Access to food stowage became difficult when the crew had reconfigured the aft cabin for an EVA (Figure 28); moving stowage lockers out of one of the side-hatches prior to EVA was necessary to ensure that crewmembers could ingress the vehicle via the side-hatch in the event that both suit ports malfunctioned.

WCS operations had some problems, especially with deploying the unit when both benches were down. The crew reported there was not enough room with both benches down, and that caused discomfort. WCS access was also unacceptable when both sleep stations were deployed, making the aisle about 0.55 m ~21.5 in.) wide. However, the crewmembers did indicate that with one bench up, comfort was more acceptable. As for the SEV hygiene mist sprayer hose, the crew stated it was not needed in the vehicle. Their preference for personal hygiene was using a wet towel or sponge to take a bath.

Figure 28. The crew consistently had to reconfigure the aft cabin before and after EVAs.

As in the 2008 field test,[7] having a dedicated stowage area, trash management system, and odor control became the issues, with odor control being rated totally unacceptable (mean = 8.5). Like other systems in the SEV, the trash management system was redesigned to help correct these issues. The new system was to take the daily trash, put it into a medium-sized Space Bag®, and vacuum seal the bag at the end of each day (Figure 29). After collecting 3 days' worth of trash, the crew would transfer the three medium Space Bags® into one large Space Bag® and vacuum seal the bag and transfer it out using the SPTM. The first issue occurred when the crew ended up putting 3 days of trash in one medium Space Bag®. This caused one bag to break, and the crew repaired it by using 2-inch duct tape. They also noted the Space Bag® did not control odor well and was heavy when it contained 3 days of trash.

Figure 29. Crewmembers doing trash operations using a Space Bag®.

Habitability of Crew Accommodations: Internal Volume and Stowage

For internal volume and stowage, seven elements were studied. Volume, accessibility, clearance, and overall design of the personal soft lockers were rated by the crew as totally acceptable. The crew reported the soft locker volume as well as the accessibility of the lockers were great for a 14-day mission. They liked the flip-down front flaps and locker depth to hold personal items (Figure 30). The crew liked the overall design and concept of the soft locker system; however, reconfiguration of the system for EVA became a major issue as previously described. Cabin reconfiguration required approximately 5 minutes following each EVA. Having four EVAs per day for 14 days times four crewmembers would require 18 hours and 40 minutes of time to be spent on reconfiguration per mission. Because the crew had to relocate the lockers, space in the vehicle started to become cramped and crowded.

Table 11. Acceptability Ratings for Internal Volume and Stowage

Element	Day 3	Day 6	Day 9	Day 12	Mean (*M*)
Volume of Personal Soft Locker Hatch Stowage	2.0	2.0	3.5	3.5	2.8
Access to Lower Personal Soft Locker	3.0	2.5	3.5	3.0	3.0
Access to Upper Personal Soft Locker	1.5	2.5	3.5	3.0	2.6
Clearance when seated at Personal Soft Locker	2.0	3.0	3.0	2.5	2.6
Clearance to Access Personal Soft Locker	2.0	3.0	3.5	2.5	2.8
Overall Design of Personal Soft Locker	2.0	3.0	3.5	3.0	2.9
Location of Vehicle Stowage Areas	3.5	4.0	5.0	5.0	4.4
Access to Items Stowed on other side of Privacy Curtains	4.0	5.0	5.0	5.0	4.8
Volume of SEV Layout for 2 crew/14 days	3.0	3.0	2.5	2.5	2.8
Volume of SEV Layout for 2 crew/30 days	4.0	3.5	4.0	3.5	3.8
Overall Habitable Living of the SEV	3.5	3.0	3.5	3.0	3.3

N = 2

Figure 30. Crewmember stowing items in the soft locker.

Location of vehicle stowage and access to items on the other side of the privacy curtain were the two elements rated “borderline – improvements warranted” by the crew. Comments on vehicle stowage stemmed from the reconfiguration issues previously discussed. The crew, however, did express that the bench stowage was the best use of available space in the vehicle. Access to items stowed on the other side of privacy curtains was also noted as an issue, especially while the cabin was in the sleep station configuration.

The last three elements of daily IVA operations in the SEV for the crew to consider were whether the present vehicle internal configuration could support a crew for a 14-day mission and for a 30-day mission, and the overall general habitation of the vehicle. The crew rated all of them acceptable with minor improvements desired. The crew reported there would be no issues with a crew of two doing a 14-day mission without ever getting out of the SEV. This concurs with the 2008 field test findings.[7] As for a 30-day mission, the crew stated that when two vehicles were docked together, the whole vehicle volume dynamic changed. Crews in both vehicles felt the increased volume gained by docking was great and reported that a crew could do a 4-week mission with no issues as long as the vehicles docked every 3 to 7 days. Also noted by the crew was the type of mission an SEV lunar mission would be. They stated it would be like a hiking trip where simple, lightweight, reusable items would be required for quick, easy access and consolidation.

Figure 31. Crewmembers watching a movie in the aft cabin at night.

Habitability of Crew Accommodations: Exercise Activities and Ergometer Design

Crewmembers were able to use the exercise ergometer for 12 out of 14 days for an hour per crewmember per day. Of the 16 elements, 10 were rated acceptable. These acceptable elements included access to the exercise equipment in the SEV, setup and stowage of the equipment, stability and adjustability of the seat, design of the ergometer for aerobic exercise in the SEV, and volume to perform both resistive and aerobic exercise in the SEV.

Table 12. Acceptability Ratings for Exercise Activities and Ergometer Design

Element	Day 3	Day 6	Day 9	Day 12	Mean (*M*)
Access to Exercise Equipment	3.0	3.5	3.5	3.0	3.3
Setup of Exercise Equipment	4.5	4.5	3.0	2.5	3.6
Comfort of Exercise Seat	5.0	5.0	6.0	5.0	5.3
Stability of Exercise Seat	2.5	4.0	3.5	3.5	3.4
Adjustability of Exercise Seat	2.5	3.5	4.5	3.5	3.5
Volume for One Crew to Perform Resistive Exercise	2.0	2.5	3.5	3.0	2.8
Ability of Non-exercising Crewmembers to Access Other Stations of SEV during Resistive Exercise	4.0	5.0	4.5	4.0	4.4
Ability of One Crewmember to Perform Resistive Exercise while SEV is Moving	6.5	4.5	6.5	4.5	5.5
Design of Ergometer to Perform Resistive Exercise	4.0	5.5	5.0	5.0	4.9
Volume for One Crewmember to Perform Aerobic Exercise	3.0	4.5	3.0	2.5	3.3
Ability of Non-exercising Crewmembers to Access Other Stations of SEV during Aerobic Exercise	5.0	5.0	5.0	4.5	4.9
Ability of One Crewmember to Perform Aerobic Exercise while SEV is Moving	6.5	6.0	6.0	6.0	6.1
Design of Ergometer to Perform Aerobic Exercise	3.5	4.0	3.5	2.5	3.4
Ability to Stow Exercise Equipment	3.0	4.5	3.5	3.0	3.5
Stowage Volume for Exercise Equipment	3.5	4.5	3.5	3.0	3.6
Overall Ability to Exercise in SEV	3.0	3.0	2.5	3.0	2.9

N = 2

The crew also rated the overall ability to exercise in the SEV as acceptable. They came up with several ways to exercise in the vehicle in conjunction with using the ergometer. The SEV provided plenty of space for doing such exercises as leg lunges, push-ups, bench press with bands, and tricep dips (Figure 32). The interior volume gave the crew the ability to use a variety of exercise elements during their hour-long session.

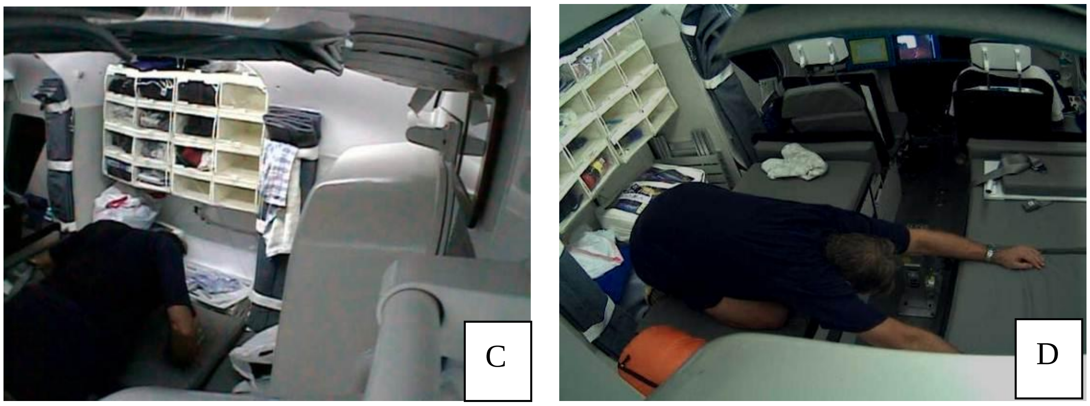


Figure 32. Crewmember doing sit-ups (A), leg lifts (B), push-ups (C), and stretches (D) using the benches in the aft section of the SEV.

However, the crew did express some issues with the system. The ability of a crewmember to perform aerobic exercise while the vehicle was moving was the highest rated concern of the crewmembers (*GM* = 6.1). They reported that it depended on the terrain in which the SEV 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. Simply walking from the aft cabin to the cockpit of the SEV while on rough terrain was difficult according to the crew. This held true for resistive exercise as well.

Accessibility of the non-exercising crewmember to other stations in the vehicle while a crewmember was performing either aerobic or resistive exercise was also rated high. The crew indicated they tried to make sure certain items were stationed in the cockpit area. In the aft-section aisle of the SEV, the pedals of the ergometer do not allow any space for the non-exercising crewmember to pass. The crew also observed this limited aisle space during ergometer setup.

Seat comfort was rated borderline by the crew. They reported the absence of any type of back support and would add several bench cushions to get comfortable on the seat. As for the design of the ergometer itself, the crew reported several concerns. Acceptability ratings for the device's design were high, with the crew complaining about the weight, pedals, and displays. The crew noted the weight several times during the test, and they noticed that for such a heavy piece of gear, the ergometer seemed fragile when it was being used. Pedals also became an annoyance to the crew. They reported the pedal attach/detach design made it much too difficult to remove. The most frequent observation on the pedal design was the fact that 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 one pedal on just so they would not have to take it off and put it back on.

Habitability of Crew Accommodations: Sleep Activities and Sleep Station

Several environmental factors such as lighting, temperature, smell, and noise can have an effect on the quality of sleep a crewmember receives during their mission. JSC's Behavioral Health Program will be detailing both the quality of sleep and mental states of the SEV crew over their 14-day mission in a related report. This report, however, will focus on the architecture of the sleep stations in the SEV.

Generally, the crew rated the SEV sleep stations acceptable. Of the 13 elements, the crew rated 5 – volume of station, layout, privacy, within-station light quality, and personal item access – as totally acceptable (Table 13). They noted that the high ceiling height and having the two soft lockers hanging in the side hatch gave them the perception of a spacious volume in the station (Figure 33)

Table 13. Acceptability Ratings for Sleep Activities and Station

Element	Day 3	Day 6	Day 9	Day 12	Mean (*M*)
Sleep Station Curtain Deployment by One Crew	4.0	3.5	3.5	3.5	3.6
Ease of Seat Reconfiguration for Sleep Station Setup	4.0	6.0	4.5	4.5	4.8
Volume for Crew Sleep Station	2.5	2.0	1.5	1.5	1.9
Sleep Station Layout	3.0	2.5	1.5	1.5	2.1
Volume for Personal Privacy in Sleep Station	2.5	2.5	2.5	1.5	2.3
Sleep Quality	4.5	4.0	3.5	3.0	3.8
Lighting Quality within Sleep Station	2.5	2.5	3.0	2.5	2.6
Lighting Control	5.5	4.0	4.0	4.0	4.4
Access to Personal Items while in Sleep Station	3.0	3.0	3.0	2.5	2.9
Ease of Ingress into Deployed Sleep Station	5.0	5.0	4.5	4.0	4.6
Ease of Egress out of Deployed Sleep Station	5.0	4.0	4.0	3.5	4.1
Sleep Station Curtains Stowed by One Crew	3.5	5.0	5.0	5.0	4.6
Overall Design of Sleep Station	3.0	4.0	3.0	3.0	3.3

N = 2

Figure 33. Fully deployed crewmember's sleep station in the SEV. Note the high ceiling and access to the personal soft stowage lockers.

Egressing out of the station when the curtains were deployed was rated somewhat acceptable. The crew noted that with the curtains down, there was limited access to the WCS and the noise from the Velcro® was a concern for the other sleeping crewmember. As for the sleep quality, the crew stated they liked the large side curtain for its sound- and light-dampening qualities that made the station much quieter and darker. However, they reported the bench cushions by the front seats were awkward to lie on and some time was spent adjusting the pads for the right comfort. The SEV's lighting controls were outside the sleep station, and this caused an issue. The crew reported there was no easy access to the controls.

Ease of ingress, stowage of the curtain by a single crewmember (Figure 34), and seat reconfiguration were rated "borderline" by the crew. They noted there was too much Velcro® in the new design. Getting into and out of the SEV was not easy without taking most of the curtains apart. Curtain stowage by a single crewmember still remains an issue, especially for the large main curtain. Though the crew stated it was possible to accomplish, the task was not easy due to the weight and curtain support straps. Finally, the front seat reconfiguration received the highest rating by the crew (*GM* = 4.8). This was because it was necessary to adjust the seat with two hands. Access to the adjusting tabs was difficult and getting the seats in the correct lateral placement was not optimal. As for the overall design of the sleep station, the crew rated it acceptable. Though it needed some minor tweaking, the crew stated it was a huge part of the successful habitability of the SEV for the 2-week mission.

Figure 34. Crewmember trying to stow large sleep station side curtain.

Habitability of Crew Accommodations: Food

JSC's Advanced Food Technology Project (AFTP) provided the test team with packaged food for a crew of two for 14 days in the SEV. The AFTP had to supplement the menu of Shuttle and ISS thermostabilized food packets with Mountain House© rehydratable food packets. A new idea implemented during the field tests was having removable liners for the drink containers to reduce cleaning. The subjective data here will only analyze how the crew perceived the packaging of food and drink items during the 14-day mission. Twelve elements were examined. Each food style (thermostabilized and rehydratable) was examined independently using the same seven elements for each style. Of these seven elements, only one – pantry food stowage access – had the same crew ratings for both food styles. The five remaining elements pertained to beverages.

Figure 35. Crew preparing dinner in the aft cabin.

The crew rated the rehydratable food "acceptable with minor improvements desired" for five of the seven elements tested (Table 14). For easy food preparation in a package, the crew reported the Mountain House© product style worked the best. This also held true for disposal of the used packaging. The crew reported that eating from these packages was easy and less messy than eating from the thermostabilized packaging. Portion sizes for both the meals and snacks were also considered acceptable. Pantry stowage accessibility (M = 4.9) and ease of opening the packaging (M = 5.1) were rated "borderline with improvements warranted." The crew stated that scissors were required to open all food packaging. They suggested having a way to open the packaging manually in case the scissors got lost or broken during the mission. Labeling was another concern. The crew suggested having all food and drink packaging marked on all sides of the package. As for stowage of rehydratable food, the crew suggested more of a bulk type of system. They also suggested minimizing trash; each crewmember could have a bowl and a liner, much like the drink container. Accessing the food was another complaint, especially when the cabin had been reconfigured for an EVA. The crew noted that having the food stowage in the side hatches made access easier. They also noted that stowage bins filled with rehydratable food felt lighter than the ones filled with thermostabilized food. (This would be expected as thermostabilized food includes water, whereas rehydratable food does not.)

Table 14. Acceptability Ratings for Rehydratable Food

Element	Day 3	Day 6	Day 9	Day 12	Mean (*M*)
Ease of Opening Package	4.5	4.0	6.0	6.0	5.1
Packaging Allowed Easy Food Prep	3.0	4.0	3.0	3.0	3.3
Packaging was Easy to Eat Out of	3.0	4.0	3.0	3.0	3.3
Packaging Compacted Easily for Disposal	3.5	3.5	4.0	4.0	3.8
Food Portion Size in Package was Just Right for Meal	3.5	4.0	3.5	3.5	3.6
Food Portion Size in Package was Just Right for Snacks	3.5	4.0	4.0	4.0	3.9
Pantry Food Stowage was Accessible	5.5	5.0	4.5	4.5	4.9

$N = 2$

Figure 36. Crewmember accessing food Crew Transfer Bag from the side hatch.

As for the thermostabilized food, the crew rated only the snack portions acceptable (Table 15). Packaging for ease of food preparation, disposal, portion size, and pantry stowage were rated borderline with improvements warranted. The depth and width of the packaging made food preparation from the package a messy proposition according to the crew. They reported that using a standard spoon to mix items like soups, fruits, and pudding resulted in a crewmember tendency to put the hand down in the narrow package, so that it became messy and more personal cleanup was required after a meal or snack. Disposal of the packaging by the crew was reported to be smelly and leaky. Finally, the portion size of this type of packaging was observed by the crew to be smaller than the portion size of rehydratable food. Ease of opening the packaging (M = 6.5) and eating from it (M = 7.0) were rated unacceptable with improvements required. Opening the packaging was rated similar to opening the rehydrated food; however, the crew noted it was messier than the rehydrated food packaging. As with the food preparation, the crew disliked getting messy when eating out of the thermostabilized food packets. Package dimensions and leaking were the main causes of the negative ratings by the crew.

Table 15. Acceptability Ratings for Thermostabilized Food

Element	Day 3	Day 6	Day 9	Day 12	Mean (*M*)
Ease of Opening Package	4.5	6.5	7.5	7.5	6.5
Packaging Allowed Easy Food Preparation	3.0	4.0	7.5	7.5	5.5
Packaging was Easy to Eat Out of	3.0	7.0	9.0	9.0	7.0
Packaging Compacted Easily for Disposal	3.5	6.5	6.5	6.5	5.8
Food Portion Size in Package was Just Right for Meal	3.5	6.5	5.0	5.0	5.0
Food Portion Size in Package was Just Right for Snacks	3.5	4.0	4.0	4.0	3.9
Pantry Food Stowage was Accessible	5.5	5.0	4.5	4.5	4.9

$N = 2$

The last five elements of food packaging concerned how the beverages aboard the SEV were packaged. Of the five, three were rated acceptable with minor improvements desired by the crew (Table 16). The liners used in the drink containers were easy to place inside the container; however, the crew indicated the liners were not large enough to obtain the maximum volume of drink for the container. One crewmember noted that during a single exercise workout, he would drink 0.6 L (20 oz) of Gatorade© easily. Using the drink container and liner, he reported he would have to refill the container three to four times to get the amount of Gatorade© he needed for that single workout, because of the limited size of both the container and liner. He stated it was too much overhead for such a minor payoff. Ease of using the sports top for drinks was deemed acceptable by the crew. They reported it was good for drinking liquids while in rough terrain. Leakage from the drink containers was only a minor issue. The crew noted only small amounts of spillage with containers of both sizes; however, they did notice a little more when they shook the drink mixture in the containers.

