SEATEST 7 Detailed Final Report Charts

October 31, 2024

Report Authors

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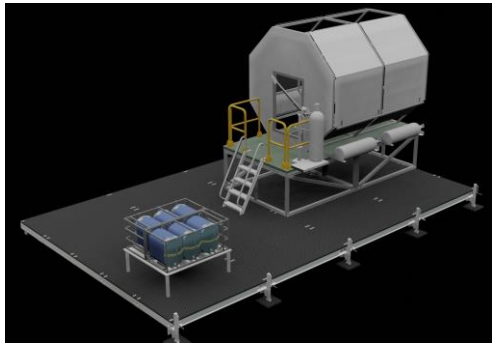
Executive Summary

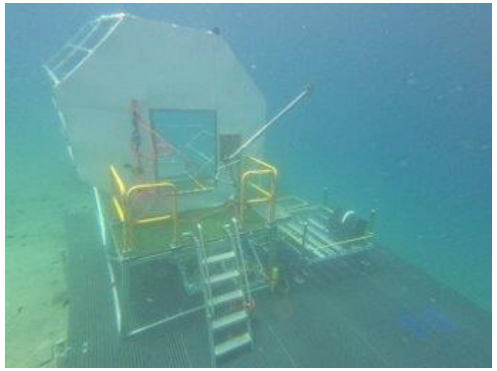
SEATEST 7 Final Report

Executive Summary

- **Sponsor:** ESDMD Strategy and Architecture Office (SAO) Lunar Architecture Team (LAT)
- **Objective:**
  - Perform Human-in-the-Loop testing to evaluate current strategies and concepts for lifting Crew Portable Carriers (CPCs) and Air Tanks to a lunar habitat
- **Rationale:**
  - Results will inform ACR/SAC 24-25 tasks and Artemis SAO teams responsible for:
    - Mobility and Logistics
      - Logistics Working Group
    - Lunar Habitation
    - Integration & Analysis Lunar Concept Team
  - Doubles as an Expeditionary Training opportunity for International Astronaut Corps
- **Methodology:**
  - 5 crewmembers to perform scenario evaluations with logistics containers at 1/6g
  - Capture objective and subjective data using rigorous metrics and protocols
- **Location:** Wrigley Marine Science Center, University of Southern California (USC) – Dornsife campus



Conceptual mockup rendering



Mockup post-assembly

Local MCC w/ video/voice for PIs & room for observers

Executive Summary

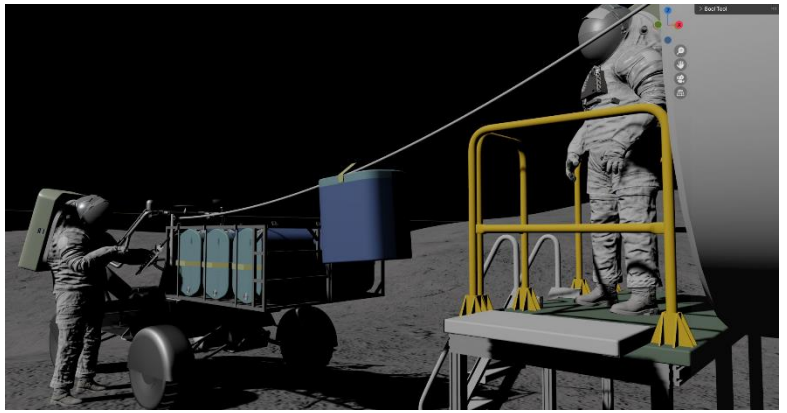
- **SEATEST (Space Environment Analog for Training, Engineering, Science and Technology) 7 evaluated:**
  - Logistics transfer ConOps between an unpressurized rover (e.g., LTV) and an elevated lunar habitat (e.g., MPH)
    - Lifting CPCs to porch level
    - Lifting air tanks to stowage location
    - Airlock size required
  - Different mechanical loading/offloading methods
    - Air Tank Davit
    - Air Tank Hoist
    - CPC Zipline
  - Choreography of cargo in the airlock to permit ingress and suit doffing
  - Impact of dust removal requirements
    - Note abrasion and potential damage (e.g., to hatch seals)
    - Quantify dust removal overhead

- **Five astronauts from NASA, ESA, CSA, and UAE evaluated 10 scenarios of cargo logistics unloading and re-loading with extensive data collected:**
  - Objective data:
    - Task times for conducting overall tasks and subtasks
    - Full audio/video of test activities
    - Inadvertent # of “dings”/collisions on hardware
    - Use of handhold aids
    - “Hang-up” periods
  - Subjective data:
    - Crew consensus of:
      - Task acceptability assessment ratings related to best practices, considerations, and constraints for EVA-driven logistics transfer ConOps
      - Sim quality of the test environment
    - Crew debrief comments

Results will inform the ARC/SAC 24-25 tasks and Artemis teams responsible for Mobility and Logistics, Lunar Habitation, and Integration & Analysis Lunar Concept Team

Results Overview

- **All planned Test Scenarios were accomplished through one or more iterations:**
  1. CPC Transfer via Zipline
  2. CPC Transfer via Davit
  3. CPC Pallet Transfer via Davit
  4. Air Tank Transfer via Hoist
  5. Air Tank Transfer via Davit
  6. Surface Habitat Airlock Cargo Transfer
  7. Team Choice for CPC and Air Tank Transfer
- All objective and subjective data outlined previously was collected on the accomplished scenarios
- Insights from debriefs, discussions and testing prior to the mission are also captured here



CPC lift via zipline

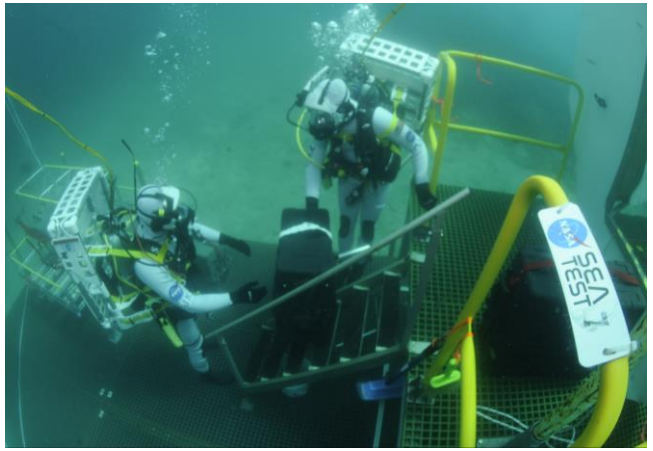
Tank lift via davit

Tank lift via hoist

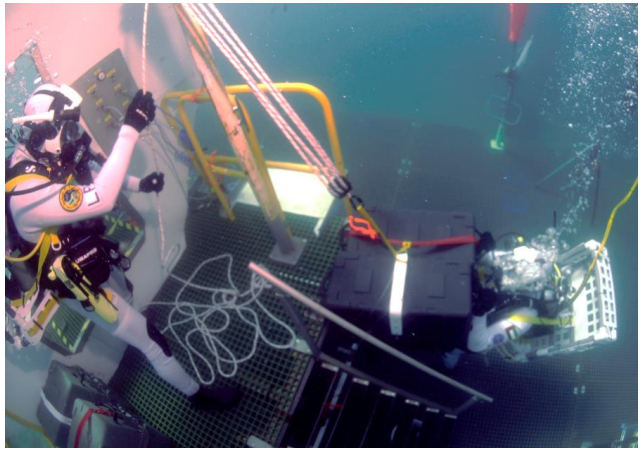
All mission minimum success criteria completed + bonus Team Choice Runs

