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NASA Space Environment Analog for Training, Engineering, Science, and Technology (SEATEST) 6 Detailed Final Report

Harry L. Litaker, Jr.
The Aerospace Corporation

Kara H. Beaton
The Aerospace Corporation

Allison P. Porter
NASA Johnson Space Center

Shonn F. Everett
Booz Allen Hamilton

Marcum L. Reagan
NASA Johnson Space Center

Jason E. Poffenberger
The Aerospace Corporation

Bill L. Todd
NASA Johnson Space Center

Taylor Phillips-Hungerford
The Aerospace Corporation

Barbara A. Janoiko
NASA Johnson Space Center

Grier L. Wilt
NASA Johnson Space Center

National Aeronautics and
Space Administration

Johnson Space Center
Houston, Texas 77058

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Available from:

NASA STI Program
Mail Stop 148
NASA Langley Research Center
Hampton, VA 23681-2199

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ACRONYMS

>	greater than
1/6-g	Lunar gravity
3-D	Three Dimensional
A/L	Airlock
ACD	Artemis Campaign Development
ALSEP	Apollo Lunar Surface Experiments Package
APFR	Articulating Portable Foot Restraint
ARGOS	Active Response Gravity Offload System
CG	center of gravity
cm	centimeters
CAD	Computer Aided Design
CapCom	Capsule Communicator (console position - communicates w/ crew)
CAVES	Cooperative Adventure for Valuing and Exercising human behavior and performance Skills
Comm	Communications
ConOps	Concept of Operations
COTS	commercial-off-the-shelf
CTB	Crew Transfer Bags
CTBE	Cargo Transfer Bag Equivalent
CWC	Contingency Water Container
D-RATS	Desert Research And Technology Studies
EAMD	NASA’s Exploration Analogs and Mission Development
EHP	NASA's Extravehicular Activity (EVA) and Human Surface Mobility (HSM) Program
EV1	Extravehicular crewmember 1
EV2	Extravehicular crewmember 2
EVA	Extravehicular Activity
FOD	Flight Operations Directorate
FRP	Fiber-Reinforced Polymer
ft	feet
ft^2	square foot
ft^3	cubic foot
g	gravity
HDL	Human-class Delivery Lander
hh:mm:ss	hours: minutes: seconds
HITL	Human-In-The-Loop
HUT	Hard Upper Torso
ISS	International Space Station
JSC	Johnson Space Center
kg	kilogram

ACRONYMS

km	kilometers
KSC	Kennedy Space Center
lbs.	pounds
LiOH	Lithium Hydroxide
m	meter
m^2	meters squared
m^3	cubic meter
MET	Metabolic Equivalent
MPLC	Medium Pressurized Logistics Containers
MSL	Medium Sized Lander
N2	Nitrogen
NASA	National Aeronautics and Space Administration
NOLS	National Outdoors Leadership School
NORS	Nitrogen/Oxygen Recharge System Tank
O2	Oxygen
Ops	Operations
PANGAEA	Planetary ANalogue Geological & Astrobiological Exercise for Astronauts
PAO	Public Affairs Office
PLSS	Portable Life Support System
PR	NASA's Pressurized Rover
PVC	Polyvinyl Chloride
SA	Artemis Logistics Strategic Architecture
SAC	Strategic and Analysis Cycle
SAO	NASA’s Strategy and Architecture Office
SEATEST	Space Environment Analog for Training, Engineering, Science, and Technology
SCUBA	Self-Contained Underwater Breathing Apparatus
SH	Surface Habitat
SPLC	Small Pressurized Logistics Container
Stbd	Starboard
t	ton
TBD	To Be Determined
TIO	NASA's Technical Integration Office
USC	University of Southern California
VR	Virtual Reality

EXECUTIVE SUMMARY

After more than 50 years since the last crewed lunar landing, plans for more missions to the moon are in development. For these missions, efficient and sustainable logistics will be critical. Additionally, innovative methods of cargo transfer to and from a lunar outpost should be considered for successfully establishing a permanent presence on the moon.

SEATEST (Space Environment Analog for Training, Engineering, Science, and Technology) is an immersive mission-analogous operational atmosphere where buoyancy effects and supplemental weights can simulate partial gravity conditions similar to those astronauts will experience on the moon. SEATEST 6 took place at the University of Southern California (USC) Wrigley Marine Science Center on Santa Catalina Island from July 18-30, 2023. The analog was used to collect preliminary logistics data on two different offloading conceptual methods (a davit and a zipline) during a simulated lunar mission.

Pre-test analysis indicated for a crew of two on a 14-day mission, approximately three Medium Pressurized Logistics Containers (MPLC) sized logistics containers (or a total of 37.5 single Cargo Transfer Bag Equivalents (CTBE)) would be needed to support a mission. A Computer-Aided Design (CAD) analysis was employed on the SEATEST airlock mockup to determine how many logistic containers would fit with two suited crewmembers, don/doff stands, and hatch operations. It was determined that for SEATEST, a total of 15 1.0 Small Pressurized Logistics Containers (SPLCs) and 8 2.0 SPLCs would adequately fit into the approximate 9.5 cubic meter airlock volume. This does not fully represent a complete 14-day logistic supply; however, it does provide a preliminary estimate to initiate design conversations between logistics teams and crew at this early stage of development.

Data were collected in eight logistics transfer scenarios over two days with four scenarios per day. Five test subject crew participated in scenarios as pairs. Scenarios included two sizes of logistics containers – 1.0 SPLC (equivalent to a single Cargo Transfer Bag (CTB) and 2.0 SPLC (equivalent to two CTBs). Planed evaluations included the use of a logistics port compared to transfer through an Airlock hatch, offloading methods based on either a davit or a zipline system, choreography of cargo in the airlock to permit ingress and suit doffing, and dust removal protocols for an understanding of the overall impact to transfer ops. Data collected included objective data (task times for conducting overall tasks and subtasks, full audio/video of test activities, and inadvertent "dings" on hardware) and subjective data (crew consensus of: task acceptability and capability assessment ratings related to best practices, considerations, and constraints for EVA-driven logistics transfer ConOps, sim quality of the test environment, and more general debrief comments).

The two logistic offloading transfer concepts (davit, zipline) presented both advantages and limitations. The davit's flexibility in allowing the crew to pick up the containers without physical interaction was well regarded by the crew. Some limitations of select davit hardware components were noted, but the overall concept was acceptable. The zipline system proved to be the most efficient way of moving logistics from the lander to the airlock and eliminated the need for dust operations. However, extended and repetitive lifting of containers to the line could be fatiguing. In conclusion, logistics transfer could hypothetically be achieved without an offloading method; however, the time requirement for such operations would be prohibitive. Results of crew subjective feedback proposed a combined or hybrid davit/zipline method to increase efficiency.

1.0 INTRODUCTION

After more than 50 years since the last crewed lunar landing, plans for more missions to the moon are in development. For these missions, efficient and sustainable logistics will be critical. Additionally, innovative methods of cargo transfer to and from a lunar outpost should be considered for successfully establishing a permanent presence on the moon.

SEATEST Test Series

SEATEST (Space Environment Analog for Training, Engineering, Science and Technology) was conceived to accomplish two primary goals. The first goal is to develop the capability to conduct Human-in-the-Loop testing that can benefit from undersea testing. It’s designed to support rapid prototyping and assessment of Artemis ConOps and capabilities, be an integrated ConOps development testbed, provide a medium fidelity partial gravity environment, and enable dedicated crew and other relevant end-operators (e.g., CapCom, EVA Officer) input toward Artemis architecture questions.

The second goal of SEATEST is to provide an “Expeditionary Training” experience for the International Astronaut participants. Good Expeditionary Training looks like operations that require a highly functioning team, risk management, and good decision making. Other hallmarks include leadership/followership opportunities, extreme environment mission operations, real risks, demanding critical training, the need for good buddymanship, high individual and team performance, and “Detachment mentality,” where the questions being answered are front and center for an extended period of time.

SAC 23 Logistics Task and SEATEST 6

The term “logistics” represents all supplies and equipment (including utilization) that must be delivered on logistics landers to support mission activities in surface elements. To obtain preliminary data on the feasibility of the proposed logistics transfer, an early exploratory study was conducted [1]. A scenario had two suited subjects carry multiple or single Cargo Transfer Bag Equivalents (CTBE) and load as possible in the hatchway before becoming too difficult for a crewmember to traverse inside. Lessons learned from this early study indicated that depressurized cabin logistics transfer will require significant effort from Extravehicular Activity (EVA) crew inside the habitable volume. However, more insight was required to fully understand operational constraints associated with logistics transfer.

SEATEST 6 tested three options for habitable element interfaces and pressurized logistics containers. First, an EVA Hatch (no dedicated interface) and small pressurized container (i.e., handheld “suitcases”). For this configuration, all logistics were brought into pressurized volume via EVA hatch – either directly into cabin or via airlock (rather than using a specific interface). The “small” size was driven by the need to maneuver carriers through hatch(es) into a pressurizable volume. The practical range to handle manually for these small containers was determined to be in the range of ~1 CTBE to 2 CTBE. Second, a dedicated logistics port and medium pressurized container (i.e., too large to be manipulated manually by the crew, but can be moved using mechanical or robotic off-loading systems). In this case, the logistics container mates with the habitable volume through a port with a hatch on the exterior shell – the container remains outside and provides additional storage volume. The “medium” size was driven by the need to maneuver the container to attach to a habitat and to travel with mobile elements. The practical range for this container is large ~5 CTBE to 25+ CTBE (with significant robotic or mechanical assistance). The final interface and container involved a berthing or docking port with a large, pressurized container (e.g., Cygnus-like module). Here, a logistics module docks/berths with surface elements and has a crew-sized hatch. Crew enters the logistics module through this hatch. SEATEST 6 studied only the first two options, which are EVA-intensive.

Primary Use of Data

SEATEST 6 was sponsored by the Strategic Archtecture Office (SAO) within the Exploration Systems Development Mission Directorate (ESDMD), which is responsible for defining and managing systems development for programs critical to NASA's Artemis program and planning for NASA's Moon to Mars exploration approach. Architecture Concept Reviews (ACR) are conducted annually by ESDMD, and during these ACRs, NASA architecture teams analyze the Moon to Mars Objectives and distill them into mission elements and how they function together to accomplish human missions to the Moon to Mars. To support the Nov. 2023 ACR, a series of Strategic Analysis Cycle (SAC) tasks are ongoing. Several of these tasks are informed by SEATEST 6 results, and will ultimately inform the Architecture Definition Document (ADD), ConOps for various cargo lander options (e.g., Human-class Delivery Lander (HDL) Large Cargo Lander ConOps, ESA Argonaut Lander ConOps, and Mid-sized Lander ConOps), and SAC 24 tasks.

Community Integration

SEATEST 6 significantly moved the community forward on EVA logistics concepts. A benefit of running a HITL field test is that it imposes arbitrary but inflexible milestones involving the crew office. Maintaining these milestone timelines for SEATEST 6 brought all stakeholders together to work toward a common solution. These stakeholders included Logistics Team, Cargo Lander Team, FOD EVA, Lunar Dust, EHP, and HITL testing teams. Designing SEATEST mockups required addressing previously unanswered touch points, such as identifying actual design decisions and techniques for notional concepts, full consideration of capabilities and limitations regarding both suits (balance, work envelope, reach, etc.) and humans (weight, size, center-of-gravity limitations). Additionally, standalone testing at JSC and CAD analysis was used to inform assumptions and designs. For instance, at the project's inception, 3.0 and 5.0 CTBE sizes for SPLCs were being considered as bounding cases by the Logistics Team. JSC testing showed that even a 3.0 CTBE is too large and bulky for two crewmembers to manipulate manually while suited. From this testing, 1.0 and 2.0 CTBE sizes were considered volume limitations moving forward. The test team determined assumptions for "reasonable" activities that would be followed throughout the test (see section 2.4). Finally, collecting focused crew input over multiple HITL test days provided valuable subjective data directly from relevant end-operators.

Test Participants and Test Support

Investigators recruited five highly trained astronauts/engineers for the study that had the prerequisite diving experience. As for other test support, the team consisted of six support divers for the astronauts, two communication personnel from the Kennedy Space Center (KSC) and approximately 9 test support personnel ranging from protocol, data collection and mockup support.

Team Leadership

Key leadership positions during testing and mission operations were:

Mission Director – The final decision maker regarding big picture objectives, priorities, safety, etc. during the testing.

Diving Lead – The person responsible for ensuring safe diving operations, including Dive Sup and support diver rotations, as well as ensuring dive plans and other USC-required products are submitted and accurate.

MCC Lead – The person responsible for ensuring MCC functionality, and oversight of the data collection, report writing, imagery and comm teams. They will also serve as the POC for any logistics questions related to USC facilities or livability support.

Mission Management Team – Will make mission priority and other decisions jointly when time permits. Consists of the Mission Director, Diving Lead, and MCC Lead.

Dive Sup – Responsible for oversight of diving operations. Will be dockside during all diving and will supervise donning, doffing, and record keeping of dive ops. Will man the comm box and have control of the dive from water entry until test subject fins are off and additional weight belts on, at which point control of the test will pass to the CapCom/Ground IV. At the end of the test, the Dive Sup will take control of the dive and comm again when fins are donned and weight belt doffed. The Dive Sup has authority to take control of the dive at any time during testing at his discretion.

CapCom – The CapCom/Ground IV will direct test activities from beginning to end. They will take the handoff of authority from the Dive Sup and pass it back at the end of the test. They will also take note of any time lost due to technical issues, for use in troubleshooting decision making.

Schedule

There are two timelines in which the test team followed regarding the study. Table 1 illustrates the overarching schedule including arrival, training, and test daysFour runs were scheduled each test day, with a target time of 60 minutes per test. The MCC team kept a close eye on crew air pressures, and provided recommendations to the Dive Sup when phases of a task could be truncated to stay within the target time/tank pressure. Support divers generally started the day with some mockup configuration tasks, and often had reconfiguration tasks after each run as well. As soon one run ended, participants would swap to their new roles and the next run would begin. Following the last run of the day, the crew and protocol team participated in crew debriefs, ratings, and consensus discussions.

Table 1. *Overall Team Schedule*

Test Dates	17-Jul Monday	18-Jul Tuesday	19-Jul Wednesday	20-Jul Thursday	21-Jul Friday	22-Jul Saturday	23-Jul Sunday	24-Jul Monday	25-Jul Tuesday	26-Jul Wednesday	27-Jul Thursday	28-Jul Friday	29-Jul Saturday	30-Jul Sunday	31-Jul Monday	1-Aug Tuesday
Dive Team	Flight to CA	Miss C. AM Assembly, Dive Re-qual	Mockup Deploy, Diver re-qual	Mockup Deploy	Mockup Deploy	Mockup Deploy	Dry Runs	Emer Trng & Dry Runs	Scenarios 1-4	Scenarios 5-8	Debrief	Teardown	Teardown	Teardown	Packing Miss C. PM	Fly Home
Crew				Flight to CA	Miss C. AM Gear c/o, orientation, Basic Trng	Basic Training, FFMs	Basic Training, FFMs	Emer Trng & Dry Runs				Fly Home Miss C. PM				
MCC & Comm				Flight to CA	Miss C. AM Setup	Setup	Dry Runs	Dry Runs				Teardown/ Reporting	Teardown/ Reporting Ferry CE PM	Fly Home		
Data/Protocol				Flight to CA	Miss C. AM Setup	Setup	Dry Runs	Dry Runs				Teardown/ Reporting	Teardown/ Reporting	Teardown/ Reporting Ferry CE PM	Fly Home	
H/W Suppt. Team	Flight to CA	Miss C. AM Mockup Assy	Mockup Assy	Mockup Assy	Mockup Assy	Mockup Assy	Mockup Assy	Mockup Support	Mockup Support Miss C. PM	Fly Home						
Visitors/Observers									July 25th Visitor Op.	July 26th Visitor Op.						

2.0 SEATEST 6 STUDY DESIGN

2.1 SEATEST 6 Test Objectives

The overall goal of the SEATEST 6 field test was to conduct a Human-in-the-Loop (HITL) trade study on a subset the above SAC objectives involving major, EVA-intensive concepts related to logistics transfer from a notional cargo lander to a surface element (SAC Task 23.12.6). This SAC task seeks to assess the feasibility of EVA crew transfer of logistics; capture best practices, considerations, and constraints that inform ConOps for logistics transfer; and capture dedicated feedback from relevant end-operators.

1) Assess feasibility of EVA crew transfer of logistics

2) Capture best practices, considerations and constraints that inform ConOps for logistics transfer

3) Capture dedicated feedback from relevant end-operators

SEATEST 6 objectives were as follows:

1) To assess options for end-to-end medium pressurized logistics containers (MPLC) and small crew-portable containers (SPLC) into a pressurized vehicle via a transfer port and/or a side hatch
2) To assess two different offloading techniques including a davit arm and zipline system to offload logistic containers to the ground from the cargo lander deck
3) To assess conceptual dust mitigation ConOps including using tools to brush off dust, adding guards to protect seals, note abrasions and potential damage to hatch seals and the time required for dust mitigation

2.2 SEATEST 6 Test Facilities

The Philip K. Wrigley Marine Science Center (WMSC) (Figure 1) is a research/educational facility located on Santa Catalina Island, CA at Big Fisherman's Cove (Figure 2) and serves as a science outpost for the University of Sourthern California. WMSC "enables researchers to investigate the intersection of people and the planet by exploring both the island's natural coastal systems and the impact of human activity in nature" [2]. Center facilities include marine research laboratories, housing, dining, and meeting areas (Figure 3).

Figure 1. Wrigley Marine Science Center.

Figure 2.. The Boone Center (left) and the dock area (right) where SEATEST 6 took place


Figure 3. Dining facility (left) and meeting room setup (right).

2.3 SEATEST 6 Hardware

2.3.1 Hardware Overview

The SEATEST 6 assembly mockups included consisted of a cargo lander with raised deck, airlock, and logistics port (which was assumed to be part of a pressurized rover). A main deck provided a way to positively secure mockups and reduce silting. The main deck sat at 9.1 m below the surface and was adjustable via jack stands up to 61 cm to accommodate leveling on an uneven sea floor. The main deck was constructed of 15 cm FRP I-Beams with a 4 cm fiber grate floor. Dimensions of the main deck were 6.1 m by 9.7 m by 1.6 m, with a weight of 2267.9 kgf dry weight and 453.5 kgf in water.

Assumptions regarding hardware design were provided by the following groups:

- Logistics carrier: SAO Logistics Team + Campaign Analysis Team
- Cargo lander: SAO Cargo Lander Team
- Airlock: SAO Surface Habitat Team
- Logistics port: SAO Surface Robotics & Mobility Team
- Offloading concepts: SAO Lunar Architecture Team (LAT), in coordination with Cargo Lander and Robotics/Mobility Teams
-

An important note regarding the mockups: all mockups were notional and do not reflect the architecture of the current lunar pressurized rover or cargo lander.

For assembly, first the base platform was be installed and leveled, then the cargo lander was installed with davit and zipline pole, followed by the rover aft deck and airlock. *Figure **4**.* The full SEATEST 6 test setup. The blue square is the dust containment area.Figure 4 shows the final layout for testing.

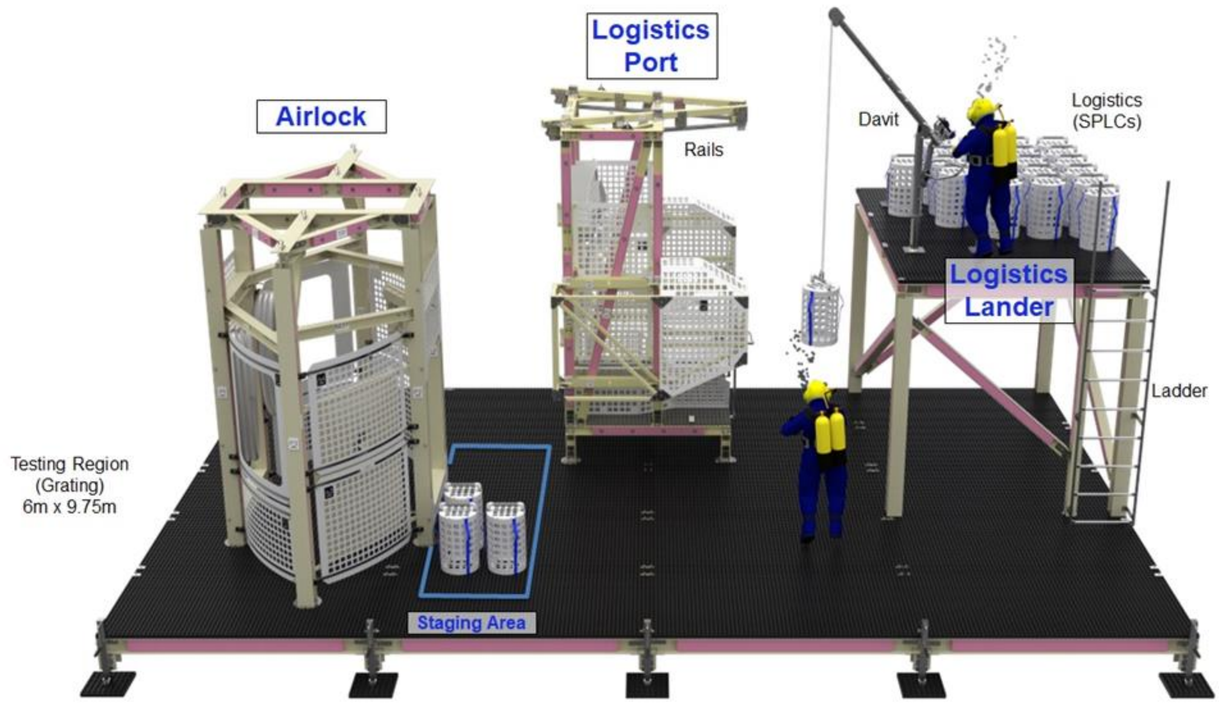

Figure 4. The full SEATEST 6 test setup. The blue square is the dust containment area.

2.3.2 Conceptual Cargo Lander

The mockup lander deck constructed for SEATEST 6 (Figure 5) was built to dimensions of 366 cm (length) by 244 cm (width) for a total workable area of 8.9 m². The approximate weight of the mockup lander was 907.2 kgf dry weight and 362.9 kgf underwater. It was made of a composition of Fiber-Reinforced Polymer (FRP) 15 cm and 10 cm beams and polystyrene embedded to reduce weight with stainless steel brackets and a fiber grate flooring. The mockup also included a 2.5 to 3 m commercial-off-the-shelf (COTS) ladder for access on and off the deck.

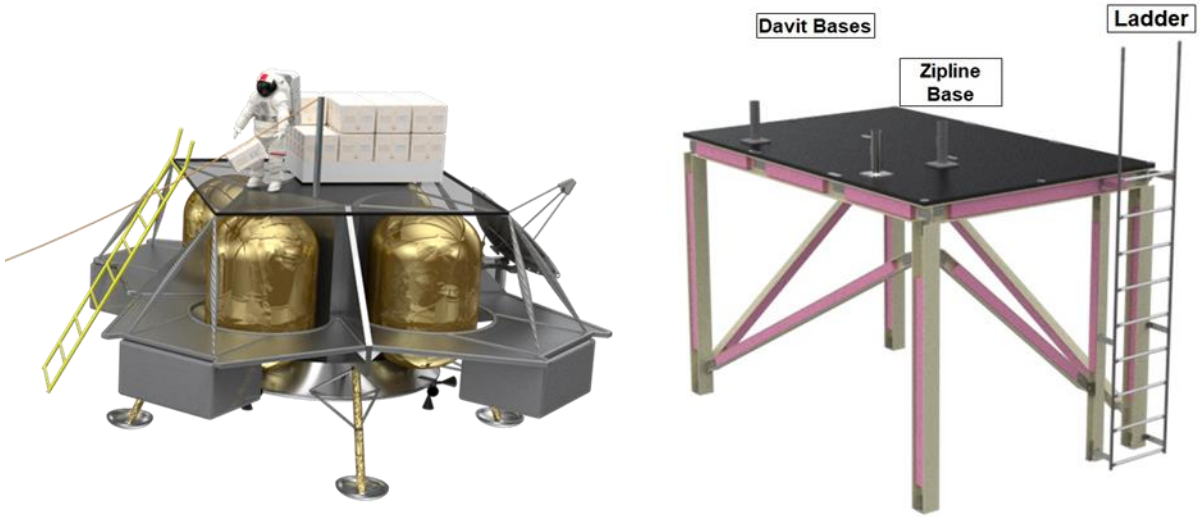

Figure 5. A notional cargo lander (left) and CAD rendering of SEATEST 6 cargo lander mockup (right).

2.3.3 Conceptual Airlock

The conceptual airlock dimensions were 383 cm (length) by 202 cm (width) with a 152 cm by 102 cm hatch that has the ability to be adjustable to test smaller hatch opening in the future (Figure 6). The workable volume of the airlock was 9.5 m³. The mockup weighed 907.2 kgf dry weight and 362.9 kgf in the water. The air lock mockup was constructed of 15 cm and 10 cm FRP I-Beams with 0.3 cm Kydex panels and 0.5 cm stainless steel brackets.

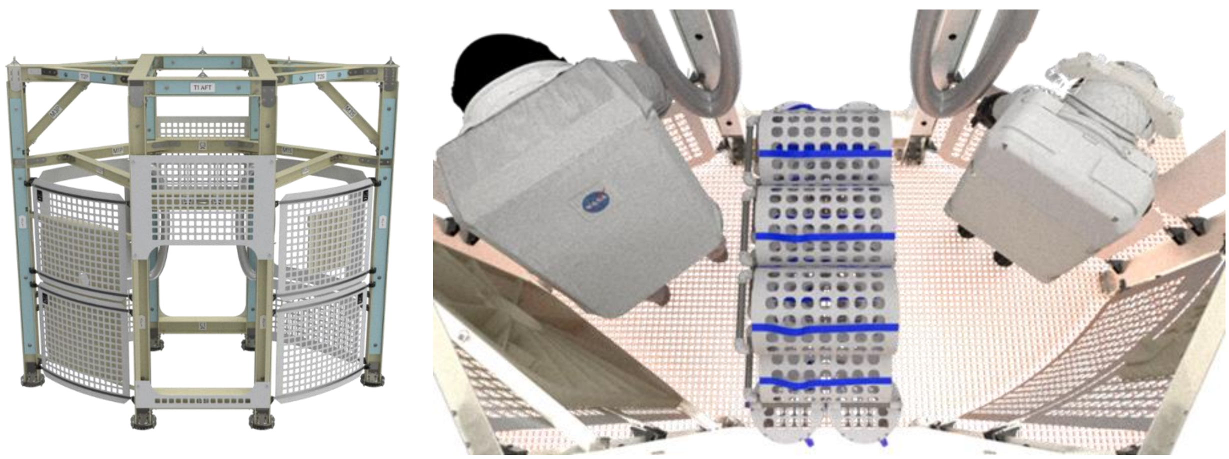

Figure 6. CAD renderings of SEATEST 6 airlock - mockup (left) and top down view inside A/L (right).

2.3.4 Conceptual Logistics Port (Pressurized Rover Aft Deck)

For the MPLC, a rover aft deck with transfer ports was required. The mockup rover aft deck was 192 cm (width) by 376 cm (height) by 203 cm (depth) and weighed approximately 11,340 kgf dry weight and 498.9 kgf in water (Figure **7**). The rover aft deck was built out of 10 cm FRP I-Beams with polystyrene embedded for weight reduction. Additional components included 2.5 cm rails for transferring the MPLC to the logistics port, a haul system for transferring the MPLC load from the davit to the rails, 4 cm fiber grate flooring and 0.3 cm Kydex panels. The mockup floor was 46 cm high off the sea deck grate.