The drink powder dispensers (*M* = 8.5) were rated the highest of all the elements examined. Though the crew liked the general concept of the dispenser, they reported that it would clog easily, the tea dispenser handle did not work properly (pouring the powder out needlessly), and the lemonade and Gatorade© had to be spooned out due to overpacking of the dispensers. The crew indicated the dispenser concept would not work well in 1/6 G because the powder would go everywhere when the drink mixture was dispensed. They suggested avoiding this by having prepackaged drink mix liners, so all the crew would have to do is insert the liner into the container and add water. However, it should be noted that these results are the first collected for a 14-day lunar mission in the SEV and further testing will be needed to improve upon all deficiencies reported during this field test. The overall rating for the reusable drink cup system was borderline with improvements warranted (*M* = 5.0).

Table 16. Acceptability Ratings for Beverages

Element	Day 3	Day 6	Day 9	Day 12	Mean (*M*)
Drink Cup Liner Was Easy to Place and Use	3.0	3.0	3.5	3.5	3.3
Sports Top was Easy to Use with Hot and Cold Beverages	3.0	3.0	4.5	4.5	3.8
Drink Powder Dispenser was Easy to Use	7.5	9.0	8.5	9.0	8.5
Drink Container Prevented Spillage	2.5	4.5	5.0	5.0	4.3
Overall Reusable Drink Cup System	4.0	3.5	6.5	6.0	5.0

N = 2

Habitability of Crew Accommodations: Maintenance Activities

New to the field tests this year were both IVA and EVA maintenance. IVA maintenance was mainly directed toward the AC issues in the vehicle (Figure 37). Over the 14 days, the crew conducted numerous AC filter changes to unclog the drainage lines. Maintenance tasks performed during EVA consisted of cleaning the SEV windows and cleaning the two mast cameras. Originally, eight maintenance factors were to be examined; however, data were collected for only four because of the immaturity of current SEV maintenance procedures (Table 17). Workspace to perform maintenance in the SEV was rated acceptable with minor improvement desired. The only comment the crew made was that some areas could be tight to fit into if maintenance was required.

Figure 37. Crewmember performing a filter change on the SEV AC unit.

Understanding maintenance procedures, access to IVA tools in the SEV, and access to areas needing maintenance were rated borderline with improvements warranted.

Table 17. Acceptability Ratings for Maintenance Activities

Element	Day 5	Day 6	Day 7	Day 8	Mean (*M*)
Access to IVA Maintenance Tools in SEV	3.5	4.5	5.0	5.0	4.5
Workspace to Perform Maintenance in SEV	3.5	4.0	4.0	3.0	3.6
Access to Areas in need of Maintenance in SEV	5.0	5.5	7.0	4.0	5.4
Maintenance Procedures were Logical and Understandable	4.0	5.0	—	—	4.5

N = 2

According to the crew, IVA maintenance tool access was affected by the configuration of the cabin. They noted the flip-up benches were a good place to stow the tools, but if an EVA had been performed before the IVA tools were needed, access became difficult because of reconfiguration of the cabin for the EVA. The crew estimated they spent about 40 minutes a day moving things around in the cabin. Generally, the crew reported a need for better stowage that could reduce the time needed for reconfiguration and ease access to maintenance tools when they are needed.

Areas that needed maintenance, especially in EVA window-cleaning operations, were reported to be too hard to reach with the currently designed tools. According to human factors field notes, the crew noted that the pole and frame for cleaning the windows did not make good surface contact to properly clean the window. The crewmembers suggested adding more foam padding to the EVA mitt in front on the wire frame assembly. Stepping the mast (lowering the mast) to clean the cameras was not considered an issue for the crew (Figure 38); however, more testing using pressurized suits will be needed.

Figure 38. Crewmembers stepped the masts to clean the camera lenses.

3.1.3 Space Exploration Vehicle Cockpit Operations

The cockpit of any vehicle is where a space has been allocated or set apart from the rest of the vehicle that includes seating, controls, and displays for the pilot and co-pilot to operate the vehicle. The SEV is designed to support a two-person crew operation for 14 days. Both SEVs have a flight configuration. The Cabin 1B cockpit evaluated during this year’s desert test was designed slightly different than the one tested last year in Cabin 1A. The Cabin 1B cockpit has arrays of four monitors with edge keys placed about the front of the cockpit. The left display is the primary driving display, and the right is for navigation. However, the SEV still has the ability to be driven from either seat position. The two center displays are mainly used for outside camera views to increase situational awareness (SA). With the addition of a larger AC unit (a volume which would house ECLSS components in the flight vehicle), the upper, front window height has been decreased by 0.1 to 0.2 m (4 to 6 in.). The distance between the seats has also been increased to better allow viewing out of the lower bubble window.

Driving-Related Human Factors

During the mission, the driving terrain varied from flat and smooth to rutted and steep rocky grades. The crew recorded 23 hours and 27 minutes of total driving time. The rating elements for driving included driving characteristics of the SEV across all ranges of terrain encountered during the field test. Cooper-Harper scores varied across the entire 14-day traverse, with the majority of the frequency distribution remaining in the level 1 area (Table 18). These ratings suggest that regardless of the type of terrain, driving performance was at a desirable level with minimal compensation needed.

Table 18. Frequency Distribution of Cooper-Harper (CH) Scores for SEV Driving, Across the 14-Day Field Test

1.0	Mission Days														
CH Scale	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	
1															**LEVEL 1**
2	2	1										9			
3	3	3	6	1	6	1	1	7	7	6	8	4	3		
4		5	3	7	3	2	5					1	6	5	**LEVEL 2**
5														1	
6															
7															**LEVEL 3**
8												1			
9															
10															

N = 2

However, on day 11 a score of 8 was reported, indicating a major difficulty, with maximum operator compensation needed to accomplish tasks with moderate errors. During this time, the crew was attempting AAMA mating with a habitat on the TRI-ATHLETE. The terrain was loose gravel material on a level plain. The display and control screens were problematic, and the crew reported having great difficulty in driving the vehicle to the desired alignment for hard-mating with the AAMA and the TRI-ATHLETE habitat. They indicated the configuration of the side stick rates was unacceptable for this task and the responses to maneuvering commands were sluggish due to the loose gravel under the wheels. This caused a type of undesirable motion that made docking very difficult.

Thirteen different driving elements of the SEV were examined during the field test. All driving aspects were rated acceptable with only minor improvements desired by the crew (Table 19).

Table 19. Acceptability Ratings for Vehicle Driving

Element	Day 3	Day 6	Day 9	Day 12	Mean (*M*)
Forward Driving Capabilities	3.0	2.5	3.0	2.5	2.8
Turning Around a Single Point	3.5	3.0	3.0	3.0	3.1
Sideways (crabbing) Driving Capabilities	3.0	3.0	4.0	3.0	3.3
Alignment Capabilities	3.5	3.0	3.0	3.0	3.1
Vehicle Acceleration	3.5	3.5	3.5	3.5	3.5
External Noise Insulation	4.0	3.0	3.5	2.5	3.3
Vibration while Driving	3.5	3.5	3.0	3.0	3.3
Situational Awareness of Vehicle Alignment	4.0	5.0	4.5	4.0	4.4
Vehicle Raising and Lowering Capabilities	3.0	3.0	4.0	3.5	3.4
Vehicle Leveling Capabilities	2.5	3.0	3.0	3.5	3.0
Vehicle Stopping Capabilities	2.5	3.0	3.5	3.5	3.1
Overall Vehicle Handling and Steering	3.0	4.0	3.5	3.5	3.5
Physical Fatigue while Driving	3.0	4.0	3.5	4.0	3.6

$N = 2$

Comments made by the crew about driving centered around four areas: alignment, vibration, SA, and fatigue. During events, such as docking, that required the crew to do some fine aligning with the vehicle, the crew indicated that having low rates of speed was key and that “car mode” was preferred to assist in eliminating any type of misalignment. They considered the yaw alignment good but wanted the pitch-and-roll alignment to be decoupled from the single top-hat switch on the joystick to prevent unwanted cross-coupling.

The vibration felt by the crew while they drove over various terrains during the 14-day field test was generally rated acceptable. The crew noted they did not mind the vibration of the joystick while in rough terrain and stated it was an excellent cue for crew SA to slow the vehicle down, keeping the stress on the suspension or drive system low, and proceed with caution. Interestingly, the crew asked that this cue not be changed for those very reasons.

Figure 39. Crew driving the SEV over rough terrain.

The crew indicated, in DRATS 2008, the need for better SA in regard to vehicle alignment, especially in the lateral field of view.[7] Both human factors and engineering teams worked on this issue to develop a system to increase the crew's SA of the vehicle. With this in mind, NASA conducted several tests over the year to redesign the cockpit instrument panel and software.[8,9] As a result, the newly redesigned cockpit housed a 0.3-m (12-in.) monitor for exterior camera views about the entire vehicle (Figure 40). In all, six cameras were used for vehicle positioning and three were used as bore site docking cameras. With the redesign in place, the crew stated that the quad view (seeing four different cameras at one time) in the cockpit was good. They indicated these views were used extensively for vehicle alignment and position. The crew reported the display helped them tremendously, especially with wheel alignment. One suggestion for improvement was to better the SA viewing for vehicle clearance.

Figure 40. Newly redesigned SEV cockpit with video monitors as SA aids for crew and vehicle alignment.

The last area of driving the crew commented on was fatigue. They noted that with the longer amount of time for the mission, driving started to require more mental and hand strength than was originally thought. The crew indicated the cruise control became a very important function to reduce both wrist and arm fatigue during long driving traverses.

3.1.4 Visibility Human Factors

For the 14-day field test, 13 visibility elements were examined. The crew rated all of these characteristics acceptable with minor improvements desired. (Table 20.)

Table 20. Acceptability Ratings for Cockpit Visibility, Camera Views, and Lighting

Element	Day 3	Day 6	Day 9	Day 12	Mean (*M*)
Visibility of Front Windows for Normal Ops	3.0	1.5	2.5	3.0	2.5
Visibility of Side Windows for Normal Ops	3.0	4.5	4.0	4.5	4.0
Visibility of Lower Corner Windows for Normal Ops	2.0	2.5	2.0	3.5	2.5
Visibility of Lower Bubble for Science Ops	1.5	1.5	1.0	1.0	1.3
Visibility of the Horizon with Upper Blockage	2.5	3.5	3.0	3.5	3.1
SA of External Side Views of Blind Spots	3.5	4.0	3.5	4.0	3.8
SA of External Aft Views of Blind Spots	3.0	4.5	4.0	5.0	4.1
Center External Camera Provide Extended Range	3.0	2.5	3.0	3.0	2.9
Window Shading Aid with Glare and Heat	3.5	3.5	4.5	4.5	4.0
Overall Daylight Visibility for Normal Ops	2.5	3.0	2.5	3.0	2.8
Overall Night Visibility for Normal Ops	3.0	—	—	4.0	3.5
External Lighting for Night Ops	5.0	—	—	4.0	4.5
Interior Lighting for Night Ops	3.5	3.5	3.5	3.5	3.5

$N = 2$

As with the driving, the crew did make comments about several areas of visibility in and around the SEV Cabin 1B vehicle. Side window visibility was still an issue, especially with docking/mating operations. However, during some actual docking tasks, such as docking with another vehicle, the crew used the side windows extensively because of frustration associated with the docking displays (Figure 41). Vehicle body alignment SA was still an issue with the crew during this test as it was during the 2008 desert test.[7] They commented they could not physically see the SEV's wheels even though external camera views of the vehicle did provide some SA. The crew also suggested that a portion of the vehicle needs to be incorporated into the side camera views. This would help the crew judge the distance between docking devices and the SEV. As for the aft camera view, the crew indicated this was a great help for the aft SA of the vehicle. However, a design issue with the cabana cover partially blocked this aft view and the crew suggested having this issued corrected on the next-generation vehicle. The center top camera improved the crew's SA for both tele-operations with the TRI-ATHLETE and geologic observation. They thought this view was extremely important for scientific observational work but suggested replacing the current lens with a gyro-stabilized lens to reduce image jitter while driving. Having this camera unit with pan, tilt, and zoom functions was a joy for the crew to work with during the mission. An interesting note to this year's test is that the visibility of the front window panels was reduced by about 0.1 to 0.2 m (~4 to 6 in.)

from the upper part of the panel. This resulted from adding some upper stowage bins to the vehicle for more personal stowage in the cockpit. The crew did not report any visibility difficulty due to this reduction in front-panel viewing. No comments were reported in the subjective questionnaires, or during post-mission interviews.

Figure 41. Crewmember using the side window to assist in docking with another SEV.

A new feature for the SEV windows on this mission was a window shade. The shade was designed to be pulled up from the bottom of the window and fastened to the top for total shading and heat reduction. The shade also aided in providing the crew more privacy during the off-duty hours of the mission. However, the crew did report they would still like a movable sun visor for the center of the window. They noted that while the pull-up shades were great when the SEV was stationary, positioning the shade for driving did not work so well. Thus, adding a movable sun visor to the pull-up shade would be advisable for future designs.

The final area of comment from the crew in the area of visibility was about vehicle lighting. Night driving was tested for the first time during this year's test. The crew reported that the current lighting configuration for driving at night illuminated a good 10- to 20-m (33- to 66-ft) distance from their driving position but after that it was difficult to see the oncoming terrain. Field notes indicated that the crew suggested a lighted viewing distance of 30 to 40 m (98 to 131 ft) while driving. The lower floodlights on the vehicle were a great help to avoid obstructions, according to the crew. They also noted that the lighting around the vehicle was good for exterior EVA operations, but for driving it needed improvement. As for the interior lighting, the crew noted they needed some type of lighting in the cockpit area.

Figure 42. Crew driving SEV at night during the rescue operation.
Note the concentration of the crewmember while driving.

3.1.5 DISPLAY AND CONTROL HUMAN FACTORS

During the 2008 DRATS field test, participants reported several major issues with the vehicle’s cockpit displays and controls (D&C).[7] The main issues centered on menu navigation and touch screens. With this in mind, engineering and human factors teams were formed to correct some of the issues raised during the 2008 tests. The teams started testing and developing an entirely new hardware and software system for the SEV cockpit. The team tested several monitor configurations with the cockpit area to replace the touchscreen computers in Cabin 1A.[8] Consensus among subjects was for the team to design an instrument panel consisting of four 0.3-m (12-in.) monitors positioned horizontally across the cockpit. The outside two monitors in the panel were specifically designed for operating the SEV from either cockpit seat. These monitors incorporated the Orion baseline edge key configuration around the monitor, with 0.025- to 0.051-m (1- to 2-in.) hand grips on either side of the monitor for stability while in rough terrain. Each edge key mapped to a specific function and these monitors were adjustable. The two center monitors are mainly for viewing external camera views and displaying a moving map of the traverse paths using Google Earth. The software redesign teams completely redesigned the SEV software to combine functions on a single page and to make the display easier to understand for critical functions such as driving.[9] With these newly designed displays and controls, Cabin 1B has more functionality than Cabin 1A (Figure 43).

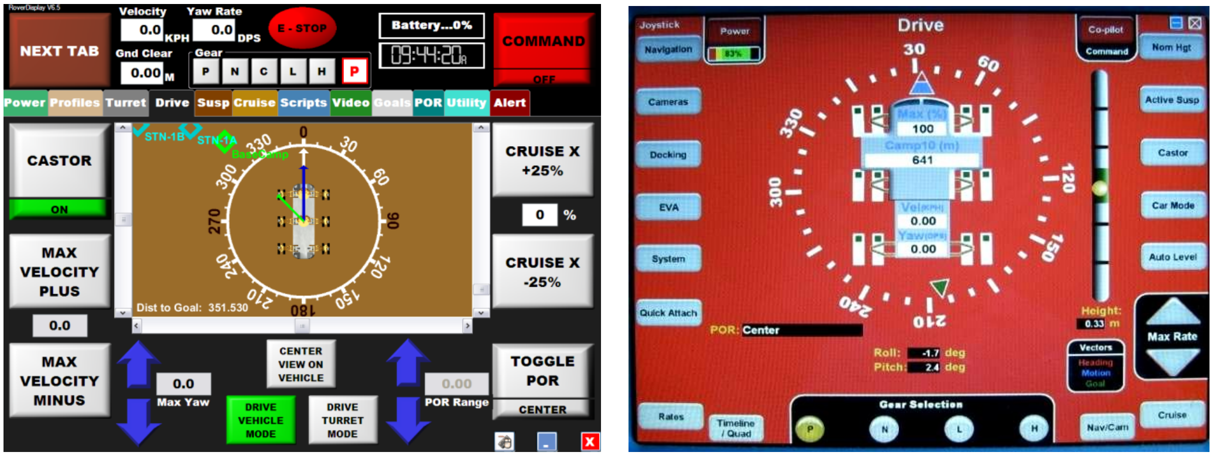


Figure 43. Cabin 1A drive page on left. Cabin 1B drive page on right. Note the difference in the way information is being presented to the crewmember.

This section provides a general overview of the SEV D&C configuration and D&C functionality while crewmembers were doing nominal tasks such as driving, navigating, docking/mating operations, TRI-ATHLETE operations, and Lunar Attachment Node for Construction Excavation operations from inside the SEV. The largest frequency of Cooper-Harper scores fell at about 3 across the 14 days; a particularly large amount of variance exists in the scores on days 1, 2, 10, 11, and 14, with ratings ranging from 2 to 9. The consistency of ratings across the 14 days is assumed to be the effect of incorporating understandable, logical interfaces into the D&C.