Key Takeaways – CPC and Air Tank Transfer

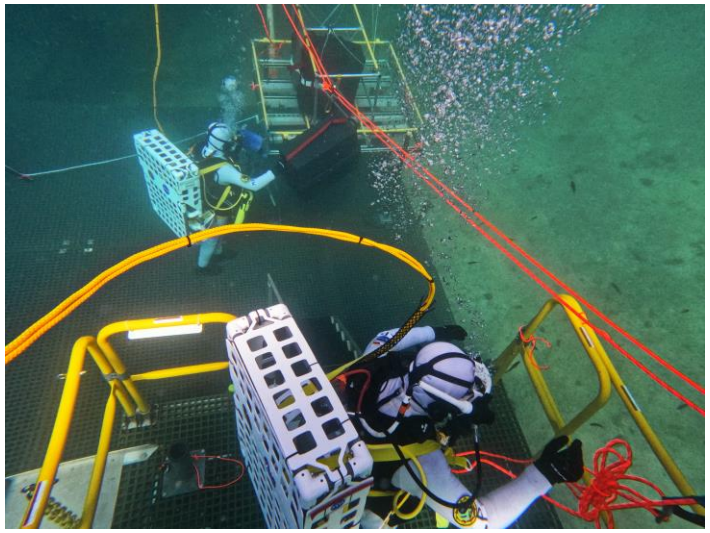
- **It should be possible to lift a small number of CPCs (4-8 were discussed) manually or with only very simple aids**
  - Smart stair design (outer stringer as a sliding rail)
  - Use of a step stool
  - Use of a hoist
  - Limiting factor might be dusting rather than the lift
- **A simple hoist is effective and versatile for a wide range of lifting tasks**
  - Additional controllability aids and lower mounting height required to better accommodate suit constraints for lifting air tanks
- **A zipline is a promising simple and lightweight solution for CPC transfer**
  - Also makes dusting easy or not required
  - Setup should come right over the top of Luggage rack and up to porch without blocking stair access



Use of step stool to transfer CPC from stair position to porch



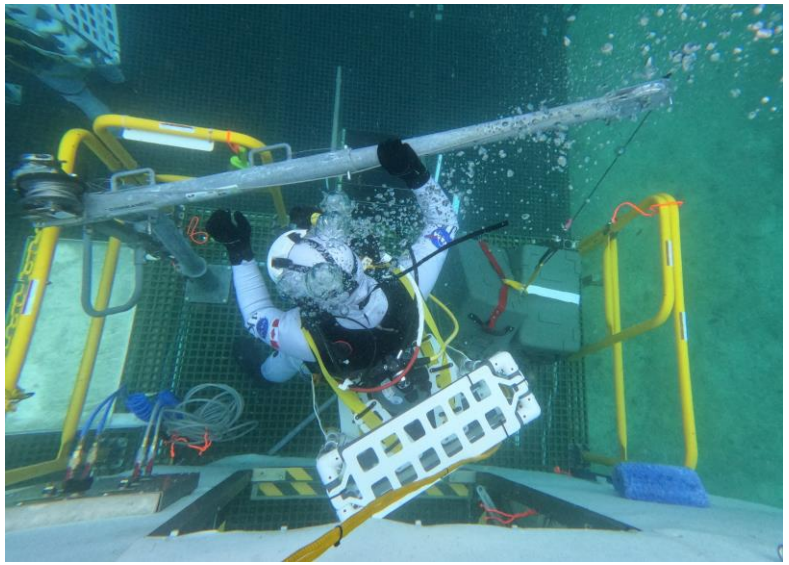
Simple hoist to lift a CPC



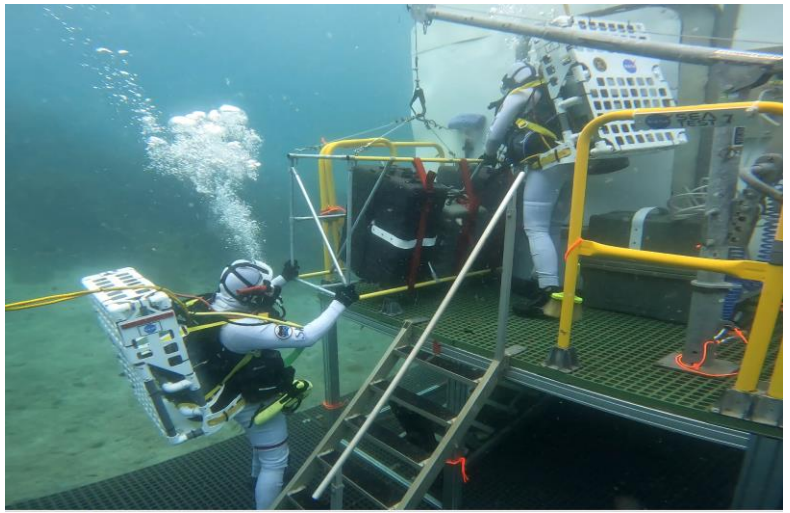
Zipline lifting a CPC and set up running over the top of the LR

Key Takeaways – CPC and Air Tank Transfer

- **Davit was universally disliked for several reasons**
  - Takes up too much precious real estate on porch
  - As implemented, too many handling limitations
  - Too easy to block access to hatch (ICR)
- **Rather than a davit, at most consider further investigation of a simpler design more like a crane**
  - Mounted above the hatch (and off the porch)
  - Adjustable reach
  - Simpler lift mechanism (e.g., hoist)
- **Lifting the whole pallet held no obvious advantages (and numerous disadvantages) over other methods**



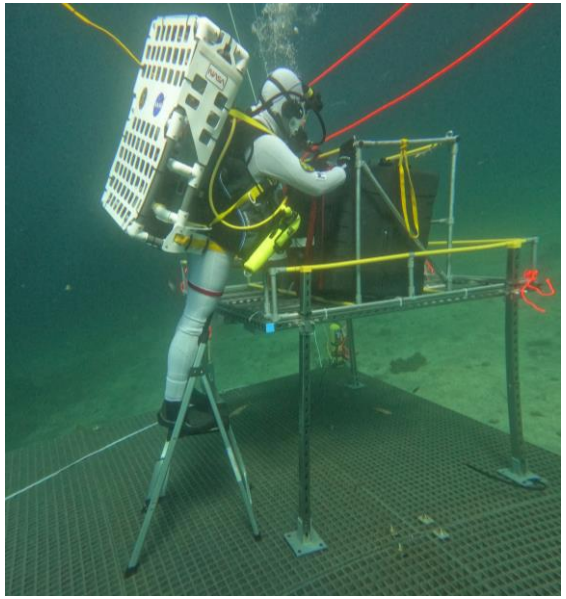
Difficulties presented with davit use



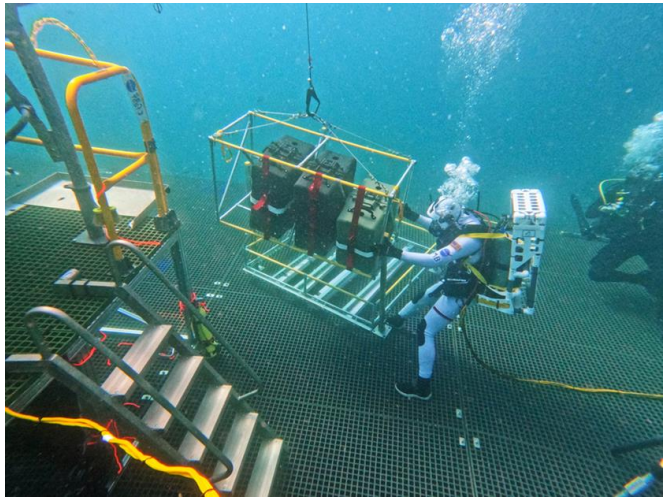
Loaded pallet positioned on porch

Key Takeaways – Luggage Rack

- **Luggage Rack**
  - Luggage rack height and alignment with lift point significantly impact operational complexity
  - Height
    - 1m height is too high for loading/offloading cargo without the use of a step stool
    - 0m and 0.5m heights about equally difficult to access
    - A “tailgate” that opens could allow cargo to be more easily slid from the LR and should be considered especially for higher LRs
  - Mis-alignment
    - All operations, especially lateral control, are more difficult at a 1m height than at the lower heights
    - Lifting in mis-aligned case was unacceptable for all LR heights (due to lateral motion control of payload) without better handling aids
    - As parking directly under a lift point is considered operationally infeasible, two options remain:
      1. Ability to adjust the position of the lifting device (such that plumb line is directly over payload)
      2. Ability to easily remove cargo by hand and carry directly under the lift point