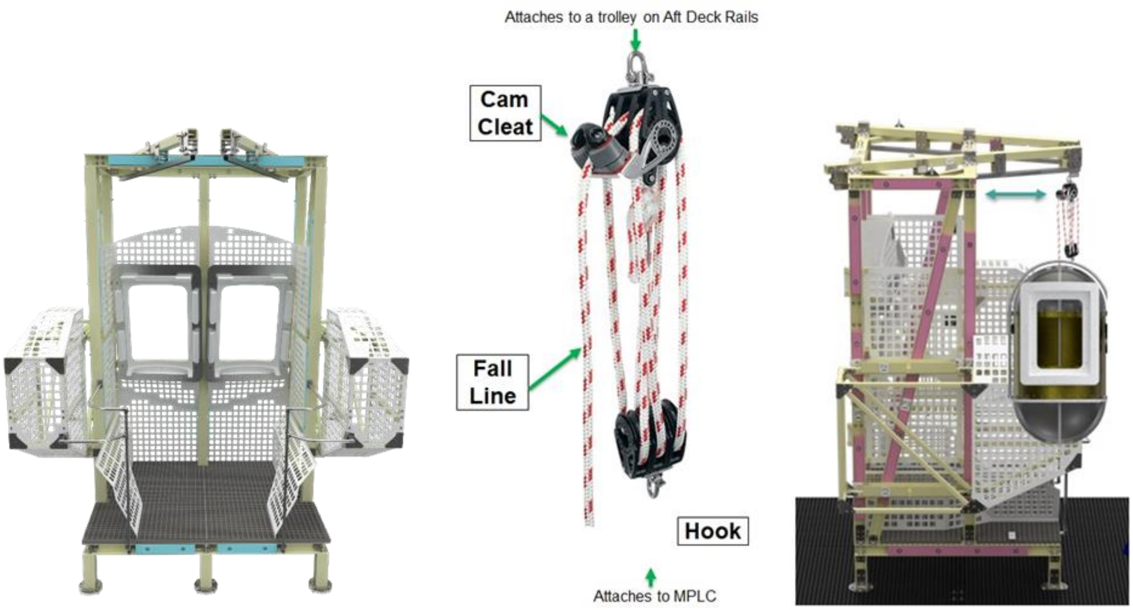

Figure 7. CAD renderings of SEATEST 6 aft deck (left) and haul system (center & right).

2.3.5 Conceptual Offloading Devices

Thern Winches and Cranes Commander 500 series davit was used for SEATEST 6 (Figure 8). The arm was made of stainless steel with a steel spur gear hand winch on a pedestal stand. The davit arm fully extended to 154 cm and was placed at a height from the cargo lander deck of 247 cm. The davit had the ability to lift below deck to a distance of 8.2 to 9.7 m. The cable was a 6 mm diameter galvanized aircraft cable with a total length of 13.7 m. Additional components of the davit arm assembly included a swivel hook, swaged ball fitting, and quick disconnect anchor. The davit had a load rating of up to 300 kg and could rotate 360º.

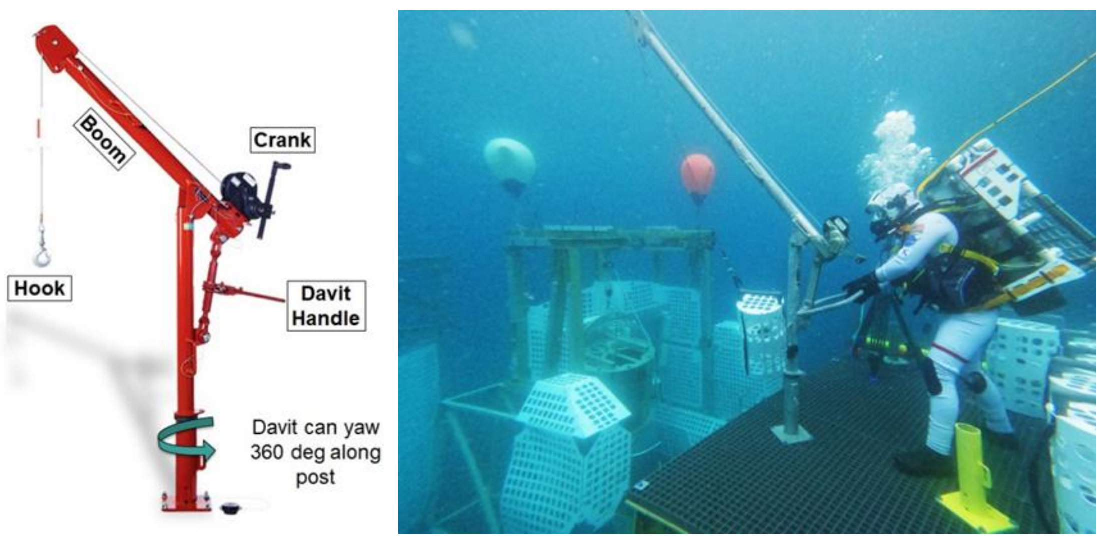

Figure 8. CAD rendering of davit (left) and davit being used in SEATEST 6 (right).

The zipline system used a 2.4 m lander base post. At a 2 meter height on the post, a 1 cm diameter static climbing rope connected to the base post using an eyehook. A boat cleat at 1.8 m position on the base post was present to secure the control line. The zipline rope was approximately 6.6m in length with 0.6 cm control line rope. The control line was attached in a Camnal pulley along with a quick draw assembly consisting of two carabineers (Figure 9).

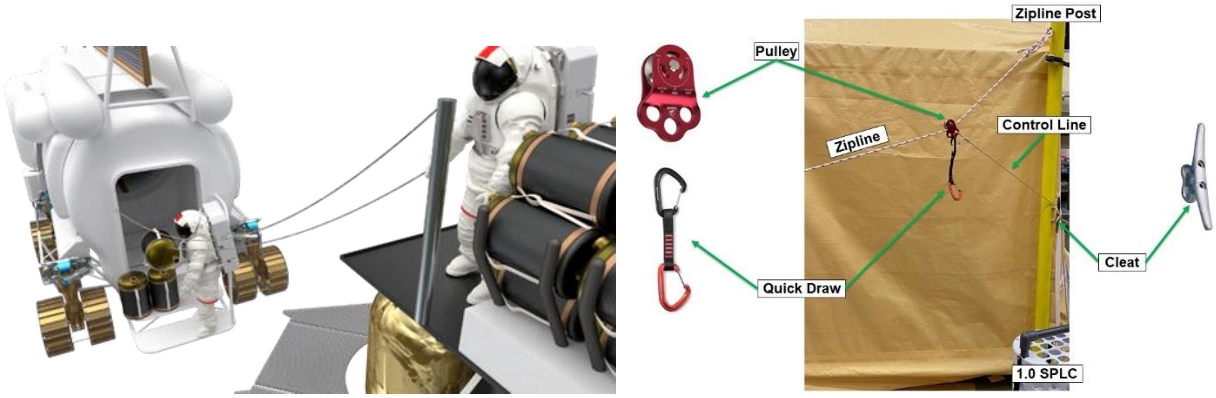

Figure 9. CAD rendering of zipline (left) and test system (right).

2.3.6 Conceptual Logistic Containers

Three different sized conceptual logistic containers were employed for the test: MPLC (Figure 10), the 1.0 CTBE SPLC (referred to as "1.0 SPLC") and the 2.0 CTBE SPLC (referred to as the "2.0 SPLC").

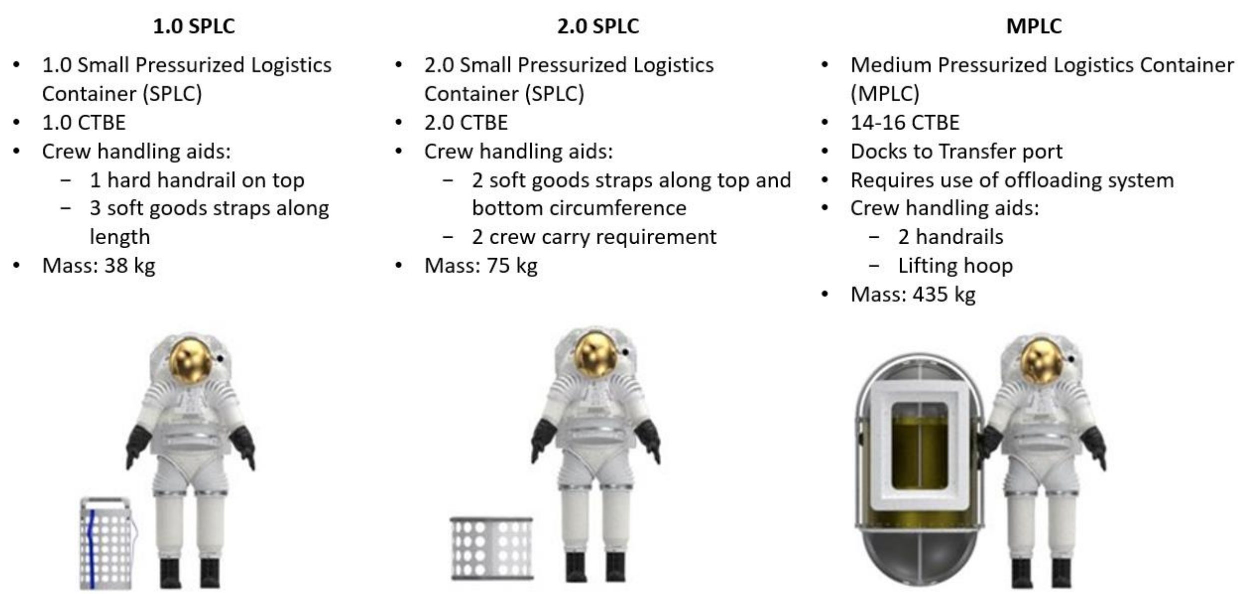

Figure 10. Chart of logistic containers used for SEATEST 6.

The total number of containers included in SEATEST was determined by estimating the number of containers of each type that could fit in the airlock while still leaving room for two suited crewmembers to ingress, close the hatch behind them, and doff their suits. Additional consideration was given to handling difficulties of each size container; e.g., a ground-rule dictated the 2.0 SPLC as too heavy/awkward for a single suited crewmember to lift/carry (Figure 11).

The SPLCs were constructed of Kydex paneling with Polyvinyl Chloride (PVC) pipe handle (1.0) or soft goods handle (2.0). The dimensions of the 1.0 SPLC were 58 cm (height) by 37 cm (diameter), with a pressurized volume of 0.05 m^2 (1 CTBE). The 1.0 SPLC used a lunar equivalent reference weight of 6.5 kgf, so it was weighted underwater to approximately 6.5 kgf.

The dimensions of the 2.0 SPLC were 46 cm (height) by 56 cm (diameter), with a pressurized volume of 0.1 m^3 (2 CTBE). The 2.0 SPLC used a lunar equivalent reference weight of 12.5 kgf, so it was weighted underwater to approximately 11 kgf.

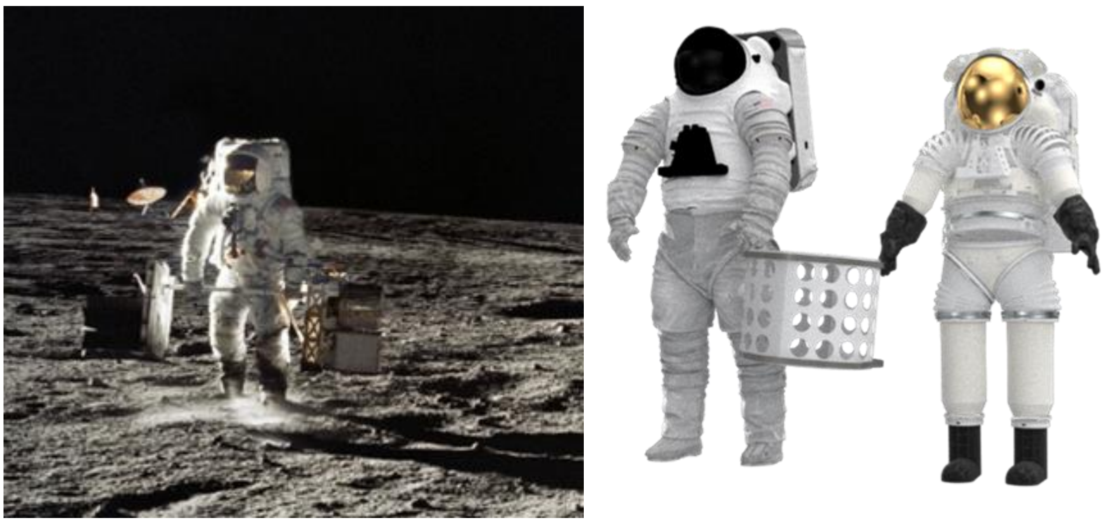

Figure 11. The Apollo Lunar Surface Experiments Package (ALSEP) used in Apollo 12 to carry experiments (left) compared to the new dual carry 2.0 SPLC concept (right).

The MPLC size was driven by the need for an astronaut to be able to maneuver the carrier to attach to a habitat or mobile element(s). The capacity of the MPLC is 14-16 CTBE inside a 1.3 m^3 volume. Dimensions of the MPLC were 160 cm (height) by 80 cm (width) with transfer port attachment. The unit weighed 81.6 kgf dry weight and 72.6 kgf in water. The body was constructed of 6061 aluminum with acrylic end domes. The MPLC cradle was also built out of 6061 aluminum and aluminum extrusion. The transfer port hatch was intended to enable medium logistics carriers (housing 19 CTBE or more) to be attached to the cabin, enabling logistics transfer across the hatch (Figure 12).

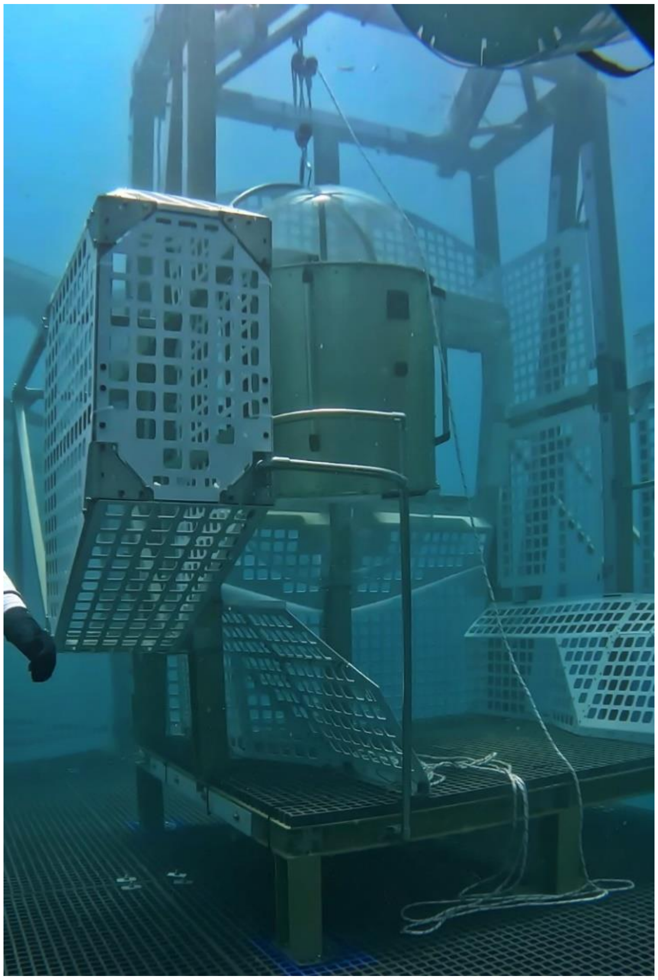

Figure 12. New SEATEST 6 MPLC mockup docked to aft deck logistics port mockup.

2.3.7 Portable Life Support System (PLSS) Mockup

While working underwater, the crew donned a PLSS mockup over their air tanks. This was used to simulate the volume a spacesuit PLSS would occupy when working in tight areas, such as an airlock. The PLSS mockup dimensions were 79 cm (length) by 60 cm (width) by 20 cm (depth) (Figure 13). From the center of the subject's head to the back of the PLSS was 41 cm. There were 2.5 cm polypropylene shoulder straps and a waist strap. The mockup was constructed of 2.5 cm PVC joints and Kydex pipes (Figure 14). Dry weight was 9.07 kgf and 3.17 kgf in water.

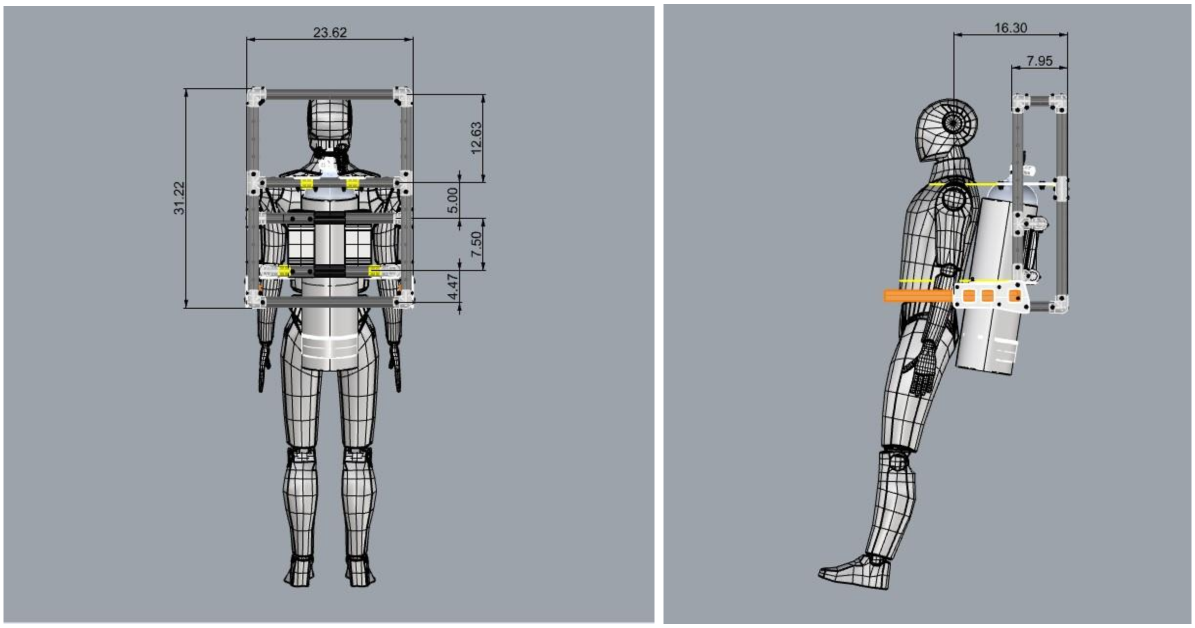

Figure 13. Design drawings for SEATEST 6 PLSS mockup (Dimensions shown are in inches).

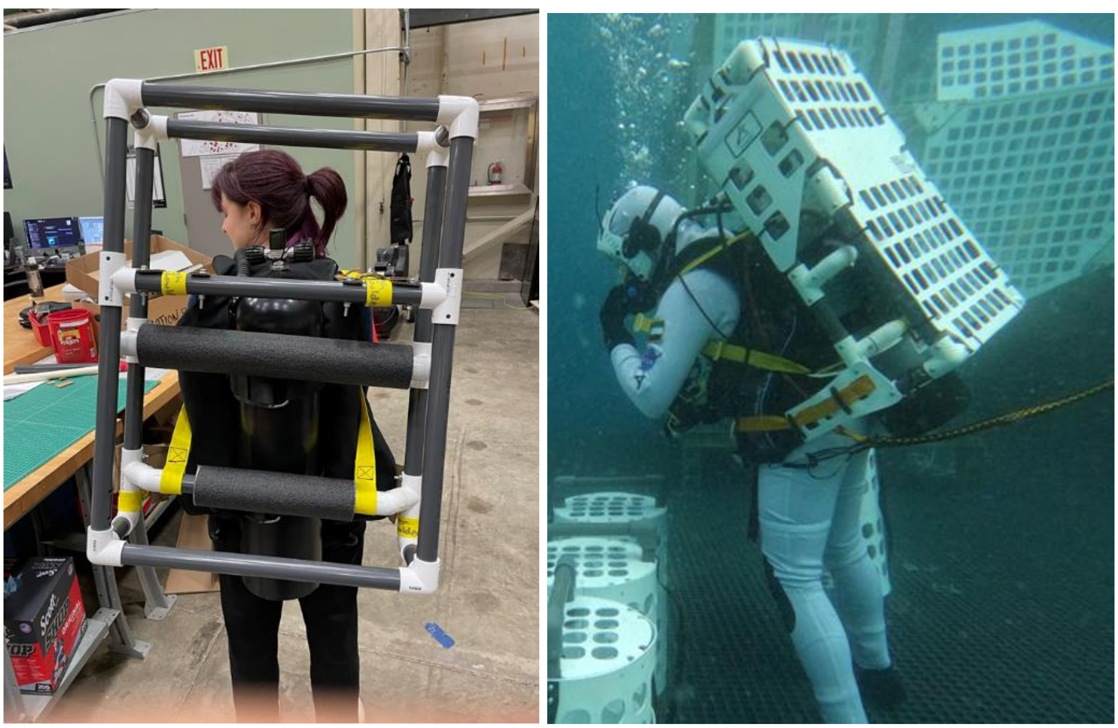

Figure 14. SEATEST 6 PLSS mockup.

2.4 Test Scenarios

2.4.1 Study Design

The study was designed to understand the Extravehicular Activity (EVA) manual logistics transfer ConOps and time requirements using various conceptual offloading methods with bounding carrier sizes and accounting for dust removal and airlock size limitations. There were two offloading methods tested: 1) A davit and 2) a zipline both starting from the cargo lander deck. Additionally, three logistics carrier sizes will be examined: 1) the MPLC, 2) a small SPLC and 3) a large SPLC. Also investigated was choreography of SPLC placement in the airlock to leave room for necessary operations (e.g., ingress, hatch closure, and suit doffing). The number of carriers were determined using a manifest for a crew of two on a 14-day lunar surface mission (Table 2), as well as estimating the number of containers of each type could fit in the airlock while leaving room for those critical operations. Consideration was also given to handling difficulties of each size of container (e.g., a ground-rule dictated that the 2.0 SPLC was too heavy/cumbersome for a single suited crewmember to lift/carry). Dust removal protocols were included for an understanding of the overall impact to transfer operations. Crew were in pairs of two evaluating eight different logistic scenarios of approximately one-hour each.

Table 2. *Pressurized Rover 14-Day Manifest*[1]

Crew Size	**2 Crew**	**2 Crew**	**2 Crew**	**2 Crew**	**4 Crew**	**4 Crew**	**4 Crew**	**4 Crew**
Elements	**PR**	**PR**	**PR**	**PR**	**PR & SH**	**PR & SH**	**PR & SH**	**PR & SH**
Duration in Surface Elements	**7 Days**	**14 Days**	**21 Days**	**28 Days**	**7 Days**	**14 Days**	**21 Days**	**28 Days**
Total Surface Duration	**12 Days**	**19 Days**	**26 Days**	**33 Days**	**12 Days**	**19 Days**	**26 Days**	**33 Days**
Food (kg)	42.64	79.40	116.16	152.92	84.18	156.60	229.02	301.44
Wipes and Gloves (kg)	2.80	5.60	8.40	11.20	5.60	11.20	16.80	22.40
Health Care Consumables (kg)	1.26	2.52	3.78	5.04	2.52	5.04	7.56	10.08
Trash Bags (kg)	0.42	0.84	1.26	1.68	0.84	1.68	2.52	3.36
Waste Collection (kg)	3.78	7.56	11.34	15.12	7.56	15.12	22.68	30.24
Operational Supplies (kg)	5.00	5.00	10.00	10.00	10.00	10.00	20.00	20.00
Recreation & Personal Stowage (kg)	10.00	10.00	20.00	20.00	20.00	20.00	40.00	40.00
Hygiene (kg)	7.45	8.61	8.61	9.19	14.90	17.22	17.22	18.38
Clothing (kg)	7.08	13.01	13.92	17.18	14.16	23.36	27.84	34.36
Towels (kg)	1.37	3.27	4.10	5.46	2.74	6.00	8.20	10.92
Replacement System Spares (kg)	76.00	76.00	76.00	76.00	152.00	152.00	152.00	152.00
LiOH Cannisters (kg)	0.00	0.00	0.00	31.50	0.00	0.00	0.00	31.50
EVA Consumables (kg)	84.30	101.66	119.02	136.37	162.18	187.83	213.48	241.77
EVA Spares (kg)	20.78	80.66	80.66	80.66	41.56	160.32	160.32	160.32
Utilization (kg)	50.00	50.00	50.00	50.00	100.00	100.00	100.00	100.00
Bags, Foam, Packaging (kg)	16.19	31.13	36.52	41.92	31.96	60.59	70.55	79.68
10% Margin (kg)	32.91	47.53	55.98	66.42	65.02	92.70	108.82	125.65
TOTAL (kg)	**345.79**	**491.66**	**579.23**	**688.74**	**683.26**	**959.07**	**1126.46**	**1302.42**
Total Volume (CTBE)	**19.50**	**37.50**	**44.00**	**50.50**	**38.50**	**73.00**	**85.00**	**96.00**

NOTE[1]: Manifest source from the NASA Explore Moon to Mars Logistics Requirements and Delivery Assessment GR&As presentation dated 30 March 2023

There is a sequence for offloading logistics that were followed for all the scenarios, excluding airlock ingress/egress choreography. Figure 15 illustrates the offloading process including definitions of each action for the davit and zipline. Figure 16 and Figure 17 illustrate this process for the MPLC and Trash Reload, respectively. Subjects had their center of gravity (CG) weight out to 1/6-g. All logistics containers were also weight out to 1/6-g. For a more flight-like detailed description of the procedures see Appendix A.

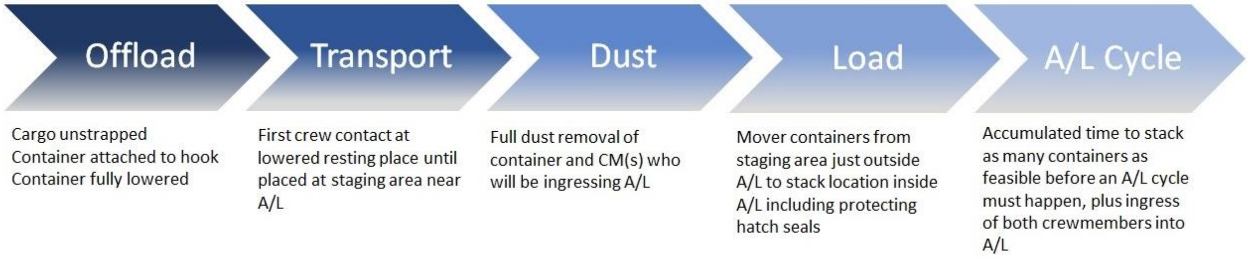

Figure 15. The logistic offloading flow for the davit and zipline.

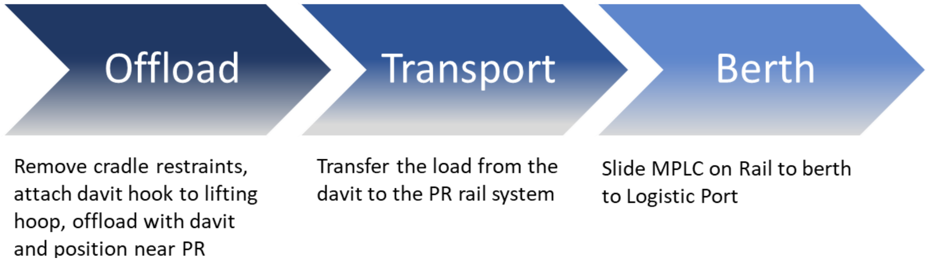

Figure 16. The logistic offloading flow for the MPLC.