Table 21. Frequency Distribution of Cooper-Harper Scores Across the 14-Day Field Test for SEV D&C Interface

2.0	**Mission Days**														
CH Scale	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	
1															**LEVEL 1**
2	1								1			11	5		
3	8		12	6	14	4	4	8	11	10	12	6	12	4	
4	1	4	2	7	1	2	7	3	1			2			**LEVEL 2**
5	6	2													
6														2	
7															**LEVEL 3**
8										1					
9											1				
10															

N = 2

For days 1 and 2, the crew reported scores of 5 for the TRI-ATHLETE D&C interfaces, which were incorporated into the SEV D&C interfaces for the field test. It should be noted that this was the first time a TRI-ATHLETE has ever been operated from another vehicle. The crew reported issues about the TRI-ATHLETE's D&C; specifically, some screens were hard to interpret and the system kept locking up and having to be rebooted. This constant rebooting cost the crew mission time. Camera views from the TRI-ATHLETE were spotty, with the crew reporting that views were freezing up or lagging behind. The crew also reported a lack of camera mobility. The crew suggested the inspection cameras need the ability to pan, tilt, and zoom. Other issues were font size, background color, understandable commands, and readability.

PUP docking was another activity to which the crew gave high Cooper-Harper scores, especially on day 2 with a score of 5, day 10 with a score of 8, and day 14 with a score of 6. The biggest issue indicated by the crew was having to toggle between multiple menu pages during critical times while trying to accomplish the task. This increased both frustration and workload on the crew, as reported in the investigator's field notes. Items such as command rates, gear selection, and camera selection should all be on one page so the operator does not have to toggle between multiple menu levels. Camera views from the PUP menu were also a major issue. The views were frozen, or they lagged so far behind the activity that the cameras became useless in assisting the crew to dock with the PUP, or they would lock up the system so that a reboot was required. The crew also suggested having a distance and height aid added to the docking menus.

Day 11 had the highest Cooper-Harper score for D&C reported by the crew (score of 9) for AAMA docking with a habitat. Unlike the driving maneuverability discussed earlier, the crew stated the high Cooper-Harper score resulted from having to go between four different menu displays and unsatisfactory camera views for situational awareness during the act of docking. None of the camera views were able to give the crew a sense of distance to the target. In fact, one crewmember stated he did not trust the camera views and would visually sight the target from the vehicle's side window. As with the PUP scenario, toggling between multiple menu screens was also a major issue. The crew reported that control of the vehicle was extremely difficult at times because of uncommanded control inputs and loose gravel. In fact, the crew reported that due to the current configuration with the SEV side stick controller, menus, software, and camera views, it became so difficult to accomplish the maneuver that the crew considered this situation a major difficulty. Intense operator compensation for the configuration problems was needed to accomplish the tasks without making frequent errors.

Sixteen different elements of the SEV's displays and controls were examined over the course of the 14-day field test. The crew rated all the D&C characteristics acceptable with minor improvements desired. (Table 22.)

Table 22. Acceptability Ratings for Cockpit Display and Controls

Element	Day 3	Day 6	Day 9	Day 12	Mean (*M*)
Layout of D&C in SEV	3.5	3.5	3.0	3.0	3.3
Reachability of D&C	2.5	2.5	2.5	2.5	2.5
Center Displays easily seen by both Crewmembers	2.5	2.5	2.5	3.0	2.6
Display of Outside Video for SA	3.0	3.0	3.0	3.0	3.0
Adjustability of D&C	3.5	4.0	3.5	4.5	3.9
Stability of D&C while Driving	2.5	3.0	3.0	2.5	2.8
Readability of Cockpit Displays	3.0	3.5	3.0	3.5	3.3
Reachability of Edge-keys	2.5	2.5	2.5	2.5	2.5
Usability of Edge-keys while Driving	3.0	2.5	3.0	3.0	2.9
Display Brightness for Day Operations	2.5	2.0	2.0	2.0	2.1
Display Brightness for Night Operations	4.0	2.0	2.0	2.0	2.5
Usability of Navigation Menus	4.0	3.0	3.5	3.0	3.4
Eye Fatigue while Viewing Displays	3.5	2.0	2.5	2.0	2.5
Responsiveness of Joystick	3.5	3.5	3.5	3.0	3.4
Hand Fatigue while Operating Joystick	4.0	4.5	4.0	3.5	4.0
Overall Usability of the D&C	4.0	4.0	4.5	4.0	4.1

N = 2

Crew comments about the nominal functionality of the SEV D&C covered several areas. Adjustability of the two operational displays for driving was considered acceptable for lateral movement; however, the crew wanted more vertical adjustability of the monitors to increase the front window panel view when necessary. As for font size, the crew noted some fonts were too small to read without difficulty, but they did not specify any particular screen menu. Menu navigation was a major issue of concern during the 2008 field test, and comments from the crew during this field test were more positive with the new software format. They liked the edge keys and the specific mapping to vehicle operations. However, for specialty operations, such as docking, the crew reported too many key inputs were necessary to do a particular task. Multiple screen switching, which led to increased workload and frustration for the crew, was also an issue during these operations. These specialty operations are further discussed in detail in the following sections of the report. The crewmembers suggested that SEV displays and controls could be improved by having certain screens integrated into one screen for specialty functions. An example would be to have the drive page and docking cue page integrated into one page so the crew does not have to toggle between screens during critical docking phases. The crew also suggested that decreasing the number of screens through integration would decrease the number of edge key inputs. They would like to see a 50% reduction in key inputs for all SEV nominal operations and docking operations.

3.1.6 SPACE EXPLORATION VEHICLE COCKPIT SEATING HUMAN FACTORS

During the 2008 field test, the crew indicated that adjustability of the seats was extremely important for reconfiguration time, stability, and flexibility for the operator. The crew also reported that the space between the two seats needed to be wider to better accommodate a crewmember ingressing into the front lower bubble for scientific observation (Figure 44).[7]

Figure 44. Cabin 1A cockpit seat design.

A redesign of the SEV seat was undertaken, with these considerations in mind, to improve the width of the seat pan to improve crewmember comfort in getting to the lower front observational bubble, to decrease reconfiguration time, and to add robustness to the adjustability of the seat mechanisms. (Figure 45.) Ten different elements for cockpit seating were studied using the same subjective characteristics as in 2008. The crew rated stability of the seat while driving, height of seat, depth of seat pan, usability of seat (activities including driving, navigating, report writing, eating, etc.), and space between the seats for lower bubble access as acceptable, with minor improvements desired.

Figure 45. Cabin 1B new cockpit seat design.

Table 23. Acceptability Ratings for SEV Cockpit Seating

Element	Day 3	Day 9	Day 12	Mean (*M*)
Comfort of Seats for Driving	5.0	4.5	4.5	4.7
Adjustability of Seats	7.5	8.0	5.5	7.0
Stability of Seats while Driving	3.0	4.0	3.0	3.3
Height of Seats	3.0	3.0	3.0	3.0
Width of Seats	4.5	6.0	3.5	4.7
Depth of Seat Pan	3.0	4.0	4.0	3.7
Foot and Arm Rests for Seats	4.5	4.5	4.5	4.5
Space Between Seats to Access Lower Bubble	2.5	2.0	3.0	2.5
Usability of Seats during Activities*	4.0	4.0	3.0	3.7
Overall Seat Configuration	3.5	5.0	5.5	4.7

** Driving, navigating, report writing, eating, etc.*

$N = 2$

Factors the crew rated "borderline" were seat comfort, seat width, foot and arm rests, and overall configuration. Comfort of the seat with its original cushions was unsatisfactory for both crewmembers because of the way the seat back felt against the lumbar region of the lower back. These cushions lasted only a few days before a decision was made to switch the cushions with the ones in Cabin 1A. Using the contingency scenario, the crew docked with Cabin 1A and retrieved the older cushions. Once the cushions were repositioned into the new Cabin 1B seats, the crew reported that comfort was restored to the seat backs, and the field test continued without further disturbance. Though ratings did decrease, the lumbar support on the new seats will need some redesign for future vehicles.

The width of the seat pan for the Cabin 1B seats was decreased to increase the space between the two cockpit seats for easier accessibility to the lower front bubble (Figure 46). The crew noted that this increase in space did make it easier to access the lower bubble; however, they thought the seat pan was too narrow. As with the comfort element, the newer cushions presented problems for the seat width rating. The crew reported the new cushions were not wide enough in the seat pan to give enough support while crabbing the vehicle down a slope. It was observed that crewmembers tended to slide off the seat pan, even while restrained, during these operations. This was not observed in Cabin 1A during the 2008 field test. However, when the Cabin 1A cushions were used, the crew reported they had more support with the bigger cushions.

Figure 46. The crew had better bubble access because of the narrower seat pan design.

The crew indicated a need for both an arm rest and a foot rest with the seat to help with comfort and support. They suggested the arm rest could be removable and the foot rest would be useful for shorter crewmembers' comfort. They thought this would also be beneficial to the overall seat configuration.

Adjustability was rated unacceptable with improvements required (M = 7.0). The new ratchet mechanisms for adjusting the seats were reported to be too complex. Crewmembers had to use two hands to release the mechanisms on opposite sides to adjust the seat back. They reported difficulty in getting the seat back in the exact position they wanted due to backlash with the mechanism. With the Cabin 1A seats, a simple lever was pushed with one hand to adjust the seat back. However, because of a broken cable, the adjustability of the seat received unacceptable ratings from the crew. They also indicated that the newly designed seats in Cabin 1B did not have the same type of head cushions on the back as the Cabin 1A seats. They observed that because of this deleted accessory, the recliner mode the crew used in Cabin 1A during the 2008 test, to rest and relax in the aft cabin, could not be accomplished with this new Cabin 1B seat design – an aspect the crew missed during off-duty times. Though the crew reported an overall favorable response to the new seat configuration, they indicated the seats in Cabin 1A were easier to reconfigure and reposition, and were more comfortable.

3.1.7 Summary and Recommendations from 14-Day Space Exploration Vehicle Habitability and Human Factors Evaluation

a) For a crew of two living and working inside the SEV, fatigue, workload, and vehicle acceptability were considered acceptable.

b) Temperatures in the cabin, however, were considered unacceptable.

c) Crewmembers stated no issues with accomplishing a 14-day mission within the current SEV design.

d) The crew predicted there would be no issues with performing a 4-week SEV mission as long as the two vehicles could dock every 3 to 7 days to benefit from the increased habitable volume and crew interaction while docked.

e) The crew recommended a dedicated trash area that is easily accessible for daily use, a more powerful vacuum unit for trash compaction, and improved training with the current trash management system.

f) Soft locker design and volume were considered acceptable by the crew for a 14-day mission, but the volume was considered almost too great for this length of mission. The crew stated the current volume would be better suited for a 4-week mission. For a 2-week mission, the crew recommended decreasing the volume by 50%.

g) Cabin reconfiguration involving the soft locker system was considered unacceptable because the crew had to spend too much time on it. It was estimated that the amount of time spent on reconfiguration was about 18 hours over a 14-day period. Access to other stowage was difficult and the crew recommended a redesign of the soft locker system for the second-generation vehicle design.

h) Bench stowage was considered the best use of available space inside the vehicle.

i) WCS operations were considered difficult due to the narrow aisle in the SEV. A wider aisle was recommended.

j) Performance of aerobic and resistive exercise inside a stationary vehicle was considered acceptable by the crew. They recommended keeping the protocol for exercising while the vehicle is stationary.

k) Ergometer design concerns of the crew included the absence of back support for the seat, overall device weight, pedal design, and display design. Recommendations included a redesign of the seat to include back support for long-duration missions, design of a better method for attaching and detaching the pedals, redesign of the display for better readability, and redesign with lighter-weight materials and easier assembly.

l) The sleep station volume was totally acceptable to the crew, as they observed that the high ceiling height made the volume seem larger.

m) Edge curtains were troublesome due to their contour shape, which increased setup time. Stowage of curtains, especially the large side curtain, by a single crewmember was not resolved. The crew observed that the Velcro on the curtains was noisy during night WCS operations. The crew also reported the absence of lighting control from within the sleep station. Crew recommendations call for using less-rigid forward- and aft-edge curtains, lightening the weight of the side curtain, designing a smaller zipper section into the side curtain for easier and quieter egress and ingress, and adding a dimmer switch inside the sleep station for lighting control.

n) Regarding food packaging, the crew recommended providing a way to manually open a food pouch in case scissors were lost or broken during the mission. They also recommended labeling on all sides of the package.

o) The volume of the drink liners was too small, according to the crew. They recommended a liner that could hold up to 0.6 L (20 oz) of beverage to reduce the amount of trash.

p) For EVA maintenance, the crew stated that the pole and frame tool used for cleaning the SEV windows did not make good surface contact to properly clean the window. They recommended adding more foam padding to the EVA mitt used on the wire frame assembly.

q) Terrain type was troublesome to vehicle maneuverability while docking. The crew observed that loose gravel made fine maneuvering commands difficult and hard to predict. The loose gravel made the vehicle erratic, sluggish, and next to impossible to precisely control, causing some undesirable motion that made docking difficult.

r) For fine alignment, the crew reported that having low rates of speed and using "car mode" eliminated any type of misalignment. The crew recommended decoupling the pitch and roll alignment for the single top-hat switch on the joystick to prevent unwanted cross-coupling.

s) The crew reported that the vibration of the joystick, while in rough terrain, was an excellent cue for crew situational awareness to slow the vehicle down and proceed with caution.

t) The crew considered the quad view display in the cockpit to be tremendously helpful for wheel alignment and position. A recommendation for improving SA was to have a view of vehicle clearance.

u) External camera views for SA received mixed reviews. Crew recommendations included having side views incorporate a portion of the vehicle into the view for vehicle position and clearance, redesigning the aft cabana cover to not interfere with the aft view, and adding a gyro-stabilized lens and pan, tilt, and zoom capability to the top center camera view.

v) The 0.1- to 0.2-m (4- to 6-in.) reduction in the front window panels did not affect visibility. It should be noted that the majority of the terrain traversed was flat and not mountainous as with a south pole lunar expedition.

w) The lighting configuration for night driving made it difficult to see oncoming terrain. With the current configuration, visibility is from 10 to 20 m (33 to 66 ft). Recommendations by the crew indicate they would want a lighted viewing distance of 30 to 40 m (98 to 131 ft) while driving at night.

x) The crew liked the edge keys especially for their specific mapping functions for vehicle operations. For specialty operations, such as docking, the crew reported having to do too many key inputs for a particular task. Toggling between multiple menu pages tended to increase workload and frustration. Recommendations by the crew included integrating certain screen functions into one composite screen for specialty functions, which should decrease the number of edge key inputs. The crew also recommended a 50% reduction in key inputs for all SEV nominal operations and docking operations.

y) The crew considered the new ratchet mechanisms for seat adjustment to be too complex and required a two-handed operation.

3.1.8 Space Exploration Vehicle Aft Station Human Factors

The human factors evaluation of the aft station and suit port interfaces was a stand-alone test hypothesis and results are in Section 3.3.

3.2 Hypothesis 2: Effect of Intermittent Communications on Crew Productivity

Hypothesis 2: Crew productivity during SEV mission tasks will not significantly vary between two different communications scenarios: a.continuous real-time communications (baseline); b. limited *communications (66% coverage, 34% no coverage – based on single relay satellite in highly elliptical orbit with apogee above the lunar south pole).*

Members of the 2009 DRATS Science Team collected EVA productivity data throughout the 14-day mission. EAMD Data Quality and Observation Quality ratings were assigned by members of the Science Backroom and also by “ground-truthers,” who were field geologists who followed behind the crewmembers to assess their performance against the defined objectives. At the end of each day, the Science Backroom and ground-truthers would compare their ratings and reach consensus on the ratings for each of the day’s objectives.

Unintentional space-to-ground communication dropouts at times when continuous communications were planned affected portions of several traverse days. However, where productivity metrics were affected by unintentional communication dropout, the scores were not used in the analysis. Although the EPI comparison showed a small but nonsignificant increase in productivity during Intermittent Communications compared with Continuous Communications, the exclusion of data from EVA stations that were inadvertently affected by communication problems precluded a meaningful comparison using EPI (the calculation of which is described in Section 2.4.2). However, missing data from affected stations does not affect the validity of average EAMD Data Quality or Observation Quality calculations. Consequently, the average EAMD Data Quality and Observation Quality ratings of the two communication modes were compared, but the Exploration Productivity Index was not used.

Figure 47 compares the average EAMD Data Quality (left) and Observation Quality (right) during the Continuous Communications and Intermittent Communications modes. The small differences between modes did not reach the prospectively defined level of practical significance for either EAMD Data Quality or Observation Quality. As described in Section 2.4.2, a difference on either scale of one or more full categories was prospectively defined as a practically significant difference between the communications modes.

These results indicate that the productivity of the exploration operations during the test was not significantly better or worse when these operations were conducted with planned periods without real-time space-to-ground communications. The extent to which real-time support from the ground is valuable depends greatly on the training and expertise of both the crew and the support team. It should be noted that although the crews and support team were experts in their respective fields, there had been relatively little opportunity to practice and refine the SEV-based exploration operations before the test. More practice would have likely improved the productivity of operations during both communication modes.

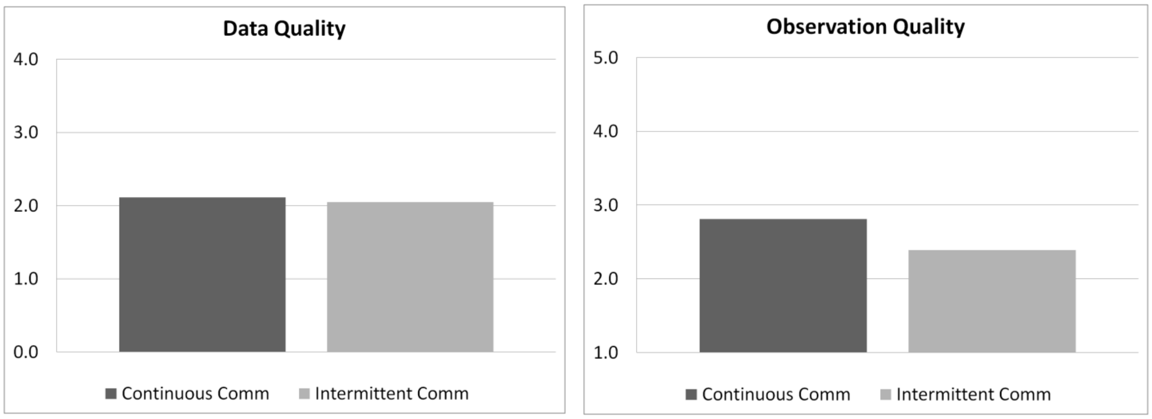


Figure 47. Comparison of average EAMD Data Quality (left) and Observation Quality (right) ratings showed no practically significant differences during Continuous Communications vs. Intermittent Communications operations.