Workaround to offload a 1m LR



Luggage Rack mis-alignment challenges

Key Takeaways – Porch, Rails

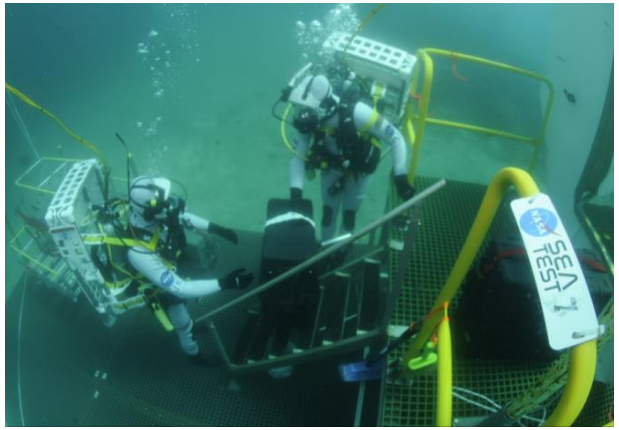
- **Porch Size**
  - 1.2m x 2.4m adequate for task (elevating 4 CPCs, dusting, A/L ingress) with or without footprint davit took up
  - Can continue looking at shape and width, but 1.2m depth is a minimum for the operations exercised, which did NOT include a method for bringing a CPC directly into the airlock
- **Porch Rails**
  - Porch railings (or some equivalent restraint/handhold/net) necessary to assist the porch crewmember during zipline operations
  - Crew did not feel forward rails were required for fall protection and functionality should prioritize hand-hold aids, rather than mitigating risk of fall
  - Should explore the option of removing forward rails or making them removable to create more functional space

Porch with 1 EV, 9 CPCs (~19 CTBE)

Starboard porch rail open (as it was for numerous operations) with CPC Pallet

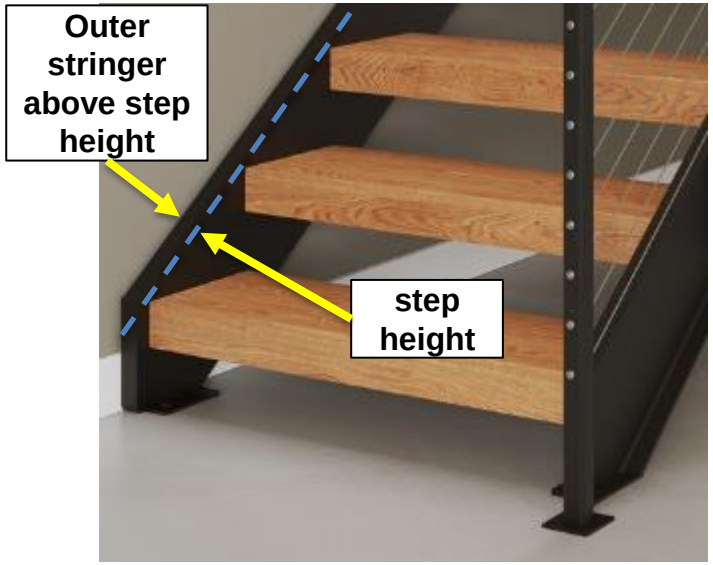
Key Takeaways –Stairs, Airlock

- **Stairs/Ladder**
  - Stair design with hand rail on one side (only) was preferred to the ladder
    - Smaller spacing between steps
    - Less steep (less thought required on balance – more like going up steps than climbing)
    - Hand rail on one side only (allows possibility to hand carry a CPC)
    - Ability to slide CPC up stair edge (though widening edge would improve this feature) or temporarily stow on stairs to hand up to porch crewmember
      - Design should have outer stringer elevated above step height to use as a sliding rail



CPC balanced on outer stringer

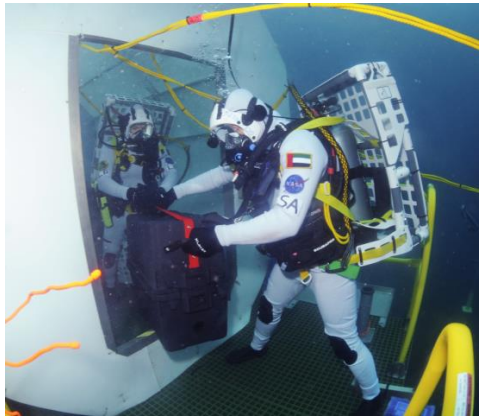
- **Airlock**
  - Airlock size assessment should continue as design and requirements mature to understand whether this size (2.1m) is adequate for the task (loading up to 19 CTBE worth of CPCs, 2 crew ingress, hatch closure, suit doffing). Fidelity and design maturity not sufficient to fully understand primary unknowns
    - Limitations and space requirements of a pressurized suit
    - Airlock floorplan
    - Airlock volume constraints
  - Need long vertical EVA stability handhold aids for ingress/egress on
    - Port and starboard side exterior
    - Port side (non hinged side) interior



Elevated outer stringer illustration

Key Takeaways – Design Considerations

- **Tank Design**
  - More handles for hand positioning and better control
  - More lift points appropriate to the orientation desired in the lift
  - Overall tank size/weight was controllable with appropriate handholds



CPC with flexible side handles

- **CPC Design**
  - The smaller CPC size (2.4 CTBE) is preferred over the larger size (2.8 CTBE) for EVA handling
  - Design considerations should include
    - Additional handholds on sides of CPC are essential
    - CPCs should fit together cleanly, both stacking vertically and aligning horizontally
    - Long axis strap preferred over short axis for ambulating with CPC to prevent wrist rotation
    - No difference noted between side vs lengthwise strap for manual handling (given that there were side handles in both cases)
    - Flexible/fabric straps preferred to rigid strap
    - If lifting by hook, a lift point should be available that keeps the CPC centered (rather than sliding down a strap and hanging awkwardly)

- **Step Stool**
  - A lightweight portable stepstool aids/enables numerous operations
    - Required to accomplish loading/offloading cargo from Luggage Rack @ 1m height
    - Used as an aid for temporary stowage for CPC dusting, CPC/tank attachment to lifting mechanisms, air tank electrical/air connections
    - Used as an aid for a couple of variations of manual CPC lift options
  - Design considerations should include
    - Interfaces on vehicle(s)
      - Consider built in steps on vehicle like on an aircraft
    - Needs to be EVA compatible (larger than used for ST7 and stable on regolith)