Figure 17. The logistic offloading flow for the MPLC.

2.4.2 Derivation of Assumptions

The current assumption for a 2-crew, 14-day Pressurized Rover mission is that it will require 37.5 CTBE of pressurized cargo with a cabin volume of approximately 9.5 m^3. Pre-mission testing was conducted to inform the SEATEST assumptions that follow. The first area of focus was regarded how well a suited crewmember could handle SPLCs of different sizes. Testing for this focus area was done in 1-g in restrictive Excon suits, with 1.0, 2.0, and 3.0 CTBE container sizes. As a note, though soft CTBs were used in the pre-mission testing shown in Figure 18, these are considered a proxy for hard, pressurized SPLCs, which would both take more volume and could not be packed as efficiently as shown.

Figure 18. Habitable airlock mockup at JSC with 37.5 CTBE in soft bags; interior volume ~ 9.5 m^3.

Previous Active Response Gravity Offload System (ARGOS) push/pull tests results were consulted to bound assumptions on dragging containers across the regolith or airlock floor while suited. An additional focus of the pre-mission testing involved determining the challenges of putting 37.5 CTBE in a volume of approximately 9.5 m^3. The SEATEST 6 airlock mockup and 1-g mockup used in testing were ~9.5 m^3. 37.5 CTBE occupies approximately half the usable volume, even without accounting for the two spacesuits (not shown) and crewmembers. Additionally, when the SPLCs are unpacked, the result is that twice the volume is occupied by a) the rigid SPLCs and b) the soft goods that were inside of the SPLCS.

2.4.3 Test Assumptions

For the SEATEST 6, there are 16 evaluation assumptions that must be recognized from both the stakeholders and the test team for implementing the study's objectives. Assumptions for the study include:

1) Pressurized Logistics containers carry food, clothing, spares, medical supplies, etc. and portable water in Contingency Water Containers (CWC) and does not include Nitrogen (N_2) or Oxygen (O_2).
2) The manifest for a 14-day PR mission was assumed, which requires 37.5 CTBE of pressurized logistics (See Table 2).
3) Container assumptions were:

	1 CTBE	2 CTBE	MPLC
Lunar wt., Full (kgf)	7	14	77
Lunar wt., Empty (kgf)	2	5	25
Number of Containers	38	19	3

4) MPLCs are not manageable without load support.
5) A single crewmember is required on the lander deck for all offloading methods with the other crewmember on the ground ready to "receive" the item.

6) Any unloading operation should require no more than a single climb onto the lander deck by each crewmember.
7) A single crewmember can lower the SPLC from the Zipline to the ground and unhook it.
8) 1.0 SPLC can be carried and handed off into the airlock (A/L) by one crewmember.
9) Both 1.0 and 2.0 SPLCs can be dragged *a few feet* to make room for unloading, but not any significant distance as a strategy. (We will not prescribe this distance, but will note what's required during testing).
10) The thermal cover on the outside of the containers is strong enough to withstand dragging along the ground.
11) Both 1.0 and 2.0 SPLCs can be dragged from the staging area outside the Airlock *across the seal protection* into the Airlock by a single crewmember.
12) 2.0 SPLCs require two crewmembers to carry.
13) All SPLCs require two crewmembers to load them into the Airlock if not dragging across seal protection.
14) All containers must be dusted prior to entering A/L, which can be accomplished by one person.
15) Each crewmember must be thoroughly brushed for dust by their buddy prior to entering the A/L.
16) Each crewmember will be inspected by their buddy as "clean" before entering A/L.

Scenarios were exercised by a two-person crewmember pair. All study crewmembers were fully briefed on all ground rules and assumptions intended for each scenario. However, the crewmembers were given autonomy to strategize and execute the activity in the most efficient manner they can find.

2.4.4 Test Scenario Details

Planned Test Scenarios:
Over the course of five days, ten scenarios were planned for data collection to map back to the SAC Task 23.12 and 23.12x requirements. Captured in the scenarios include offloading the MPLC with a conceptual davit and transfer it to the rover aft deck and mating the container to a conceptual transfer hatch. Two scenarios used the same davit to offload small and large SPLCs into a conceptual airlock (Figure 19). A davit reload task took empty SPLCs and returned them to the cargo lander deck. Additionally, using a zipline as a variation in offloading method, both small and large SPLCs were transferred into the airlock (Figure 20). Finally, the test team examined the airlock choreography where subjects were inside the airlock moving containers around to doff (ingress) or don (ingress) their suits. Figure 21 shows the scenarios and the test days that were planned. Appendix A provides a detailed description of procedures for each scenario.

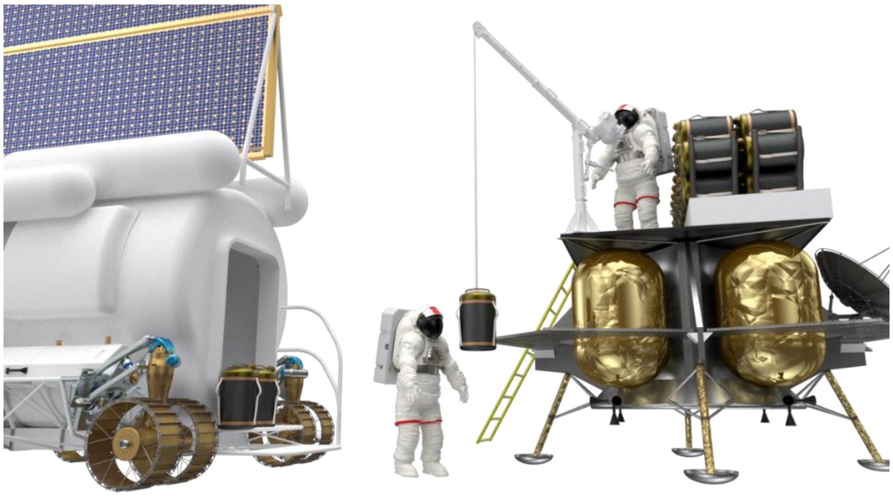

Figure 19. Concept depicting use of davit to offload 1.0 SPLCs to the airlock/Pressurized Rover.

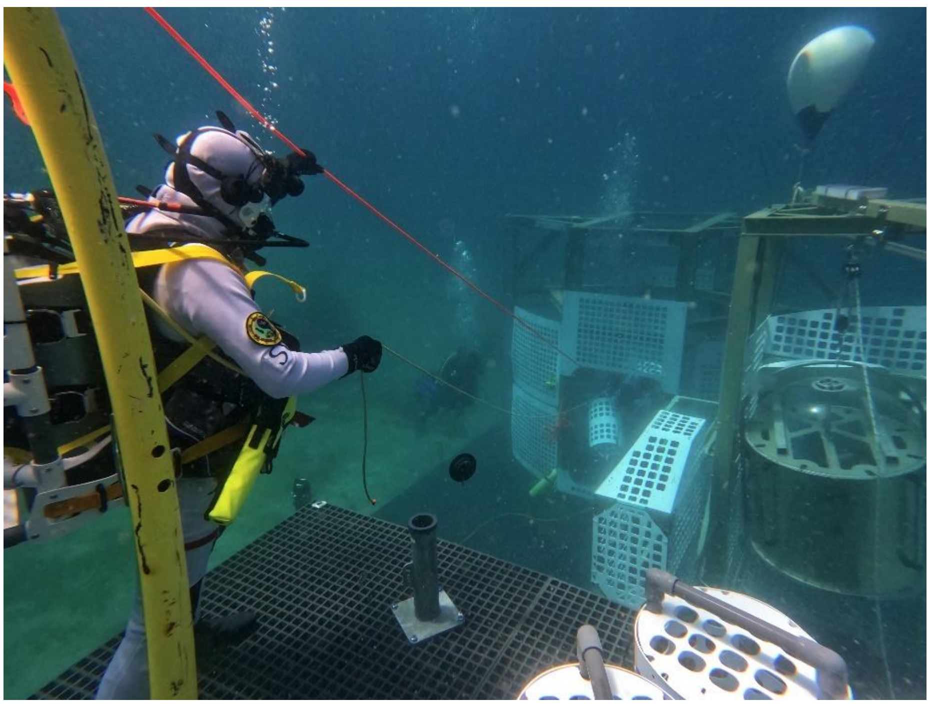

Figure 20. Using a zipline to offload 1.0 SPLCs to the airlock in SEATEST 6.

Davit	1. 1.0 CTBE SPLC Transfer to Staging Area using Davit
	2. 2.0 CTBE SPLC Transfer to Staging Area using Davit
	3. 2.0 CTBE SPLC Reload using Davit (raising from surface back to lander deck)
Zipline	4. 1.0 CTBE SPLC Transfer to Staging Area using Zipline
	5. 1.0 CTBE SPLC Transfer to Airlock using Zipline
	6. 2.0 CTBE SPLC Transfer to Airlock using Zipline
A/L	7. Airlock Egress Choreography with 2.0 CTBE SPLCs
	8. Airlock Ingress Choreography with 1.0 CTBE SPLCs
	9. Airlock Ingress Choreography with 2.0 CTBE SPLCs
MPLC	10.MPLC

Figure 21. Protocol SEATEST 6 Scenarios.

2.5 Data Collection

The test ground support team had access to full communications with the crew. The crew were equipped with full-face masks that included a helmet camera and microphone (Neptune III) that streamed live video and audio back to the ground support team. A situational awareness video camera was positioned around the mockup areas being streamed back live to ground support. Therefore, both video and audio test data were captured for in-test and post-test monitoring/analysis. The test team also broadcasted a live feed to a secure TEAMS channel that was recorded as a data backup. Support drivers for each crew pair documented the events through underwater still and video photography.

Objective and subjective data were collected from Crewmembers playing the role of an Artemis crew during each scenario (objective) and after each test day (subjective). Objective data gathered included task timing and collisions/hang-up events recorded by two data collectors seated in MCC observing scenario runs in real time. MCC data collector 1 and 2 recorded objective data for EV1 and EV2, respectively. Timing data were in the form of marked events to record time durations of scenario subtasks. Events included time required for crew to climb up/down the cargo lander ladder, time on the lander deck, time moving the logistic containers off the lander deck and onto the ground, time moving the logistic containers to the staging area, time for dusting operations, time moving the logistic containers into the airlock, as well as a total end-to-end logistic operations time see Table 3 for list of subtasks and descriptions). An additional objective measure included a count and locations of all "hang-up" points and any inadvertent "dings" or collisions of the airlock hatch or lander deck.

Table 3. *Objective Timing and Collisions Data Collection*

Data Type	Objective Data	Data Description
Objective Timing (hh:mm:ss)	Climb/Descending Ladder	Amount of time it takes a crewmember to climb/descend the cargo lander ladder
	Lander Deck	Amount of time the crewmember is physically on the lander deck from the point of first step onto the deck to the last step off the deck
	Offloading	Amount of time to offload all logistic containers
	Transport	Time moving the logistic containers from the feet of the cargo lander to the staging area at the Airlock

Table 3. *Objective Timing and Collisions Data Collection*

Data Type	Objective Data	Data Description
	Staging	Amount of time it takes a crewmember(s) to stack the logistic containers at the staging area
	Dusting Ops	Amount of time it takes a crewmember(s) to dust off all logistic containers and themselves
	Loading in A/L	The amount of time in takes two crewmembers to stow all the logistic containers into the Airlock, ingress the Airlock and close the Airlock Hatch
	Total Task Time	Amount of time for the entire end-to-end logistics operations from first step up on the ladder to closing the Airlock hatch
	AL Dance Clearing EV 1 suit stand	Amount of time to reconfigure AL and logistics containers to clear EV1 suit stand for doffing
	AL Dance Clearing EV 2 suit stand	Amount of time to reconfigure AL and logistics containers to clear EV2 suit stand for doffing
	AL Dance Total Task Time	Amount of time for entire reconfiguration of logistic containers to clear suit don/doff stands. Timing starts when crew starts reconfigure of logistic containers to going to internal hatch
Objective "Hang-ups"	Overall Offloading Zone Area	Any areas within the overall offloading zone where the crew got hung up and burned unnecessary time
Objective Collisions	Airlock Hatch	Amount and location of any collisions on the Airlock hatch with logistic containers, PLSSs, or human body parts

Subjective data were collected during consensus discussions among all crew at the end of each test day. Comments vocalized by crew in real-time during testing were recorded as field-notes when feasible to be used as "conversation starters" and "memory jogs" during consensus discussions.

Subjective data collection involved the use of three subjective feedback/rating scales. The Acceptability Scale was developed by NASA's Exploration Analogs and Mission Development (EAMD) project during analog field testing in 2008 [3] is based on a 10-point Likert scale (1-10) where the scale is divided into five distinct categories with two numerical ratings within each category to discriminate preferences (Figure 22). The scale was designed, in part, from the Cooper-Harper Quality Handling Scale to have a scale that could quantify how the acceptability of the logistic operations by the subject using a simple scale. Likert scale data can be considered as either interval or ordinal depending on the presentation of the rating scale to the subject [4]. The Acceptability rating scale is interval because only the rating category, e.g., totally acceptable, acceptable, etc. has a label and descriptor, each individual rating does not have a label. A reasonable interpretation of this scale by a subject is that the distance between the data points along the scale are equal [4]. This is reinforced by the constant width of the scale itself. Interval data can be analyzed with descriptive statistics. The individual acceptability ratings will be analyzed to provide minimum, maximum, and median acceptability using a 95% confidence interval for each timeline task. Additionally, there was a crew consensus rating for each of the tasks at the end of each mission day (Appendix B).

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

Figure 22. The EAMD Acceptability Rating Scale.

Simulation quality ratings (Figure 23) reflect the extent to which the simulation allows meaningful evaluation of the aspects of logistic operations being assessed in this study. Unplanned communications drop-outs, unresolved hardware failures, and low-fidelity mockups are examples of factors that could affect simulation quality ratings. Aspects of logistic operations that are not being assessed in this test will be intentionally excluded from consideration when providing ratings of simulation quality. See Appendix C for the simulation quality questionnaire.

Scale Rating	Criteria
1	Simulation quality (e.g. hardware, software, procedures, comm., environment) presented either zero problems or only minor ones that had no impact to the validity of test data.
2	Some simulation limitations or anomalies encountered, but minimal impact to the validity of test data.
3	Simulation limitations or anomalies made test data marginally adequate to provide meaningful evaluation of test objectives (please describe).
4	Significant simulation limitations or anomalies precluded meaningful evaluation of major test objectives (please describe).
5	Major simulation limitations or anomalies precluded meaningful evaluation of all test objectives (please describe).

Figure 23. The EAMD Simulation Quality rating scale.

Each HITL test crew provided consensus simulation quality ratings along with each acceptability rating because the same simulation may differ in quality depending on the types of operations being assessed or the perspectives from which it is being assessed (e.g., by different groups). When a simulation quality rating of 4 or 5 is given, the corresponding ratings by that group will not be used in objective testing because, by definition, significant simulation limitations or anomalies preclude meaningful evaluation of major test objectives. Due to the exploratory nature of this study, it is understood (and expected) that not all logistics operations elements provided throughout the scenarios of this test will provide a flight-like simulation and obtaining this metric will enable the study team to place other ratings in context.

A primary objective of this study is to identify which capabilities are required for transfer operations to support crew and which capabilities might enhance logistics but are not essential. It is also important to identify capabilities that provide marginal or no meaningful enhancement, and can therefore be excluded, resulting in cost savings without impact to mission success. Thus, a 10-point Capability Assessment rating scale (Figure 24) has been devised to rate the extent to which candidate capabilities are expected to enable and enhance future exploration missions. This scale consists of 5 categories: essential/enabling, significantly enhancing, moderately enhancing, marginally enhancing, and little to no enhancement. Throughout testing, the test subjects will use capability assessment ratings to describe the level of mission enhancement provided by a given capability (Appendix D).

Essential/Enabling		Significantly Enhancing		Moderately Enhancing		Marginally Enhancing		Little or No Enhancement	
Impossible or highly inadvisable to perform mission without capability		Capabilities are likely to significantly enhance one or more aspects of the mission		Capabilities likely to moderately enhance one or more aspects of the mission or significantly enhance the mission on rare occasions		Capabilities are only marginally useful or useful only on very rate occasions		Capabilities are not useful under any reasonable foreseeable circumstances	
1	2	3	4	5	6	7	8	9	10

Figure 24. The Capability Assessment Scale.

2.6 Test Execution

2.6.1 Test Team Training and Qualifications

Test subject crew were qualified/certified in 1) Open Water SCUBA (Self-Contained Breathing Apparatus), 2) American Academy of Underwater Sciences (AAUS), and 3) full face mask. Topside divers were qualified/certified in 1-3, as well as 4) Aquarius Reef Base "Working Diver". Topside divers had previous NASA Extreme Environment Mission Operations (NEEMO) diving experience. Other training included familiarity ("fam") and mission briefings at JSC and deck fam with hardware at the test site. Participants also completed mission-specific dive training that included familiarization with Neptune III Full Face Mask, undersea familiarizations with the logistics mockups, end-to-end engineering dry runs, and mission-configuration out-of-air emergency drills.

2.6.2 Diving ConOps: Test Scenario Execution

There were five test subject crewmembers for SEATEST 6. To execute the test scenarios, crew were paired as a team of two for approximately one hour per scenario. Crew performed various cargo transfer scenarios as a two-person team. Crewmembers not currently conducting the scenarios underwater observed from MCC so that all crew could participate in consensus discussions. Five crewmembers rotated through EV1, EV2, and MCC observation roles and experienced each scenario type (davit, zipline, airlock). Four scenarios were tested per day, over the course of the test days.

The primary role of the support diver was to provide primary operations support. One support diver was buddied with one crewmember for each scenario. Additionally, these divers also provided configuration support (e.g., fin and PLSS don/doff, negative buoyancy weighting to achieve partial gravity simulation, in-test hardware troubleshooting), communication umbilical management, and photo documentation. Following the test scenario, support divers re-configured hardware in preparation for the next scenario test.

2.6.3 MCC/Crew Comm Protocol

To increase test fidelity, a communications protocol between MCC and the crew were defined prior to the test. The protocol included the following points:

- Crewmembers referred to as EV1/EV2.
- CapCom referred to as MCC.
- CapCom relayed procedure steps to crew and managed scenario timeline during run.
- Crew would speak "aloud" to provide rationale for their techniques and approaches.
- Thermal/Tank Pressure/Glove checks every ~10 mins (similar to ISS EVA Glove checks).

Additionally, when crew were interacting with suspended or unsecured loads, overcommunication was encouraged. Crew were instructed to be explicit with diver locations and enunciating who has "eyes-on" and who has control of the load. Crew also were instructed to verify the location of all divers (including the test support divers) prior to motion of the load.

2.6.4 Minimum Success Criteria

To help manage priorities and resources, the following minimum success criteria were defined pre-mission:

Mockup deployment: Deployment of the deck, lander, airlock, and all supplemental hardware (davit, zipline, 1.0 and 2.0 SPLCs, and MPLC).

Communications ("Comm") Setup: Verification of good internet connection and Wi-Fi connectivity both at MCC and at the dock where scenarios were to occur. Verification of the Diver Comm Box at the dock, including 2-way voice to all divers, diver helmet cameras, and situation awareness camera. Verification of the capability of recording all video and audio streams. Confirmation of an alternate method of communication between the dock and MCC in the event of primary communication equipment failure (achieved via radio).

Training: All support divers and test subject crew divers complete all elements of training to qualify to participate and support the mission. Crew familiarization training session (where there were no test objectives) to include full communication setup. Test subject crew to complete out-of-air emergency drills while in full mission configuration (fins off and wearing PLSS and additional weights).

Dry Runs: One full day of dry runs with the assembled mockups – exercise of zipline system in offloading direction; exercise of davit system in both offloading and loading directions; demonstration of: reconfiguration of zipline pole, davit, and container weights; end-to-end comm check with MCC; and a designated opportunity for the crew to see all assembled hardware.

Test Runs (in priority order):

A. 1.0 SPLC transfer with davit
B. 1.0 SPLC transfer with zipline to airlock
C. 2.0 SPLC ingress airlock choreography
D. 2.0 SPLC egress airlock choreography
E. 2.0 SPLC transfer with davit

Mockup Retrieval: All pieces of the mockup must be retrieved from the sea floor and placed in local storage.

Crew Data: Capture of crew ratings from each run and consensus feedback for the entire mission.

Mission Statuses: Dissemination of mission status to DSB every other day of the mission, and status reports to mission management at three timepoints (after training/setup, mid-test week, and post mission).

Mission Data Capture: All video, audio, and still photo captured for this test and returned to Houston.

All minimum success criteria were completed except the 2.0 SPLC ingress airlock choreography. Note: test duration was not long enough to necessitate a mid-test week status report and was excluded.

2.6.5 Additional Objectives to Meet Full Mission Success

While the criteria listed in 2.6.4 define the minimum basis of mission success, additional criteria were defined to qualify full mission success. These additional objectives to meet full mission success are as follows:

Mockup Deployment: Deployment of the pressurized rover aft deck mockup.

Communications ("Comm") Setup: Verify connectivity between Diver Comm Box and MCC – these items include confirmation of MCC ability to view both diver helmet cameras and situation awareness camera, 2-way voice with divers 1 and 2, and diver 3 ability to hear MCC.

Dry Runs: A second day of dry runs with the assembled mockups for an additional opportunity to familiarize themselves with the mockups and transfer hardware.

Test Runs (in priority order):

A. 1.0 SPLC transfer with zipline to staging area
B. 1.0 SPLC ingress airlock choreography
C. 2.0 SPLC transfer with zipline to airlock

Lowest Priority Test Runs:

A. 2.0 SPLC reload with davit
B. MPLC load/reload with davit

Flexible scenario ("dealer's choice") defined by the test team, in the event that an opportunistic scenario is deemed of higher value than pre-determined scenarios.

Of the above Full Mission Success criteria, all were accomplished with the exception of the ability for diver 3 to hear MCC, the MPLC load/reload with davit scenario, and the "dealer's choice" scenario.

3.0 RESULTS

3.1 Results Overview

The SEATEST test team accomplished evaluating four scenarios per day for two days (Figure 25). Of the ten scenarios proposed, eight were completed. Crew and logistics containers were weighted out to approximately 1/6g. Data collected consisted of timing data (in hh:mm:ss) and frequency of collision data for the lander deck and the airlock hatch. All transfer methods were tested with both the 1.0 and 2.0 SPLCs. Figure 26 shows the tested scenarios and their actual field-tested sequence.

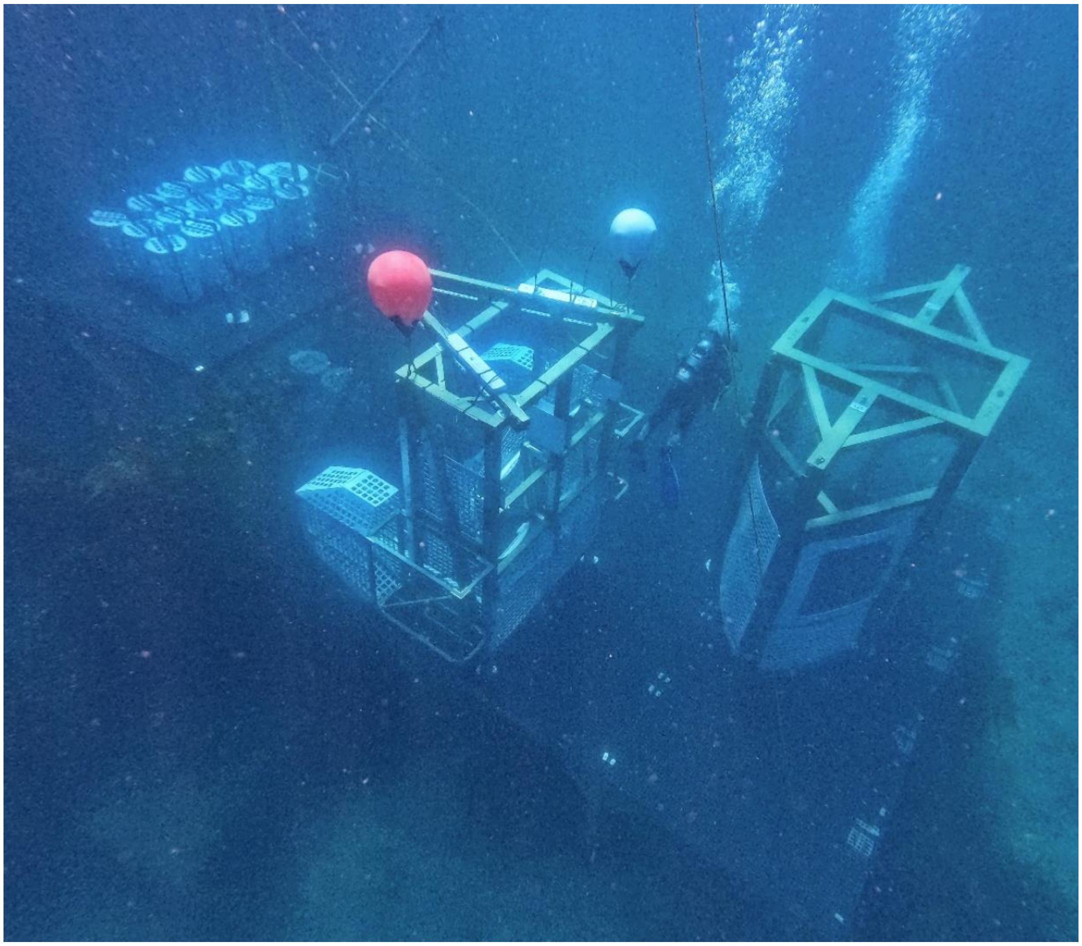

Figure 25. Underwater view of the SEATEST 6 lunar mockup.

Davit	1. 1.0 CTBE SPLC Transfer to Staging Area using Davit
	2. 2.0 CTBE SPLC Transfer to Staging Area using Davit
	3. 2.0 CTBE SPLC Reload using Davit (raising from surface back to lander deck)
Zipline	4. 1.0 CTBE SPLC Transfer to Staging Area using Zipline
	5. 1.0 CTBE SPLC Transfer to Airlock using Zipline
	6. 2.0 CTBE SPLC Transfer to Airlock using Zipline
A/L	7. Airlock Egress Choreography with 2.0 CTBE SPLCs
	8. Airlock Ingress Choreography with 1.0 CTBE SPLCs
	9. Airlock Ingress Choreography with 2.0 CTBE SPLCs
MPLC	10.MPLC

Figure 26. Study scenario sequence.

The remaining 2 (with lowest priority) were not accomplished as the test was terminated early due to circumstances beyond the control of the team (3 key participants became ill). All objective and subjective data outlined previously was collected on the accomplished scenarios. Insights from debriefs, discussions, and testing prior to the mission were also captured in these scenarios.

The tasks that were not accomplished were the MPLC task, and 2.0 SPLC airlock ingress choreography. The following section is a summary of the data collected and further analysis will be undertaken by the primary stakeholders.

3.2 Objective Data

The objective data collected was constructed around the logistic offload flow model which consisted of five different logistical phases: 1) Offload Phase – where the lander crewmember unstraps the cargo, attaches a hook (davit or zipline) to the logistic container and fully lowers the container down to an awaiting crewmember who is on the lunar surface: 2) Transport Phase – where the surface crewmember makes first contact with the lower logistic container, unhooks the container from the hook (davit or zipline) and places the container either in a staging area or inside the airlock; 3) Dust Phase – if the container is placed in a staging area, one crewmember commences dust operations of each container at the staging area and passes the cleaned container to another crewmember in the airlock; however, this phase step can be omitted if the container is transported straight into the airlock; 4). Load Phase – working as a team, both crewmembers move the logistic containers from the staging area to the airlock interior and stack the containers, being careful to maintain an ingress path into the airlock while at the same time protecting the hatch seals; and 5) Airlock Cycle – this is the accumulated time it takes the crewmember(s) to stack or reconfigure the logistic containers to maintain a path to suit don/doff stands and both hatches and ingress the airlock. For these flows see Figure 27, Figure 28, and Figure 29. In the context of these phases, the test team collected granular timing data of events including ascending/descending the cargo lander ladder, the amount of time the crewmember is on the lander deck, the amount of time getting the logistic containers off the lander deck and onto the ground, time moving the logistic containers to the staging area/airlock, time it takes for dusting operations, and the time moving the logistic containers into the airlock (Figure 30). Additionally, the total end-to-end logistic operations time was recorded.