3.3 HYPOTHESIS 3: HUMAN INTERFACES OF SPACE EXPLORATION VEHICLE AFT DECK

Hypothesis 3: Human interfaces of the redesigned SEV prototype aft deck (suit ports, alignment guides, aft enclosure, and aft driving station) will be acceptable as assessed by established human factors metrics.

Following up on concerns about operation of the suit ports and dust on the space suits from the 3-day mission during the 2009 DRATS field test, the team examined 20 different elements associated with the newly redesigned SEV aft station during the 14-day desert field test.

3.3.1 EXTRAVEHICULAR ACTIVITY OPERATIONS

During the 14-day field test, two types of EVA mock-ups were used by the crew for all aft station operations. Conditions for each suit mock-up type were the same over the 14-day mission. For days 1-4 and 12-14, the crew used the lightweight (LW) EVA suits (Figure 48). These mock-up suits were designed to be lighter weight than the Global Effect suits, which were used during the 2008 field test. On days 5-11, the crew used the relatively lighter-weight and non-constricting EVA Back Pack mock-up (Figure 49). The Apollo Program used a similar type of mock-up during their testing of the Lunar Roving Vehicle in the late 1960s and early '70s (Figure 50). Fatigue and workload data were collected for both suit mock-up types for 7 days each. An overall EVA fatigue and workload assessment for the 14-day mission was also calculated.

Figure 48. Crewmember wearing the lightweight EVA suit mock-up during the field test.

Figure 49. Crewmember wearing the EVA Back Pack mock-up during the field test.

Figure 50. Crewmember wearing the Apollo EVA Back Pack mock-up.

The pre-EVA phase consisted of the crewmember donning the suit mock-up through the suit port, going through all the pre-check procedures, and disconnecting from the suit port. For both the LW EVA Suit mock-up and the EVA Back Pack mock-up, pre-EVA fatigue was essentially equal across the mission, with ratings ranging from 2.0 to 3.5, indicating no to minor fatigue with performance not compromised (Figure 51). As for workload during pre-EVA, the crew rated the LW EVA Suit slightly higher in workload than the EVA Back Pack. This is not surprising, because the back pack configuration had lighter weight and better mobility than the LW EVA Suit configuration (Figure 52).

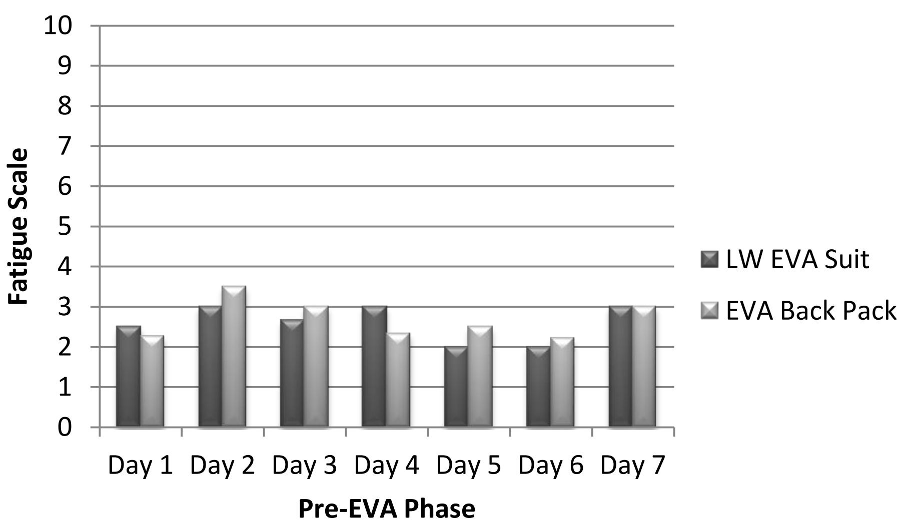


Figure 51. Pre-EVA crew fatigue in two different EVA mock-up suit configurations over a 7-day period.

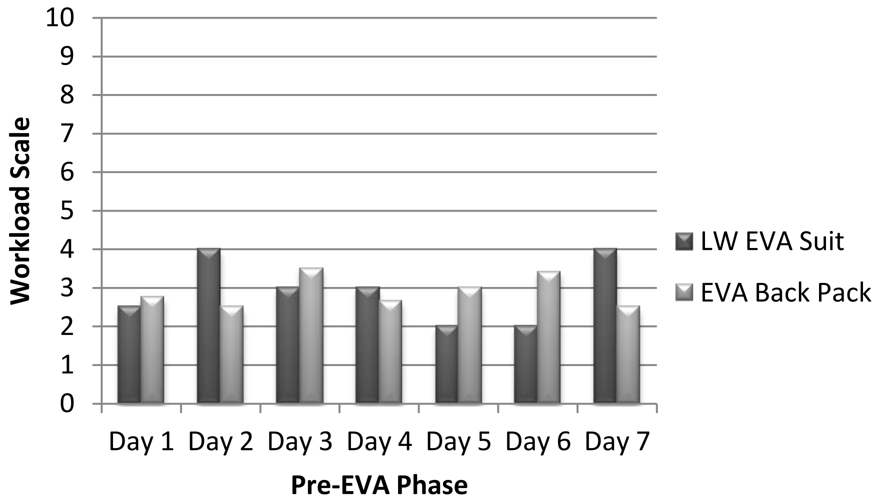


Figure 52. Pre-EVA crew workload in two different EVA mock-up suit configurations over a 7-day period.

During the post-EVA phase, the crew connected back into the suit port, went through all suit port procedures, and ingressed back into the SEV. The crew gave the LW EVA Suit mock-up slightly higher fatigue ratings (ranging from 2.5 to 3.4) than the EVA Back Pack mock-up (Figure 53). Again, this is not surprising due to the fact that crewmembers doffed the EVA back pack before getting into the suit ports. This was done because the current EVA Back Pack configuration does not have an SEV suit PLSS plate attached to the back. However, this is being corrected for the 2010 tests. Post-EVA workloads for the two types of EVA suit mock-ups were rated equally by the crew. With the highest rating being a 3.2 over the 14-day mission, the crew considered the workload in either suit mock-up type to be light with desirable spare mental capacity remaining (Figure 54).

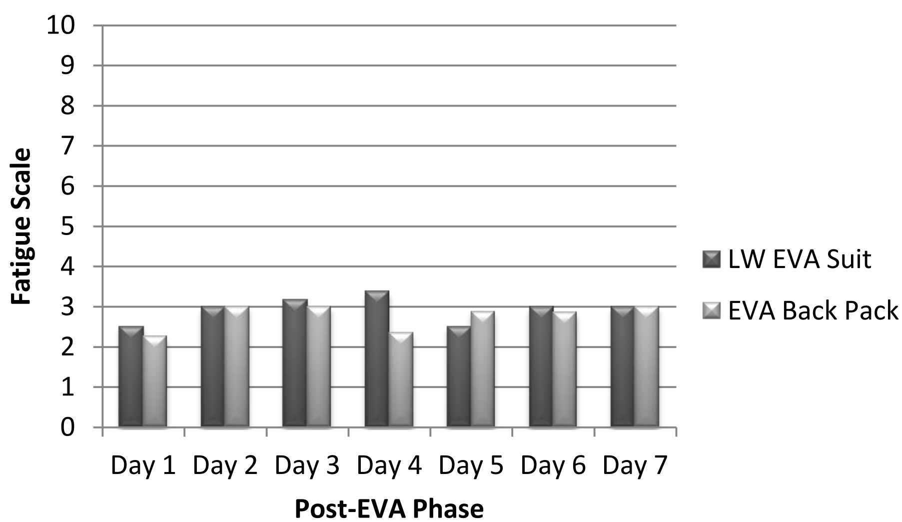


Figure 53. Post-EVA crew fatigue in two different EVA mock-up suit configurations over a 7-day period.

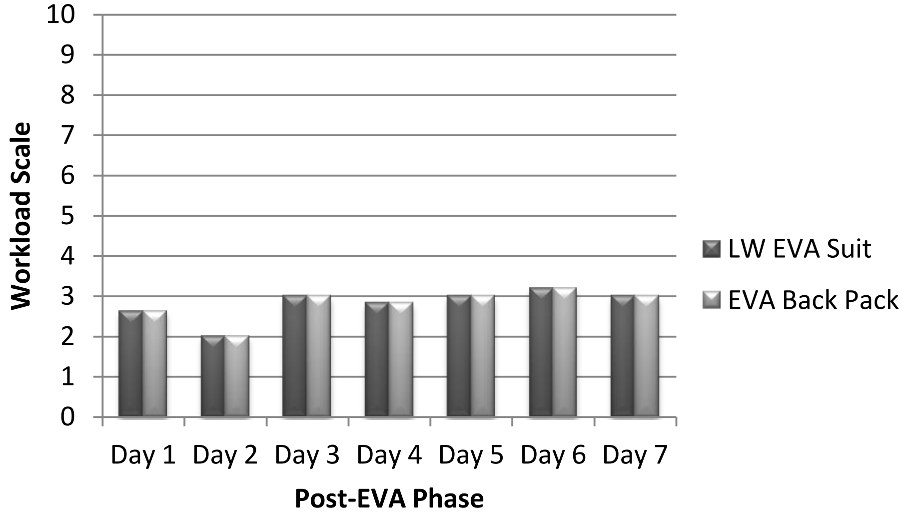


Figure 54. Post-EVA crew workload in two different EVA mock-up suit configurations over a 7-day period.

As for EVA operations overall, crewmember fatigue for both the pre- and post-EVA phases during the 14-day field test, regardless of suit mock-up type, was considered minor with performance not compromised (Figure 55). Over the entire 14-day mission, regardless of suit mock-up type, the crew considered the workload in both pre-EVA and post-EVA phases to be light, with desirable spare capacity remaining (Figure 56).

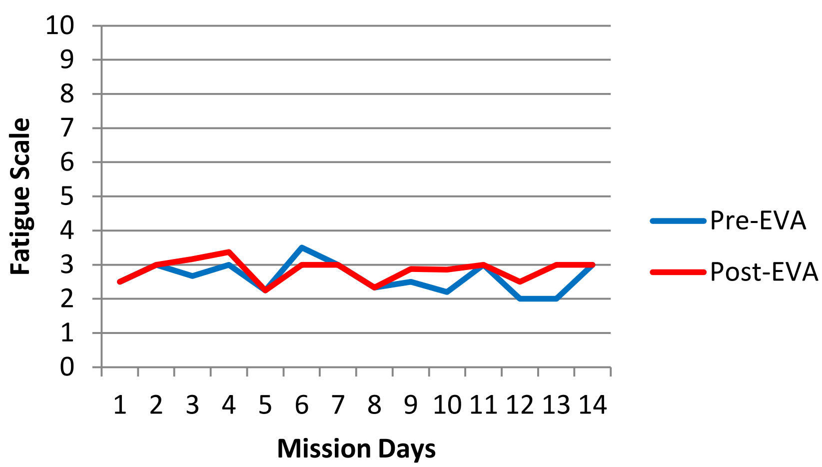


Figure 55. Pre- and post-EVA crew fatigue over a 14-day field test.

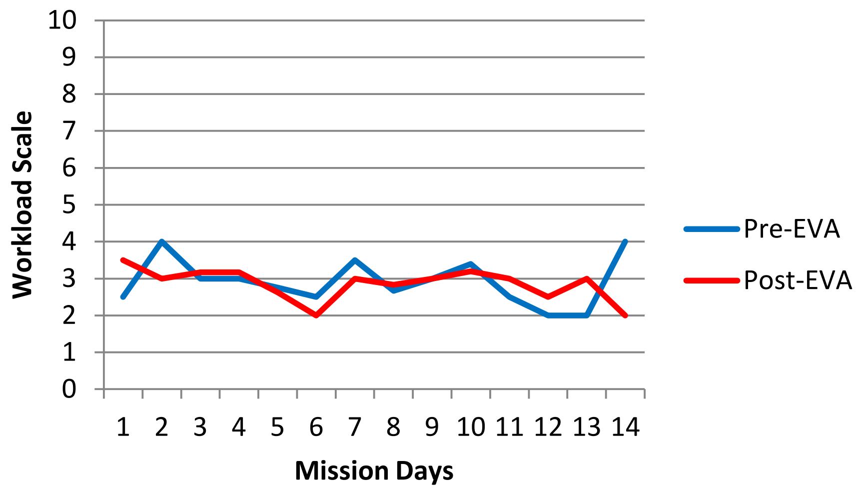


Figure 56. Pre- and post-EVA crew workload over a 14-day field test.

3.3.2 Aft Deck, Suit Enclosure, and Translation

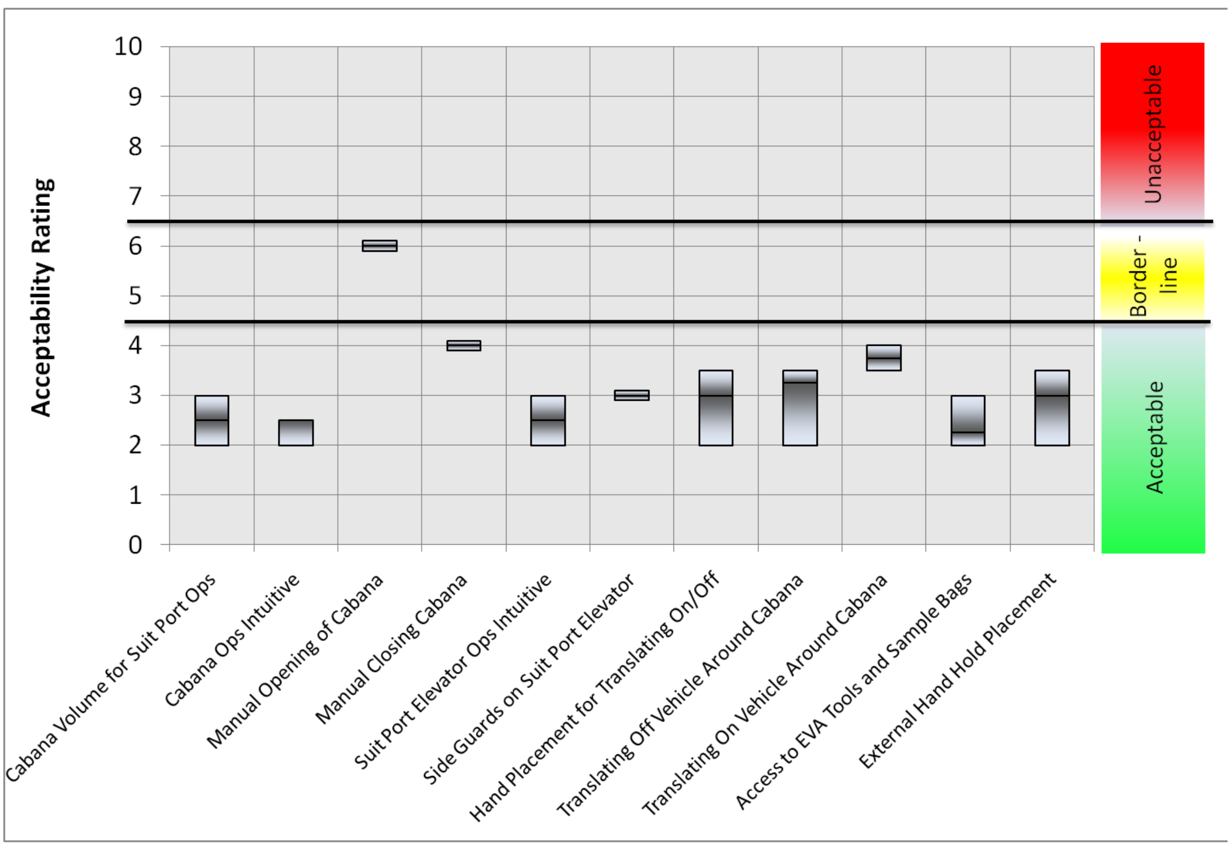
New to the vehicle aft deck was the suit environmental enclosure called the cabana. Being a soft-covered shell over five aluminum ribs, the cabana was designed to protect the suits from dust during the field test (Figure 57). This design resulted from the finding on the 3-day mission that dust accumulation was significant over the whole suit.[7] The team investigated 11 factors of the cabana during the 14-day mission. Of these 11 factors, the crew reported that most were acceptable, including the cabana interior volume, operations software, elevator operations, hand placement, external hand holds, tool accessibility, and translation off the vehicle. (Table 24.)

Figure 57. The SEV cabana protects the EVA suits from dust and was a new addition to the vehicle aft deck.

Table 24. Acceptability Ratings for Aft Station Cabana and Aft Translation

Element	Day 3	Day 6	Day 9	Day 12	Mean (*M*)
Cabana Volume Adequate for Suit Port Ops	2.0	2.5	3.0	2.5	2.6
Cabana Ops Intuitive?	2.0	2.5	2.5	2.5	2.4
Manual Opening of Cabana	—	—	—	6.0	6.0
Manual Closing of Cabana	—	—	—	4.0	4.0
Suit Port Elevator Ops Intuitive?		2.5	3.0	2.0	2.6
Side Guards on Suit Port Elevator	—	3.0	3.0	3.0	3.0
Hand Placement for Translating On/Off	2.0	3.0	3.5	3.0	3.0
Translating Off Vehicle Around Cabana	2.0	3.5	3.5	3.0	3.1
Translating On Vehicle Around Cabana	4.0	3.5	3.5	4.0	3.7
Access to EVA Tools and Sample Bags	2.0	3.0	2.0	2.5	2.4
External Hand Hold Placement	2.0	3.0	3.5	3.0	2.9

N = 2



The crew noted three elements as being somewhat problematic. It was difficult for crewmembers to open or close the cabana in a manual override mode while suited; thus, the crew gave a borderline rating with improvements warranted ($M = 6.0$). They indicated that when the cabana rose it would not lock into place. For the crew to accomplish the task, one crewmember had to hold the cabana up while the second crewmember translated onto the vehicle and into the suit port. Once this was accomplished, the crewmember in the cabana held it open while the first crewmember climbed into their suit port. A recommendation for redesign is to have an extension pole that the crew could attach to the last cabana rib to support the cabana while they translate into the suit port area. Another observation noted by the crew about this task was the mobility of the EVA suit. They reported that this task would be very difficult to do in a pressure suit. Lastly, the crew indicated that some minor improvements needed to be considered for translation back onto the SEV. When the cabana was added, the external handhold poles were redesigned so the crew still had some assistance in getting back onto the vehicle. However, field observations indicated the crew tended to use the aft station control arm and battery box for climbing back onto the vehicle instead of using the redesigned handholds (Figure 58). On the other hand, the field test was conducted in a 1-G environment with mock-up suits, instead of in the partial gravity that would be expected on another planetary body; therefore, climbing aboard the aft deck remained cumbersome for the suited crew as the mission continued.