Key Takeaways - General

- **Developing a SEATEST mission served as a forcing function to:**
  - Address logistics challenges with key Artemis stakeholders (Logistics, Habitation, Concept Analysis, FOD EVA)
  - Identify POCs from each team for future work between teams
  - Build a common framework and vocabulary for discussing the challenges
- **The arbitrary but inflexible deadline ensured full team engagement and prioritization for a rapid test**
- **Simulation quality was sufficient to support meaningful evaluation of all test objectives**
- **The SEATEST mission model proved that a small team with limited resources can rapidly plan, execute and document meaningful HITL test data (< 6 mos. from first concept briefing to final report)**
- **Having Logistics and Habitation team stakeholders present during testing to witness results and discussions firsthand was very valuable**
- **The results documented in this report will immediately be fed forward to inform ongoing SAC 24 tasks, Architecture Definition Document (ADD), SAC25 tasks, and various ConOps Documents**

Detailed Report

Section 1.0

Introduction

Background: Artemis Surface Elements Logistics Resupply

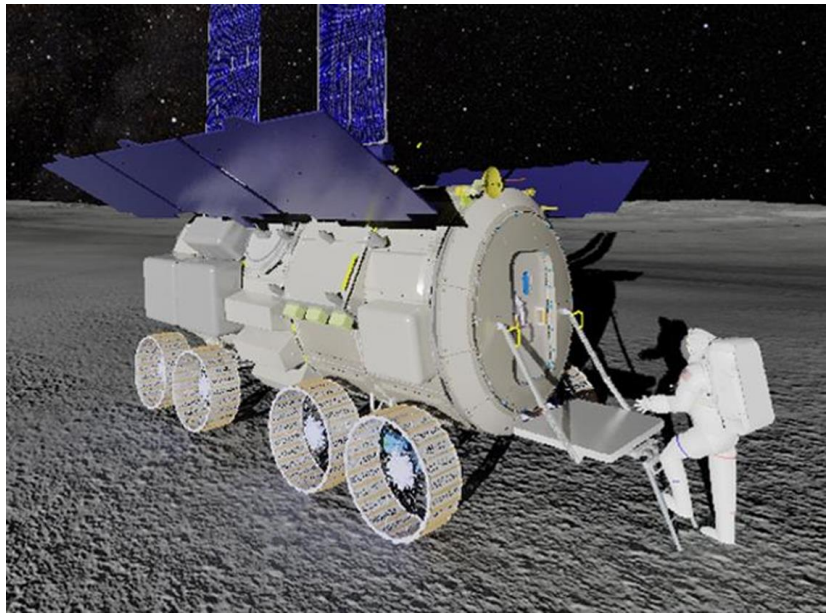
- NASA is planning for efficient and sustainable logistics operations to support ~annual crewed missions to the lunar surface
- Today, teams are evaluating and testing innovative ways to transport logistics from cargo logistics landers to crewed pressurized living volumes (e.g., pressurized rover, surface habitat)
  - Some logistics will need to be hand carried while EVA
  - Robotic concepts that may allow some shirt-sleeve transfer
- **SEATEST 7 was focused on the EVA carried crew-in-the-loop concepts** to obtain relevant data related to feasibility of concepts and crew task timing
- **Reference Mission:** a 7-day mission in the Artemis ~8/9 timeframe
  - Logistics for 2 crew for 7 days = ~19 CTBE of pressurized logistics

A soft-sided Cargo Transfer Bag (CTB), the traditional container for transferring cargo around inside or between pressurized spacecraft

Key Concepts: MPH and CPCs

The MPH is an initial lunar surface habitat being contributed to the Artemis program by the Italian Space Agency (ASI) with support from their contractor Thales Alenia Space (TAS-I).

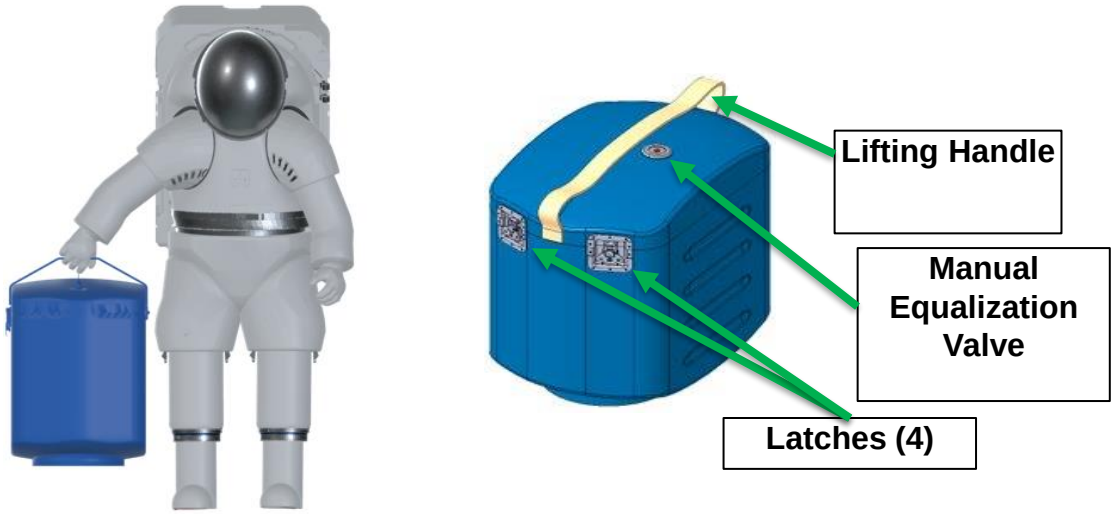
- Designs are changing rapidly as solutions are being iterated and evolving
- Most recent concepts at the time of SEATEST 7 assumed mobility and a wheeled chassis



Early TAS-I artist rendering of MPH

A CPC is a small, conditioned pressure vessel intended to deliver pre-supplied logistics for Lunar Missions

- 2 sizes are under consideration: 2.4 and 2.8 CTB Equivalent (CTBE)
- Total loaded CPC: 75kg (27.6lbs, lunar weight)



Notional Crew Portable Carrier (CPC)

Note: *All artist renderings in this report are notional and do not reflect the actual design of the current MPH, LTV or any other elements or functions*

Key Concepts: LTV Luggage Rack

- Several LTVS contractor concepts for unpressurized Lunar Terrain Vehicles (LTV) are currently under evaluation
- Each has a unique cargo carrying proposal, such that the "luggage rack" (where the cargo is carried) may be at a different height than that of the competitors
- Further, the capability of placing cargo directly under a habitat lift point is unproven and will be challenging on lunar terrain regardless of the design(s) chosen
- For these reasons SEATEST 7 testing also considered the challenges
  - Luggage Rack heights of 0m, 0.5m, and 1.0m as crude testing bounds
  - Luggage rack mis-alignment, where the cargo was not directly underneath a lift point
  - Ambulation cases where cargo was manually removed from the Luggage Rack and carried to the lift point

Note: *All artist renderings in this report are notional and do not reflect the actual design of the current MPH, LTV or any other elements or functions*

Artemis ConOps

- **SEATEST 7 was about understanding how those air tanks and CPCs that accompany the crew get lifted and installed onto MPH**
- **Previous suit-constrained HITL tests concluded mechanical assistance is needed for both**
- **Multiple concepts were investigated for comparison**
- **Full EVA load of the A/L was also be investigated (to inform A/L sizing)**

SEATEST Test Series

SEATEST (Space Environment Analog for Training, Engineering, Science and Technology) was conceived to accomplish two primary goals:

- **Develop the capability to conduct Human-in-the-Loop (HITL) testing that can benefit from undersea testing**
  - Rapid prototyping and assessment of Artemis ConOps and Capabilities
  - Integrated ConOps development testbed
  - Medium fidelity, partial gravity environment
  - Dedicated crew input toward Artemis architecture questions
  - Direct cost offset via International Partner Astronaut participation costs
  - Dedicated feedback from other relevant end-operators (e.g., CapCom, EVA Officer)
- **Provide an "Expeditionary Training" experience for the International Astronaut Corps**
  - Leadership/followership opportunities
  - Extreme environment mission operations
  - Real risks, demanding critical training, good buddymanship, and high individual and team performance
  - "Detachment mentality" where the questions being answered are front and center for an extended period of time

SEATEST is a capability to rapidly assess ConOps questions with dedicated crew and end-user feedback

Primary Use of Data

- **Exploration Systems Development Mission Directorate (ESDMD)** 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** - during these ACRs, NASA architecture teams analyze the Moon to Mars Objectives and distill them into mission concepts and how they function together to accomplish human missions to the Moon to Mars
- **To support the November 2024 ACR, a series of Strategic Analysis Cycle (SAC) tasks are ongoing**
- **SAC 24 and LAT 24 tasks informed by SEATEST 7 include:**
  - SAC Task 24.12 – Lunar surface logistics strategy refinement: Refine lunar surface logistics sub architecture centered around hybrid carrier approach
  - LAT Task 24.101, 24.102 – Define target states for FE and SLE. Refine SAC24 GRACs
  - LAT Task 24.51 – Refinement of Sub-architecture book, mapping of UC&Fs to sub-architectures
  - LAT Task 24.53 – Habitation strategy for future lunar surface exploration with updated reference concepts
- **Ongoing and SAC 25 High Priority tasks informed by SEATEST 7 include:**
  - Logistics and Mobility BAA
  - Architecture Concept Reference Missions
  - POD work on target states/GRACs
  - MPH Pre-SRR Trade Studies
  - Lunar Surface Logistics Strategy (SAC 25.12)
  - Alpha Task for Carrier Concept Maturation - CPCs
- **Results will also inform:**
  - MPH Integrated Surface Logistics Strategy
  - MPH Airlock Sizing
  - Architecture Definition Document (ADD)

Test Team

Mission Management Team

Mission Director
M. Reagan / XM

Dive Ops Lead
W. Todd / XM

Team Comm/Coord
B. Rohde / XM

University Partner
University of Southern California (USC) / Wrigley Marine Science Center

Mission Support
- Medical – J. Schmid / SD
- Communications, Network, & Data
  - M. Downs / KSC
  - J. Busto / KSC
  - M. Miller / KSC

Engineering Week
- Mockup Support
  - T. Gelo / SF3
  - E. Fesel / SF3
- Execution Support – T. Phillips-Hungerford / Aerospace

MCC Support

Primary Team
- Capcom/Ground IV – A. Dill / CB
- EVA – G. Wilt / CX
- Data Collection – A. Porter / XM
- Imagery – S. Everett / XM

Stakeholders
- LAT observers
  - V. Alvarez / KSC (Logistics)
  - A. Quesenbery / MSFC (Hab)
  - D. Perri / MSFC (Hab)
- TAS-I (MPH contractor) observer
  - F. Vagnone

Mission Execution Support

Crew
- Megan Behnken / NASA
- Marcos Berrios / NASA
- Sultan Alneyadi / UAE
- Josh Kutryk / CSA
- Luca Parmitano / ESA

Support Divers
- J. Poffenberger / XM
- K. Beaton / Aerospace
- K. Shreeves / XM Temp
- J. Talacek / XM Temp
- J. Council / XM Temp

SEATEST 7 Team

Schedule

General test timeline:

Test Dates	16-Sep Monday	17-Sep Tuesday	18-Sep Wednesday	19-Sep Thursday	20-Sep Friday	21-Sep Saturday	22-Sep Sunday	23-Sep Monday	24-Sep Tuesday	25-Sep Wednesday	26-Sep Thursday	27-Sep Friday	28-Sep Saturday	29-Sep Sunday	30-Sep Monday
Dive Support Team	Flight to CA	Miss C. AM Mockup Assy, Dry Runs	Scenario Fam, Dry Runs	Emer Trng, Dry Runs	Evals 1&2	Evals 3&4	Evals 5&6	Evals 7&8	Evals 9 & 10	Contingency or Debrief or Teardown	Teardown	Teardown	Teardown	Packing (am) Cat Ex PM	Fly Home
Crew	Flight to CA	Miss C. AM New Diver Qual	New Diver Qual	Emer Trng, Dry Runs	Evals 1&2	Evals 3&4	Evals 5&6	Evals 7&8	Evals 9 & 10	Contingency or Debrief	Packing (am) Miss C. PM	Fly Home			
MCC & Comm Support Teams		Flight to CA	Miss C. AM Scenario Fam, Dry Runs	Emer Trng, Dry Runs	Evals 1&2	Evals 3&4	Evals 5&6	Evals 7&8	Evals 9 & 10	Contingency or Debrief	Packing (am) Miss C. PM	Fly Home			

Minimum Success Criteria

1. **Mockup Deployment**
   - ✓ a. Deck
   - ✓ b. MPH
   - ✓ c. LTV LR
   - ✓ d. Supplemental (Davit, zipline pole, hoist, ladder/stairs, containers)
2. **Comm Setup**
   - ✓ a. Verify good internet connection/Wi-Fi at Dock and MCC
   - ✓ b. Verify Diver comm box dockside
     - ✓ i. Both Diver cams and SA cam
     - ✓ ii. 2-way voice to all divers
   - ✓ c. Verify Diver comms “Big Loop”
     - ✓ i. Both dive/crew cameras viewable in MCC
     - ✓ ii. 2-way voice between both crew, Dive Sup, and Capcom/Ground IV
   - ✓ d. Verify capability to record all video and audio
   - ✓ e. Verify underwater hailer
3. **Training**
   - ✓ a. Minimum required support and Crew divers complete all elements of training to qualify to support the mission
   - ✓ b. Crew fam dive in mission config (full face masks, comm, config and deconfig (fins, weights, PLSS))
   - ✓ c. Mission config, out-of-air emergency drills with participation from all crew and support divers
4. **Test runs (in priority order)**
   - ✓ a. CPC (2) Transfer via Davit
   - ✓ b. Air Tank Load via Davit
   - ✓ c. CPC Pallet Load via Davit
   - ✓ d. Air Tank Load via Hoist
   - ✓ e. CPC Load via Zipline
   - ✓ f. Airlock Config - Load
5. **Mockup Retrieval**
   - ✓ a. All pieces of the mockups retrieved from the sea floor and put in local storage
6. **Crew Data**
   - ✓ a. Crew ratings from each run captured
   - ✓ b. Crew consensus captured for the entire mission
7. **Mission Statuses**
   - ✓ a. 3 management status reports
     - ✓ i. 1.Post mockup deployment
     - ✓ ii. 2.Post training/dry runs
     - ✓ iii. 3.Mid test week
     - ✓ iv. 4.Post mission (after test runs and crew debrief complete)
   - ✓ b. Email status to Dive Safety Board (DSB) post mission
8. **Mission Data capture**
   - ✓ a. All video, audio, still photo, and crew data captured and copied to return to Houston
     - ✓ i. Video (EV1, EV2, Sonly PTZ, 360 camera, dock SA camera, MCC SA camera)
     - ✓ ii. Audio (Big loop)
     - ✓ iii. Still photos (Karl, GoPros, Team member personal)
     - ✓ iv. Crew consensus ratings, Debrief comments, qualitative data