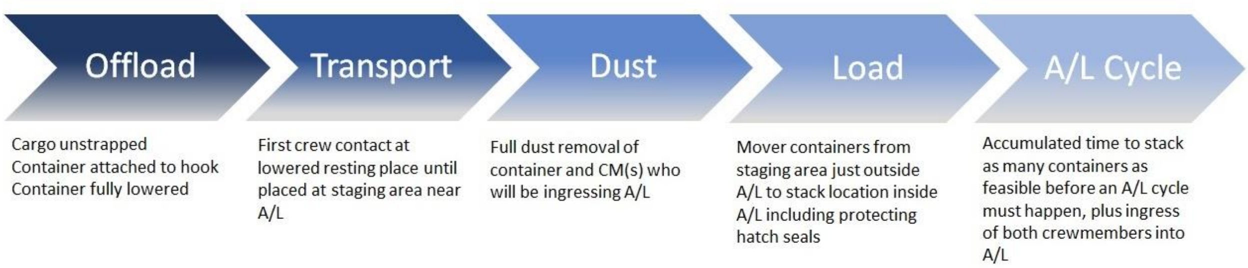

Figure 27. The logistic offloading flow for the davit and zipline.

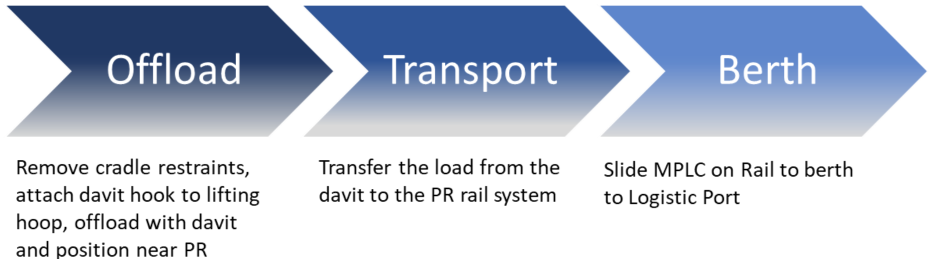

Figure 28. The logistic offloading flow for the MPLC.

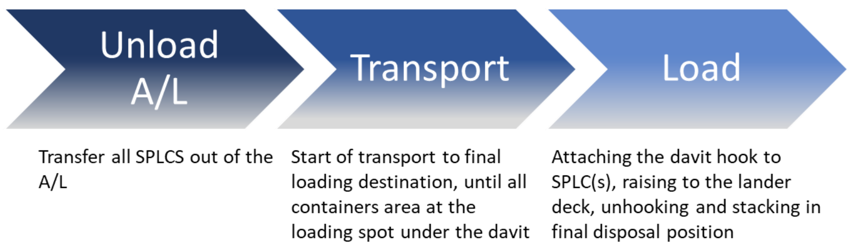

Figure 29. The logistic offloading flow for the MPLC.

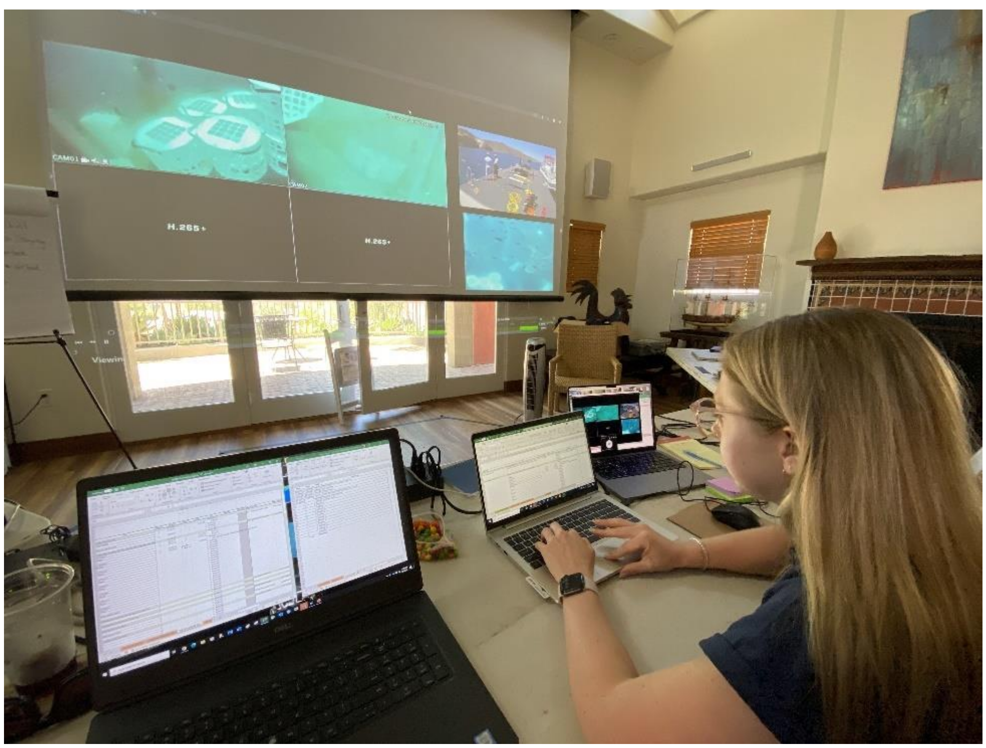
Figure 30. Protocol team in MCC collecting timing data.

As another objective measure, the team noted locations of all "hang-up" points and any inadvertent "dings" or collisions of the lander deck and airlock hatch (Table 4) with the objective of enabling primary stakeholders to analyze significant granular events of the task for future timeline development, while also having cumulative time data for the larger picture of the logistic flow process. Table 5 is an example of the field timing data collected. The team constructed data tables for each scenario and pre-processed the field data for dissemination to stakeholders.

Table 4. *Lander Deck and Airlock Hatch Collision Data*

Scenario Number	Scenario	Lander Deck	Hang ups in Offload Zone Area	Airlock Hatch			
				Top	Stbd Side	Port Side	Bottom
01	1.0 Davit	0	0	0	0	0	0
02	1.0 Zipline Airlock	11	0	0	0	0	0
03	1.0 Zipline Staging Area	1	1	0	0	0	0
04	1.0 Airlock Transfer Ops	0	0	0	0	0	0
05	2.0 Zipline Airlock	3	0	0	0	0	0
06	2.0 Reverse Davit (Reload)	0	0	0	0	0	3
07	2.0 Davit	0	0	0	0	0	0
08	2.0 Airlock Transfer Ops (Reverse)	0	0	0	0	0	1

Table 5. ***Example of The SEATEST 6 Timing Data***

MISSION DAY	*1*							
SCENARIO:	*1*							
DESCRIPTION:	*1.0 SPLC Transfer to Staging Area Using Davit*							
EV1								
EVENT MARKERS		**EVENT**			**TIME FORMAT: h:mm:ss**			
EVENT START	EVENT END		Clock Time Start	Clock Time Stop	Interval Start	Interval Stop	Δt	NOTES:
CAPCOM "Go"	End of last scenario task	Task Total	9:20:49	9:47:53	0:00:00	0:27:04	0:27:04	
First foot on first step	Foot on deck	Climb Ladder	9:21:49	9:22:11	0:01:00	0:01:22	0:00:22	
Foot on deck	Foot on ladder	Time on Lander Deck	9:22:07	9:39:18	0:01:18	0:18:29	0:17:11	
First contact with first container	EV2 remove hook from last container	Offloading Containers (Cumulative)	9:22:27	9:38:41	0:01:38	0:17:52	0:16:14	EV2 going to airlock with container (3 containers total in AL)
First contact with container	EV2 remove hook from container	Offload Container 1	9:22:27	9:23:49	0:01:38	0:03:00	0:01:22	standing on the side of davit while cranking wench
EV2 remove hook from container	EV1 contact with next container	Reset Davit	9:24:09	9:25:09	0:03:20	0:04:20	0:01:00	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
First foot on ladder	Last foot off ladder	Descend Ladder	9:38:53	9:39:26	0:18:04	0:18:37	0:00:33	
First step of walk towards A/L	Reach A/L	Translate to Airlock	9:39:26	9:40:08	0:18:37	0:19:19	0:00:42	
First swipe brush	Last swipe of brush	Dust Ops - EV2	9:40:16	9:42:48	0:19:27	0:21:59	0:02:32	wants a longer brush when dusting off EV2
First swipe brush	Last swipe of brush	Dust Ops - Containers	9:43:54	9:47:42	0:23:05	0:26:53	0:03:48	7 containters in staging area (EV1 dusting container only while EV2 loading in container. EV1 dusting sides, bottom, and top)
Lift of first container	Last container contact and crew over ha	Staging in Airlock (handover to EV2)	9:44:16	9:47:44	0:23:27	0:26:55	0:03:28	offloaded 10 1.0 splcs total

MISSION DAY	*1*							
SCENARIO:	*1*							
DESCRIPTION:	*1.0 SPLC Transfer to Staging Area Using Davit*							
EV2								
EVENT MARKERS		**EVENT**			**TIME FORMAT: h:mm:ss**			
EVENT START	EVENT END		Clock Time Start	Clock Time Stop	Interval Start	Interval Stop	Δt	NOTES
CAPCOM "Go"	End of last scenario task	Task Total	9:20:49	9:47:53	0:00:00	0:27:04	0:27:04	
EV1 climb ladder	First container contact for transfer	Wait for Transfer Start	9:21:42	9:23:47	0:00:53	0:02:58	0:02:05	
First contact with first container	Last contact with last container after transfer	Transfer Containers (Cumulative)	9:23:47	9:38:22	0:02:58	0:17:33	0:14:35	Deposit into A/L
First contact with container	Last contact with container after transfer	Transfer Container 1	9:23:48	9:24:45	0:02:59	0:03:56	0:00:57	Deposit into A/L
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
First swipe of brush	Last swipe of brush	Dust Ops - EV1	9:39:42	9:41:40	0:18:53	0:20:51	0:01:58	
First swipe of brush	Last swipe of brush	Dust Ops - EV1 Brush EV2 Feet	9:44:01	9:44:11	0:23:12	0:23:22	0:00:10	
Ingress A/L	Last container down in A/L	Configure/Staging in Airlock (handover from EV	9:44:28	9:47:42	0:23:39	0:26:53	0:03:14	

<u>**Table Note:**</u> *Example table of objective timing data collected for EV1 and EV2, representative for each scenario (grayed out boxes/break in table indicates similar data that is not shown). Similar tables were constructed for each scenario. Start/Stop event markers are included for each event. Clock Time Start/Stop indicate local task times (when available), Interval Start/Stop indicate event timing within the task timeline. Δt indicates the time duration of each subtask (hh:mm:ss). Notes were provided for added event context when appropriate.*

3.3 Subjective (Crew Consensus) Data

Subjective data collected consisted of the 5-point simulation quality ratings and the 10-point capability assessment and acceptability ratings (see section 2.5 for rating scale descriptions). After each day of testing, the crew assembled for approximately two to three hours to rate and discuss the scenarios for that day without any outside interference (Figure 31). Eliminating distractions and interference ensured the crew had the freedom to discuss and rate the events of the day in a way that was fair and unbiased without, pressures from stakeholders. During these consensus sessions, a senior member of the test team was with the crew as a mediator if questions or a technical issue arose. After each session, the data were saved and backed up on two different servers to protect from any lost. During this phase of the subjective data collection, crew were asked to score the simulation quality for the day and the acceptability of each task. Much like the objective data, granularity of these tasks was key to understanding the entire task as well as more subtle task components. On the last day of testing, the crew was asked additional questions regarding the mission as a whole. This consists of the 10-point capability assessment which covered the essentiality of using each tested transfer method for the success of the mission. This is also conducted with a senior test team member in a closed environment, much like the one described for the simulation quality and acceptability. Finally, the crew participated in a more open discussion with primary stakeholders with an open-ended question debrief which was provided to the crew in advance. In this hour-long session, the stakeholders were permitted to interact with the crew to gain further understanding of the tasks from the crew directly. Stakeholders were encouraged to couple their findings from the debrief with the data collected in the field for the most comprehensive understanding of each event.

Figure 31. A crew consensus session during the SEATEST 6 study.

3.3.1 Simulation Quality Results

As previously discussed, simulation quality ratings reflect the extent to which the simulation allows meaningful evaluation of the aspects of logistic operations being assessed in the study. Two areas were considered – the environment as compared to expected lunar environment (e.g., 1/6g effects, mass management, offloading concept fidelity, etc.) and the environment's ability to provoke relevant operational considerations (e.g., dusting requirements, suit maneuverability, mechanisms, system fidelity, etc.) (Figure 32). It was stated during this part of the consensus session, that the simulation did provoke much thought about the relevant operational considerations. Regarding the 1.0 and 2.0 SPLC scenarios in the underwater environment when compared to expected lunar environment, a rating of 3 was given indicating the simulation limitations made the test data marginally adequate to provide meaningful evaluation of test objectives. The major concerns included the slack in the zipline required a substantial change in how the crew used this method to complete the scenario (Figure 33). Additionally, the zipline control line needed to be extended approximately 10 feet (3.05 meters). A rating of 3 was also given for the 2.0 containers, with the comment that using the davit for larger containers forced the lander crewmember to the edge of the lander deck. Further, while positioned on the edge of the lander deck, the water resistance provided an increased stability (i.e., "leaning" against the water) that would not be present in a lunar environment. As for the environment's ability to provoke relevant operational considerations, a score of 2 given for both transfer methods and container size indicated that there were some simulation limitations or anomalies encountered, but minimal impact to the validity of testing. Items of note were the limited simulation of the volume of the suit beyond the PLSS, limited fidelity of the airlock, lack of lunar simulation communications, and range of motion limitations were not simulated. All the simulation quality criteria were met for successful objective testing (Figure 34).

1.0 SIMULATION QUALITY					
Questionnaire Element	**Simulation quality (e.g. hardware, software, procedures, comm., environment) presented either zero problems or only minor ones that had no impact to the validity of test data**	**Some simulation limitations or anomalies encountered, but minimal impact to the validity of test**	**Simulation limitations or anomalies made test data marginally adequate to provide meaningful evaluation of test objectives (please describe)**	**Significant simulation limitations or anomalies precluded meaningful evaluation of major test objectives (please describe)**	**Major simulation limitations or anomalies precluded meaningful evaluation of all test objectives (please describe)**
	1	**2**	**3**	**4**	**5**
The environment as compared to expected lunar environment (1/6 g effects, mass management, offloading concept fidelity, etc.)					
The environment's ability to provoke relevant operational considerations (dusting requirements, suit maneuverability, mechanism and system fidelity, etc.)					

Figure 32. Simulation quality of the test environment for the 1.0 containers.

2.0 SIMULATION QUALITY					
Questionnaire Element	**Simulation quality (e.g. hardware, software, procedures, comm., environment) presented either zero problems or only minor ones that had no impact to the validity of test data**	**Some simulation limitations or anomalies encountered, but minimal impact to the validity of test**	**Simulation limitations or anomalies made test data marginally adequate to provide meaningful evaluation of test objectives (please describe)**	**Significant simulation limitations or anomalies precluded meaningful evaluation of major test objectives (please describe)**	**Major simulation limitations or anomalies precluded meaningful evaluation of all test objectives (please describe)**
	1	**2**	**3**	**4**	**5**
The environment as compared to expected lunar environment (1/6 g effects, mass management, offloading concept fidelity, etc.)					
The environment's ability to provoke relevant operational considerations (dusting requirements, suit maneuverability, mechanism and system fidelity, etc.)					

Figure 33. Simulation quality of the test environment for the 2.0 containers.

Figure 34. Test setup used during the SEATEST 6 study.

3.3.2 Capability Assessment Results

Capability Assessment enables the identification of capabilities required to support the crew for successful transfer operations how mission enhancing (or not) each method was for conducting the specific tasks under the simulated environment. A capability assessment rating of 2 was given for the davit, indicating this method was an *essential and enabling* capability to successful perform the logistic transfer operations for a given mission (Figure 35). Comments about the davit transfer capabilities included the need flexibility for loading/unloading of containers without having to physically lift the container at any time during the offloading process and therefore minimizing crew fatigue. With the lander deck at a significant height from the surface (2.5 m), a tool for logistics transfer, such as a davit, is needed to accomplish safe transfer (especially for larger items) (Figure 36). The zipline transfer method received a capability assessment rating of 3, indicating capabilities of this method are *significantly enhancing* aspects for a successful mission. This method allows for potential dust-free transfer (containers transported directly from the lander into the airlock do not touch the lunar surface, and therefore would not require dusting) and seems especially useful for smaller items, saving EVA and dust operations time. The crew noted that of the two methods, the zipline seemed to be the quickest and most efficient way to transfer cargo. However, it does require the crew to physically lift the container to attach to the zipline. Additionally, the current attachment points seemed restrictive. A major takeaway is that a logistic transfer could be achieved without an offloading method; however, the time requirement for such operations would be prohibitive. The crew suggested that the most efficient means for logistics transfers of small containers could include a hybrid method using both a davit and zipline. For example, for larger payloads, the crew could use the davit as it has a greater mechanical advantage and makes the process easier for the crew, while the zipline could be used for smaller payloads that could be sent directly into the pressurized surface element.

CAPABILITY ASSESSMENT										
Questionnaire Element	Essential/Enabling		Significantly Enhancing		Moderately Enhancing		Marginally Enhancing		Little to No Enhancement	
	Impossible or highly inadvisable to perform mission without capability		Capabilities are likely to significantly enhance one or more aspects of the mission		Capabilities likely to moderately enhance one or more aspect of the mission or significantly enhance the mission on rare occasions		Capabilities are only marginally useful or useful only on very rare occasions		Capabilities are not useful under any reasonable foreseeable circumstances	
	1	2	3	4	5	6	7	8	9	10
The davit transfer concept										
The zipline transfer concept										

Figure 35. Capability assessment of the tested logistic transfer methods.

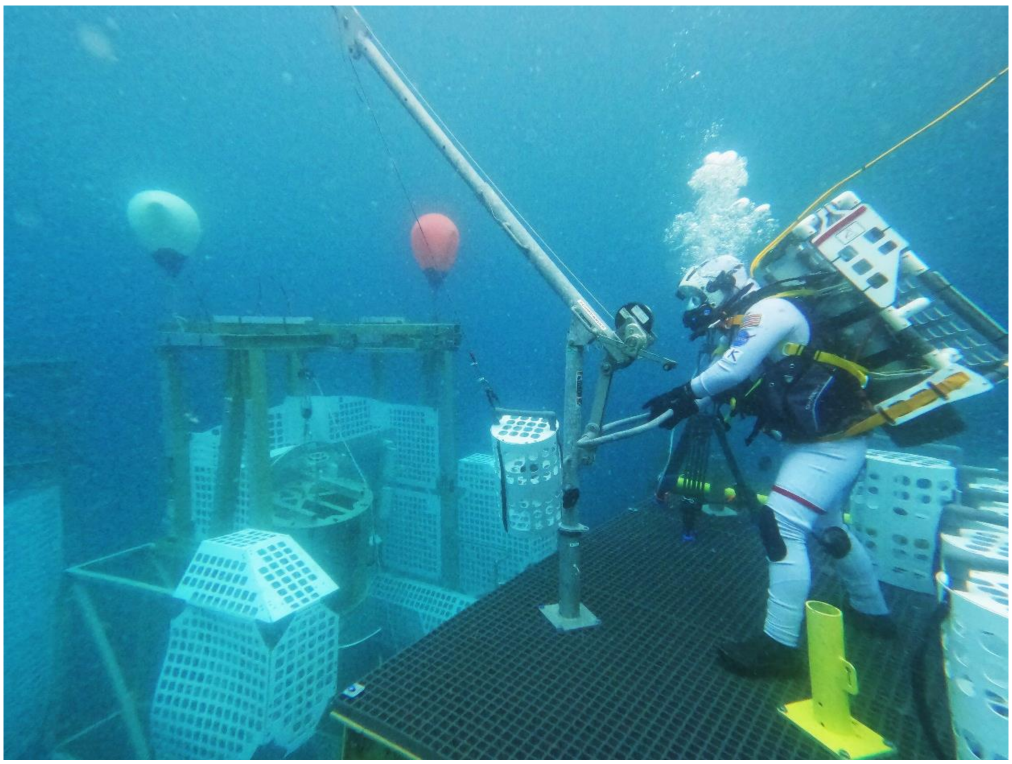

Figure 36. Crew working with the davit on the lander deck.

With simulation quality and capabilities scores indicating a positive result, the next five sections will discuss a summary of the acceptability ratings for davit operations, zipline operations and airlock operations. More detailed analysis of the data will be conducted by individual stakeholders.

3.3.3 Acceptability Results

An acceptability rating describes how acceptable (or unacceptable) a task (i.e., hand cracking a davit winch, attaching a container to a zipline, or reconfiguring containers in an airlock, etc.) was under the given simulated environment. There were eight acceptability surveys in total: 1.0 and 2.0 davit operations (2), zipline operations (including staging area and airlock) (3), 2.0 davit reloading operations (1), airlock choreography for 1.0 and 2.0 logistic containers (2). Table 6 illustrated the breakdown of acceptability by scenario elements (Table 6). The overall acceptability of each scenario is as follows:

- Airlock Choreography for both the 1.0 and 2.0 containers was scored as *acceptable* with only *minor deficiencies* requiring desired *minor improvements*.
- 1.0 Zipline Operations for both Airlock and Staging Area was scored as borderline with *moderate deficiencies* with *improvements warranted.*
- 2.0 Davit, Reverse Davit (Reload), and Zipline Airlock was scored as *unacceptable* with *unacceptable deficiencies with improvements required.*

Figure 37 illustrates the overall acceptability of each scenario in the sequence they were tested.

Table 6. *Breakdown of Acceptability by Scenario*

Scenario Number	Scenario	Total Elements/Scenario	Totally Acceptable	Borderline	Unacceptable
01	1.0 Davit	8	4	3	1
02	1.0 Zipline Airlock	8	2	6	0
03	1.0 Zipline Staging Area	8	3	5	0
04	1.0 Airlock Ingress Choreography	4	4	0	0
05	2.0 Zipline Airlock	8	1	4	3
06	2.0 Reverse Davit (Reload)	8	2	3	3
07	2.0 Davit	8	2	3	3
08	2.0 Airlock Egress Choreography	4	4	0	0

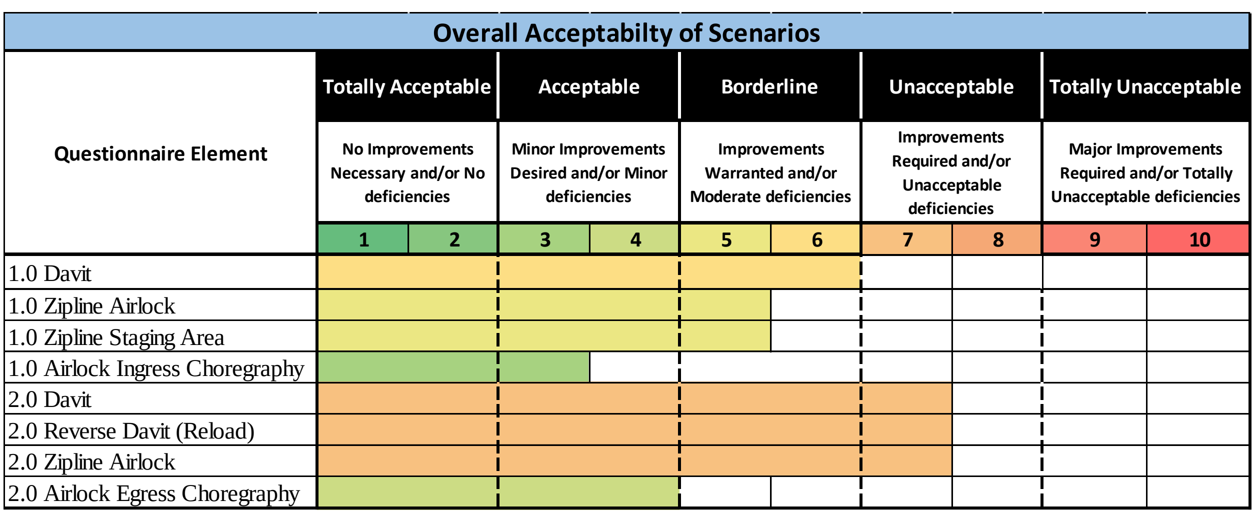

Figure 37. Overall acceptability of the tested logistic transfer methods across scenarios.

Davit Operations

For davit operations, overall acceptability scores varied depending on 1.0 versus 2.0 SPLCs. The scores were mainly driven by the proximity of the crewmember to the lander deck edge and the dust mitigation issues (Figure 38). It was noted that for a real lander with a significant deck height above the surface (2.5 m) a safety mechanism or barrier was strongly recommended (Figure 39). Some options were a rail, tether, or strap guard around the perimeter as a visual or physical aid to orient the crew as to where the lander deck ends. Any safety mechanism developed should still allow for continued offloading operations while restricting the crew to a safe area on top of the lander. For dusting operations, during the test, crew used a "paintbrush technique" (Figure 40) (mobilizing the wrist in both flexion and extension). However, wrist mobility in the space suit is limited, so a similar flexion/extension motion will likely be infeasible. Additionally, a longer handle brush would be required as well as handrails on the outside of the airlock for stability of suited crew. To further minimize time spent dusting, stacking the containers proved effective (i.e., stacked containers do not touch the regolith and would therefore would require less dusting).

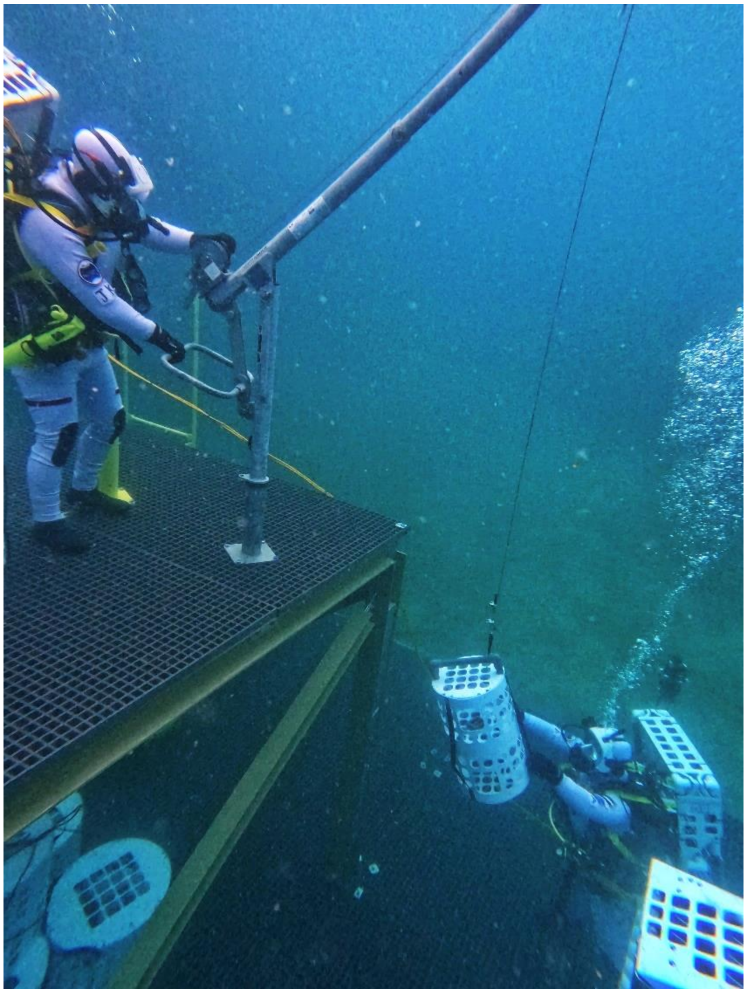

Figure 38. Crew using the davit transfer mode of operation.