Figure 58. Suited crewmember translating back onto the aft deck of the SEV. Note his hand placement on the aft station control arm and battery box. The "L" shaped gold poles are the redesigned handhold poles.

3.3.3 AFT DECK DISPLAYS & CONTROLS

Cooper-Harper scores for the SEV's aft station D&C interfaces did not vary much over the course of the 14-day field test. In fact, across the entire 14-day mission, only one score was in the level 3 range while the majority of the scores were in level 1 (Table 25). This would suggest that aft display interfaces, which consisted of suit port procedural operations and the SEV driving page, were quickly understood by the crew, rating the interface as acceptable with fair to mild compensation being required to attain adequate performance.

Table 25. Frequency Distribution of Cooper-Harper Scores For Aft Station D&C

3.0	**Mission Days**														
CH Scale	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	
1															**LEVEL 1**
2	1				1	2			1	1		2			
3	1		4	7	8		1	6	8	6	2	1	2	1	
4			2	2								2			**LEVEL 2**
5															
6															
7		1													**LEVEL 3**
8															
9															
10															

N = 2

The exception is the score of 7 reported on day 2. This was the first SPTM operations using the aft station D&C. The crew reported that once they had docked the SPTM to the suit port, there were no procedural menus for this particular operation in the system. A modification of the suit port procedures was developed in the field to continue with testing, but the crew wanted the score to show specific SPTM procedures need to be developed for the vehicle's interface. Readability and display position were also reported and concur with the subjective data collected (Table 26; Figure 59).

The crew reported that, overall, the aft station improvements provide for this year's test worked well. The display edge keys were considered acceptable; however, the crew did note when they were faced with an oblique view of the display screen during a two-person EVA, it was difficult to see which edge keys lined up with which command. Suggested recommendations included using either a numbering or a color coding system on the edge keys to correspond with the command.

Table 26. Acceptability Ratings for Aft Station D&C

Element	Day 3	Day 6	Day 9	Day 12	Mean (*M*)
Display Edge Key Reachability	5.0	3.0	2.5	2.5	3.0
Display Edge Key Gloved Operations	5.0	3.0	3.0	3.0	3.3
Display Menus Intuitive and Logical?	3.0	2.0	2.5	3.0	2.6
Display Readability	7.0	3.0	4.0	3.5	4.0
Display "Out of way" Adjustment	3.0	3.0	4.0	3.5	3.3
Aft Joystick Reach	—	6.5	7.0	5.0	6.0
Driving Aft Station in Suit Port	—	—	—	4.5	4.5
Driving Visibility Aft Station	—	—	—	5.0	5.0
Stability Using Joystick Aft	—	—	—	4.0	4.0
Hand Fatigue Using Joystick	—	—	—	3.5	3.5

N = 2

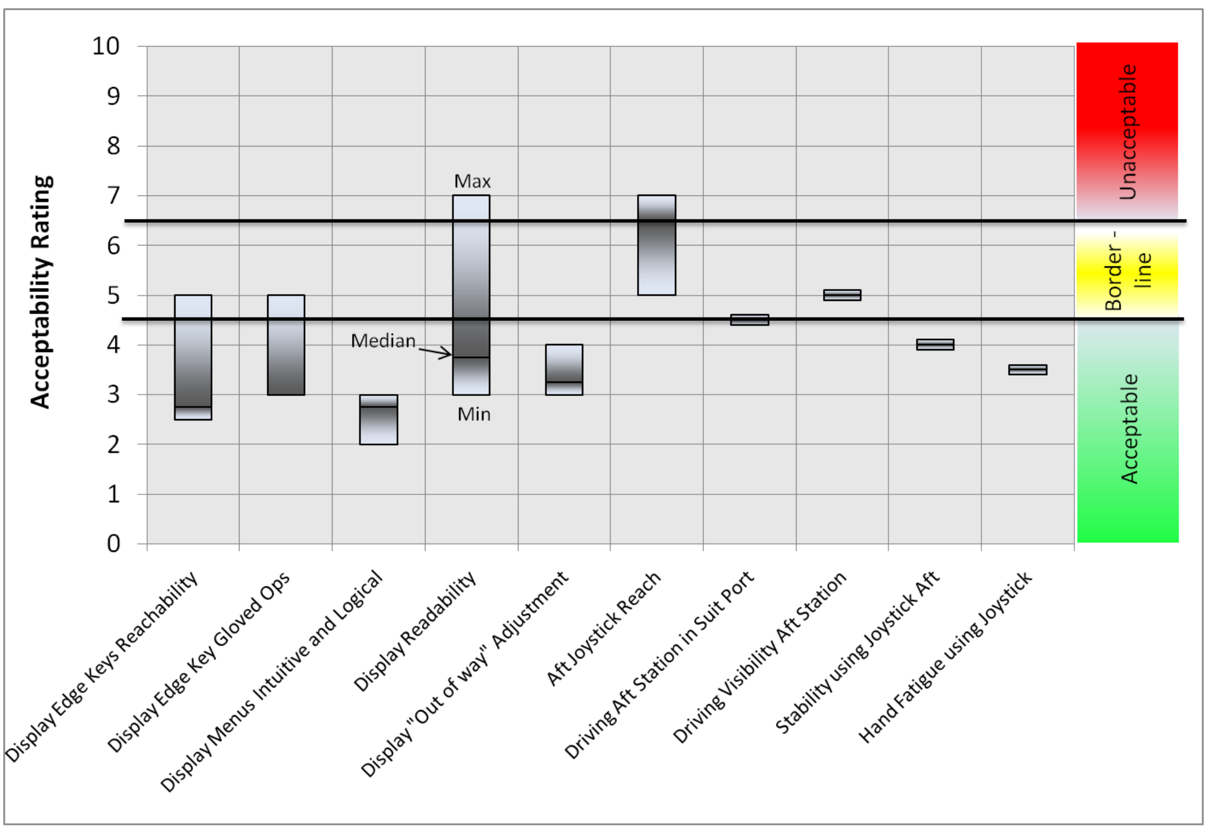


Figure 59. Acceptability ratings for aft driving station displays and controls.

Figure 60. Crew sharing the aft display screen during a two-person EVA.

Readability of the display screen was not an issue when nominal suit port operations, such as an EVA, were performed. On the other hand, the crew reported difficulty with readability when doing SPTM operations. They indicated the display screen needed to have the ability to swivel 180° when the SPTM is docked into the suit port so that they could access the SPTM operational procedures.

Figure 61. Crewmember trying to see aft display screen during an SPTM operational event.

Because of some suit operational issues, the aft station joystick was tested only during the Lunar Attachment Node for Construction Excavation blade operations on day 12. Some crew observations on the joystick were also made earlier in the test as well. Generally, the crew rated the aft control borderline with improvements warranted. The reach to the joystick from the suit port position ($M = 6.0$) was considered too far and the crew noted that the position of the joystick was not natural to the arm position within the suit. This also made stability of the arm and fatigue of the hand a notable concern, with the crew wanting some minor improvements in the design. Suggestions for redesign included bringing the control stick closer in the suit ports and possibly having a fold-down panel incorporating the control stick with some of the key functional buttons, allowing the crew to easily actuate critical suit port elements.

Visibility for operating the SEV from the aft station was rated borderline ($M = 5.0$), mainly because the field of view from the suit helmet was limited.

As with the subjective ratings, Cooper-Harper scores indicated that the crew thought the task of aft driving was acceptable with some mildly annoying compensation required to attain adequate performance. The concern voiced by the crew on aft driving in general was mainly with dust getting on the suits while they did a construction task. However, it should be noted the crew drove from the aft station for only a few hours on day 12, and further study will be needed in this area to understand all the complexities of this task.

Table 27. Frequency Distribution of Cooper-Harper Scores For Aft Driving

4.0	**Mission Days**														
CH Scale	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	
1															**LEVEL 1**
2															
3												1			
4												1			**LEVEL 2**
5															
6															
7															**LEVEL 3**
8															
9															
10															

$N = 2$

3.3.4 Suit Port Operations

One of the most unique features of the SEV is the suit port design. These ports, located at the rear of the SEV, hold the suit to the back of the SEV while allowing access to them through the back of the suit via the PLSS, which swings open. The suit has the same internal pressure as the SEV, eliminating the need for pressurization. Once a suit has been donned, the cabin of the SEV is sealed via an internal hatch, and the person in the suit simply detaches from the suit port and steps off the vehicle. Several modifications were made to the suit port prototypes following the 2008 DRATS field test,[1] including the addition of an automatic mechanism that locks and detaches the suit from the SEV, as well as opening and closing both the suit and internal SEV hatches. Many features were evaluated, including manual operation of the locking mechanism, and donning and doffing of the suit. Human performance measures were taken on 18 different elements of the SEV suit port device during the 14-day desert mission. Lessons learned from the 3-day mission were put to good use, and ratings by the crew were substantially improved during the 14-day mission.[7]

Table 28. Acceptability Ratings for Suit Port Operations

Element	Day 3	Day 6	Day 9	Day 12	Mean (*M*)
Internal Access to Suit Port	3.5	3.0	5.0	4.5	4.0
Ease of Use of Inner Hatch Manual Lock	2.5	2.5	2.5	3.0	2.6
Inner Hatch Motor Breakaway Operation	3.0	3.0	3.0	3.0	3.0
Ease of Inner Hatch Manual Override	3.0	3.0	3.0	3.0	3.0
Effectiveness of Interior Handholds for Suit Donning	3.0	2.5	3.0	2.5	2.8
Body Translation into Suit Port	3.5	3.5	3.5	3.5	3.5
Operation of Suit Port Mechanism	2.5	2.0	2.5	2.5	2.4
Detaching Suit from Suit Port	2.0	2.0	2.5	2.0	2.1
Aligning Guides for Suit Port	3.0	3.0	3.5	3.5	3.3
Attaching Suit to Suit Port	3.0	3.0	3.0	3.0	3.0
Effectiveness of Boot Doffing Aid	3.0	3.0	3.0	3.0	3.0
Effectiveness of Interior Handholds for Suit Doffing	3.0	2.5	2.5	2.5	2.6
Ease of Use of Ottoman for Donning and Doffing	3.0	3.5	3.0	3.0	3.1
Body Translation Out of Suit Port	3.5	3.5	3.5	4.0	3.6
Suit Port Motor Breakaway Operation	3.5	3.5	3.5	3.5	3.5
Ease of Use of Suit Port Manual Override	3.0	3.0	3.0	3.0	3.0
Overall Design of Suit Port	2.5	2.0	3.0	2.5	2.5
Ease of Soft-locker Reconfiguration for EVA Ops	6.5	6.0	8.0	6.5	6.8

N = 2

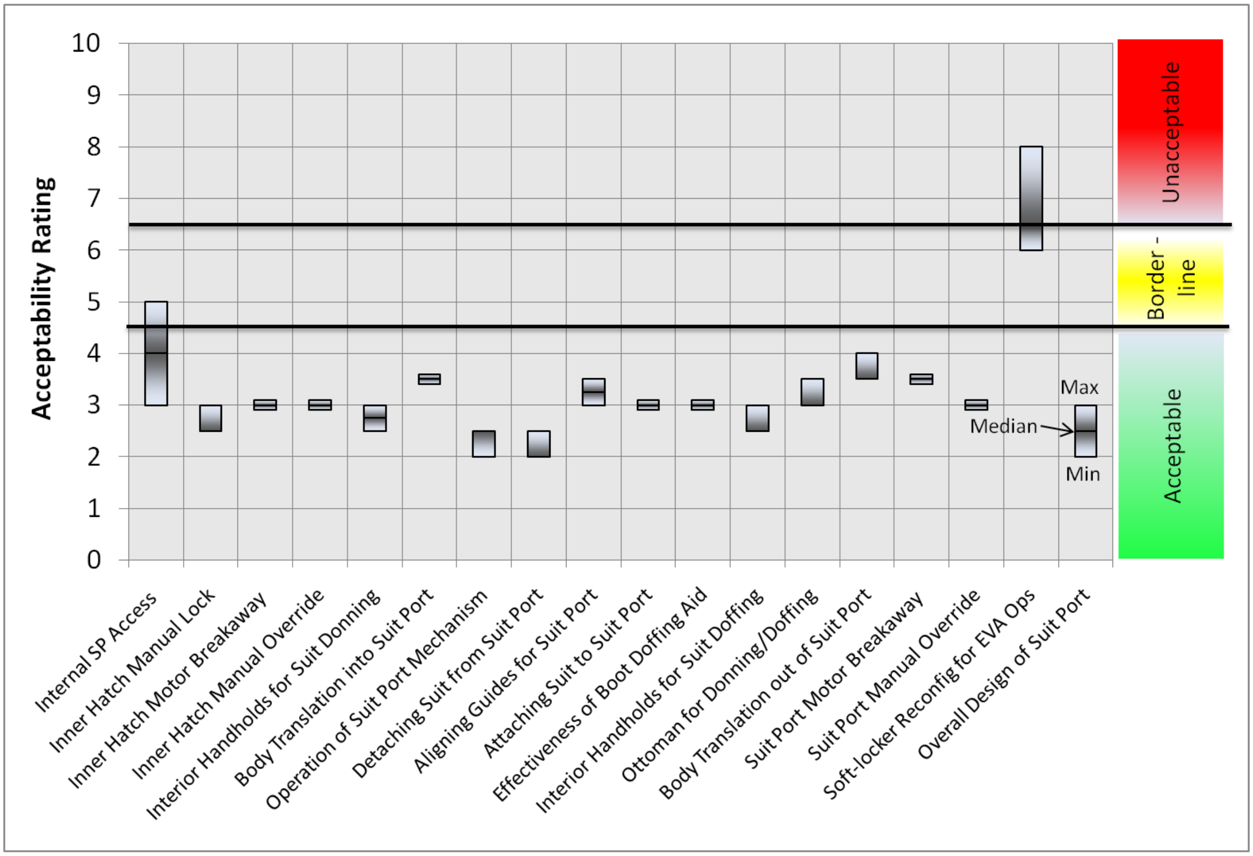


Figure 62. Acceptability Ratings for Suit Port Operations.

The crew rated the suit port with the new electromechanical mechanisms for the hatches as totally acceptable. They indicated that practice in docking the PLSS to the suit port before testing in the desert was beneficial to understanding one's posture when using the alignment guides and backing into the suit port. The crew did note that some work was needed on the manual override system.

Figure 63. Crewmember using suit port alignment guides to assist in orienting the PLSS.

Of the 18 elements tested, the only two areas of concern were internal access to the suit port (rated acceptable with minor improvements desired) and the ease of personal soft locker reconfiguration (rated unacceptable with improvements required, M = 6.8). The crew noted that their personal soft lockers, when in a nominal configuration, were fine and caused no issues. However, when they had to reconfigure the cabin for EVA operations, rearrangement of the lockers consumed a considerable amount of time, made it inconvenient to access stowage in the side benches, frustrated the crew, and created a significant amount of clutter throughout the cabin.

In fact, the crew noted that the clutter became so overwhelming, at times, that it limited their areas of access around the suit port for ingress and egress, especially during a two-person EVA. With the rearrangement of items for EVA, the crew also observed that once the personal lockers were stacked, they became unstable and often fell, thereby blocking the side hatch. With this is mind, the crew suggested that they should have access to interior camera views from the aft suit port display to check on stowage status and blockage of either the side hatch or the suit port hatch. The crew also suggested decreasing the amount of supplies in the lockers to help reduce the overhead associated with stowage.

Summary and Recommendations from Space Exploration Vehicle Aft Deck Human Factors Evaluation

a) The crew considered the overall EVA fatigue and workload acceptable for a 14-day field test.

b) The cabana's manual override mode was difficult and problematic for the crew. They recommended redesigning the system to have an extension pole that they could attach to the last cabana rib to support the cabana cover while they translate into the suit port area. Also, the design should take into account accomplishing this task in a pressurized suit.

c) Aft station display edge keys were rated acceptable; however, the crew reported that, when faced with an oblique view of the display screen during a two-person EVA, it was difficult to tell which edge keys lined up with which command line. Recommendations included using a numbering or color coding system on the edge keys to correspond with the command.

d) The crew had difficulty reading the display during SPTM operations. They recommended the display have the ability to swivel 180° so they could gain access to the SPTM operational procedures while the SPTM is in place in the suit port.

e) The aft joystick needs refinement. The crew reported it was too far from the suit port and not natural to a suited arm position. Arm stability and hand fatigue were also notable concerns expressed by the crew. One recommendation from the crew was to bring the joystick closer to the suit ports. Another recommendation was a possible fold-down panel design incorporating some of the key functional buttons, allowing the crew to easily reach critical suit port elements.

f) Visibility for SEV operations from the aft station was rated borderline because the crew's field of view from the suit helmet was limited.

g) Alignment guides into the suit port remained an issue. The crew also noted that some redesign work needs to be done for the manual suit port override system.

3.4 Hypothesis 4: Portable Utility Pallet Dock and Undock Performance

Hypothesis 4: A prototype PUP will meet the functional requirement that it can successfully dock with (≤ 5 min) and undock from (≤ 5 min) the SEV.

The team examined seven functional elements for docking with the PUP during the 14-day desert test. Data were collected whenever the mission operations plan called for the crew to dock with the PUP. The crew's average rating for the majority of the elements was borderline with improvements warranted.

Figure 64. The PUP standing alone after the SEV had de-mated from it earlier.

Table 29. Acceptability Ratings for Docking to the PUP

Element	Day 2	Day 5	Day 8	Day 12	Mean (*M*)
Usability of Aft PUP Docking Displays	5.0	4.5	3.5	4.5	4.4
External Camera Views of PUP	5.5	5.0	4.5	5.5	5.1
Bore Site Camera Views of PUP	5.0	5.0	4.5	6.0	5.1
Ease of Seeing and Maneuvering to PUP Target	5.5	4.5	4.5	6.5	5.3
Responsiveness of Joystick to Fine Docking Commands	5.0	5.0	4.0	4.5	4.6
Responsiveness of X-Box Controller to Fine Docking Commands	—	—	—	5.0	5.0
Overall Cockpit Layout for PUP Operations	4.5	4.0	3.5	5.0	4.3

N = 2

Note: X-Box controller not used on days 2, 5 and 8.