All minimum success criteria completed

Additional Objectives to meet Full Mission Success

1. **Enhancing and/or Redundant comm functionality:**
   - ✓ a. Verify alternate audio comm method between dock and MCC (e.g. walkie talkies)
   - ✓ b. Verify underwater 360 deg camera is viewable dockside and in MCC
   - ✓ c. Verify underwater SA camera (pan/tilt/zoom) is viewable in MCC
   - ✓ d. Verify dock SA cam is viewable in MCC
   - ✓ e. Verify MCC SA cam is functional
2. **Dry Runs prior to test start with the assembled mockups**
   - ✓ a. Exercise of zipline system with one CPC, in loading direction
   - ✓ b. Exercise of davit system, with loaded pallet
   - ✓ c. Exercise of hoist system, with one tank
   - ✓ d. End-to-end comm with MCC
   - ✓ e. Crew opportunity to see all assembled hardware
3. **Test runs (in priority order)**
   - ✓ a. Unload direction for all methods
   - ✓ b. Variations of Luggage Rack height
   - ✓ c. Variations of Luggage Rack alignment
   - ✓ d. Variations of ladder options
   - ✓ e. Variations on davit presence on porch
4. ✓ **Team choice test runs (as determined by the team, in the event an opportunistic scenario is deemed of higher value than the pre-determined ones)**

All full mission success criteria completed + Team Choice Runs

Section 2.0

SEATEST 7 Study Design

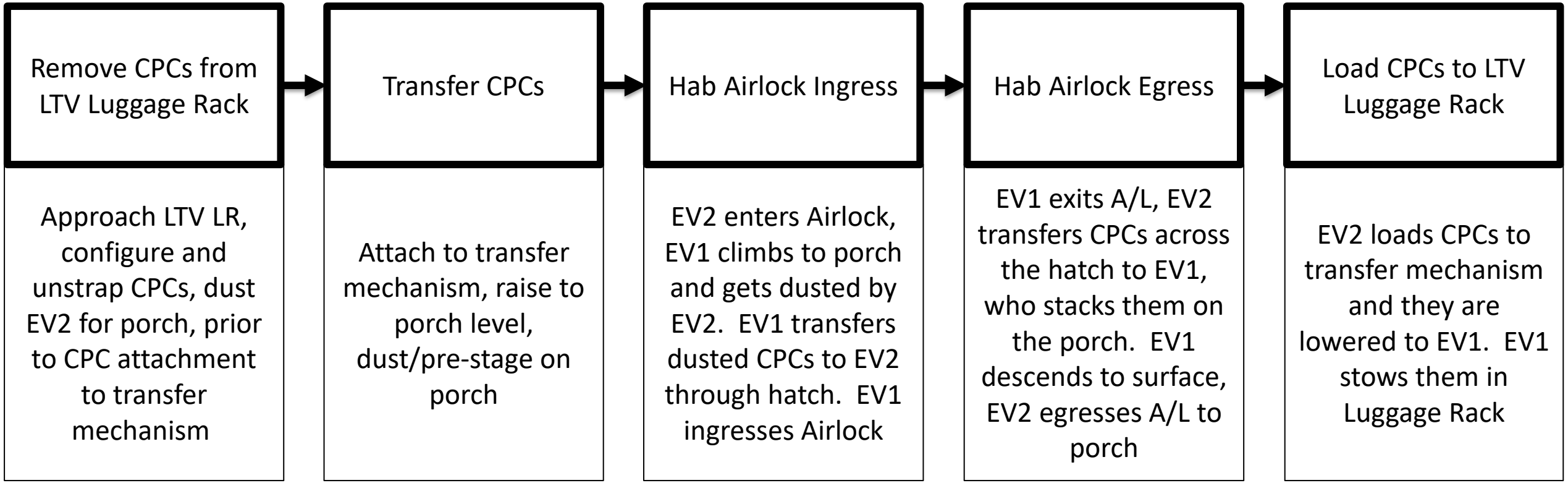
Study Design

Study designed to understand the EVA manual logistics transfer ConOps and time requirements using notional point design solutions:

- **Three conceptual mechanical lifting/lowering methods:**
  - Davit
  - Zipline system
  - 6:1 hoist system
- **Evaluation of**
  - Different sizes of CPCs (2.8 and 2.4 CTBE)
  - Different packaging of CPCs (singly, two at a time, or in an entire pallet containing 3)
  - Three sizes of Crew Portable Carriers (CPC) logistic containers: 2.8 CTBe
  - Larger air tanks
- **Choreography of CPC placement in the airlock to leave room for necessary ops: e.g., ingress, hatch closure, suit doffing**
  - The number of containers used for the test was determined by estimating the number of containers of each type could fit in the airlock, while leaving room for those critical ops
- **Dust removal protocols were included for an understanding of the overall impact to transfer ops**

Study Design (cont.)

Sequence for CPC transfer (sequence subset varied between runs)



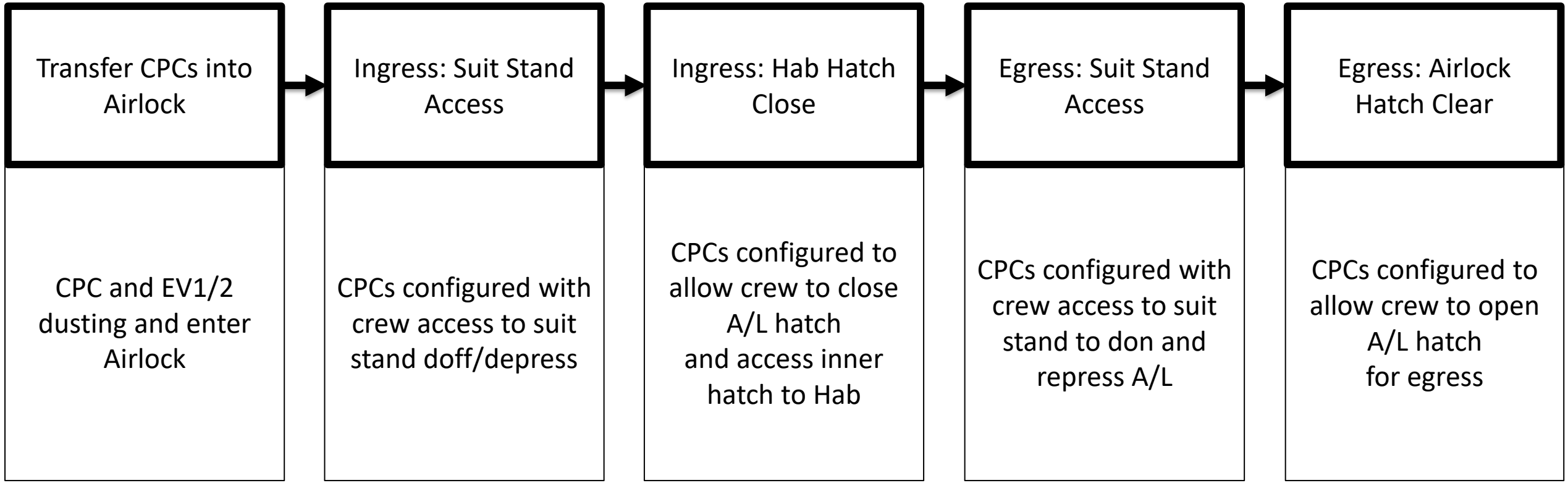
Study Design (cont.)