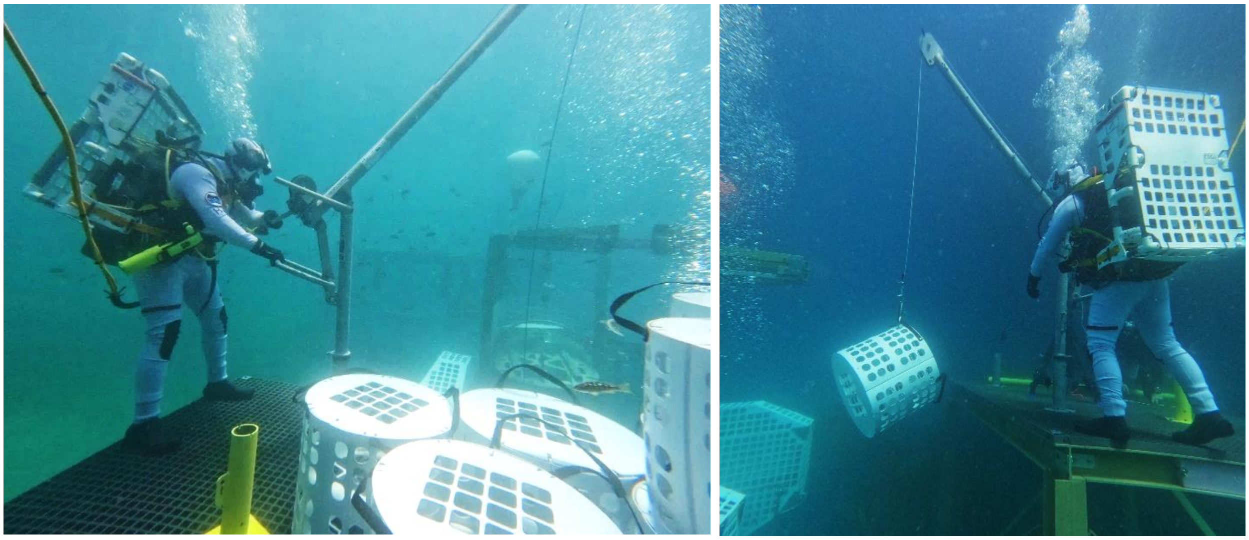

Figure 39. Crew's foot near the edge of the lander deck during offloading operations.

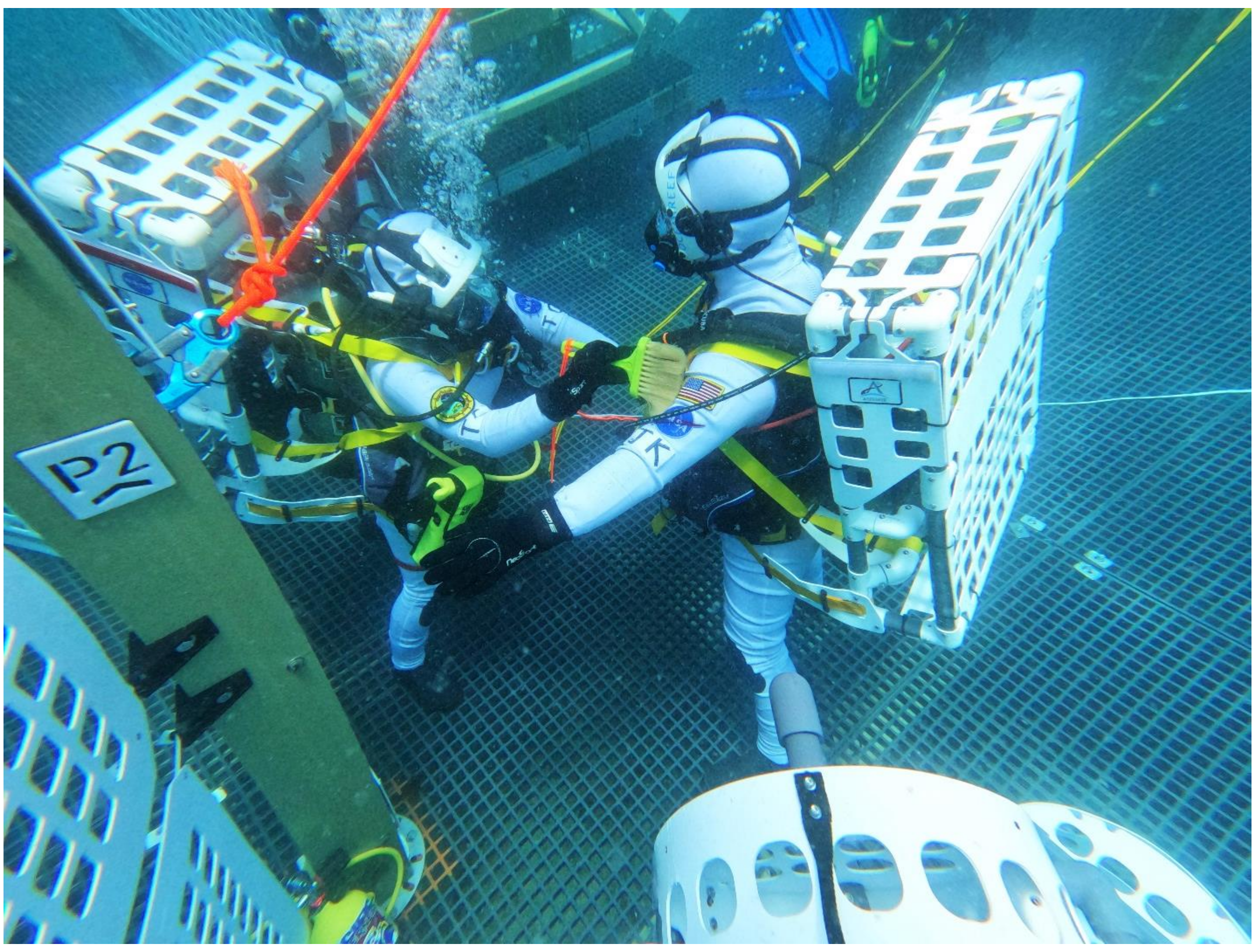

Figure 40. Crewmember dusting another crewmember.

The extended ladder handles allowed the crew to successfully reach the lander deck with enough clearance to accommodate the PLSS. The crew also developed an alternate method of swinging around one handrail to get their feet on the first ladder rung for an easier descent strategy (Figure

41). However, having a ladder that was sloped approximately 5 to 15 degrees would better aid a suited crewmember in ascending/descending with the weight of the suit and PLSS. As tested, the ladder was in a 90-degree vertical plane to the lander deck.

Figure 41. Crewmember using the ladder handle extension for an alternate descend path.

Davit mechanisms, especially the winch, showed some significant issues with the current design (Figure 42). The metabolic demand to manually operate a winch for offloading/onloading was rated as unacceptable. With the current suit design, crew cited it would be very difficult to accomplish this operation as the existing shoulder mobility capabilities are not conducive to this type of rotational motion of the shoulder. Additionally, it is hypothesized that such action would significantly increase the usage of critical resources, namely time and oxygen, which was reflected in the increased air usage from the SCUBA tanks for crew that manually operated the davit. To address this concern, a well-developed motorized davit winch or foot pedal (similar to the International Space Station (ISS) Articulating Portable Foot Restraint (APFR)) for yaw motion was suggested as a solution to make davit operations acceptable to the crew. Additional options included a davit arm pitch capability (~ 0 to 45 degrees) for flexibility in adjusting the radius that the davit arm can access (e.g., increase pitch angle for containers closer to the lander base pole), a hook design to handle multiple containers, an addition of a clutch for efficient lowering, and a ratchet mechanism to prevent inadvertent movement in the opposite direction.

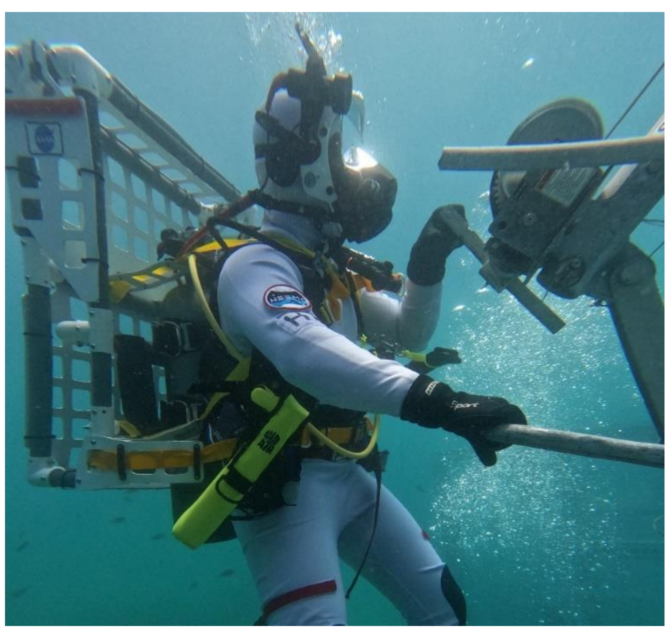
Figure 42. Crewmember using the davit winch.

Efficient stacking of logistics containers on the lander deck minimizes bending in the suit, resulting in more efficient offloading operations by reducing the time for dusting operations and crew fatigue. However, the weight of the 2.0 containers, did make the transfer phase of the process more challenging.

Zipline Operations

Overall acceptability for zipline operations ranged from *borderline* to *unacceptable*. With this method, loading and unloading was straightforward (Figure 43). However, there was some difficulty in the test maintaining line tautness; due to the height of the zipline on the lander base post, if the line were tightented then the container would collide with the tip of the airlock hatch. The resulting slackness that was necessary in the line lead to occasional impacts of the container on the edge of the lander deck. In order to mitigate the issue, the crew had to hold one hand above their head to tighten the line, which is not reasonable considering suit mobility (Figure 44).

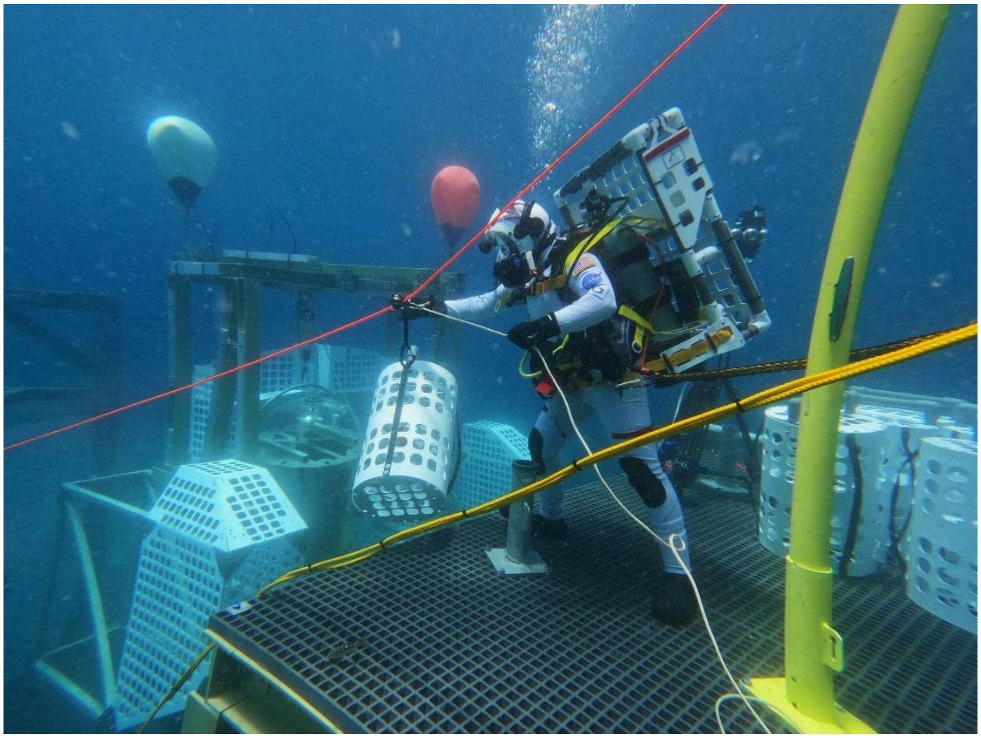

Figure 43. Crew using the zipline transfer option.

Figure 44. Crewmember holding up the zipline to avoid a collision with the lander deck.

For the receiving end of the zipline near or in the airlock, the crew noted it would be beneficial to have method to raise and lower the airlock attach point to account for variable distances from lander platform to create correct angle for container to clear airlock hatch. The distance of the zipline between the airlock and the landerdeck tested (4.89 m) was considered by the crew to be the maximum range (Figure 45) because the zipline angle may become too shallow for containter movement down the line.

Figure 45. A view of the 16-foot (4.89 meter) distance between the lander deck and the airlock.

There must be a control line slack management system. Additionally, the length of the control line must be increased by a minimum of 3.05 meters for improved controllability (Figure 46). As with the davit hook, requiring a hook design for multiple logistic containers would be beneficial. Another beneficial feature would include a bungee or a retractable line system to bring the container to the zipline attach point so crew would not have to physically pick up the container and attach it to the zipline system.

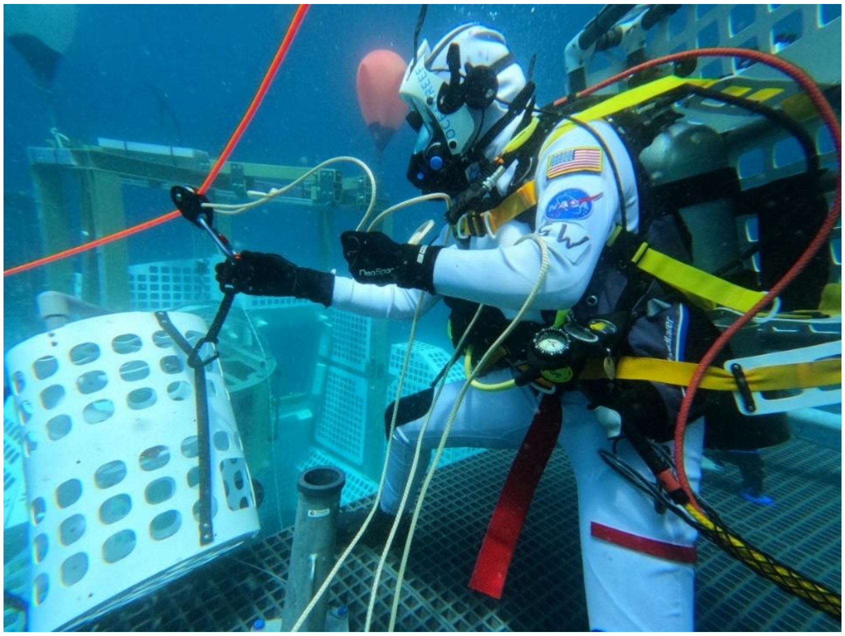

Figure 46. Control line management will be key.

For container improvement, additional soft tether points/D-rings integrated on the soft goods handles near the top and center of the handle would make loading of the 2.0 container more balanced and thus minimize reorientation requirements once the SPLC reaches the lunar surface or lander deck. Regardless of where the receiving end of the zipline was located (inside or outside the airlock) the crewmember could grab the soft handle upon receiving the SPLC (Figure 47) thereby eliminating dusting operations altogether. Additionally, stacking the containers reduced dusting time. Other options for dust mitigation included tarps, a form of grating at the entrance to the airlock or a "foot brush" to wipe off feet and equipment.

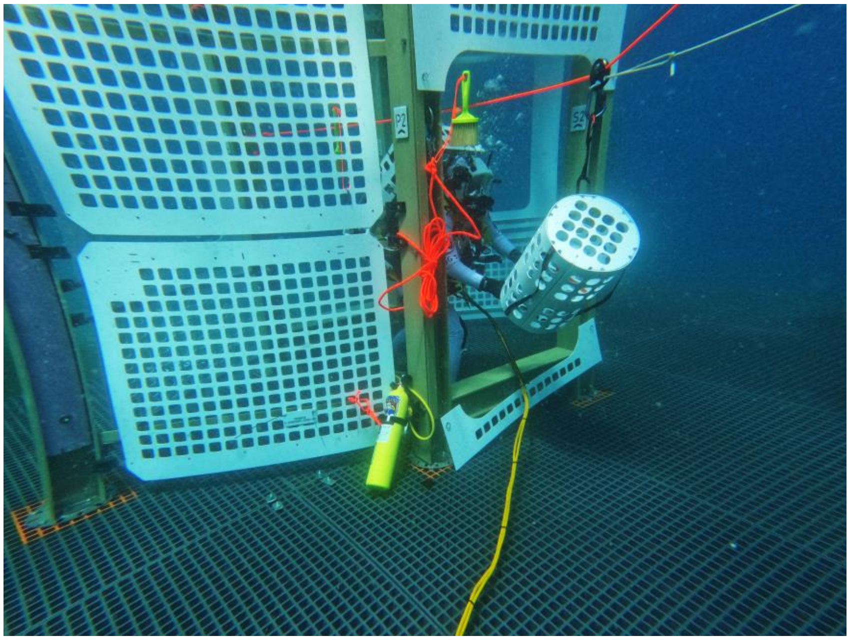

Figure 47. Crewmember grabbing handle on container to bring into the airlock. Note: In a previous capture the crewmember hit the bottom on the airlock as seen by the displaced Kydex panel.

If an outside staging area were to be used, the crew noted a more detailed procedure is needed to include a dust order of the container such as top, sides, bottom.

Of note, the height and size of the 2.0 containers made it challenging for the the crew to maneuver between the confines of the hatch when in the hatchway (with a container(s)) while maintaining awareness of the suit volume around their legs (Figure 48).

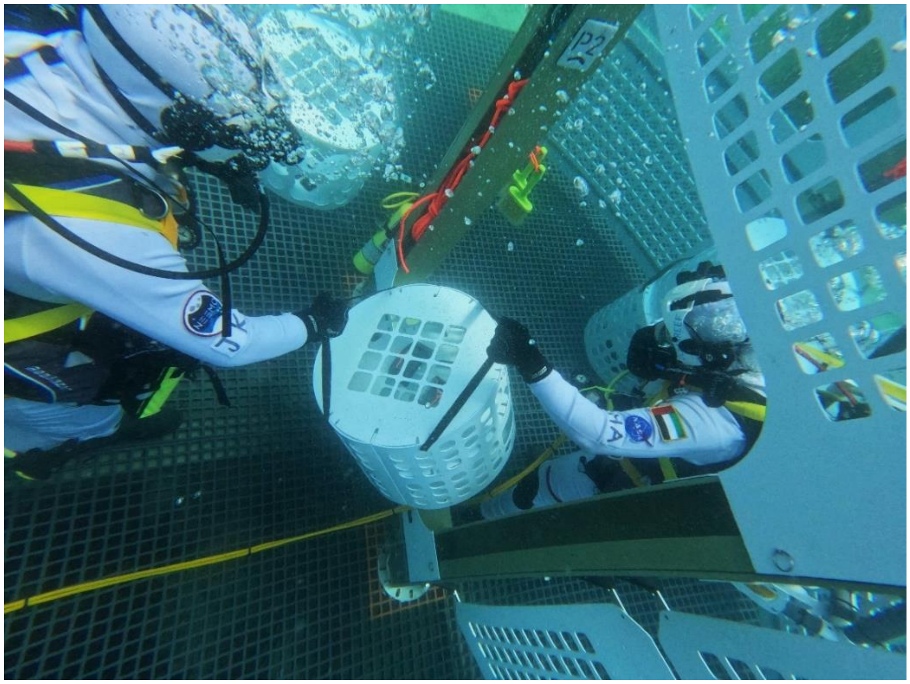

Figure 48. Two crewmembers taking a 2.0 container through the airlock hatchway.

Airlock Transfer Operations

Airlock transfer operations were rated as *acceptable*, regardless of container size. Stacking strategies included stacking the containers in the center between the two suit don/doff stands. This stacking location appeared to be a crew preference with both 1.0 and 2.0 SPLCs. They noted there was enough space to walk and work around the containers while both crewmembers were in the airlock (Figure 49).

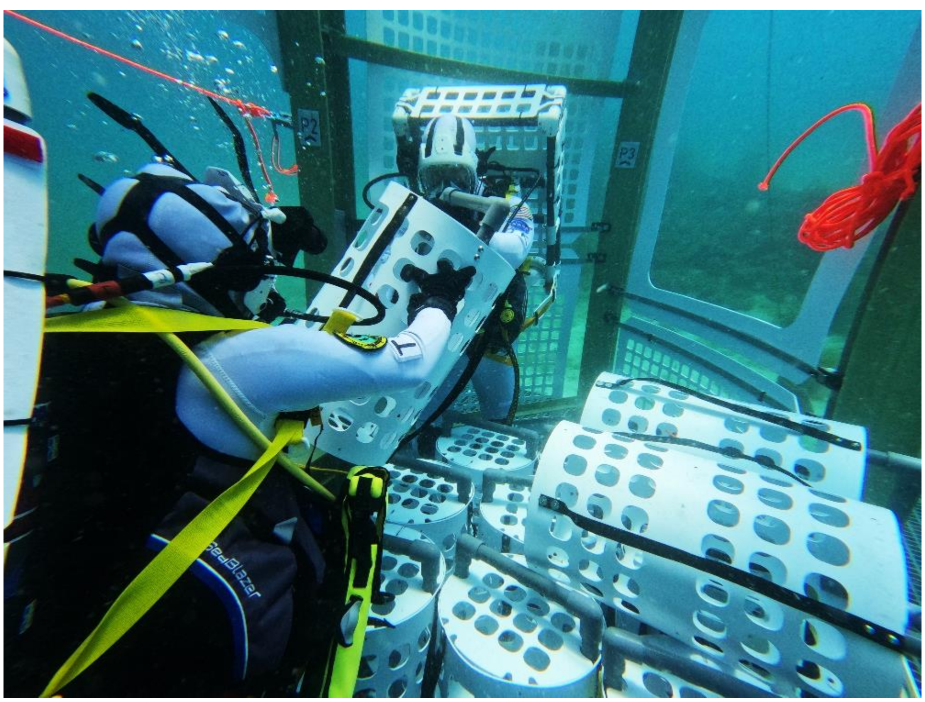

Figure 49. Crewmember working around containers in airlock.

When reconfiguring to access the opposite suit stand, it was observed that the crew moved approximately half of the containers to a opposite side airlock wall to further improve access to the suit don/doff stand (Figure 50). Crew stacked the containers to a height of three SPLCs with no issue.

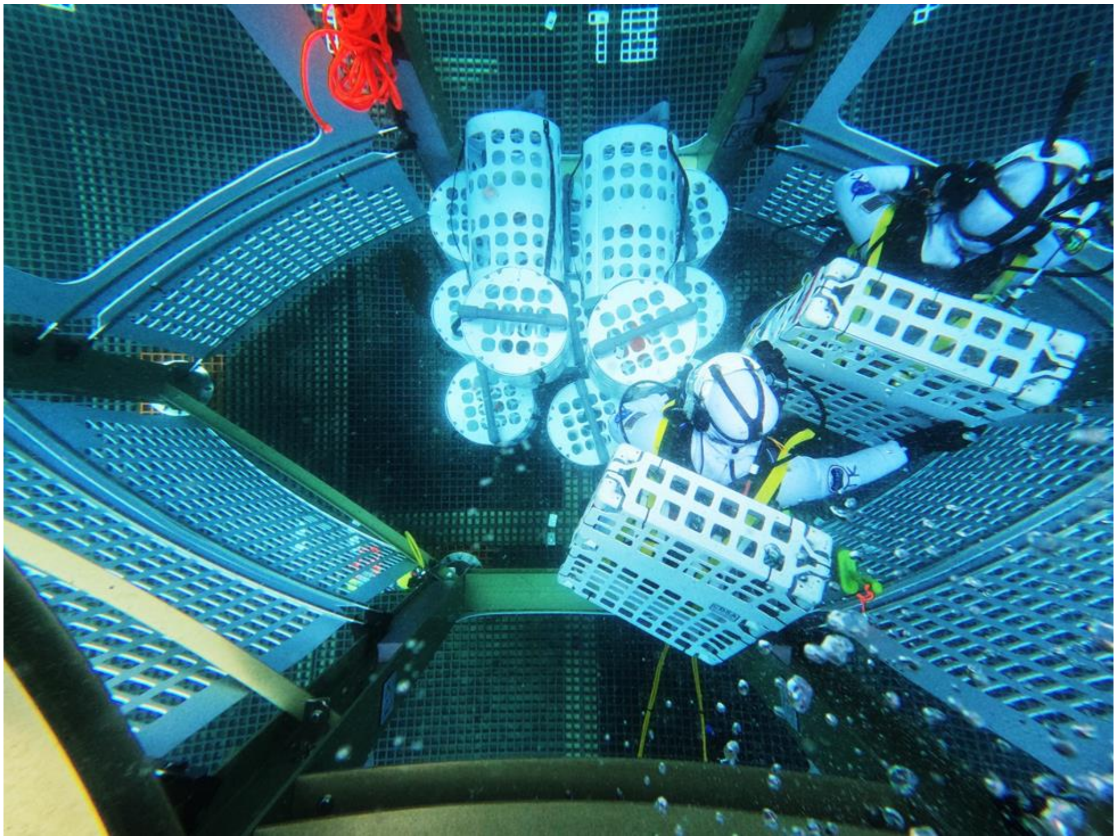

Figure 50. Crewmember reconfiguring container for improved access to suit stand.

For the scenario involving all 15 1.0 SPLCs, the stacking consensus was one row vertical and two rows horizontal (Figure 51). The arrangement for the 8 2.0 SPLCs resembled a 4 by 2 matrix with four containers on the bottom and two on the top (Figure 52). If a stack three SPLCs in height was implemented, then involved two rows of three SPLCs stacked vertically (Figure 53). Additionally, for most crewmembers, a second row of containers was easy to accomplish as it was within the work envelop of the suit; shorter crewmembers had more difficulty stacking in a second row.

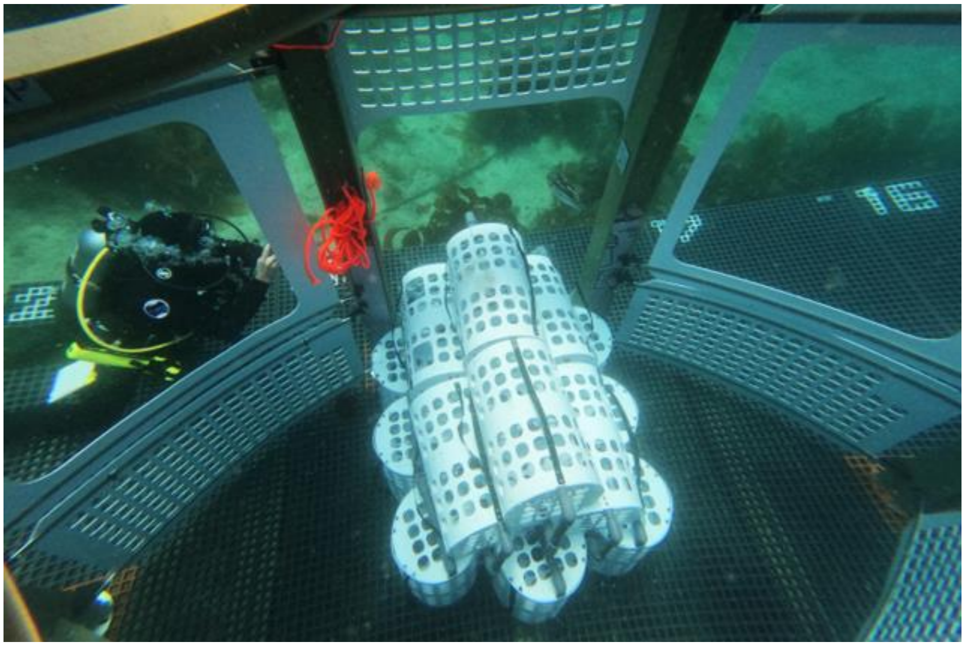

Figure 51. Stack of 1.0 containers in airlock.