Maneuvering to the PUP target was rated highest by the crew (*M* = 5.3). Visualizing the PUP with the aft center camera was hampered by the addition of the aft cabana, which made the aft camera useless. With this is mind, the crew developed a technique for PUP mating by first driving parallel to the PUP and looking out the side window until the side hatch was visible in the PUP target mirror. The crew would stop the vehicle and do a 90° pivot. This would put the SEV in the proper gross alignment for mating with the PUP. By using the alignment strips on the cabana, the crew would make fine adjustments and then slowly decrease the x, y, and z rates of speed about 21%. The crew would then put the vehicle in "car mode" and drive backward toward the PUP using a combination of the aft cabana and the bore site docking camera until the PUP was captured. Field observations from the crew indicated that "car mode" worked better for docking with the PUP, and the alignment stripes on the cabana were also helpful while docking. One of the issues the crew noted was that height cues were not really captured for the docking operations. One recommendation was to design a system to capture height and distance cues better to improve crew situational awareness of the vehicle/PUP alignment from outside 0.9 m (3 ft). Another suggestion by the crew was to redesign a better capture interface on the PUP.

Responsiveness of the SEV side control joystick to fine docking adjustment commands was also rated high by the crew. They indicated that the cross-coupling of the terrain and wheel alignment was difficult and needed improvement. Because they had to power cycle the system when it locked up, the crew reported they always had to re-input their controller rate values. They recommended having an easier way to save these values for each type of docking by crew preference and incorporating the drive gears and rate values from the drive page to the same position on all docking screens since these are used frequently.

The vehicle displays and controls were rated somewhat better by the crew, but issues were still noted. The crew reported that, when docking with the PUP, the task required multiple display screens that needed to be changed during the actual operations; switching between the drive screen, docking screen, and camera screen caused frustration for the crew. The crew stated that with the combination of multiple screen changes and edge key inputs the software tended to lock up the entire system, which caused the crew to stop the docking task and power cycle the SEV to reboot the system's software. Suggestions for improvement included designing a composite screen with all the critical information displayed on one screen, which would reduce the number of edge key inputs. Also, the crew suggested having a capture zone indicator to indicate to the crew if the SEV is in the correct zone to capture the PUP or if it is clear of the PUP when de-mating.

Human factors personnel also looked at how long it took the crew to mate the SEV with the PUP. During the 14-day field test, the crew attempted 11 PUP docking and undocking operations. Of the 11 total attempts, six were successful and five were unsuccessful. In this case, successful mating was defined as the crew actually mating the SEV with the PUP, regardless of time. However, as described in Section 2.4.4, the functional requirement for docking or undocking the PUP is that it be completed in less than 5 minutes; this was the prospectively defined criterion for accepting or rejecting the hypothesis. Of the six successful attempts, only two met this criterion.

Table 30. Total PUP Docking Attempts

Successful	Mean Time	Unsuccessful	Mean Time	Total Attempts
6	0:07:23	5	0:05:50	11

3.5 Hypothesis 5: Active-Active Mating Adapter Dock and Undock Performance

Hypothesis 5: A prototype AAMA will enable docking (≤ 5 min) and undocking (≤ 5 min) between two SEVs on representative terrain.

Eight different elements of the AAMA for docking with the Cabin 1A SEV on day 11 as well as docking with the micro-habitat on the TRI-ATHLETE on day 13 were evaluated. The crew‘s average rating for the majority of the factors was borderline with improvements warranted. It should be noted that, in most cases, the systems were not working as intended.

Figure 65. The AAMA used on the SEV for docking with another SEV and a habitat during the field tests.

Table 31. AAMA Docking Elements

Element	Day 11	Day 13	Mean (*M*)
Docking Displays Intuitive and Logical?	6.5	4.0	5.7
External Camera Views Provided SA to Crew?	7.0	4.0	5.5
Bore Site Camera Views Provided SA to Crew?	6.5	6.0	6.3
Ease of Seeing and Maneuvering to AAMA Target	7.5	6.0	7.0
Visibility from Side Window to Assist Docking	6.0	4.0	5.3
Responsiveness of Joystick to Fine Docking Commands	6.5	3.0	5.3
Responsiveness of X-Box Controller to Fine Docking Commands	6.5	6.0	6.3
Overall Cockpit Layout for AAMA Operations	6.0	4.0	5.3

N = 2

The ability of the crew to see and maneuver to the AAMA docking target was the element rated highest (*M* = 7.0, where 1 = best and 10 = worst) by the crew, which deemed the target unacceptable with improvements required. The crew reported they could not see the target from far away and it also did not show up very well in the camera views. As for the bore site cameras, the crew indicated these were borderline (*M* = 6.3). Misalignment, insufficient cues from the cameras until the SEV was too close to the other vehicle to precisely orient the docking vehicle, and the need for more passive compliance and better alignment cues from about 1.5 m (~5 ft) away were among the problems on which the crew commented. They suggested a need for a short mast camera to aid in giving yaw cues along with alignment marks on the side hatches. With respect to the external camera views (*M* = 5.5), the crew indicated the same issues, with cues not being helpful until they were only inches away from another vehicle, yaw being the most difficult axis to see from the cameras. Though the external camera was more usable than the bore site cameras, the crew suggested it was not advisable to try to precisely dock up close without improved passive compliance and alignment cues for distance. However, the visibility of docking from the SEV side window needs only minor improvement. The crew indicated that their SA from the cockpit seat was not bad and noted it was better to "fly" visually out the window instead of using the cameras.

Figure 66. Crewmember "flying" a visual approach docking pattern with Cabin 1A using the side window.

Responsiveness of both the X-Box controller and the SEV side joystick to fine maneuvering commands were also rated borderline with improvements warranted (M = 6.3 and M = 5.3 respectively). Terrain was noted as the major factor affecting the maneuverability of the SEV while docking. In the first docking event on day 11, the crew observed that the soil, which was loose gravel, made maneuvering the vehicle erratic, and it was next to impossible to precisely control the fine adjustments during the final phases of docking with the AAMA. This also increased the workload on the crew significantly. As with the visibility mention above, the crew suggested more compliance, better cue alignment, and redesigned docking procedures. However, on day 13, when the crew used the AAMA for docking to a habitat on the TRI-ATHLETE on a different terrain (hard-packed soil), the crew was able to meet the AAMA docking requirements of ≤ 5 minutes to dock and found they did not try to fine-tune the vehicle for perfect docking alignment during the final docking phase. This also held true for the rescue docking on the same day.

Displays used for docking with the AAMA were rated borderline (M = 5.7) by the crew. As with the PUP, the crew reported frustration with having to toggle between multiple screens while actually performing the docking task. They stated a need to redesign the procedures so they could access the drive page information on the docking page without toggling between multiple menus.

Human factors personnel also looked at crew docking times for the AAMA. During the 14-day field test, the crew attempted AAMA docking and undocking operations 15 times, where docking involved the SEV with the AAMA attaching to another vehicle or habitat. Of these attempts, seven were successful and eight were unsuccessful (Table 32) with the definition of successful being that the SEV completed docking with another vehicle or habitat. A functional requirement to be able to dock or undock in ≤ 5 minutes is being pursued by the SEV project; of the seven successful attempts, only two met this criterion (Appendix E).

Table 32. Total AAMA Docking/Undocking Attempts

Successful	Mean Time	Unsuccessful	Mean Time	Total Attempts
7	0:09:36	8	0:05:00	15

3.6 HYPOTHESIS 6: 24-HOUR CREW RESCUE SCENARIO

Hypothesis 6: The habitability and human factors of the SEV will be acceptable to support a 24-hour contingency scenario.

The crew gave “acceptable” ratings for the volume between vehicles for transferring equipment and supplies from one SEV to the other. They also reported that, once both crews were in the Cabin 1B vehicle, the volume of the vehicle for personnel and equipment was quite acceptable.

Figure 67. Photo taken by Crew B looking into Cabin 1B from inside Cabin 1A during equipment transfer.

Most of the issues regarding the rescue activity involved the EVA suits. The primary issue surrounded moving the suits off the inoperable SEV to either the PUP or the rescue SEV. The crew noted this was extremely difficult to do (*M* = 6.5), mainly because of the 1-G environment and the weight of the transferred suits. This was also a concern when detaching the suits from the suit port. However, it should be noted that the weight of the test suits (~36.3 kg [80 lbs]) is close to the lunar equivalent weight expected for actual suits on the moon. A recommendation was to have a handle apparatus, attached to either the suit or the PLSS, that was flush with the sides of the SEV so the suit could still fit into the suit port.

Figure 68. Two SEVs docked using the AAMA. EVA suits for Cabin 1A are shown.

With four people living on board the SEV during a rescue operation, it is important to understand the factors that could affect habitability. The remaining 17 elements investigated involved four crewmembers living in one SEV for a 24-hour rescue period. Generally, the crew found the habitability of the SEV acceptable during the rescue. Crew consensus indicated they were pleasantly surprised at how well the interior volume of the vehicle was able to support a crew of four. The rescued crew reported the primary crew of Cabin 1B had already designed a very good system for maintaining a neat, clean order of items in the interior. Both crews observed they made the best use of the interior volume when storing transferred items, with room to spare for exercise, meal preparation, water access, and suit port access.

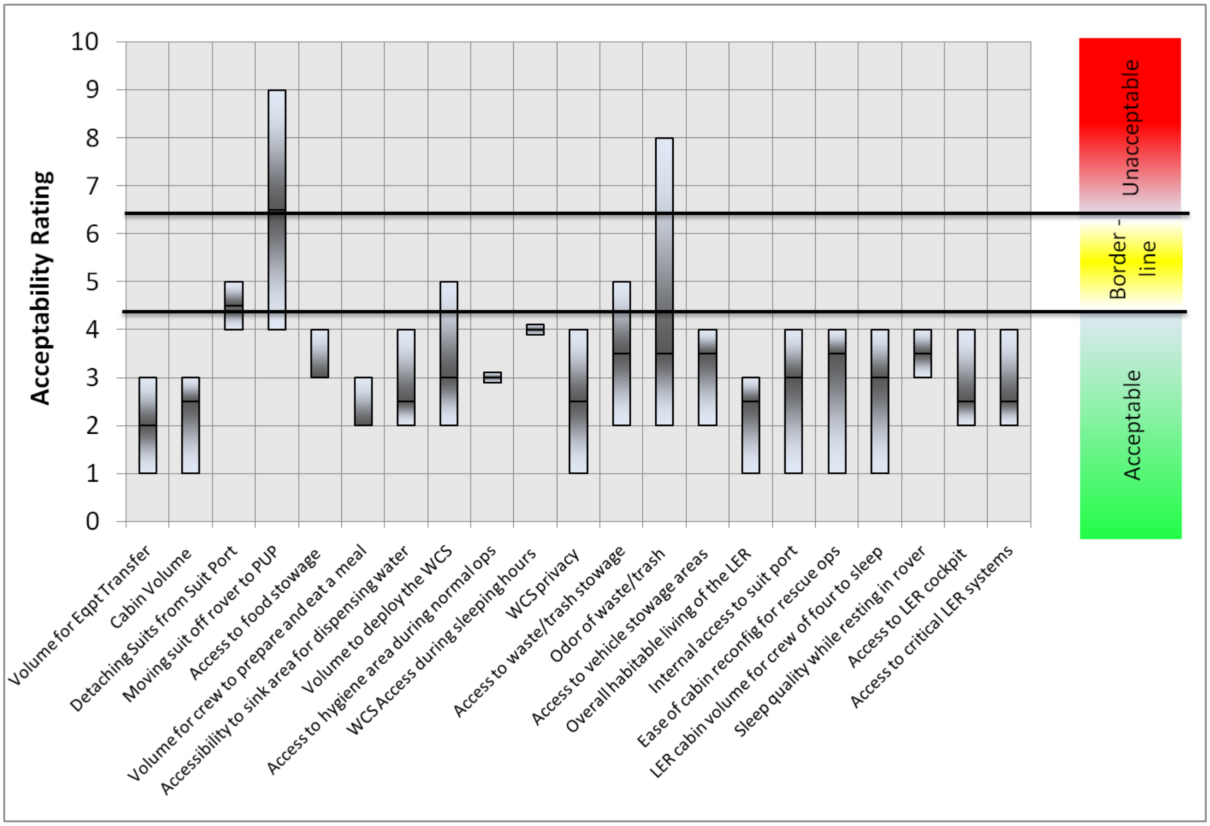


Figure 69. Acceptability ratings for four-person habitation during a rescue scenario.

One concern the crews noted was trash odor and stowage. Though the trash system had been redesigned from lessons learned in the 3-day mission[7] so that the crew was using vacuum-sealed containers and using the SPTM to deposit trash every 3 days, the crew still noticed the odor. More work will need to be done in this area. As for trash stowage, the crew noted that areas needed to be designated for both daily trash and the larger consolidated trash stowage. Originally, the crew had designated the front port bench stowage box for the trash, but later relocated the bunk trash to the third floor panel in front of the WCS. This panel was assigned to stow EVA spares, but the fidelity of this field evaluation did not include sufficient EVA spares to fully utilize this volume, making it available for trash stowage. There was no designation for smaller daily trash. The crew also suggested the use of smaller bags for personal trash.

As for the sleeping arrangements during the rescue scenario, the crews decided to demonstrate an actual 24-hour driving event. With this in mind, they took rotating work/rest shifts of 4 to 6 hours each. The Cabin 1A crewmembers (the ones who were rescued) were given the first sleep period while the Cabin 1B crewmembers simulated driving by staying in the cockpit. Observational field notes indicate that the crews deployed the sleep stations as would be done for nominal operations. This gave both crews some privacy.

Figure 70. In the left photo (A), the Cabin 1A crew is preparing for a rest cycle. In the right photo (B) the Cabin 1B crew is setting up in the cockpit for their work cycle.

However, during WCS operations, the crews noted some issues. First, the crew noted that if all four crewmembers were sleeping, there would not be any room to deploy the WCS, thereby suggesting the crew might have to develop another type of sleep plan if the need arose. Second, the volume was somewhat tight with four crewmembers (see Figure 71). However, the crew was able to perform this task with three crewmembers in the cockpit – two in the seats and one on the floor. With this arrangement, the privacy curtains could still be closed for the fourth crewmember using the WCS. As for quality of sleep with four crewmembers in the vehicle, both crews reported the “two working and two resting” plan was good as long as the crew working was somewhat quiet.

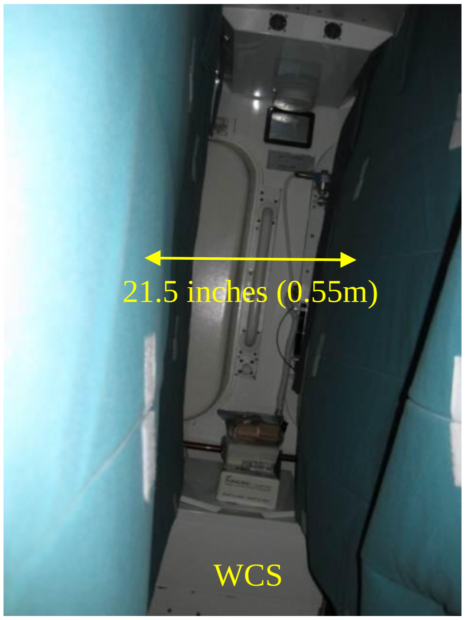


Figure 71. Photo taken by Crew B showing deployed sleep stations. Note the WCS in lower center of photo. Space for using the WCS was reported tight.

3.7 SECONDARY OBJECTIVE: ASSESSING THE EFFECT OF INCREASED NAVIGATIONAL UNCERTAINTY

Objective 1: Assess the ability to navigate to predefined targets under different levels of navigational uncertainty (± 50 m, 100 m).

Six targets were identified and a traverse plan developed with an annotated map and photographic references for the crew to use during the task. The crew attempted to reach the exact target locations using the traverse plan, photographs, and vehicle position data with a root mean square (RMS) error of 50 m (164 ft) or 100 m (328 ft). Although quantitative metrics were not collected for this secondary objective, the crew reached the targets with minimal difficulty and a high degree of certainty in all cases. Figure 72 shows the paths driven by the crew (blue) overlaid with the navigational information provided to them as they drove (yellow). It was concluded that, for this type of terrain, 100 m (328 ft) RMS error in navigational data did not affect the ability to return to a previously visited and photographed location.

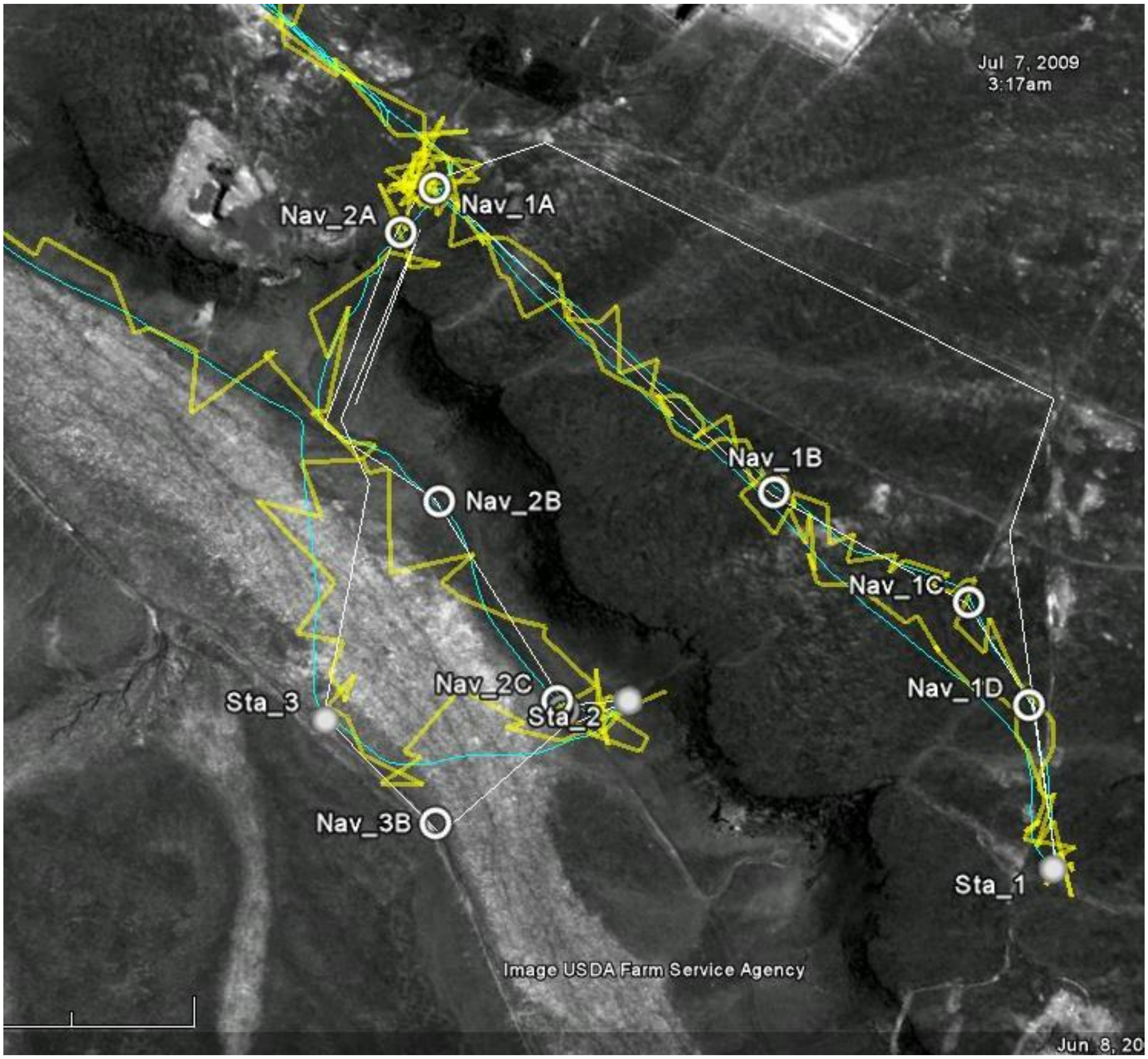


Figure 72. Comparison of navigation information with added random noise provided to crew (yellow) and actual paths driven (blue).