Sequence for Air Tank transfer (sequence subset varied between runs)

Remove Air Tanks from LTV Luggage Rack	Tank Installation to Hab holder	Tank Electrical/Air Connection	Tank Electrical/Air Disconnection	Air Tank loading to LTV
EV1/2 approach LTV LR, remove 1st air tank and carry to staging area	Attach first tank to lifting mechanism and secure to the designated mount. Repeat previous step and this for 2nd tank	Connect air and electrical lines to tank. Run activation procedure with controls at both tank and Universal Control Panel positions	Run de-activation procedure with controls at both tank and Universal Control Panel positions to disconnect power and air lines	Carry Air Tanks to LTV LR and place into LR

Study Design (cont.)

Sequence for Airlock Configuration (sequence subset varied between runs)



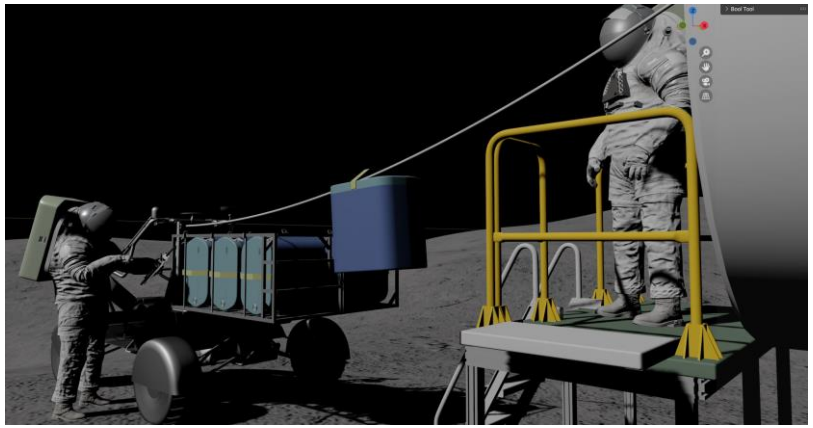
Test Assumptions

1. Crew Portable Carriers (CPCs) are pressurized logistics containers that carry food, clothing, spares, medical supplies, etc. and portable water in contingency water containers (CWC)
2. A 7-day MPH mission will require approximately 19 CTBe of pressurized cargo.
3. Container assumptions were:

	2.4 CTBE	2.8 CTBE
Lunar wt., Full (kgf)	75	75
Lunar wt., Full (lb)	28	28
Number of Containers	8	7

4. CPC transport from the surface to the “porch” will be done with one crewmember on the ground and one on the porch
5. Any loading/unloading operation should be designed to require no more than a single climb onto the porch deck by each crewmember
6. A single crewmember can attach and detach a CPC from the Zipline unassisted

Notional CPC concept

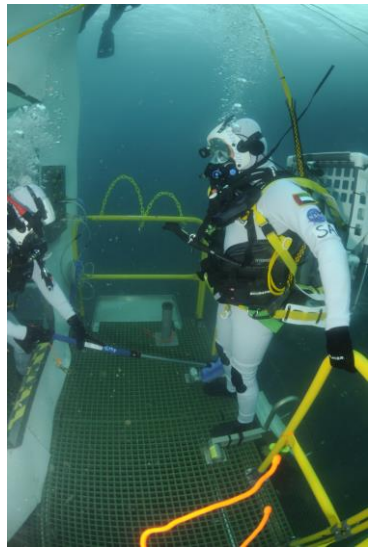


Artist concept of crew utilizing a zipline to transport a CPC to the MPH porch level

Test Assumptions (cont.)

7. A CPC can be carried and handed off into the airlock (A/L) by a single crewmember
8. A CPC can be received and placed on the ground by a single crewmember
9. The CPC handover across the airlock hatch requires 2 crewmembers
10. All CPCs must be dusted prior to entering A/L
11. Each crewmember must be thoroughly brushed for dust by their buddy prior to entering the A/L.
12. Each crewmember will be inspected by their buddy as “clean” before entering A/L

EV1 transferring a CPC across the hatch to EV2



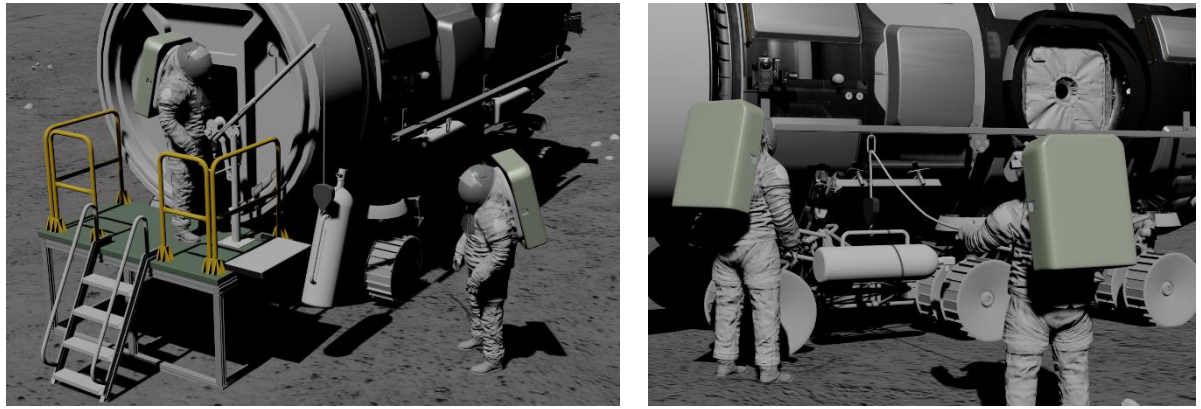
Dusting a CPC (left) and a crewmember (right)

Section 2.1

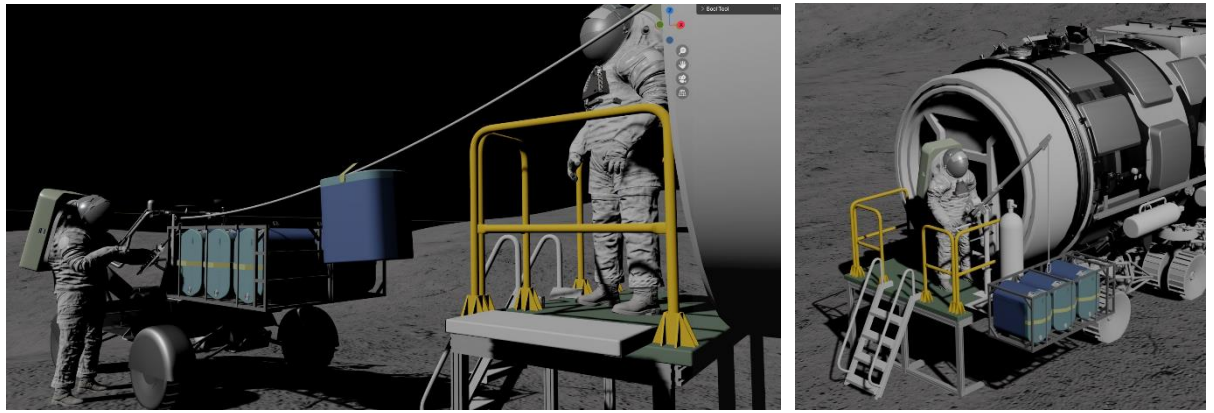
SEATEST 7 Test Objectives

Objectives and Knowledge Capture

- **Understand logistics transfer conops between an unpressurized rover and an elevated lunar habitat (e.g., MPH)**
  - Lifting CPCs to porch level
  - Lifting air tanks to stowage location
  - Airlock size required
- **Evaluate different mechanical loading/offloading methods**
  - Davit
  - Pulley hoist
  - Zipline
- **Evaluate impact of dust removal requirements**
  - Note abrasion and potential damage (e.g., to hatch seals)
  - Quantify dust removal overhead
- **Collect Objective Data:** Task times, full audio/video of test activities, inadvertent # of “dings” on hardware, etc.
- **Collect Subjective Data:** Task acceptability and capability assessment ratings related to best practices, considerations, and constraints for EVA-driven logistics transfer conops