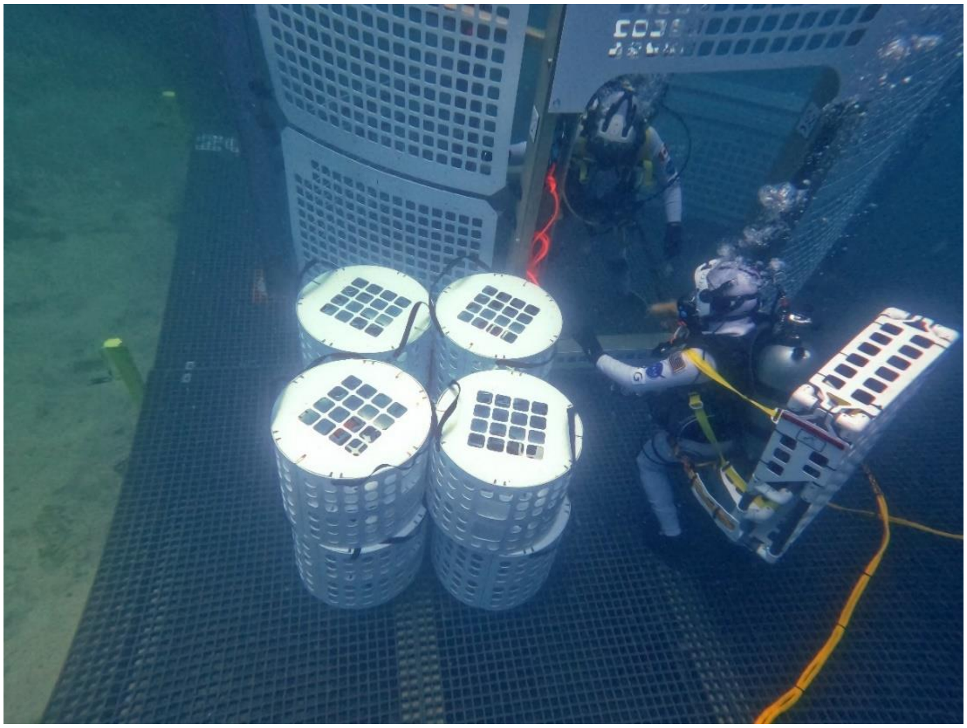

Figure 52. Stack of 2.0 containers two high by two wide.

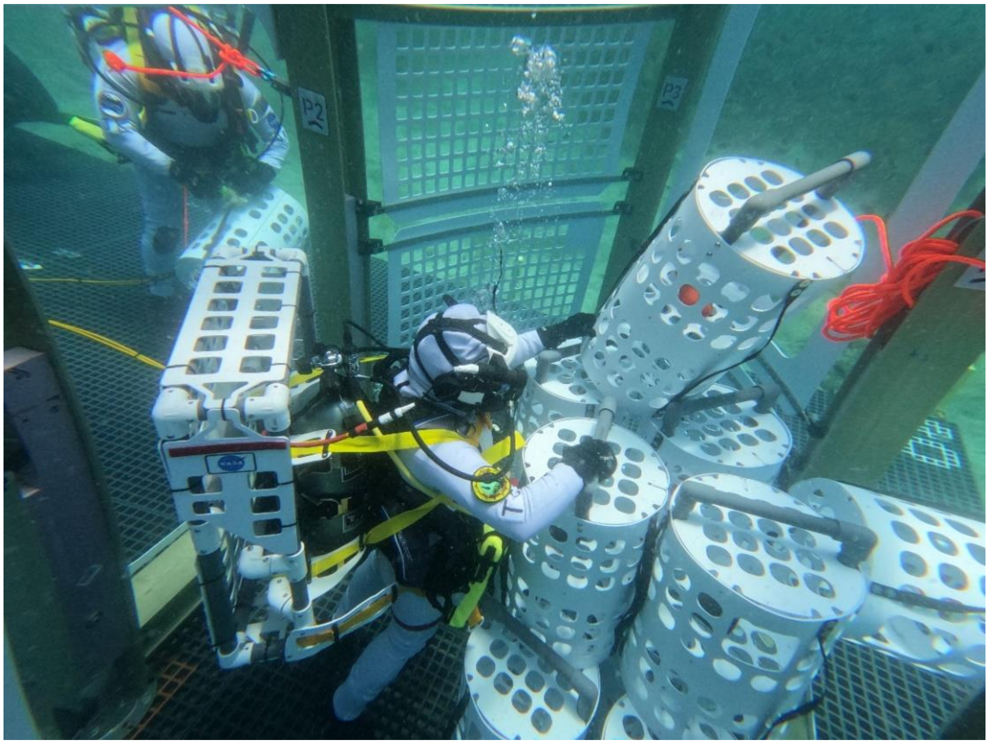

Figure 53. If stacked 3 high, two rows of containers stacked 3 high vertically.

Crew feedback regarding options for stacking included a “Lego type” capability to snap containers in place and stabilize the stack, a potential hand hold notch or retractable hand hold for easier stacking. Also, for stacking outside the airlock, containers could be stacked like logs in a holding device.

For all stacking, due to a small volumetric space, the crew indicated a need for the capability to secure the containers. To minimize hatch seal damage, the crew noted that a fulcrum over the airlock hatch protector would be desired to move large loads in and out of the airlock easily, especially if two crewmembers are required to lift the load (as is the was the case with the 2.0 SPLC). While a test-defined ground-rule indicate that the 2.0 SPLC required a two-crew carry, the test crew did feel that they could have moved a 2.0 container with ease using only one crewmember.

3.3.4 Crew Debrief

During the Crew Debrief, general thoughts about logistics were discussed. Regarding the current logistics manifest for a 14-day mission with a crew of 2, the crew indicated that the MPLC with a transfer port was much more preferred over the 1.0 and 2.0 containers - further discussion on this point can be found in section 3.3.5.

As for the simulation itself, including the ability to simulate the lunar surface environment and Artemis mission operations in a SEATEST analog, some major improvements would be required. First, space suit simulation could be improved by the addition of higher fidelity gloves (e.g., hocky gloves), higher fidelity boots (e.g., ski boots), and a mobility restraint with the ability to simulate the motion envelope of a space suit (i.e., a 3-D printed Hard Upper Torso (HUT) to simulate shoulder range-of-motion). Second, the addition of a realistic safety system on the lander deck would be essential in the real lunar environment, so it should be included in the field test mockup. However, a limitation to this type of analog is the added stability provided by the water resistance, which gave the crew an unrealistic sense of safety while on the lander deck. Third, airlock mockup fidelity should be improved, such as including umbilicals and hatches to better simulate the constrained volume. Additionally, improving the weigh-out process to more accurately simulate lunar gravity would benefit the analog. Zipline position/height should be optimized to prevent lander deck contact, and ensure sufficient line tension and clearance through hatch (Appendix E and F).

3.3.5 Crew Debrief on Container Relative Advantages

Although the test was shortened and the MPLC scenario was not run, it was discussed at length as a logistics concept by the crew. A key observation was that in concept, the MPLC with transfer port is much preferred over both the 1.0 and 2.0 SPLC solutions. This preference was based in the hypothesis that EVA time required for each CTBE of pressurized cargo transferred would be much less than what was seen for the smaller containers. Additionally, space would be optimized with the MPLC design because each attached MPLC adds temporary new volume, rather than taking up precious cabin volume (as the case with the SPLCs, because the empty containers require storage space inside of the cabin after being unpacked). Dust mitigation would also be optimized with the MPLC design – rather than needing to dust each container (like in the case of the MPLCs), at most the MPLC would require logistics port seal dusting prior to berthing. Further crew feedback concluded that if the MPLC is not feasible, the size of the 2.0 SPLCs seem preferable to 1.0s to minimize the extra volume occupied by the containers. The major takeaway from this discussion is that it is recommended that the team plan a future test for MPLC unload and re-load scenarios.

3.4 Discussion on Airlock Packing Limitations

The Airlock mockup used for SEATEST 6 was ~ 9.5 m^3, which is approximately equal to the volume of the PR and the mockup used in 1-g pre-mission testing at JSC. Due to suit restrictions and difficulty of handling SPLCs of different sizes either solo or with a buddy, estimations were also made on the number of SPLCs that could reasonably be stacked in the Airlock. The number of SPLCs of each type used at SEATEST 6 was determined by estimating the number of containers of each type that could fit in the airlock, still leaving room for 2 suited crewmembers to ingress, close the hatch behind them, and doff their suits.

Once the Airlock is functionally full of SPLCs, an Airlock cycle must occur to bring them into the cabin. SEATEST 6 did NOT have 38 1.0 SPLCs or 19 2.0 SPLCs included in the scenario protocol. Rather, the estimate based on pre-mission 1-g and CAD analysis was that concluded that 15 1.0 SPLCs and 8 2.0 SPLCs would be sufficient to fill the Airlock and require an airlock cycle. In the case of 15 1.0 SPLCs, it would require 3 airlock cycles (to get to 37.5 CTBE). In the case of 8 2.0 SPLCs, it would also require 3 airlock cycles. Our SEATEST 6 crewmembers were able to find stacking strategies and preserve space to ingress, doff suits, etc. with 15 and 10 SPLCs, respectively. Arguably, they could have strategized how to configure more efficiently to fit a few more containers into the airlock, but only a few more containers at most would be feasible without violating handling assumptions.

Another consideration is that an airlock cycle is functionally an EVA. All required airlock cycles could be attempted in the same day, but it becomes increasingly more difficult to find space to store all the SPLCs in the cabin. Additionally, SPLCs must be disposed of via EVA eventually – presumably full of trash. Therefore, a strategy to recharge as needed, and combine the recharge/trash emptying on the same EVA may be most efficient.

SEATEST 6 only investigated at a single airlock cycle for each container type; once timing was understood to get one airlock cycle, the full impact could be extrapolated.

The major takeaway from airlock packing limitations is that better understanding SPLC design, stackability, packing efficiency of containers, handling constraints while suited, etc. is important forward work

3.5 Expeditionary Training Benefits

The international astronauts involved unanimously thought SEATEST was a worthy addition to the Expeditionary Training they frequently receive (e.g., NOLS, CAVES, PANGAEA, Zero to Helo, D-RATS, etc.). Attributes that make it good Expeditionary Training included:

- Extreme environment mission operations with real risks demanding:
    - Critical and challenging training
    - Good buddymanship
    - High individual and team performance
- Leadership/followership opportunities
- Detailed procedures
- "Detachment mentality" where primary focus was directed to the questions being answered for an extended period of time
- Opportunity to learn from more experienced crew members

To emphasize the crew's positive feedback regarding the benefits of using SEATEST as expeditionary training, direct comments included:

"There's a reason organizations like the service branches and NASA conduct training detachments away from home. It enables the team to be fully immersed with the tasks at hand, while forging the necessary tight-knit bonds that are required of all teams facing immense challenges, such as what we aim to do with Artemis."– J. Kim

"I get now why it makes sense to do these evaluations here (instead of in Houston). We were immersed in this exercise and evaluation, allowing us to have timely and thorough discussions and consensus building on forward logistics plans. Here we are at 7:00 at night still talking this, whereas at home we would have scattered by now as folks went to get the kids to soccer practice…"– S. Williams

"By performing these activities on an expedition, we benefit much more than we would by completing the evaluations independently. We are able to put our expeditionary behavior skills into practice, which is crucial for mission success." – J. Sidey-Gibbons

3.6 Other Activities

NASA Public Affairs Office (PAO) included a media objective of collecting underwater 3D Virtual Reality (VR) video. This objective was accomplished; VR video was collected by Felix & Paul Studios (FPS). Setup to collect this video included the use of support divers to position cameras on the lander deck and "lunar surface" (main deck) prior to the runs of the day and remove them at the end of the day. The cameras were moved as required for optimal recording of the activities at hand throughout the dive day. The FPS team monitored camera footage in real time from the dock to ensure quality video capture. A PAO Officer was present to support crew interviews with FPS.

4.0 CONCLUSIONS

Key Takeaways – Specific to Logistics Transfer

The SEATEST 6 Simulation Quality was sufficient to support meaningful evaluation of all test objective. The two offloading transfer concepts tested presented both advantages and limitaitons. The davit's flexibility allowed crew to pick up containers without physical interaction, though limitation in the hardware components were identified that will likely be resolved via winch improvements. The zipline proved to be the most efficient method of moving logistics containers to the airlock due to its potential to significantly reduce the required EVA dust mitigation.

A hybrid method combining the davit and zipline systems was proposed to increase efficiency; the davit could be used for larger payloads since it has the mechanical advantage to reduce crew fatigue, and the zipline could be used for smaller/easier to handle payloads for direct transfer into the pressurized element.

Airlock Choreography will be a significant challenge and is highly dependent on airlock size and layout, as well as container size/dimensions/stackability/etc. How well this works will constrain how many EVAs are required to transfer an entire logistics manifest. The crew identified several container stacking strategies and container securing options for future consideration.

The MPLC scenario was not evaluated, but given the potential advantages to this concept, it should be evaluated in future HITL testing in both unload and re-load scenarios. In concept, the MPLC with transfer port would be preferred over the 1.0, 2.0 solutions since EVA time required for each CTBE of pressurized cargo transferred should be much less than was seen for the smaller containers. Additially, space is optimized with MPLC design because each attached MPLC adds temporary new volume, rather than taking up precious cabin volume. Finally, dust mitigation is optimized with MPLC design (at most requiring logistics port seal dusting prior to berthing).

If MPLCs are not feasible, the size of 2.0 SPLCs seem preferable to 1.0s to minimize extra volume taken up by the containers. EVA manual logistics transfer will be very challenging and time consuming. For the current manifest for a 14-day mission, it's clear that 2-3 EVAs will be required to get all the supplies and corresponding trash into and out of the Pressurized Rover using Small Pressurized Logistics Containers.

Looking deeply at possible hardware and technique solutions uncovered many subsequent questions, for example:

- What size container is reasonable for a single EV to carry?
- What size container requires 2 EVs to carry?
- At what size is it too big for even 2 EVs to carry?
- Is dragging a container across the regolith feasible?
- How many containers can reasonably fit in an airlock (or PR) and still have room for 2 suited
  crewmembers to ingress, pressurize, and assist each other in doffing suits?

Key Takeaways – General

Developing a SEATEST mission served as a forcing function to start an integration forum with all the primary stakeholders (Logistics, Cargo Lander, EVA, Dust, FOD) from multiple Artemis program offices. SEATEST 6 planning identified key stakeholders from each team for future work between teams and built a common framework and vocabulary for discussing the challenges associated with test objecitves. Further, the arbitrary but inflexible deadline ensured full team engagement and prioritization for a rapid test.

The SEATEST mission model proved that a small team with limited resources can rapidly plan, execute and document meaningful HITL test data (less than six months from first concept briefing to final report). Having Logistics and Lander team stakeholders present during testing to witness results and discussions firsthand was very valuable in confirming the relevance of test metrics and operations in real-time. The results documented in this report will immediately inform ongoing SAC 23 tasks, Architecture Definition Document (ADD), SAC24 tasks, and various ConOps Documents.

If EVA intensive methods of pressurized cargo transfer end up being used in the Artemis Program, considerable forward work is warranted in developing concepts further, and testing them with humans in the loop. SEATEST is an excellent way to rapidly assess Conops in a medium fidelity environment, with focused end-operator feedback

5.0 REFERENCES

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[3] A. F. Abercromby, M. L. Gernhardt, and H. L. Litaker, "Desert Research and Technology Studies (DRATS) 2008 evaluation of Small Pressurized Rover and unpressurized rover prototype vehicles in a lunar analog environment," NASA Johnson Space Center, Houston, TX NASA-TP-2010-216136, 2010.

[4] Tullis, T., & Albert, B. (2008). *Measuring the User Experience.* Boston: Morgan Kaufmann.

APPENDIX A. DETAILED FLIGHT-LIKE PROCEDURES

<table>
<tr><th>IV/SSRMS</th><th>EV1</th><th>EV2</th></tr>
<tr>
<td>Scenario 1

</td>
<td>TRANSFER MPLC FROM LANDER TO LOGISTICS PORT

√Tank Pressure________ / Thermal / Gloves

1. Climb ladder and translate to MPLC worksite
2. Attach davit hook to top portion of MPLC lifting hoop
3. Crank davit line until taut (hook should rise to top of MPLC hoop)
4. Release launch locks (3)
☐ Check launch bars are pulled away from MPLC
5. Lift MPLC via davit hand crank until clear from MPLC carrier
6. Rotate davit to move MPLC clear of lander deck
7. On EV2 GO, lower MPLC to EV2's discretion
8. √Tank Pressure________ / Thermal / Gloves
9. On EV2 GO, release tension in davit line
10. Once EV2 has released davit hook, crank handle to reel hook back to davit
11. Safe davit
12. √Tank Pressure________ / Thermal / Gloves

TRANSFER MPLC FROM LOGISTICS PORT TO LANDER
13. Lower davit hook
14. On EV2 GO, tension davit line to transfer load
15. On EV2 GO, raise MPLC
16. Once MPLC is above MPLC cradle, rotate davit to reposition MPLC over cradle
17. Lower MPLC onto cradle and release tension in line (not fully)
18. Engage MPLC launch locks
19. Release davit hook; release remaining tension in davit line as required
20. Stow hook on davit and safe davit

21. √Tank Pressure________ / Thermal / Gloves
</td>
<td>TRANSFER MPLC FROM LANDER TO LOGISTICS PORT

√Tank Pressure________ / Thermal / Gloves

1. Translate to Logistics Transfer Port aft deck
2. Dust logistics transfer port
3. Unstow aft deck hook
4. When personnel are clear of MPLC lowering corridor, give EV1 GO to lower MPLC.
5. Give EV1 GO to stop lowering MPLC when at desired height
6. Retrieve aft deck hook and attach to MPLC lifting hoop
7. Pull fall line until:
☐ Centered under haul system
☐ Line is taut
☐ Clear of aft deck floor
8. Once MPLC load is transferred, give EV1 GO to release tension in davit line
9. Release EV1's davit hook
10. Raise MPLC to hard stop
11. Slide/push MPLC to port berthing position
12. Soft dock MPLC (magnets)
Note: do not release aft deck hook
13. √Tank Pressure________ / Thermal / Gloves
TRANSFER MPLC FROM LOGISTICS PORT TO LANDER
14. Release MPLC from soft dock and slide to end of aft deck rail
15. Lower MPLC until davit hook can be attached (diver assist to release tension in fall line)
16. Attach davit hook to MPLC lifting hoop
17. Give EV1 GO to tension davit line
18. Release tension in haul system (diver assist) and remove aft deck hook
19. Give EV1 GO to raise MPLC; tend clear of any structure
20. When MPLC is clear, stow aft deck hook and lines
21. √Tank Pressure________ / Thermal / Gloves
</td>
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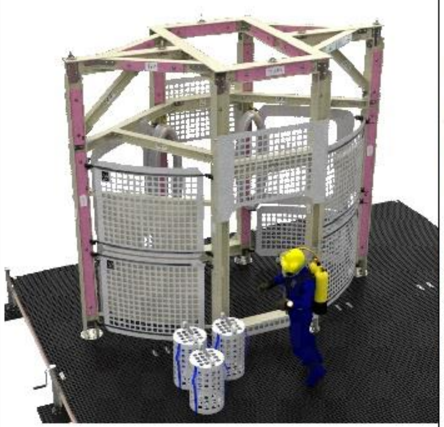
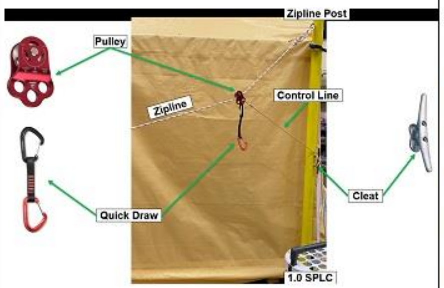
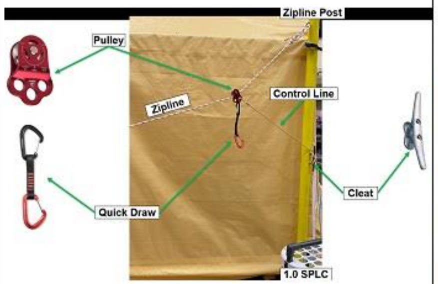
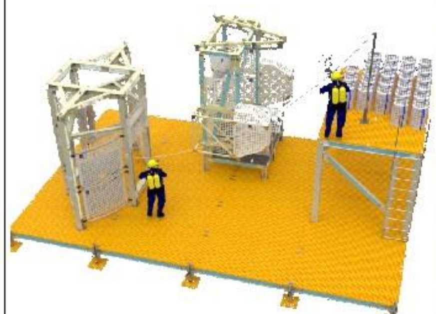
</table>

IV/SSRMS	EV1	EV2
Scenario 2  	TRANSFER 1.0 SPLC FROM LANDER TO AIRLOCK **√Tank Pressure_________ / Thermal / Gloves** 1. Climb ladder and translate to davit worksite 2. Attach davit hook to hard handle of SPLC 3. Crank davit handle to lift SPLC and rotate clear of lander deck 4. **On EV2 GO**, lower SPLC to lunar surface 5. **On EV2 GO**, raise davit hook and repeat SPLC transfer 6. **√Tank Pressure_________ / Thermal / Gloves** Once SPLC transfer is complete: 7. Stow hook on davit and safe davit 8. Descend ladder and assist transferring SPLCs to Staging Area 9. **√Tank Pressure_________ / Thermal / Gloves** At Airlock: 10. Join EV2 and assist with dust ops of SPLCs 11. Get dusted by EV2 12. Dust EV2 13. Transfer SPLCs through Airlock hatch to EV2 14. Repeat until all SPLCs are transferred 15. Ingress Airlock and close simulated hatch 16. **√Tank Pressure_________ / Thermal / Gloves**	TRANSFER 1.0 SPLC FROM LANDER TO AIRLOCK **√Tank Pressure_________ / Thermal / Gloves** 1. Position to receive SPLCs at the base of Lander 2. When personnel are clear of SPLC lowering corridor, **give EV1 GO** to lower SPLC 3. **Give EV1 GO** to stop lowering SPLC when at lunar surface 4. Remove davit hook from SPLC and transfer to Airlock staging area 5. **Give EV1 GO** to raise davit hook 6. Repeat SPLC transfer 7. **√Tank Pressure_________ / Thermal / Gloves** At Airlock: 8. Start dust operations on SPLCs in stowage area 9. Dust EV1 10. Get dusted by EV1 11. Ingress airlock 12. Receive and stack SPLCs, while maintaining work volume for EV1 ingress 13. **√Tank Pressure_________ / Thermal / Gloves**

IV/SSRMS	EV1	EV2
Scenario 3	<u>TRANSFER 2.0 SPLC FROM LANDER TO AIRLOCK</u>	<u>TRANSFER 2.0 SPLC FROM LANDER TO AIRLOCK</u>
	**√Tank Pressure________ / Thermal / Gloves**	**√Tank Pressure________ / Thermal / Gloves**
	1. Climb ladder and translate to davit worksite 2. Attach davit hook to hard handle of SPLC 3. Crank davit handle to lift SPLC and rotate clear of lander deck	1. Position to receive SPLCs at the base of Lander
	4. **On EV2 GO**, lower SPLC to lunar surface	2. When personnel are clear of SPLC lowering corridor, **give EV1 GO** to lower SPLC 3. **Give EV1 GO** to stop lowering SPLC when at lunar surface 4. Remove davit hook from SPLC and drag SPLC to Lander staging area
	5. **On EV2 GO**, raise davit hook and repeat SPLC transfer	5. **Give EV1 GO** to raise davit hook
		6. Repeat SPLC transfer
	6. **√Tank Pressure________ / Thermal / Gloves**	7. **√Tank Pressure________ / Thermal / Gloves**
	Once SPLC transfer is complete: 7. Stow hook on davit and safe davit 8. Descend ladder 9. Transfer (2-crew carry) SPLCs from Lander staging area to Airlock staging area	8. Transfer (2-crew carry) SPLCs from Lander staging area to Airlock staging area
	10. **√Tank Pressure________ / Thermal / Gloves**	9. **√Tank Pressure________ / Thermal / Gloves**
	At Airlock: 11. Join EV2 and assist with dust ops of SPLCs 12. Get dusted by EV2 13. Dust EV2	At Airlock: 10. Start dust operations on SPLCs in stowage area 11. Dust EV1 12. Get dusted by EV1 13. Install hatch seal protection 14. Ingress airlock
	14. Push/pull SPLCs into Airlock	15. Push/pull SPLCs into airlock while maintaining work volume for EV1 ingress
	15. Ingress Airlock and assist EV2 to stack SPLCs 16. Stack SPLCs with EV2 assistance 17. Close simulated hatch	16. Drag SPLC out of hatchway 17. Stack SPLCs with EV1 assistance
	18. **√Tank Pressure________ / Thermal / Gloves**	18. **√Tank Pressure________ / Thermal / Gloves**

IV/SSRMS	EV1	EV2
Scenario 4 • Reverse with process with 2.0 SPLC only 	TRANSFER 2.0 SPLC FROM AIRLOCK TO LANDER **√Tank Pressure________ / Thermal / Gloves** 1. Open Airlock hatch and install hatch seal cover 2. Jointly place first SPLC on floor of Airlock, leaving room for egress 3. Egress Airlock 4. Push/pull SPLCs through hatch 5. Drag SPLC to staging area clear of hatchway; repeat Note: EV1 may need to ingress A/L multiple times to assist unstacking SPLCs to ground level 6. **√Tank Pressure________ / Thermal / Gloves** Once all SPLCs are in staging area: 7. Transfer (2-crew carry) SPLCs from Airlock staging area to Lander staging area 8. **√Tank Pressure________ / Thermal / Gloves** After all SPLCs are transferred to Lander staging area: 9. Climb ladder and translate to davit worksite 10. Release davit hook and rotate davit to lower position 11. **On EV2 GO**, lower davit hook to lunar surface and slack line 12. Raise SPLC and rotate davit to stowage position 13. Lower SPLC to stowage position and slack line 14. Release davit hook and repeat Once all SPLCs are transferred: 15. Stow davit hook and safe davit 16. Descend ladder 17. **√Tank Pressure________ / Thermal / Gloves**	TRANSFER 2.0 SPLC FROM AIRLOCK TO LANDER **√Tank Pressure________ / Thermal / Gloves** 1. Jointly place first SPLC on floor of Airlock 2. Push/pull SPLCs through hatch 3. Repeat until all SPLCs are transferred out of airlock Note: EV1 may need to ingress A/L multiple times to assist unstacking SPLCs to ground level 4. **√Tank Pressure________ / Thermal / Gloves** Once all SPLCs are in staging area: 5. Transfer (2-crew carry) SPLCs from Airlock staging area to Lander staging area 6. **√Tank Pressure________ / Thermal / Gloves** After all SPLCs are transferred to Lander staging area: 7. Give EV1 GO to lower davit hook 8. Attach davit hook to SPLC and give EV1 GO to raise SPLC 9. Drag next SPLC to offloading zone and repeat until all SPLCs are transferred 10. **√Tank Pressure________ / Thermal / Gloves**