4.0 CONCLUSIONS

1) After completing a 14-day mission simulation in an SEV prototype vehicle, two crewmembers rated the overall SEV habitability and human factors acceptable for a 14-day mission. The crew perceived that the SEV would also be adequate for 28-day missions if the two SEVs could dock with each other every 3to 7 days.

2) The SEV prototype was found to be acceptable overall for 24 hours of habitation by four crewmembers as assessed during a simulated crew rescue scenario on the final day of the 14-day mission simulation.

3) Systematic human factors assessment of each SEV system resulted in multiple specific design recommendations that immediately informed the design of the next-generation SEV prototype.

4) Comparison of standard crew productivity metrics showed no practically significant difference in crew productivity when the crew was operating for extended periods without space-to-ground communications compared with continuous space-to-ground communications.

5) Docking the SEV prototype with the PUP prototype was completed successfully, but the average docking time (5 min 50 sec) did not meet the predefined functional requirement of less than 5 minutes. Multiple improvements were identified that are expected to improve docking times.

6) Docking the SEV prototype with a second SEV via the AAMA was completed successfully, but the average docking time (9 min 36 sec) did not meet the predefined functional requirement of less than 5 minutes. Multiple improvements were identified that are expected to improve docking times.

7) When 50-m (164-ft) and 100-m (328-ft) RMS noise was deliberately added to SEV navigational data, crewmembers were able to successfully and quickly navigate to exact rock sample locations using the traverse plan, photographs, and the noisy vehicle position data.

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6.0 ACKNOWLEDGMENTS

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Figure 73. DRATS 2009 Team (many other team members not shown).

7.0 APPENDIX A: RATIONALE FOR USE OF ANALOG TEST SITE

7.1 FACILITIES AND PERFORMANCE SITE

Analyses performed during the LAT-2 study in 2007 suggested that science and exploration EVA could constitute more than 90% of total EVA time over a 10-year lunar architecture. A geologically relevant and scale-appropriate test site (such as BPLF) is essential when testing productivity, performance, and human factors during exploration, mapping, and geological traverses.

Test subject training and dry-run activities were conducted at the JSC Rock Yard and in the Space Vehicle Mockup Facility (Building 9) at JSC. Testing occurred at the BPLF test site, about 25 km (~40 miles) north of Flagstaff, Arizona.

The SEV's theoretical performance, productivity, and safety capabilities and constraints have been tested and previously documented during the LAT-2 and CxAT_Lunar projects; this test was designed to validate previous findings and to add fidelity and realism to the comparisons, particularly with respect to SEV IVA productivity and human factors. The primary test site requirements with respect to EVA and surface operations are discussed and detailed below.

7.2 GEOLOGICALLY RELEVANT TERRAIN

Geologically relevant terrain was necessary to assess the ability of subjects to make geological contextual observations from inside the SEV. It was also required for estimation of SEV performance and productivity metrics such as number of EVAs, maximum separation of EVA astronaut and SEV, boots-on-surface EVA time, and average drive speed, all of which are largely terrain dependent. To the extent that productivity and performance metrics can be accurately estimated on the basis of realistic field tests, the accuracy of estimated ranges, masses, dimensions, and requirements for power, energy storage, and consumables produced by models of existing mobile surface systems can also be improved.

The BPLF test site includes a wide variety of surface features with geological relevance. The geological features and terrain, particularly along the edge of the lava flow, provided many opportunities to evaluate the IVA and EVA science and exploration capabilities of the SEV during exploration, mapping, and geological traverses. (See Figure 74 and Figure 75.)

Figure 74. View of lava flow escarpment approximately 4 km (~2.5 miles) from proposed base camp location.

Figure 75. Examples of geological sites of interest at BPLF.

7.3 SCALE-APPROPRIATE TEST SITE

Theoretical SEV sorties developed during the LAT-2 and CxAT_Lunar studies involved driven distances of up to 40 km (25 miles) per day. Although extensive engineering evaluations were performed with the SEV prototype vehicles at JSC, there are several reasons why long-distance science-exploration sorties must be performed during field testing, which relate to the anticipated benefits of SEV-based traverses. The capability to extend exploration range beyond the distance that can be driven during an 8-hour EVA is among the most significant benefits of the SEV concept. SEVs also offer more boots-on-surface EVA time during which to perform science tasks because of the EVA time that is saved by driving to and from exploration sites inside the shirtsleeve SEV environment. Furthermore, the shirtsleeve environment inside the SEV when driving between EVA sites potentially enables more productive use of crew time.

Evaluating the extent to which these perceived benefits are realized required that detailed and accurate exploration, mapping, and geological traverses were planned and executed on scales comparable to those anticipated during actual lunar traverses and that translation distances and times were not artificially constrained.

The size of the BPLF site (Figure 76) and the abundance of exploration, mapping, and geological features would potentially enable extended-range exploration, mapping, and geological SEV traverses (potentially > 100 km [62 miles] + driven distance with 7 to 14 days of operational time).

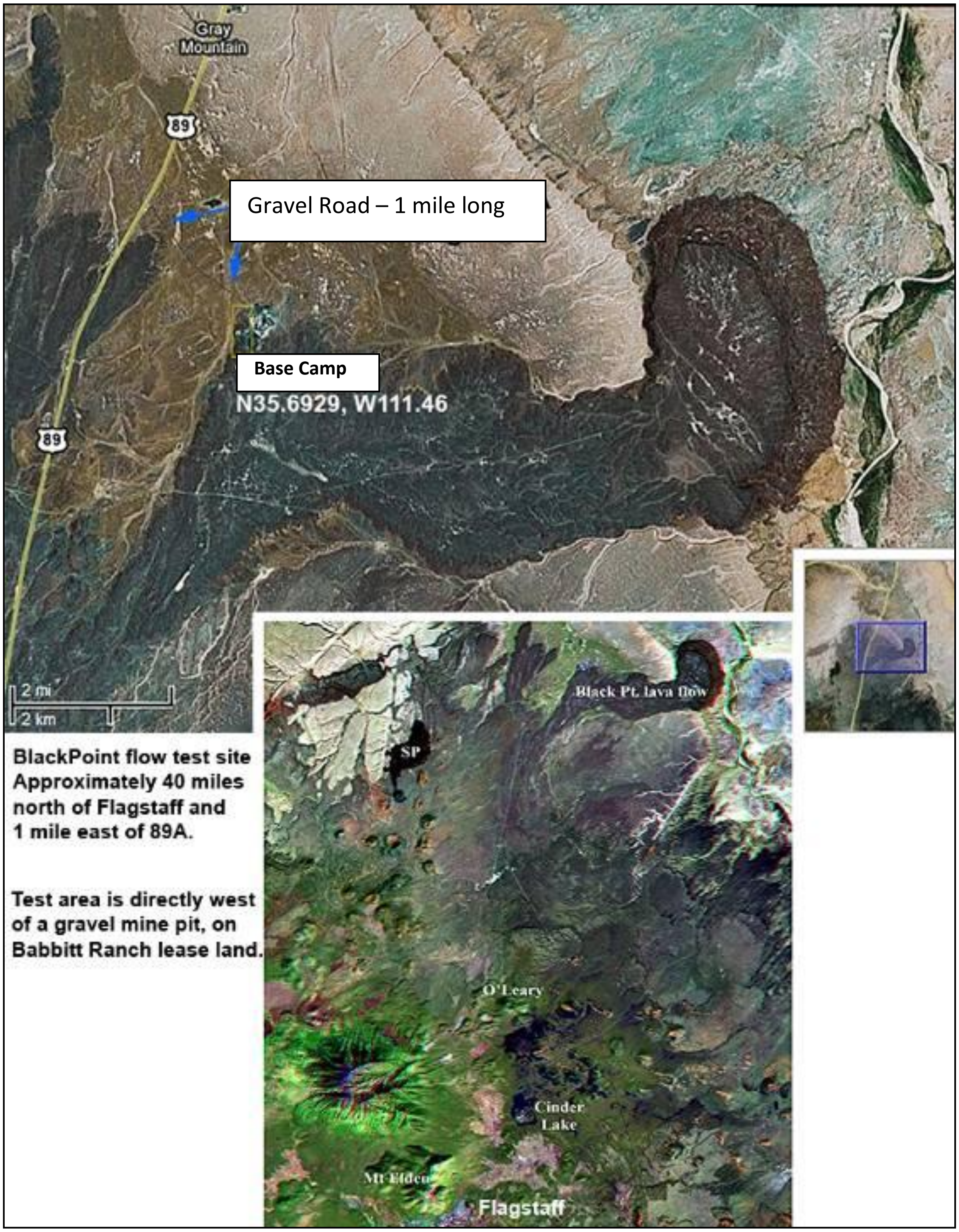

Figure 76. Test Site: BPLF, Arizona.

7.4 SPACE EXPLORATION VEHICLE NEGOTIABLE TERRAIN CONDITIONS

The slopes, soil mechanics, surface properties, and existing terrain features of the test site were required to be negotiable by the SEV. The slopes from the top to the base of the BPLF vary from very slight (approx 6^o) to vertical. Terrain conditions vary from powdery sand with minimum to significant vegetation (<30 cm [12 in.]) to harder packed ground with numerous small and medium-sized rocks and minimal vegetation.

The base camp location was on top of the lava flow on a hard-packed surface (193 kPa /28 psi load-bearing capability) artificially created next to a gravel quarry (Figure 77). Vegetation was minimal in the base camp area and the nearby ash and gravel quarry but became denser in some locations (Figure 78 and Figure 79).

Figure 77. Test site base camp location.

Figure 78. Looking south along the edge of BPLF; note varying slopes, varied geology, and representative vegetation.

Figure 79. Example of slope variation, geological features, and moderate vegetation at edge of BPLF.

8.0 APPENDIX B: BLACK POINT LAVA FLOW SCIENCE TRACEABILITY MATRIX

Priority **1=high 3=low**	**Science Question**	**Relevance to the Moon**	**Observation(s) & Analysis Needed**	**Traverse Task(s)**	**Traverse Tools Needed**	**Further Analysis**
Geology						
Volcanics						
Black Point Lava Flow						
1	What is the absolute age of the BPLF?	Dating lunar volcanic events	Radiometric dating of a sample representative of the BPLF	**EVA Station A** Collect 2 fresh (edge of flow) hand samples from the BPLF.	Positioning Tool + Camera + Rock Hammer (igneous) + Sample Bag	Radiometric Dating in Lab
1	What is the composition (mineralogy, chemistry) of the BPLF?	Composition of lunar volcanic materials	Mineralogy and geochemistry of a representative sample of the BPLF	**EVA Station A** Collect 2 fresh (edge of flow) hand samples from the BPLF.	Positioning Tool + Camera + Rock Hammer (igneous) + Sample Bag	Mineralogy and Geochemistry Analysis in Lab

Priority 1=high 3=low	Science Question	Relevance to the Moon	Observation(s) & Analysis Needed	Traverse Task(s)	Traverse Tools Needed	Further Analysis
2	Does the BPLF present spatial variations in composition?	Spatial variation in composition of materials from a single volcanic event	Mineralogy and geochemistry of a suite of samples collected along the length of the BPLF	**EVA Stations A, B, C.** Collect 2 fresh (edge of flow) hand samples at each of at least 3 locations 1 km apart along the length of the BPLF.	Positioning Tool + Camera + Rock Hammer (igneous) + 3 Sample Bags	Mineralogy and Geochemistry Analysis in Lab
1 Target of Opportunity	Does the BPLF contain large xenoliths?	Search for lunar mantle xenoliths in lunar volcanic materials	Look out for any occurrence of large xenoliths along length of the BPLF	**EVA Stations X** Collect 2 fresh hand samples from at least one location if encountered.	Positioning Tool + Camera + Rock Hammer (igneous) + 3 Sample Bags	Mineralogy and Geochemistry Analysis in Lab
2	What petrologic textures does the BPLF present? Any lateral variations?	Petrologic textures of lunar volcanic materials	Petrology of a suite of samples collected along the length of the BPLF	**EVA Stations X** Collect 2 fresh hand samples of any instance of significant lateral petrologic variation along the length of the BPLF.	Positioning Tool + Camera + Rock hammer (igneous) + 10 Sample Bags	Petrology analysis in Lab

Priority 1=high 3=low	Science Question	Relevance to the Moon	Observation(s) & Analysis Needed	Traverse Task(s)	Traverse Tools Needed	Further Analysis
2 Target of Opportunity	What petrologic textures does the BPLF present? Any vertical variations?	Petrologic textures of lunar volcanic materials	Petrology of a suite of samples collected along one or more vertical sections of the BPLF	**EVA Stations X** If vertical variations in rock texture are found: Collect at least 2 hand samples at each of 3 levels along a vertical section of the BPLF. Repeat at other vertical section locations along the length of the BPLF if needed.	Positioning Tool + Camera + Rock Hammer (igneous) + 3 Sample Bags	Petrology analysis in Lab

Priority **1=high 3=low**	**Science Question**	**Relevance to the Moon**	**Observation(s) & Analysis Needed**	**Traverse Task(s)**	**Traverse Tools Needed**	**Further Analysis**
2	What morphologic and structural features does the BPLF present? (Lava Tubes, Collapse Features, Sags, Faults, Joints, etc.)	Morphologic and structural features associated with lunar volcanic units	Morphologic and structural observations and analysis of the BPLF	**EVA Stations X** Document any significant structural features of the BPLF. **EVA Station S** Examine sag associated with High Albedo Feature on surface of BPLF 2 km south of camp.	Positioning Tool + Camera	Morphologic and structural analysis
1	What features are present in the apparent “Source Area” of the BPLF?	Investigation of “Source Areas” of lunar volcanism	Geologic characterization of “Source Area” of the BPLF	**EVA Station Z** Document and sample materials from the apparent “Source Area” of the BPLF.	Positioning Tool + Camera + 10 Sample Bags	Radiometric dating, petrology, mineralogy, and geochemistry of samples

Priority 1=high 3=low	Science Question	Relevance to the Moon	Observation(s) & Analysis Needed	Traverse Task(s)	Traverse Tools Needed	Further Analysis
1	What is the geologic relationship between the BPLF and underlying lithologic units? What is the geologic and evolutionary history nature of these underlying units?	Investigations of the geologic relationship between lunar volcanic flows and underlying lithologic units.	Geologic characterization of the contact between the BPLF and underlying lithologic units	**EVA Stations A to C** Follow contact between BPLF and underlying lithologic units. Note dip and strike of any underlying layered units.	Positioning Tool + Camera + 10 Sample Bags	Dating (absolute or relative), petrology, mineralogy, and geochemistry of samples. Morphologic and structural analysis
2	What is the nature of the High Albedo Features on the top surface of the BPLF? Do the albedo features represent eolian deposits?	Investigation of discrete and/or anomalous albedo features on the Moon	Geologic characterization of the High Albedo features on top of the BPLF	**EVA Station S** Document and sample materials from the High Albedo Units on top of the BPLF.	Positioning Tool + Camera + 3 Sample Bags	Mineralogy, and geochemistry of the High Albedo Units materials

Priority **1=high** **3=low**	**Science Question**	**Relevance to the Moon**	**Observation(s) & Analysis Needed**	**Traverse Task(s)**	**Traverse Tools Needed**	**Further Analysis**
Other Lava Flows and Volcanic Features						
2	What is the absolute age of Other Lava Flows and Volcanic Features near the BPLF?	Dating lunar volcanic events	Radiometric dating of samples representative of the Other Lava Flows and Volcanic Features near the BPLF	**EVA Stations D, E, F** Collect 2 fresh hand samples from the Other Lava Flows and Volcanic Features near the BPLF.	Positioning Tool + Camera + Rock Hammer (igneous rocks)+Sample Bag	Radiometric Dating in Lab
2	What is the composition (mineralogy, chemistry) of the Other Lava Flows and Volcanic Features near the BPLF?	Composition of lunar volcanic materials	Mineralogy and geochemistry of representative samples of the Other Lava Flows and Volcanic Features near the BPLF	**EVA Stations D, E, F** Collect 2 fresh hand samples from the Other Lava Flows and Volcanic Features near the BPLF.	Positioning Tool + Camera + Rock Hammer (igneous rocks) + Sample Bag	Mineralogy and Geochemistry Analysis in Lab

Priority **1=high 3=low**	**Science Question**	**Relevance to the Moon**	**Observation(s) & Analysis Needed**	**Traverse Task(s)**	**Traverse Tools Needed**	**Further Analysis**
3 Target of Opportunity	Do the Other Lava Flows and Volcanic Features near the BPLF present spatial variations in composition?	Spatial variation in composition of materials from a single volcanic event	Mineralogy and geochemistry of a suite of samples collected along the length of a selected Lava Flow or Volcanic Feature near the BPLF	**EVA Stations D, E, F.** Collect 2 fresh hand samples at each of at least 3 locations 1 km apart along the length of a selected Lava Flow near the BPLF and/or from distinct Volcanic Features near the BPLF.	Positioning Tool + Camera + Rock Hammer (igneous rocks) + 3 Sample Bags	Mineralogy and Geochemistry Analysis in Lab
1 Target of Opportunity	Do the Other Lava Flows near the BPLF contain large xenoliths?	Search for lunar mantle xenoliths in lunar volcanic materials	Look out for any occurrence of large xenoliths along length of Other Lava Flows near the BPLF	**EVA Stations X** Collect 2 fresh hand samples from at least one location if encountered.	Positioning Tool + Camera + Rock Hammer (igneous rocks) + 3 Sample Bags	Mineralogy and Geochemistry Analysis in Lab