IV/SSRMS	EV1	EV2
Scenario 5	<u>ZIPLINE 2.0 SPLC FROM LANDER TO STAGING AREA</u>	<u>ZIPLINE 2.0 SPLC FROM LANDER TO STAGING AREA</u>
	**√Tank Pressure_________ / Thermal / Gloves**	**√Tank Pressure_________ / Thermal / Gloves**
	1. Climb ladder and translate to zipline worksite 2. Raise SPLC and attach to zipline quick draw 3. While maintaining tension on load, release control line from cleat	1. Translate to Airlock staging area
	4. **On EV2 GO**, pay out slack to lower SPLC to Airlock	2. **Give EV1 GO** to lower SPLC 3. Lower SPLC to ground and unhook once line is slack
	5. **On EV2 GO**, haul on control line to reset quick draw back to loading position 6. Secure control line to cleat	4. **Give EV1 GO** to reset zipline
	7. **√Tank Pressure_________ / Thermal / Gloves**	5. **√Tank Pressure_________ / Thermal / Gloves**
	8. Retrieve next SPLC and repeat steps 2-6	6. Repeat until SPLCs are transferred
	When all SPLCs have been transferred: 9. Descend ladder and translate to Airlock	
	At Airlock: 10. Join EV2 and assist with dust ops of SPLCs 11. Get dusted by EV2 12. Dust EV2	At Airlock: 7. Start dust operations on SPLCs in stowage area 8. Dust EV1 9. Get dusted by EV1 10. Install hatch seal protection 11. Ingress airlock
	13. Push/pull SPLCs into Airlock	12. Push/pull SPLCs into airlock while maintaining work volume for EV1 ingress
	14. Ingress Airlock and assist EV2 to stack SPLCs 15. Stack SPLCs with EV2 assistance 16. Close simulated hatch	13. Drag SPLC out of hatchway 14. Stack SPLCs with EV1 assistance
	17. **√Tank Pressure_________ / Thermal / Gloves**	15. **√Tank Pressure_________ / Thermal / Gloves**

IV/SSRMS	EV1	EV2
Scenario 6	ZIPLINE 1.0 SPLC FROM LANDER TO STAGING AREA	ZIPLINE 1.0 SPLC FROM LANDER TO STAGING AREA
	**√Tank Pressure_________ / Thermal / Gloves**	**√Tank Pressure_________ / Thermal / Gloves**
	1. Climb ladder and translate to zipline worksite	1. Translate to Airlock staging area
	2. Raise SPLC and attach to zipline quick draw	
	3. While maintaining tension on load, release control line from cleat	
	4. **On EV2 GO**, pay out slack to lower SPLC to Airlock	2. **Give EV1 GO** to lower SPLC
		3. Lower SPLC to ground and unhook once line is slack
	5. **On EV2 GO**, haul on control line to reset quick draw back to loading position	4. **Give EV1 GO** to reset zipline
	6. Secure control line to cleat	
	7. **√Tank Pressure_________ / Thermal / Gloves**	5. **√Tank Pressure_________ / Thermal / Gloves**
	8. Retrieve next SPLC and repeat steps 2-6	6. Repeat until SPLCs are transferred
	When all SPLCs have been transferred:	
	9. Descend ladder and translate to Airlock	
	At Airlock:	At Airlock:
	10. Join EV2 and assist with dust ops of SPLCs	7. Start dust operations on SPLCs in stowage area
	11. Get dusted by EV2	8. Dust EV1
	12. Dust EV2	9. Get dusted by EV1
	13. Transfer SPLCs through Airlock hatch to EV2	10. Ingress airlock
	14. Repeat until all SPLCs are transferred	11. Receive and stack SPLCs while maintaining work volume for EV1 ingress
	15. Ingress Airlock and close simulated hatch	
	16. **√Tank Pressure_________ / Thermal / Gloves**	12. **√Tank Pressure_________ / Thermal / Gloves**

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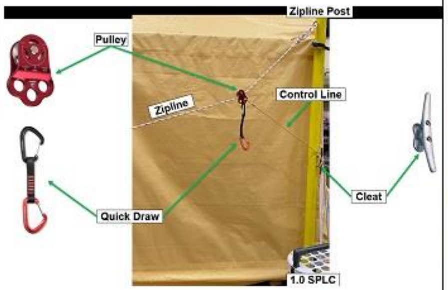
Scenario 7




</td>
<td>
<u>ZIPLINE 1.0 SPLC FROM LANDER TO AIRLOCK</u>

√Tank Pressure_________ / Thermal / Gloves

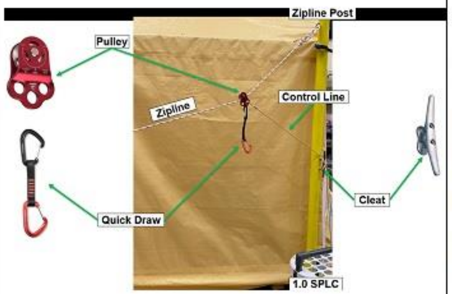
1. Translate to Airlock and perform dust operations on EV2
2. Translate to Lander
3. Climb ladder and translate to zipline worksite
4. Raise SPLC and attach to zipline quick draw
5. While maintaining tension on load, release control line from cleat
6. **On EV2 GO**, pay out slack to lower SPLC to Airlock
7. **On EV2 GO**, haul on control line to reset quick draw back to loading position
8. Secure control line to cleat
9. **√Tank Pressure_________ / Thermal / Gloves**
10. Retrieve next SPLC and repeat steps 2-6

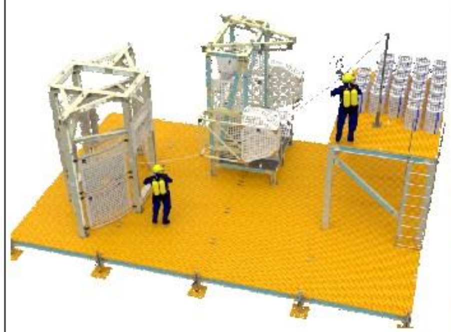
When all SPLCs have been transferred:
11. Descend ladder and translate to Airlock

At Airlock:
12. Perform self-dust operations
13. Ingress Airlock and close simulated hatch
14. **√Tank Pressure_________ / Thermal / Gloves**
</td>
<td>
<u>ZIPLINE 1.0 SPLC FROM LANDER TO AIRLOCK</u>

√Tank Pressure_________ / Thermal / Gloves

1. Translate to Airlock and get dusted by EV1
2. Ingress Airlock
3. Position to receive SPLCs
4. **Give EV1 GO** to lower SPLC
5. Lower SPLC to floor of airlock and unhook once line is slack
6. **Give EV1 GO** to reset zipline
7. Stack SPLCs while maintaining work volume for EV1 ingress
8. **√Tank Pressure_________ / Thermal / Gloves**
9. Repeat until SPLCs are transferred
10. **√Tank Pressure_________ / Thermal / Gloves**
</td>
</tr>
</table>

<table>
<tr><th>IV/SSRMS</th><th>EV1</th><th>EV2</th></tr>
<tr>
<td>Scenario 8


</td>
<td><u>ZIPLINE 2.0 SPLC FROM LANDER TO AIRLOCK</u>

√Tank Pressure________ / Thermal / Gloves

1. Translate to Airlock and perform dust operations on EV2
2. Translate to Lander
3. Climb ladder and translate to zipline worksite
4. Raise SPLC and attach to zipline quick draw
5. While maintaining tension on load, release control line from cleat
6. On EV2 GO, pay out slack to lower SPLC to Airlock

7. On EV2 GO, haul on control line to reset quick draw back to loading position
8. Secure control line to cleat

9. √Tank Pressure________ / Thermal / Gloves

10. Retrieve next SPLC and repeat steps 2-6

When all SPLCs have been transferred:
11. Descend ladder and translate to Airlock

At Airlock:
12. Perform self-dust operations
13. Ingress Airlock
14. Assist with SPLC stacking as required
15. Close simulated hatch

16. √Tank Pressure________ / Thermal / Gloves</td>
<td><u>ZIPLINE 2.0 SPLC FROM LANDER TO AIRLOCK</u>

√Tank Pressure________ / Thermal / Gloves

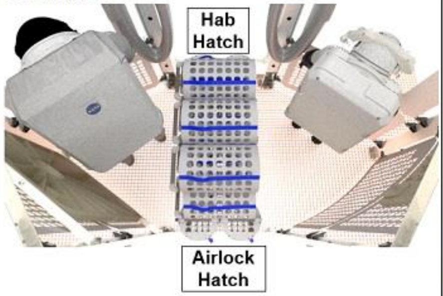
1. Translate to Airlock and get dusted by EV1
2. Ingress Airlock
3. Position to receive SPLCs

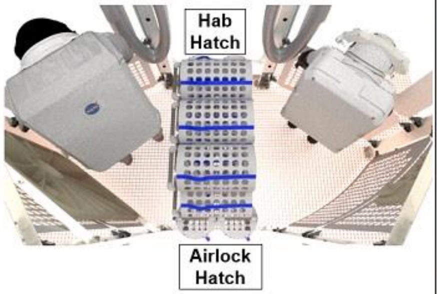
4. Give EV1 GO to lower SPLC
5. Lower SPLC to floor of airlock and unhook once line is slack
6. Give EV1 GO to reset zipline
7. Drag and stack SPLCs while maintaining work volume for EV1 ingress

8. √Tank Pressure________ / Thermal / Gloves

9. Repeat until SPLCs are transferred

10. √Tank Pressure________ / Thermal / Gloves</td>
</tr>
</table>

IV/SSRMS	EV1	EV2
Scenario 9 	AIRLOCK CHOREOGRAPHY (INGRESS)	AIRLOCK CHOREOGRAPHY (INGRESS)
	√Tank Pressure________ / Thermal / Gloves	**√Tank Pressure________ / Thermal / Gloves**
	1. Ingress Airlock 2. Attach suit umbilical	1. Ingress Airlock 2. Remove and stow hatch seal protection 3. Close hatch 4. Attach suit umbilical
	3. Start repress of Airlock 4. Reorganize SPLCs into center of airlock 5. **√Tank Pressure________ / Thermal / Gloves**	5. Reorganize SPLCs to center of airlock for EV1 access to donning stand 6. **√Tank Pressure________ / Thermal / Gloves**
	6. Attach to donning stand 7. Doff suit 8. Reorganize logistic carriers for EV2 access to donning stand 9. Assist EV2 in doffing suit 10. Reorganize SPLCs to clear path to Hab hatch	7. Assist EV1 in doffing suit 8. Reorganize SPLCs for EV2 access to donning stand 9. Attach to donning stand 10. Doff suit 11. Reorganize SPLCs to clear path to Hab
	11. **√Tank Pressure________ / Thermal / Gloves**	12. **√Tank Pressure________ / Thermal / Gloves**

IV/SSRMS	EV1	EV2
Scenario 10  	AIRLOCK CHOREOGRAPHY (EGRESS) **√Tank Pressure________ / Thermal / Gloves** 1. Ingress Airlock (from Hab) 2. Unstow hatch seal protection and temp stow 3. Don suit 4. Attach umbilical 5. Egress donning stand 6. **√Tank Pressure________ / Thermal / Gloves** 7. Reorganize SPLCs for EV2 access to donning stand 8. Assist EV2 in suit donning 9. Reorganize SPLCs to clear path to Airlock hatch Depress Airlock After depress complete: 10. Detach from umbilical 11. Open Airlock hatch 12. Egress Airlock 13. **√Tank Pressure________ / Thermal / Gloves**	AIRLOCK CHOREOGRAPHY IN REVERSE (EGRESS) **√Tank Pressure________ / Thermal / Gloves** 1. Ingress Airlock (from Hab) 2. Close Hab hatch 3. Assist EV1 in suit donning 4. **√Tank Pressure________ / Thermal / Gloves** 5. Assist EV1 to reorganize SPLCs for EV2 access to donning stand 6. Don suit 7. Attach umbilical 8. Egress donning stand Depress Airlock After depress complete: 9. Retrieve hatch seal protection from temp stow location and install on Airlock hatch seal 10. Egress Airlock 11. **√Tank Pressure________ / Thermal / Gloves**

APPENDIX B. ACCEPTABILITY QUESTIONNAIRE

Table 1B. *Crew Questions for Davit*

Transfer Ops Using Davit	
Rate the overall acceptability of the following transfer operation elements:	
Q1	Using the Davit for transfer operations (reach, attachments, loading/unloading containers, davit handle, crank, hook, etc.)
Q2	The lander deck for transfer operations (deck volume, lander height, etc.)
Q3	The conceptual 1.0/2.0 SPLC container for use- with a davit (handrails, size, shape, connection points, etc.)
Q4	Size of Staging area
Q5	The number of crew for this transfer method
Q6	The conceptual dust migration procedures
Q7	The cargo packing (i.e., layout of SPLCs) on the lander deck for transfer operations
Q8	Overall acceptability of using this transfer method from end-to-end (including risk to crew) for 1.0 SPLCs
Q9	Additional comments

Table 2B. *Crew Questions for Reverse Davit (Reload)*

Transfer Ops Using A Davit for Reload	
Rate the overall acceptability of the following transfer operation elements:	
Q1	Using the Davit for transfer operations (reach, attachments, loading/unloading containers, davit handle, crank, hook, etc.)
Q2	The lander deck for transfer operations (deck volume, lander height, etc.)
Q3	The conceptual large SPLC container for use with a davit (handrails, size, shape, connection points, etc.,)
Q4	Transfer of SPLCs from A/L to staging area (below davit)
Q5	Size of Staging area (below the davit)
Q6	The number of crew for this transfer method
Q7	The cargo packing (i.e., layout of SPLCs) on the lander deck for transfer operations
Q8	Overall acceptability of using this transfer method from end-to-end (including risk to crew) for 2.0 SPLCs
Q9	Additional comments

Table 3B. *Crew Questions for Zipline and Staging Area*

Transfer Ops Using A Zipline and Staging Area	
Rate the overall acceptability of the following transfer operation elements:	
Q1	Using the zipline for transfer operation (reach, attachments, loading/unloading containers, quick draw, control line, pulley, zipline post, etc.)
Q2	The lander deck for transfer operations (deck volume, lander height, etc.)
Q3	The conceptual small SPLC container for use with a zipline (handrails, size, shape, connection points, etc.)
Q4	Size of Staging area
Q5	The number of crew for this transfer method
Q6	The conceptual dust migration procedures
Q7	The cargo packing (i.e., layout of SPLCs) on the lander deck for transfer operations
Q8	Overall acceptability of using this transfer method from end-to-end (including risk to crew) for 1.0 SPLCs
Q9	Additional comments

Table 4B. *Crew Questions for Zipline and Airlock*

Transfer Ops Using A Zipline and Airlock	
Rate the overall acceptability of the following transfer operation elements:	
Q1	Using the zipline for transfer operation (reach, attachments, loading/unloading containers, quick draw, control line, pulley, zipline post, etc.)
Q2	The lander deck for transfer operations (deck volume, lander height, etc.)
Q3	The conceptual 1.0/2.0 SPLC container for use with a zipline (handrails, size, shape, connection points, etc.)
Q4	The number of crew for this transfer method
Q5	Transfer of 1.0/2.0 SPLCs through the Airlock hatch (hatch opening, Airlock volume, disconnecting container, stacking containers, "dings" to hatch seals, etc.)
Q6	The conceptual dust migration procedures
Q7	The cargo packing (i.e., layout of SPLCs) on the lander deck for transfer operations
Q8	Overall acceptability of using this transfer method from end-to-end (including risk to crew) for 1.0 SPLCs
Q19	Additional comments

Table 5B. *Crew Questions for Airlock Ops*

Airlock Choreography	
Rate the overall acceptability of the following transfer operation elements:	
Q1	Stacking the containers
Q2	Airlock container reconfiguration within the given airlock volume
Q3	Suit don/doff in the given airlock volume
Q4	Overall acceptability of using this transfer method from end-to-end (including risk to crew)
Q5	Additional comments

APPENDIX C. SIMULATION QUALITY QUESTIONNAIRE

Table 1C. *Crew Simulation Quality Questions*

Rate the simulation quality of the following elements:	
Q1	The environment as compared to expected lunar environment (1/6 g effects, mass management, offloading concept fidelity, etc.)
Q2	The environment's ability to p[provoke relevant operational considerations (dusting requirements, suit maneuverability, mechanism and system fidelity, etc.)
Q3	Additional comments are appreciated

APPENDIX D. CAPABILITY QUESTIONNAIRE

Table 1D. *Crew Capability for Transfer Operations*

Capability Questionnaire for Transfer Operations	
Provide a capability assessment rating and comments for the following transfer operation methods:	
Q1	The davit offloading concept
Q2	The zipline offloading concept
Q3	Additional comments are appreciated

APPENDIX E. DEBRIEF QUESTIONNAIRE

Table 1E. *Crew Debrief Questionnaire*

Crew Debrief Questionnaire	
Q1	Any other general thoughts on cargo logistics lander configurations (e.g., how logistics are packaged on a lander for offloading) and capabilities (e.g., specs for ladders, davits, winches, etc.)? E.g., can you envision lander details that are extremely prohibitive vs. extremely mission enhancing, etc.?
Q2	Any other general thoughts on dust mitigation strategies for logistic transfer ops?
Q3	What are your thoughts on the current logistics manifest for a 14-day rover mission for a crew of 2 (i.e., all 15 of the 1.0 SPLCs + 8 of the 2.0 SPLCs)? How do you propose we think about logistics for ~7 to 30-day surface mission (e.g., in pressurized rover and/or surface habitat)? What are your recommendations for determining (e.g., through analysis, testing + eval, etc.) what quantity of logistics is appropriate for these missions?
Q4	What are your concerns and recommendations w.r.t. our ability to simulate the lunar surface environment and Artemis mission operations in these SEATEST analog tests?
Q5	Any other feedback (e.g., for logistic handling)

APPENDIX F. CREW CONSENSUS DATA

SEATEST 6
DAY 01

Crew Consensus

25 July 2023

Day 01 Simulation Quality

SIMULATION QUALITY SCALE

1	2	3	4	5
Simulation quality (e.g. hardware, software, procedures, comm., environment) presented either zero problems or only minor ones that had no impact to the validity of test data	Some simulation limitations or anomalies encountered, but minimal impact to the validity of test	Simulation limitations or anomalies made test data marginally adequate to provide meaningful evaluation of test objectives (please describe)	Significant simulation limitations or anomalies precluded meaningful evaluation of major test objectives (please describe)	Major simulation limitations or anomalies precluded meaningful evaluation of all test objectives (please describe)

- **Q1. The environment as compared to expected lunar environment (1/6g effects, mass management, offloading concept fidelity, etc.)**
- **Rating = 3**
- **Comments:**
  - The slack in the zipline required a substantial change to the method the crew member used to complete the scenario (one hand always tightening the slack on the zipline, meaning the control line is operated with one hand only).
  - Current management requires too much dexterity/tending (do we really want the cleat?).
  - Control line needs to be longer when the zip line is tethered at the forward side of the airlock (near the IV hatch) [approximately 10 feet more]
  - Recommend developing a way to simulate slack management in the zipline control line.

- **Q2. The environment's ability to provoke relevant operational considerations (dusting requirements, suit maneuverability, mechanism and system fidelity, etc.)**
- **Rating = 3**
- **Comments:**
  - Comm would be substantially different on a lunar mission (delay, call frequency, crew-to-crew calls).
  - Limited simulation of the volume of the suit beyond the PLSS. Water resistance allowed crewmembers to complete tasks unrealistically (and added comfort to operations on the lunar lander platform).
  - Limited fidelity of the airlock allowed for SLPCs to stick out open gaps in the mockup.
  - Range of motion limitations are not well simulated, which would be especially limiting during dusting operations.

1

Scenario 01 – 1.0 DAVIT (Acceptability)

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q1. Using the Davit for transfer operations (reach, attachments, loading/unloading containers, davit handle, crank, hook, etc.):**
- **Rating = 7**
- **Comments:**
    - Davit crank operation required too much motion to be acceptable for the suit. Suggest this as a manual back up system (contingency only).
    - Crew member adjusted the crank length to allow for reasonable speed and torque. In doing so, back end of the crank handle extended toward the crewmember, creating a potential visor contact risk, requiring them to stand on the perpendicular side of the davit to the crank itself.
    - Electric motor for prime system would be ideal.
    - Although the task did not require it, additional recommendations include:
        - Pitch adjustments for the arm of the davit to maximize flexibility.
        - Change the hook design to enable multiple SPLCs.
        - Addition of clutch for efficient lowering.
        - Ratchet mechanism to prevent inadvertent movement in opposite direction.
        - Consider pedal/foot operated system to allow for hand free operation.

- **Q2. The lander deck for transfer operations (deck volume, lander height, etc.):**
- **Rating = 5**
- **Comments:**
    - Height of the lander is reasonable, but a safety mechanism needs to be in place (railing, tether, etc.).
    - Consider placement of the davit mount in proximity to zipline and edge of the lander to optimize for usability.
    - Flush davit mount would increase safety when davit is not installed. If safety (including fall and trip hazard) was not considered, rating would be 3.
- **Q3. The conceptual small SPLC container for use with a davit (handrails, size, shape, connection points, etc.):**
- **Rating = 4**
- **Comments:**
    - Crew member felt comfortable handling 1.0 SLPC and utilized the handle to stack SLPCs effectively.
    - Soft handles helpful for providing additional tether points allowing for various orientations during lowering.
    - Handles could be collapsible or all soft good handles if hard handle is not required for reorientation.
    - If volumetric trade is not too prohibitive, a change in shape would allow for better stacking.
    - Consider a mechanism which would allow SPLCs to interface with one another to facilitate stacking (base of SPLC fits the handle of the top of the SPLC so they fit together).
    - Attachment point for davit could center on the CG.

2

Scenario 01 – 1.0 DAVIT (Acceptability) cont.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q4. Size of staging area:**
- **Rating = 3**
- **Comments:**
    - Staging area should be sized to accommodate 15 stacked SPLCs (number could vary with operation).
    - Crew designated staging area to the port side of the A/L EV hatch.
    - Stacking strategies:
        - In staging area, stacking the SPLCs three high and two deep (pyramid configuration) worked well.
        - SPLCs could be stacked on their sides like a pile of logs if some side restraints were built in the staging area.
    - Stacked SPLCs require minimal dusting; however, crew height needs to be a consideration
- **Q5. The number of crew for this transfer method:**
- **Rating = 2**
- **Comments:**
    - Airlock volume is a limitation to number of crew.
    - For the as tested distance (16 feet) between the lander and the airlock/staging area is sufficient for two crew.
        - By the time one crewmember dropped off an SLPC at the airlock, the crew member on the lander had loaded another SLPC on the davit and was prepared to lower it.
    - If the two are further apart, an additional crew member on the lunar surface would improve the efficiency of the operation.

- **Q6. The conceptual dust migration procedures:**
- **Rating = 5**
- **Comments:**
    - In the suit, wrist mobility is limited so operations may be limited to one direction (as opposed to a "paintbrush" technique).
    - There needs to be a procedure for dusting, including order (top to bottom) and crew member movements.
    - A long handle brush would be helpful, along with handrails for single-footed stability during dusting.
    - Without a staging area, stacking SPLCs is preferred as stacking minimizes dusting.
- **Q7. The cargo packing (i.e., layout of SPLCs) on the lander deck for transfer operations**
- **Rating = 4**
- **Comments:**
    - Stacking is helpful on the lander platform and on the lunar surface during transfer.
    - Stacking minimizes crew member bending in the suit and improves dust mitigation.
    - Stacking also limits the need to travel on the lunar lander platform to retrieve SPLCs.
    - Ensuring the SLPCs interface with one another would minimize the potential for them to tumble.

3

Scenario 01 – 1.0 DAVIT (Acceptability) cont.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q8. Overall acceptability of using this transfer method from end-to-end (including risk to crew) for 1.0 SPLCs**
- **Rating = 6**
- **Comments:**
  - Low risk to crew member on the lunar surface as long as stacking is deliberate.
  - Some phases are acceptable, but the design of the davit used for this operation is not reasonable for a suited subject.
  - A more well-developed motorized davit would make this operational more acceptable.
  - If the davit and dust mitigation procedures were improved, acceptability would improve to a 3-4.

4

Scenario 02 – 1.0 ZIPLINE AIRLOCK (Acceptability)

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q1. Using the zipline for transfer operation (reach, attachments, loading/unloading containers, quick draw, control line, pulley, zipline post, etc.)**
- **Rating = 5**
- **Comments:**
  - Loading and unloading was straight forward.
  - Zipline
    - Rope was slack which made this operation inefficient. A realistic zipline would be a taught wire.
    - To mitigate issue, crew had to hold one hand above their head to tighten the line, which is not reasonable considering suit mobility.
    - Control line needs to be longer with a slack management system (retractable or tended).
    - A brake mechanism for the control line would be ideal (magnetic or mechanical).
    - Improvement to the quick draw to facilitate loading would be beneficial, i.e., a retractable portion of the attachment.
  - The zipline attachment point and post
    - Were too close to the edge of the lunar lander platform.
    - Should be within the work envelope for most crew members, but should still allow for multiple container sizes, if possible.
    - Hook attachment should be changed to allow for multiple SPLCs on one zipline run.
    - SPLCs were loaded with the attachment to the soft good handle to allow the receiving crew member to grab the hard handle upon receiving the SPLC.
    - Crew member did not use the cleat to tie off the line when they had to retrieve SPLCs far from the zipline post (they held the control line in their hand).
  - Zipline in Airlock
    - The tie off (receiving end) of the zipline could be inside the A/L or outside the A/L without any difference to the position of the receiving crew member.
    - If zipline was tethered inside the airlock, receiving crew member retrieved the SPLC outside the hatch to prevent inadvertent contact with the hatch seals.
    - Enabled better control for the orientation for stacking in the airlock and minimized re-grips during that process.
    - For both the zipline airlock and zipline staging area, the receiving crew member can stand inside the airlock to enable stacking and minimize dusting.
    - To add extra stability for the receiving crew member both for SPLC retrieval and dusting, an internal handrail should be added near the EV hatch

5

Scenario 02 – 1.0 ZIPLINE AIRLOCK (Acceptability) cont.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q2. The lander deck for transfer operations (deck volume, lander height, etc.)**
- **Rating = 25**
- **Comments:**
    - Height of the lander is reasonable, but a safety mechanism needs to be in place (railing, tether, etc.).
    - Consider placement of the zipline mount in proximity to zipline and edge of the lander to optimize for usability.
    - Flush zipline mount would increase safety when davit is not installed. If safety (including fall and trip hazard) was not considered, rating would be 3.

- **Q3. The conceptual small SPLC container for use with a zipline (handrails, size, shape, connection points, etc.)**
- **Rating = 4**
- **Comments:**
    - Soft good handles were used with zip line hooks while handrail was used for controllability entering airlock.

- **Q4. The number of crew for this transfer method**
- **Rating = 2**
- **Comments:**
    - Unlike the DAVIT 1.0 the further away the HAB is from the logistics lander is less impact due to less walking.

- **Q5. Transfer of 1.0 SPLCs through the Airlock hatch (hatch opening, Airlock volume, disconnecting container, stacking containers, "dings" to hatch seals, etc.)**
- **Rating = 6**
- **Comments**
    - Crewmember inside airlock at the EV hatch and disconnected the container outside the hatch to protect the hatch seals and maintained a clean dust free environment for both crew and container.
    - Containers were reoriented into final configuration later to allow focus on clearing area to prep for next container.
    - Containers were staked in clean config for both crew ingress. handrail aided in control through airlock, addition recommended.
    - Mockup setup potentially limited container from smooth passage into airlock and required either detachment outside airlock or crew aid to pull into airlock.

6

Scenario 02 – 1.0 ZIPLINE AIRLOCK (Acceptability) cont.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q6. The conceptual dust migration procedures**
- **Rating = 5**
- **Comments**
    - Task didn't require container dust mitigation with this method.

- **Q7. The cargo packing (i.e., layout of SPLCs) on the lander deck for transfer operations**
- **Rating = 5**
- **Comments:**
    - Pre-staged with integrated line to handles for easy interface to connect to line (i.e., like a running clothesline).
    - "A dry cleaner feeder capability" instead of one at a time.

- **Q8. Overall acceptability of using this transfer method from end-to-end (including risk to crew) for 1.0 SPLCs**
- **Rating = 5**
- **Comments**
    - More acceptable than Davit but still needs improvement

7

Scenario 03 – 1.0 ZIPLINE STAGING AREA (Acceptability)

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q1. Using the zipline for transfer operation (reach, attachments, loading/unloading containers, quick draw, control line, pulley, zipline post, etc.)**
- **Rating = 5**
- **Comments:**
  - Loading and unloading was straight forward.
  - Zipline
    - Rope was slack which made this operation inefficient. A realistic zipline would be a taught wire.
    - To mitigate issue, crew had to hold one hand above their head to tighten the line, which is not reasonable considering suit mobility.
    - Control line needs to be longer with a slack management system (retractable or tended).
    - A brake mechanism for the control line would be ideal (magnetic or mechanical).
    - Improvement to the quick draw to facilitate loading would be beneficial, i.e., a retractable portion of the attachment.
  - The zipline attachment point and post
    - Were too close to the edge of the lunar lander platform.
    - Should be within the work envelope for most crew members, but should still allow for multiple container sizes, if possible.
    - Hook attachment should be changed to allow for multiple SPLCs on one zipline run.
    - SPLCs were loaded with the attachment to the soft good handle to allow the receiving crew member to grab the hard handle upon receiving the SPLC.
    - Crew member did not use the cleat to tie off the line when they had to retrieve SPLCs far from the zipline post (they held the control line in their hand).
  - Zipline in Airlock
    - The tie off (receiving end) of the zipline could be inside the A/L or outside the A/L without any difference to the position of the receiving crew member.
    - If zipline was tethered inside the airlock, receiving crew member retrieved the SPLC outside the hatch to prevent inadvertent contact with the hatch seals.
    - Enabled better control for the orientation for stacking in the airlock and minimized re-grips during that process.
    - For both the zipline airlock and zipline staging area, the receiving crew member can stand inside the airlock to enable stacking and minimize dusting.
    - To add extra stability for the receiving crew member both for SPLC retrieval and dusting, an internal handrail should be added near the EV hatch

8

Scenario 03 – 1.0 ZIPLINE STAGING AREA (Acceptability) cont.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q2. The lander deck for transfer operations (deck volume, lander height, etc.)**
- **Rating = 5**
- **Comments:**
  - Height of the lander is reasonable, but a safety mechanism needs to be in place (railing, tether, etc.).
  - Consider placement of the davit mount in proximity to zipline and edge of the lander to optimize for usability.
  - Flush davit mount would increase safety when davit is not installed.
  - If safety (including fall and trip hazard) was not considered, rating would be 3.

- **Q3. The conceptual small SPLC container for use with a zipline (handrails, size, shape, connection points, etc.)**
- **Rating = 4**
- **Comments:**
  - Soft handles were used for controllability entering airlock.

- **Q4. Size of staging area**
- **Rating = 3**
- **Comments:**
  - Crew designated area to the port side of the A/L EV hatch.
  - In this staging area, stacking the SPLCs three high and two deep (pyramid configuration) worked well.
  - Crew member height is a consideration.
  - Stacked SPLCs require minimal dusting.
  - Should be sized to accommodate 15 stacked SPLCs (number could vary with operation).
  - SPLCs could be stacked on their sides like a pile of logs if some side restraints were built in the staging area.

- **Q5. The number of crew for this transfer method**
- **Rating = 2**
- **Comments:**
  - Unlike the DAVIT 1.0 the further away the HAB is from the logistics lander is less impact due to less walking.

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Scenario 03 – 1.0 ZIPLINE STAGING AREA (Acceptability) cont.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q6. The conceptual dust migration procedures**
- **Rating = 5**
- **Comments:**
  - In the suit, wrist mobility is limited so operations may be limited to one direction (as opposed to a "paintbrush" technique).
  - There needs to be a procedure for dusting, including order (top to bottom) and crew member movements.
  - A long handle brush would be helpful, along with handrails for single-footed stability during dusting.
  - Without a staging area, stacking SPLCs is preferred as stacking minimizes dusting.
- **Q7. The cargo packing (i.e., layout of SPLCs) on the lander deck for transfer operations**
- **Rating = 5**
- **Comments:**
  - Stacking is helpful on the lander platform and on the lunar surface during transfer.
  - Stacking minimizes crew member bending in the suit and improves dust mitigation.
  - Stacking also limits the need to travel on the lunar lander platform to retrieve SPLCs.
  - Ensuring the SLPCs interface with one another would minimize the potential for them to tumble.
  - Plus, pre-staged with integrated line to handles for easy interface to connect to line (i.e., like a running clothesline).
  - "A dry cleaner feeder capability" instead of one at a time.

- **Q8. Overall acceptability of using this transfer method from end-to-end (including risk to crew) for 1.0 SPLCs**
- **Rating = 5**
- **Comments:**
  - More acceptable than Davit but still needs improvement

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Scenario 04 – 1.0 AIRLOCK TRANSFER OPS (Acceptability)

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q1. Stacking the containers**
- **Rating = 4**
- **Comments:**
  - See comments from previous scenarios.
  - Summary:
    - 1) add "Lego type" capability to help stabilize stacking.
    - 2) potential handrail notch or retract handrail for easier stacking
    - 3) stacking like logs in airlock wont work unless have brackets to hold not rolling.
    - 4) could stack two vertical one horizontal
    - 5) can stack three high
    - 6) second row was in easy work envelope of 6) due to small space need capability to secure stack
- **Q2. Airlock container reconfiguration within the given airlock volume**
- **Rating = 3**
- **Comments:**
  - Stacking in airlock was centered between two crew don/doff stands with enough space to walk one way around to access other crew.
  - Stacked center/stbd.
  - Half of the containers needed to be moved around to access other side. 15 1.0 in airlock in this scenario

- **Q3. Suit don/doff in the given airlock volume**
- **Rating = 2**
- **Comments:**
  - Given airlock volume suit don doff volume was reasonable

- **Q4. Consensus Acceptability Ratings + Comments**
- **Overall acceptability of using this transfer method from end-to-end (including risk to crew)**
- **Rating = 3**
- **Comments:**
  - No comments

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SEATEST 6
DAY 02

Crew Consensus

26 July 2023

Day 02 Simulation Quality

SIMULATION QUALITY SCALE

1	2	3	4	5
Simulation quality (e.g. hardware, software, procedures, comm., environment) presented either zero problems or only minor ones that had no impact to the validity of test data	Some simulation limitations or anomalies encountered, but minimal impact to the validity of test	Simulation limitations or anomalies made test data marginally adequate to provide meaningful evaluation of test objectives (please describe)	Significant simulation limitations or anomalies precluded meaningful evaluation of major test objectives (please describe)	Major simulation limitations or anomalies precluded meaningful evaluation of all test objectives (please describe)

- **Q1. The environment as compared to expected lunar environment (1/6g effects, mass management, offloading concept fidelity, etc.)**
- **Rating = 3**
- **Comments:**
  - Slack in the zipline allowed the 2.0 SPLC to stay on the zipline directly into the airlock without contacting the hatch seals.
  - Larger containers forced crew members to the edge of the lunar lander platform, which is unrealistic given the additional stability from water resistance.

- **Q2. The environment's ability to provoke relevant operational considerations (dusting requirements, suit maneuverability, mechanism and system fidelity, etc.)**
- **Rating = 2**
- **Comments:**
  - Mechanisms
    - No simulated mechanism to lift 2.0 SPLC to the zipline hook.
  - System Fidelity
    - A/L simulations challenging with majority of hardware missing (SCUs, donning stands, hatches, etc.)
      - Recommend the addition of umbilical, suit donning procedure, volumetric suit after doffing, dusting procedure
    - A/L height above the ground is low fidelity/unrealistic and can alter some of the test conclusions
  - Suit Maneuverability
    - Mobility of the wetsuit is not comparable to that in the xEMU. Kayak suit, shoulder limiter, 3D printed HUT, hockey gloves, ski boots all recommended additions for space suit simulations.
    - Height and size of the 2.0 SPLCs made it challenging to maneuver between them in the airlock while maintaining awareness of the suit volume around the legs. No simulation mockup of lower half of the suit, so it was more challenging to consider size/volume limitations in that region.

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Scenario 05 – 2.0 ZIPLINE AIRLOCK (Acceptability)

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q1. Using the zipline for transfer operation (reach, attachments, loading/unloading containers, quick draw, control line, pulley, zipline post, etc.)**
- **Rating = 7**
- **Comments:**
  - Attachment
    - Attachment of the 2.0 SPLCs to the zipline hook was challenging (sim limitation).
    - Bungee or RET system recommended to bring soft goods handle to zipline attachment point.
    - The end point of the zipline inside the airlock should be adjustable zenith/nadir in order to change the angle of the zipline.
      - Accounts for a varying distance from lander to airlock while still ensuring payloads clear the hatch seal.
  - Mechanisms
    - Locking mechanism could reduce need for a hook swap
    - Longer control line and control line management system (Velcro, magnetic, or mechanical brake) required.
  - Loads and Containers
    - Additional soft tether point/d-ring integrated on a soft goods handle recommended at the center top of the SPLC such that the load may be balanced after attachment.
      - Minimize reorientation requirements once the SPLC reaches the lunar surface/lander deck.

- **Q2. The lander deck for transfer operations (deck volume, lander height, etc.):**
- **Rating = 5**
- **Comments:**
  - Height of the lander is reasonable, but a safety mechanism needs to be in place (railing, tether, etc.).
  - Consider placement of the davit mount in proximity to zipline and edge of the lander to optimize for usability.
  - Flush davit mount would increase safety when davit is not installed. If safety (including fall and trip hazard) was not considered, rating would be 3.

- **Q3. The conceptual large SPLC container for use with a davit (handrails, size, shape, connection points, etc.):**
- **Rating = 6**
- **Comments:**
  - See question 1 for additional comments on tether point and handrail recommendations.

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Scenario 05 – 2.0 ZIPLINE AIRLOCK (Acceptability) cont.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q4. Transfer of 2.0 SPLCs through the Airlock opening. (Airlock volume, disconnecting container, stacking containers, "dings" to hatch seals, etc.):**
- **Rating = 3**
- **Comments:**
  - Very straight forward due to the slack in the zipline (sim issue).
  - Easy to control.
  - No bumps on the hatch seals.
  - Center tether point would have been helpful for unloading, avoiding the need for reorientation by the receiving crew member.

- **Q5. The number of crew for this transfer method:**
- **Rating = 7**
- **Comments:**
  - If two crewmembers are required to lift 2.0 SPLCs, an additional crew member on the lander is required.
  - We believe we could lift/move them with one crewmember.
  - No additional crew required in A/L.

- **Q6. The conceptual dust migration procedures:**
- **Rating = 5**
- **Comments:**
  - Task didn't require container dust mitigation with this method.
  - In the suit, wrist mobility is limited so operations may be limited to one direction (as opposed to a "paintbrush" technique).
  - There needs to be a procedure for dusting, including order (top to bottom) and crew member movements.
  - A long handle brush would be helpful, along with handrails for single-footed stability during dusting.
  - Without a staging area, stacking SPLCs is preferred as stacking minimizes dusting.

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Scenario 05 – 2.0 ZIPLINE AIRLOCK (Acceptability) cont.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q7. The cargo packing (i.e., layout of SPLCs) on the lander deck for transfer operations:**
- **Rating = 5**
- **Comments:**
  - If single crew member is on the lander and two is required to lift 2.0 SPLCs, lifting/lowering device is required.
  - A jack/palette could be involved in packing.

- **Q8. Overall acceptability of using this transfer method from end-to-end (including risk to crew) for 2.0 SPLCs**
- **Rating = 7**
- **Comments:**
  - Handling heavy payloads with a single crew member on the platform leads to additional crew risk. A/L ops risk is minimal.

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Scenario 06 – 2.0 REVERSE DAVIT (Acceptability)

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q1. Using the Davit for transfer operations (reach, attachments, loading/unloading containers, davit handle, crank, hook, etc.)**
- **Rating = 7**
- **Comments:**
  - Mechanisms
    - Ratchet design helpful as mechanical stop for crew member brakes.
      - » Increasing the crank length was required for the crew member to get additional torque on the handle while raising 2.0 SPLCs.
    - Yawing the davit inboard brought the crewmember very close to the lunar lander edge.
    - The davit needs to be more centered on the lunar lander, or the arm needs to be able to pitch to facilitate these operations and keep the crew member safely away from the platform edge or lunar lander barrier/wall.
    - A telescoping/articulating davit could also alleviate some of these issues. .
  - Loading/Unloading
    - Manually lowering/raising anything with the davit is not a reasonable solution.
    - Heavier 2.0 SPLCs exacerbated issues associated with 1.0 Regardless, motion is not feasible with the limited range of motion in the suit. SPLC davit operations.
    - Raising SPLCs was substantially more challenging than lowering them.
    - Unloading the davit was awkward considering the lack of a centered tether point on the SPLCs.
      - » Work required substantial reorientation.

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Scenario 06 – 2.0 REVERSE DAVIT (Acceptability) cont.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q2. The lander deck for transfer operations (deck volume, lander height, etc.)**
- **Rating = 7**
- **Comments:**
  - Lander deck/davit placement and 2.0 geometry brings the crew member substantially closer to the edge of the lunar lander platform.
    - An unacceptable level of risk.
- **Q3. The conceptual large SPLC container for use with a zipline (handrails, size, shape, connection points, etc.)**
- **Rating = 6**
- **Comments:**
  - We consider a 2.0 SPLC feasible to be lifted by one crew member. Translation may require two crew members.
  - Unloading the davit was awkward considering the lack of a centered tether point on the SPLCs.
    - Work requires substantial reorientation.
  - Yawing the davit inboard brought the crewmember very close to the lunar lander edge.
    - Davit needs to be more centered on the lunar lander, or the arm needs to be able to pitch to facilitate these operators and keep the crew member safely away from the platform edge or lunar lander barrier/wall.
    - A telescoping/articulating davit could also alleviate some of these issues.
- **Q4. Transfer of SPLCs from A/L to staging area (below davit)**
- **Rating = 6**
- **Comments:**
  - Dust generation from dragging the SPLC over the hatch seal protector at the open A/L hatch would be untenable.
  - Some lowering mechanism through the A/L would be helpful. A mechanism for blocking dust (door protector?) could help. Ideally, one crew member would be staged outside the A/L.
    - Crew member would receive the SPLC from a crew member inside the A/L, then be able to carry the SPLC a few feet away on the lunar surface.
- **Q5. Size of Staging area (below the davit)**
- **Rating = 2**
- **Comments:**
  - Stacking the 2.0 SPLCs on top of each other, using a 4 x 2.0 SPLC area, seemed reasonable.
  - One crew member could stack the SPLCs.
  - Hook is mobile, so attaching the hook to SPLCs throughout the staging area was reasonable.

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Scenario 06 – 2.0 REVERSE DAVIT (Acceptability) cont.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q6. The number of crew for this transfer method**
- **Rating = 4**
- **Comments:**
  - Additional crew member at the lunar lander for reorientation assistance would be helpful/efficient.
  - Centered tether point would also be helpful with a single crew member on the lander platform.
  - Mechanical/automatic release of a payload would be ideal.
- **Q7. The cargo packing (i.e., layout of SPLCs) on the lander deck for transfer operations**
- **Rating = 6**
- **Comments:**
  - Additional crew member at the lunar lander for reorientation assistance would be helpful/efficient.
  - Centered tether point would also be helpful with a single crew member on the lander platform.
  - Mechanical/automatic release of a payload would be ideal.
- **Q8. Overall acceptability of using this transfer method from end-to-end (including risk to crew) for 2.0 SPLCs**
- **Rating = 7**
- **Comments:**
  - The davit is not a reasonable solution for 2.0 SPLCs.
  - The requirement for two crewmembers to translate the 2.0 SPLC makes this scenario challenging.

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Scenario 07 – 2.0 DAVIT (Acceptability)

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q1. Using the Davit for transfer operations (reach, attachments, loading/unloading containers, davit handle, crank, hook, etc.)**
- **Rating = 6**
- **Comments:**
  - Attachments
    - Centered tether point would also be helpful with a single crew member on the lander platform
  - Loading/Unloading
    - Davit as lifting device (did not maneuver 2.0 SPLCs toward davit, rather let out davit hook to meet SPLC soft good handles).
    - Crewmember would then raise the SPLC slightly with the davit crank before yawing, enabling the payload to always clear the lunar platform edge.
  - Mechanisms:
    - Use of the davit (cranking) is challenging.

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Scenario 07 – 2.0 DAVIT (Acceptability) cont.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q2. The lander deck for transfer operations (deck volume, lander height, etc.)**
- **Rating = 7**
- **Comments:**
  - Largest concern with the lander deck was the size and the crew member getting too close to the edge.
  - Lander deck/davit placement and 2.0 geometry brings the crew member substantially closer to the edge of the lunar lander platform.

- **Q3. The conceptual 2.0 SPLC container for use with a davit (handrails, size, shape, connection points, etc.)**
- **Rating = 7**
- **Comments:**
  - We consider a 2.0 SPLC feasible to be lifted by one crew member.
  - Unloading the davit was awkward considering the lack of a centered tether point on the SPLCs.
    - Work requires substantial reorientation.
  - Yawing the davit inboard brought the crewmember very close to the lunar lander edge.
    - Davit needs to be more centered on the lunar lander, or the arm needs to be able to pitch to facilitate these operations and keep the crew member safely away from the platform edge or lunar lander barrier/wall

- **Q4. Size of Staging area**
- **Rating = 6**
- **Comments:**
  - Dust generation from dragging the SPLC over the hatch seal protector at the open A/L hatch would be untenable.
  - Some lowering mechanism through the A/L would be helpful.
  - A mechanism for blocking dust (door protector?) could help. Ideally, one crew member would be staged outside the A/L.
  - Crew member would receive the SPLC from a crew member inside the A/L, then be able to carry the SPLC a few feet away on the lunar surface.

- **Q5. The number of crew for this transfer method**
- **Rating = 3**
- **Comments:**
  - Two crew members seemed suitable for this operation. Moving to the SPLCs to hook them up to the davit seemed inefficient.

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Scenario 07 – 2.0 DAVIT (Acceptability) cont.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q6. The conceptual dust migration procedures**
- **Rating = 7**
- **Comments:**
  - With our dust mitigation procedures, we would have kicked up a lot of dust at the A/L EV hatch over the hatch seal protector.
  - Dusting should occur further from the hatch seal or there needs to be additional protection in the proximity of the A/L.

- **Q7. The cargo packing (i.e., layout of SPLCs) on the lander deck for transfer operations**
- **Rating = 2**
- **Comments:**
  - Suitable

- **Q8. Overall acceptability of using this transfer method from end-to-end (including risk to crew) for 2.0 SPLCs**
- **Rating = 7**
- **Comments:**
  - Overall acceptability scores driven largely by proximity of crew member to lander platform edge and dust mitigation issues.

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Scenario 08 – 2.0 AIRLOCK TRANSFER OPS (Acceptability)

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable deficiencies	
1	2	3	4	5	6	7	8	9	10

- **Q1. Stacking the containers**
- **Rating = 4**
- **Comments:**
  - Stacking 2.0 SPLCs three-high was a huge efficiency and seemed reasonable for two crew members.
  - 8 2.0 SPLCs stacked seemed better than 16 1.0 SPLCs.
  - To manage unstacking the containers, crew member used one hand on the soft good handles and used one hand to tend the SPLC as it slid toward the A/L floor.

- **Q2. Airlock container reconfiguration within the given airlock volume**
- **Rating = 4**
- **Comments:**
  - If stacked 3 high, A/L volume easily manageable.
  - If 2 high, one suit port would likely be blocked to allow one crew member to assist the other to doff their suit.
  - If 2.0 SPLCs are stacked 2 high both forward in front of the IV hatch and aft/port or stbd around the EV hatch, maneuvering in the corridor created by the SPLCs would be too tight in the suit.
  - If one of the suit ports is blocked by SPLCs, this becomes more manageable

- **Q3. Suit don/doff in the given airlock volume**
- **Rating = 4**
- **Comments:**
  - If stacked 3 high, this is reasonable with minimal reconfig.
  - If stacked 2 high, reconfig is required which would block one suit port at a time.

- **Q4. Consensus Acceptability Ratings + Comments**
- **Overall acceptability of using this transfer method from end-to-end (including risk to crew)**
- **Rating = 4**
- **Comments:**
  - Overall acceptable if we are able to stack SPLCs 3 high.

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SEATEST 6
DAY 03

Crew Consensus

27 July 2023

Day 03 – CAPABILITY DATA

CAPABILITY ASSESSMENT SCALE				
Essential/Enabling	Significantly Enhancing	Moderately Enhancing	Marginally Enhancing	Little to No Enhancement
Impossible or highly inadvisable to perform mission without capability	Capabilities are likely to significantly enhance one or more aspects of the mission	Capabilities likely to moderately enhance one or more aspect of the mission or significantly enhance the mission on rare occasions	Capabilities are only marginally useful or useful only on very rare occasions	Capabilities are not useful under any reasonably foreseeable circumstances
1 2	3 4	5 6	7 8	9 10

- **Q1. The davit transfer concept**
- **Rating = 2**
- **Comments:**
  - Some mechanism to lift the PLCs which has a flexible loading/unloading capability is essential to the mission.
  - The lunar platform is too high to safely operate without such a mechanism.
  - This capability assessment does not include the functionality of the specific davit used in this test.
  - Rather, crew consider some mechanism to transfer payloads from the lunar platform to the surface essential since not all payloads need to go directly to the A/L.

- **Q2. The zipline transfer concept**
- **Rating = 3**
- **Comments:**
  - Allows for potentially dust free transfer.
  - Fast way to transfer cargo.
  - The attachment points of the zipline are restrictive, and the attachment itself requires lifting.
  - These are limitations of the zipline.
  - However, the dust free transfer method and ease of transfer is worthwhile.
  - While we might achieve mission success without the zipline, the time requirement for such operations would be prohibitive

- **Q3. Additional Comments:**
  - Depending on the height of the lander, some mechanism is needed to do a couple things:
    - 1) Lift the cargo to the attach point
    - 2) Deliver the cargo to the lunar surface/directly to the airlock.
  - Seems intuitive to use the zipline to lower equipment dust free to a certain place.
  - Efficient operations:
    - Difficult to use the zipline to raise equipment.
    - The davit concept is good for lifting equipment (especially large items like the 2.0 SPLC or MPLC).
    - A combination or hybrid of these two concepts would be useful.

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Day 03 – CREW DEBRIEF

- **Q1. Any other general thoughts on cargo logistics lander configurations (e.g., how logistics are packaged on a lander for offloading) and capabilities (e.g., specs for ladders, davits, winches, etc.)? E.g., can you envision lander details that are extremely prohibitive vs. extremely mission enhancing, etc.?**
- **Comments:**
  - Safety
    - Feel strongly that some railing or safety mechanism is required for operations on the lander deck.
    - Can be a rail/strap guard around the perimeter or a tether system which allows you to continue operations while restricting you to the safe area of the lander deck.
  - Ladder
    - Ladder mockup had a helpful height to allow crew members to push through the gap between the ladder handrails while cleaning the PLSS.
    - Height was good for the alternate method of swinging around one handrail to get to the ladder rails with your feet.
    - A sloped ladder would aid the crewmember in ascending/descending with the weight of the suit and PLSS (estimate 5-15deg).
  - Mechanisms:
    - Concept of a winch operation to lift and lower payloads of various sizes and mass is a valuable concept, however there are significant problems with the current davit iteration.
      - » 1) The metabolic demands to manually operate a crank to lower and raise a hook is unacceptable.
        - It is very difficult in current suit designs with the existing shoulder mobility capabilities to freely operate a crank handle such as the manual davit in SEATEST-6.
        - Even if the shoulder mobility of the next gen spacesuit could support that kind of mobility, the metabolic demands of such an operation are not sound. It would use up a lot of resources, namely time and oxygen, which was reflected in the increased air usage from the SCUBA tanks for the astronaut that was manually operating the davit.
          - A solution would be to have an electric motor operated by push buttons or pedal design with manual operation as a backup.
      - » 2) Having the ability to offset payloads closer or farther from the davit is useful.
        - Effectively, being able to adjust the cosine of the davit angle (the arm of the davit is the hypotenuse) can bring payloads closer or further away.
        - Being able to increase the offset of payloads is helpful if the payload is large and needs to be offset further to avoid hitting the lander platform as it's being lowered.
          - There are a couple ways to accomplish this.
            - Make the pitch of the davit adjustable or use a telescoping davit arm.
            - We'll leave it to the engineers to figure out the best solution to accomplish the function we are looking for.
      - » 3) The yawing capability of the davit is very important but feel having a pedal to lock/unlock the davit yaw angle in place would be helpful, similar to how the APFR on station has a pedal to unlock/lock its yaw angle.

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Day 03 – CREW DEBRIEF

- **Q2. Any other general thoughts on dust mitigation strategies for logistic transfer ops?**
- **Comments:**
  - Dust mitigation with the zipline into the airlock was great.
    - Should be some way to raise and lower the attach point on the rover to account for different distances away from the lander platform to create the correct angle for the equipment to slide into the airlock.
  - Tarps could be used in temporary staging areas.
  - Possibly some type of grating at the entrance to the airlock to rest/set dusty equipment.
  - A "foot brush" also could help to wipe off feet and equipment.

- **Q3. What are your thoughts on the current logistics manifest for a 14-day rover mission for a crew of 2 (i.e., all 15 of the 1.0 SPLCs + 8 of the 2.0 SPLCs)? How do you propose we think about logistics for ~7 to 30-day surface mission (e.g., in pressurized rover and/or surface habitat)? What are your recommendations for determining (e.g., through analysis, testing + eval, etc.) what quantity of logistics is appropriate for these missions?**
- **Comments:**
  - MPLC with transfer port is much preferred over the 1.0, 2.0 solutions.
  - Space and dust mitigation are optimized with MPLC design.
  - If MPLCs are not feasible, the size of 2.0 SPLCs seem preferable to 1.0s to minimize extra volume taken up by the containers.
  - See suggestions in scenario feedback regarding requirements for handles and stacking.

- **Q4. What are your concerns and recommendations with regard to our ability to simulate the lunar surface environment and Artemis mission operations in these SEATEST analog tests?**
- **Comments:**
  - The major concerns are:
    - 1) lack of ability to simulate the space suit (the addition of a 3-d printed HUT, gloves, boots, or some sort of mobility restraint would add fidelity to this test).
    - 2) the additional stability added by water resistance giving the crewmember an unrealistic sense of safety on the lunar lander platform.
    - 3) the addition of a realistic safety system on the lander deck is essential in the real lunar environment, so should be mocked up here.
    - 4) Finally, weight the subject to lunar gravity (1/6 g) while working on the mockup.

- **Q5. Any other feedback (e.g., for logistic handling)**
- **Comments:**
  - A fulcrum over the A/L hatch protector could be helpful to move large loads in/out of the A/L easily, especially if two crew members are required to lift the load

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