Priority **1=high 3=low**	**Science Question**	**Relevance to the Moon**	**Observation(s) & Analysis Needed**	**Traverse Task(s)**	**Traverse Tools Needed**	**Further Analysis**
3	What petrologic textures do the Other Lava Flows near the BPLF present? Any lateral variations?	Petrologic textures of lunar volcanic materials	Petrology of a suite of samples collected along the length of a selected Lava Flow near the BPLF	**EVA Stations X** Collect 2 fresh hand samples of each instance of significant lateral petrologic variation along the length of a selected Lava Flow near the BPLF.	Positioning Tool + Camera + Rock hammer (igneous rocks) + 10 Sample Bags	Petrology analysis in Lab

Priority **1=high 3=low**	**Science Question**	**Relevance to the Moon**	**Observation(s) & Analysis Needed**	**Traverse Task(s)**	**Traverse Tools Needed**	**Further Analysis**
3 Target of Opportunity Target of Opportunity	What petrologic textures do the Other Lava Flows and Volcanic Features near the BPLF present? Any *vertical* variations?	Petrologic textures of lunar volcanic materials	Petrology of a suite of samples collected along one or more vertical sections of a selected Lava Flow near the BPLF	**EVA Stations X** If vertical variations in rock texture are encountered: Collect at least 2 hand samples at each of 3 levels along a vertical section of a selected Lava Flow near the BPLF. Repeat at other vertical section locations along the length of the selected Lava Flow near the BPLF if needed.	Positioning Tool + Camera + Rock Hammer (igneous rocks) + 3 Sample Bags	Petrology analysis in Lab

Priority 1=high 3=low	Science Question	Relevance to the Moon	Observation(s) & Analysis Needed	Traverse Task(s)	Traverse Tools Needed	Further Analysis
2	What morphologic and structural features do the Other Lava Flows and Volcanic Features near the BPLF present? (Cinder Cones, Vents, Lava Tubes, Collapse Features, Sags, Faults, Joints, etc.)	Morphologic and structural features associated with lunar volcanic units	Morphologic and structural observations and analysis of the Other Lava Flows and Volcanic Features near the BPLF	**EVA Stations X** Document any significant structural features of the Other Lava Flows and Volcanic Features near the BPLF.	Positioning Tool + Camera	Morphologic and structural analysis
Other Geologic Units and Features						
Marbled Terrain North of Flow						

Priority **1=high** **3=low**	**Science Question**	**Relevance to the Moon**	**Observation(s) & Analysis Needed**	**Traverse Task(s)**	**Traverse Tools Needed**	**Further Analysis**
1	What is the nature and evolutionary history of the *Marbled Albedo Unit*?	General lunar geology science *operations*. Lunar regolith science *operations*.	Systematic geologic observations, characterization, and sample analysis	**EVA Stations A, B, C, G, H**	Positioning Tool + Camera + Rock Hammer (Sedimentary) + Trenching Tool + 8 Sample Bags	Dating (absolute or relative), petrology, mineralogy, and geochemistry of samples. Morphologic and structural analysis.
3	What is the nature and evolutionary history of the dissection in the *Dissected Unit*?	Lunar rill science *operations*.	Systematic geologic observations, characterization, and sample analysis	**EVA Station J**	Positioning Tool + Camera + Rock Hammer (Sedimentary) + Trenching Tool + 4 Sample Bags	Dating (absolute or relative), petrology, mineralogy, and geochemistry of samples. Morphologic and structural analysis.

Priority **1=high** **3=low**	**Science Question**	**Relevance to the Moon**	**Observation(s) & Analysis Needed**	**Traverse Task(s)**	**Traverse Tools Needed**	**Further Analysis**
3	What is the nature and evolutionary history of the *Non-Dissected Transitional Unit*?	General lunar geology science *operations*. Lunar regolith science *operations*.	Systematic geologic observations, characterization, and sample analysis	**EVA Stations J and K**	Positioning Tool + Camera + Rock Hammer (Sedimentary) + Trenching Tool + 4 Sample Bags	Dating (absolute or relative), petrology, mineralogy, and geochemistry of samples. Morphologic and structural analysis.
2	What is the nature and evolutionary history of the *Knobby Unit*?	Lunar hummocky terrain science *operations.*	Systematic geologic observations, characterization, and sample analysis	**EVA Station K**	Positioning Tool + Camera + Rock Hammer (Sedimentary) + Trenching Tool + 2 Sample Bags	Dating (absolute or relative), petrology, mineralogy, and geochemistry of samples. Morphologic and structural analysis.
Layered Terrain Northeast (NE) of ("Below") Scarp						

Priority **1=high 3=low**	**Science Question**	**Relevance to the Moon**	**Observation(s) & Analysis Needed**	**Traverse Task(s)**	**Traverse Tools Needed**	**Further Analysis**
2	What is the nature and evolutionary history of the Layered Unit Below?	General lunar geology science *operations*. Lunar regolith science *operations*.	Systematic geologic observations, characterization, and sample analysis	**EVA Station L**	Positioning Tool + Camera + Rock Hammer (Sedimentary) + Trenching Tool + 4 Sample Bags	Dating (absolute or relative), petrology, mineralogy, and geochemistry of samples. Morphologic and structural analysis.
Scarp						
1	What is the nature and evolutionary history of the Scarp separating the *Marbled Terrain North of the Flow* and the *Layered Unit NE of the Scarp*?	Lunar tectonics science *operations*. Lunar wrinkle ridge science *operations*.	Morphologic and structural observations and analysis	**EVA Station L**	Positioning Tool + Camera	Morphologic and Structural Analysis
Marbled Terrain South of Flow						

Priority 1=high 3=low	Science Question	Relevance to the Moon	Observation(s) & Analysis Needed	Traverse Task(s)	Traverse Tools Needed	Further Analysis
2	What is the nature and evolutionary history of the Marbled Unit South of the Flow?	General lunar geology science *operations*.	Systematic geologic observations, characterization, and sample analysis	**EVA Station T**	Positioning Tool + Camera + Rock Hammer (Sedimentary) + Trenching Tool + 2 Sample Bags	Dating (absolute or relative), petrology, mineralogy, and geochemistry of samples. Morphologic and structural analysis.
Other Albedo Features						
3. Target of Opportunity	What is the nature and evolutionary history of the discrete and/or anomalous albedo features near the BPLF?	Investigation of discrete and/or anomalous albedo features on the Moon.	Geologic characterization and analysis of discrete/anomalous albedo features near the BPLF	**EVA Stations A to C**	Positioning Tool + Camera + Rock Hammer (Sedimentary) + Trenching Tool + 12 Sample Bags	Dating (absolute or relative), petrology, mineralogy, and geochemistry of samples. Morphologic and structural analysis.

Other Geologic Units and Features						
Marbled Terrain North of Flow						
1	What is the nature and evolutionary history of the *Marbled Albedo Unit*?	General lunar geology science *operations*. Lunar regolith science *operations*.	Systematic geologic observations, characterization, and sample analysis	**EVA Stations A, B, C, G, H**	Positioning Tool + Camera + Rock Hammer (Sedimentary) + Trenching Tool + 8 Sample Bags	Dating (absolute or relative), petrology, mineralogy, and geochemistry of samples. Morphologic and structural analysis.
3	What is the nature and evolutionary history of the dissection in the *Dissected Unit*?	Lunar rill science *operations*.	Systematic geologic observations, characterization, and sample analysis	**EVA Station J**	Positioning Tool + Camera + Rock Hammer (Sedimentary) + Trenching Tool + 4 Sample Bags	Dating (absolute or relative), petrology, mineralogy, and geochemistry of samples. Morphologic and structural analysis.

3	What is the nature and evolutionary history of the *Non-Dissected Transitional Unit*?	General lunar geology science *operations*. Lunar regolith science *operations*.	Systematic geologic observations, characterization, and sample analysis	**EVA Stations J and K**	Positioning Tool + Camera + Rock Hammer (Sedimentary) + Trenching Tool + 4 Sample Bags	Dating (absolute or relative), petrology, mineralogy, and geochemistry of samples. Morphologic and structural analysis.
2	What is the nature and evolutionary history of the *Knobby Unit*?	Lunar hummocky terrain science *operations*.	Systematic geologic observations, characterization, and sample analysis	**EVA Station K**	Positioning Tool + Camera + Rock Hammer (Sedimentary) + Trenching Tool + 2 Sample Bags	Dating (absolute or relative), petrology, mineralogy, and geochemistry of samples. Morphologic and structural analysis.

Layered Terrain NE of ("Below") Scarp						
2	What is the nature and evolutionary history of the Layered Unit Below	General lunar geology science *operations*. Lunar regolith science *operations*.	Systematic geologic observations, characterization, and sample analysis	**EVA Station L**	Positioning Tool + Camera + Rock Hammer (Sedimentary) + Trenching Tool + 4 Sample Bags	Dating (absolute or relative), petrology, mineralogy, and geochemistry of samples. Morphologic and structural analysis.
Scarp						
1	What is the nature and evolutionary history of the Scarp separating the *Marbled Terrain North of the Flow* and the *Layered Unit NE of the Scarp*?	Lunar tectonics science *operations*. Lunar wrinkle ridge science *operations*.	Morphologic and structural observations and analysis	**EVA Station L**	Positioning Tool + Camera	Morphologic and structural analysis.

Marbled Terrain South of Flow						
2	What is the nature and evolutionary history of the Marbled Unit South of the Flow?	General lunar geology science *operations*.	Systematic geologic observations, characterization, and sample analysis	**EVA Station T**	Positioning Tool + Camera + Rock Hammer (Sedimentary) + Trenching Tool + 2 Sample Bags	Dating (absolute or relative), petrology, mineralogy, and geochemistry of samples. Morphologic and structural analysis.
Other Albedo Features						
3. Target of Opportunity	What is the nature and evolutionary history of the discrete and/or anomalous albedo features near the BPLF?	Investigation of discrete and/or anomalous albedo features on the Moon.	Geologic characterization and analysis of discrete/anomalous albedo features near the BPLF	**EVA Stations A to C**	Positioning Tool + Camera + Rock Hammer (Sedimentary) + Trenching Tool + 12 Sample Bags	Dating (absolute or relative), petrology, mineralogy, and geochemistry of samples. Morphologic and structural analysis.

9.0 APPENDIX C: SPACE EXPLORATION VEHICLE 14-DAY MANIFEST

Item	14-Day Pre-FLT Status	Related TABS
15 inch Laptop Computers	2	
Extra Laptop Batteries	2	
DC to AC Power Converters	2	
2GB USB Flash Drives	2	
Saliva Tubes	56	
12vDC Power Boxes	2	
Wag Bags	128	
Rolls of Toilet Paper	4	
2oz Hand Sanitizer	2	
Boxes of Scott Flushable Wipes (51ct)	2	
Pkg of Disposable Gloves (500ct)	1	
Boxes of Ziploc Gallon Bags (60ct) +8 bags	2	
Medium Space Bags (18x22.5")	12	
Boxes of Gallon Ziploc Bags (60ct)	2	
Rolls of Paper Towels	2	
Large Space Bags	6	
Medium Space Bags (18x22.5")	16	
100 sheet Field Notebooks	2	
G2 Rolling Ballpoint Pens	10	
0.7mm Mechanical Pencils	8	
Large LED/Halogen Flashlight w/12v Charge Cable	1	
Small Vacuum 12V w/Accessories	1	
Roll 2" Duct Tape	1	
Large White Garbage Bags	14	
Extra Large Black heavy Duty Garbage Bags w/Ties	6	
Pkgs of Heavy Handi Wipes (3ct/pkg)	2	
IVA Tool Kit: (1) Roll 1" Duct tape; (1) Roll IFM Wire; (1) Wire Stripper [12, 14, 16, 18, 20]; (1) Safety Glasses; (1) Allen Wrench Set [5/64, 3/32, 7/64, 1/8, 9/64, 5/32, 3/16, 7/32, 1/4"];(1) Flat Blade Screw Driver; (1) Phillips Screw Driver: (1) Wire Cutter; (1) 6" Adjustable Wrench; (1) Large Pliers; (1) Needle Nose Pliers; (1) 3/8 to 7/16" Box Wrench; (1) Box Cutter; (1) Roll Blue Electrical Tape; (30) Small Black Wire Ties; (31) Large White Wire Ties; (4) AA Batteries; (2) 45603 Bolts; (1) 43508 Bolt; (1) Small Red Tool Bag	1	
EVA Tool Kit: (1) 1 1/2" Paint Brush, (1) 4" Paint Brush; (1) 2" Paint Brush; (1) EVA Wipe Pad; (1) EVA Wipe Pad Frame; (1) Torque Wrench; (1) Wretch Wrench; (1) 3/4" Socket; (1) 3/8" Long Extension; (1) 3/8" Short Extension	1	
Sleeping Bag	1	See Related CMDR Tabs
Twin Blanket	1	See Related CMDR Tabs
Small Blow-up Travel Pillow	1	See Related CMDR Tabs
Personal Meal Kit: (1) Metal Spoon; (1) Metal Fork; (1) Metal Knife; (1) Small Scissors	1	See Related CMDR Tabs
Small Personal Head Lamp	1	See Related CMDR Tabs
3-Pack Combo Dry Sacks; (1) Small 7.75x13"; (1) Medium 9.5x15.5";(1) Large 6.75x10.7x22"	1	See Related CMDR Tabs
Sham wow, Large, Yellow (23.5 x 20")	2	See Related CMDR Tabs
Sham wow, Small, Blue (15x15")	3	See Related CMDR Tabs
EVA Cooling Vest	1	See Related CMDR Tabs
Personal EVA Kit: (1) TCU, Top, Long Sleeve; (1) TCU, Pants, Long; (3) Pairs of socks; (1) Head Band; (2) Wrist Bands; (1) Chest Heart Monitor	1	See Related CMDR Tabs
Days of Breakfast	16	See Food Menu Tab
Snacks	16	See Food Menu Tab
16oz Silver Bottles	2	See Related CMDR Tabs
16oz Black Tops (Silver bottles)	4	See Related CMDR Tabs
16oz Liners	16	See Related CMDR Tabs
24oz Water Bottles	2	See Related CMDR Tabs
Container of Powered Lemonade	1	See Related CMDR Tabs
Container of Powered Tea	1	See Related CMDR Tabs
Days of Lunch	16	See Food Menu Tab
Days of Dinner	16	See Food Menu Tab

Item	14-Day Pre-FLT Status	Related TABS
Days of Personal Items	14	See Food Menu Tab
Days of Personal Items	14	See Food Menu Tab
Sleeping Bag	1	See Related GEO Tabs
Twin Blanket	1	See Related GEO Tabs
Small Blow-up Travel Pillow	1	See Related GEO Tabs
Personal Meal Kit: (1) Metal Spoon; (1) Metal Fork; (1) Metal Knife; (1) Small Scissors	1	See Related GEO Tabs
Small Personal Head Lamp	1	See Related GEO Tabs
3-Pack Combo Dry Sacks; (1) Small 7.75x13"; (1) Medium 9.5x15.5";(1) Large 6.75x10.7x22"	1	See Related GEO Tabs
Sham wow, Large, Yellow (23.5 x 20")	2	See Related GEO Tabs
Sham wow, Small, Blue (15x15")	3	See Related GEO Tabs
EVA Cooling Vest	1	See Related GEO Tabs
Personal EVA Kit: (1) TCU, Top, Long Sleeve; (1) TCU, Pants, Long; (3) Pairs of socks; (1) Head Band; (2) Wrist Bands; (1) Chest Heart Monitor	1	See Related GEO Tabs
Days of Breakfast	16	See Food Menu Tab
Snacks	16	See Food Menu Tab
16oz Silver Bottles	2	See Related GEO Tabs
16oz Black Tops (Silver bottles)	4	See Related GEO Tabs
16oz Liners	16	See Related GEO Tabs
24oz Water Bottles	2	See Related GEO Tabs
Container of Instant Coffee	1	See Related GEO Tabs
Container of Powered Gatorade	1	See Related GEO Tabs
Days of Lunch	16	See Food Menu Tab
Days of Dinner	16	See Food Menu Tab
Days of Personal Items	14	See Related GEO Tabs
Camel Back 1 Gallon Water Bag	2	
Mockup EVA Leg Assembly	1	
Form Block to Finish Out Volume	1	
Mockup EVA Gloves	2	
Mockup EVA Leg Assembly	1	
Mockup EVA Arm Assembly	2	
Mockup EVA COMM Hat (Snoopy)	1	
Dust Brush, Large	1	
Mockup EVA Diapers	3	
Exercise Device Seat	1	
Ergometer Base Plate	1	
Ergometer Exercise Unit	1	
Pedal Arm w/Pedal	2	
Bodylastics Padded Handle	1	
Rectangular Silver Plate w/ 2 Holes on each End	1	
Base Plate Bolts	5	
Base Plate Bolts, Long	4	
Base Plate Nuts	6	
Carabineer	1	

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13. ABSTRACT *(Maximum 200 words)*

The primary purpose of the 2009 Desert Research and Technology Studies (DRATS) test was to conduct a quantitative habitability and usability evaluation of the Space Exploration Vehicle (SEV) 1B prototype during a high-fidelity simulation of a 14-day Constellation Program lunar mission. Although future exploration operations are expected to involve two SEVs, the operations at DRATS 2009 focused primarily on operations by a single SEV with a two-person crew because only one mobile SEV prototype was available for testing. A two-person crew remained within the SEV for the entire 14-day mission, leaving the vehicle only through the suit ports to perform extravehicular activities (EVAs). Standard metrics were used to longitudinally quantify habitability and usability of all aspects of the SEV prototype. Vehicle and crewmember descriptive statistics were collected, including task times for EVA and intravehicular activity, distances traveled, scientific productivity, and egress and ingress durations. Multiple design modifications were identified, but the data indicated that the overall SEV habitability and human factors to be acceptable for a 14-day mission. The SEV prototype was also found to be acceptable for 24 hours of habitation by four crewmembers, as assessed during a simulated crew rescue scenario on the final day of the mission.

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