Tank lift concepts



CPC pallet lift concepts

Note: *All artist renderings in this report are notional and do not reflect the actual design of the current MPH, LTV or any other elements or functions*

Section 2.2

SEATEST 7 Test Facilities

2.2.1 Testing Facilities

- University of Southern California Wrigley Marine Science Center (WMSC) on Santa Catalina Island, CA
  - Diving infrastructure
  - Protected cove to exercise test scenarios
  - Team housing and dining facilities
  - Meeting area configurable as an MCC

Expansive dock for gear

Dive supervisor/MCC communications area

Fisherman's Cove

Diver Suit-Up and Tending Area

2.2.1 Testing Facilities (cont.)

Mission Control is ~500m from the dock where test operations take place

- Video Projected on front screen
  - EV1 and EV2 helmet cameras
  - 1 underwater SA camera (pan/tilt/zoom)
  - 1 dockside SA camera
- 360 camera view
- Room audio with Ground IV on a headset
- Stations for Team monitoring each test run:
  - In-sim personnel: Capcom/Ground IV
  - Out of sim personnel:
    - Test subjects not involved in current run
    - Protocol/data lead
    - Imagery/Report support
    - Comm
    - Stakeholders

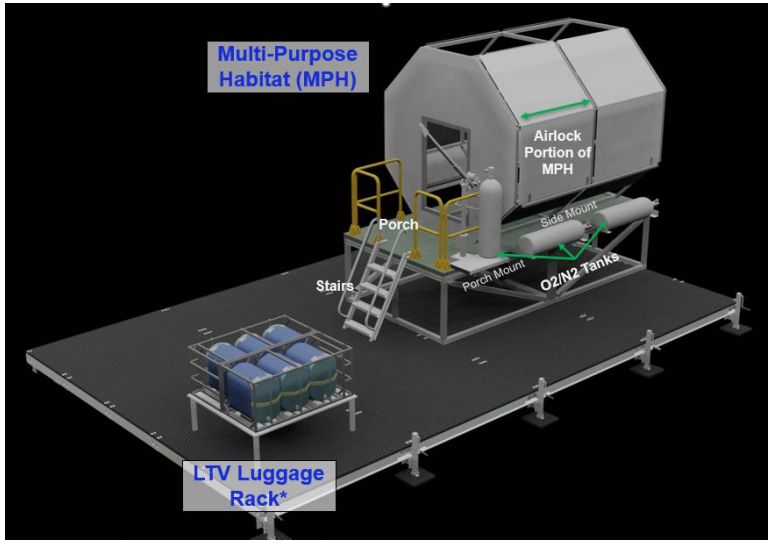
SEATEST 7 MCC Layout

Section 2.3

SEATEST 7 Hardware

2.3.1 Hardware Overview

- **Mockups included:**
  - Multi-Purpose Habitat (MPH)
    - A/L hatch and volume, porch, ladder and stair variants, O_2/N_2 Tank Mounts (porch shelf and side mount variations), porch-mounted davit, side-mounted hoist, wheel standoff
  - Pressurized Cargo containers (CPCs, Air Tanks, CPC pallet)
  - LTV Luggage Rack
- **Main deck provided a way to positively secure mockups to the seafloor and reduce silting. It sat at 9.1 m below the surface**
- **Hardware design and assumptions provided by:**
  - Logistics carrier assumptions provided by SAO Logistics Team
  - MPH assumptions provided by SAO Habitation Team, Italian Space Agency (ASI) and Thales-Alenia Space (TAS-I)
  - Logistics transfer concepts provided by SAO Integration & Analysis Lunar Concept Team
  - Top/side loaded luggage rack based on potential conops from publicly available LTVS concepts



Artist rendering of mockup assembly

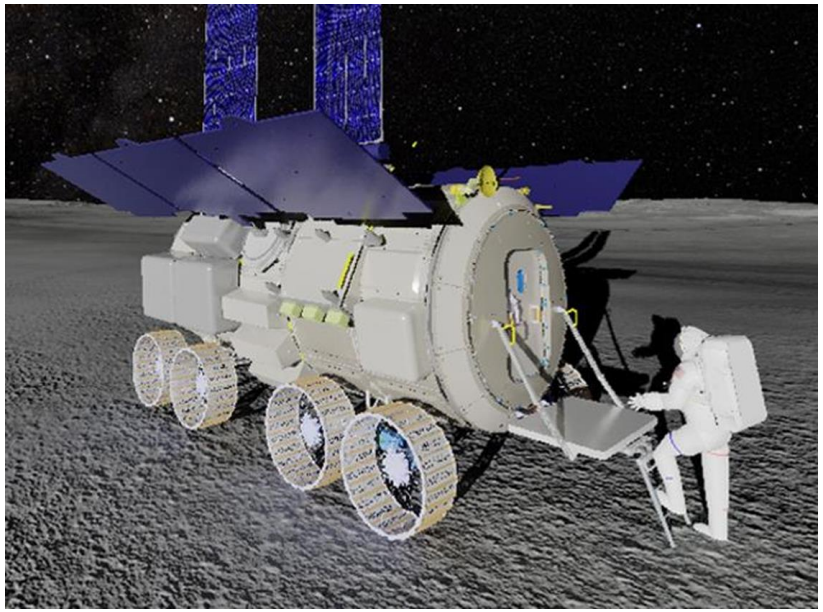
SEATEST 7 mockup assembly on sea floor

2.3.2 Multi-Purpose Habitat (MPH)

MPH Concept

The MPH is an initial lunar surface habitat being contributed to the Artemis program by the Italian Space Agency (ASI) with support from their contractor Thales Alenia Space (TAS-I).

- Designs are changing rapidly as solutions are being iterated and evolving
- Most recent concepts at the time of SEATEST 7 assumed mobility and a wheeled chassis

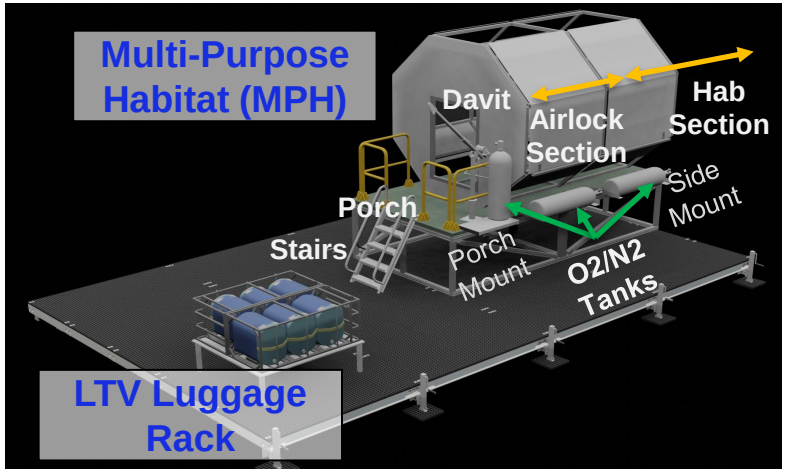


Early TAS-I artist rendering of MPH

SEATEST 7 MPH Mockup

SEATEST MPH consisted of multiple pieces:

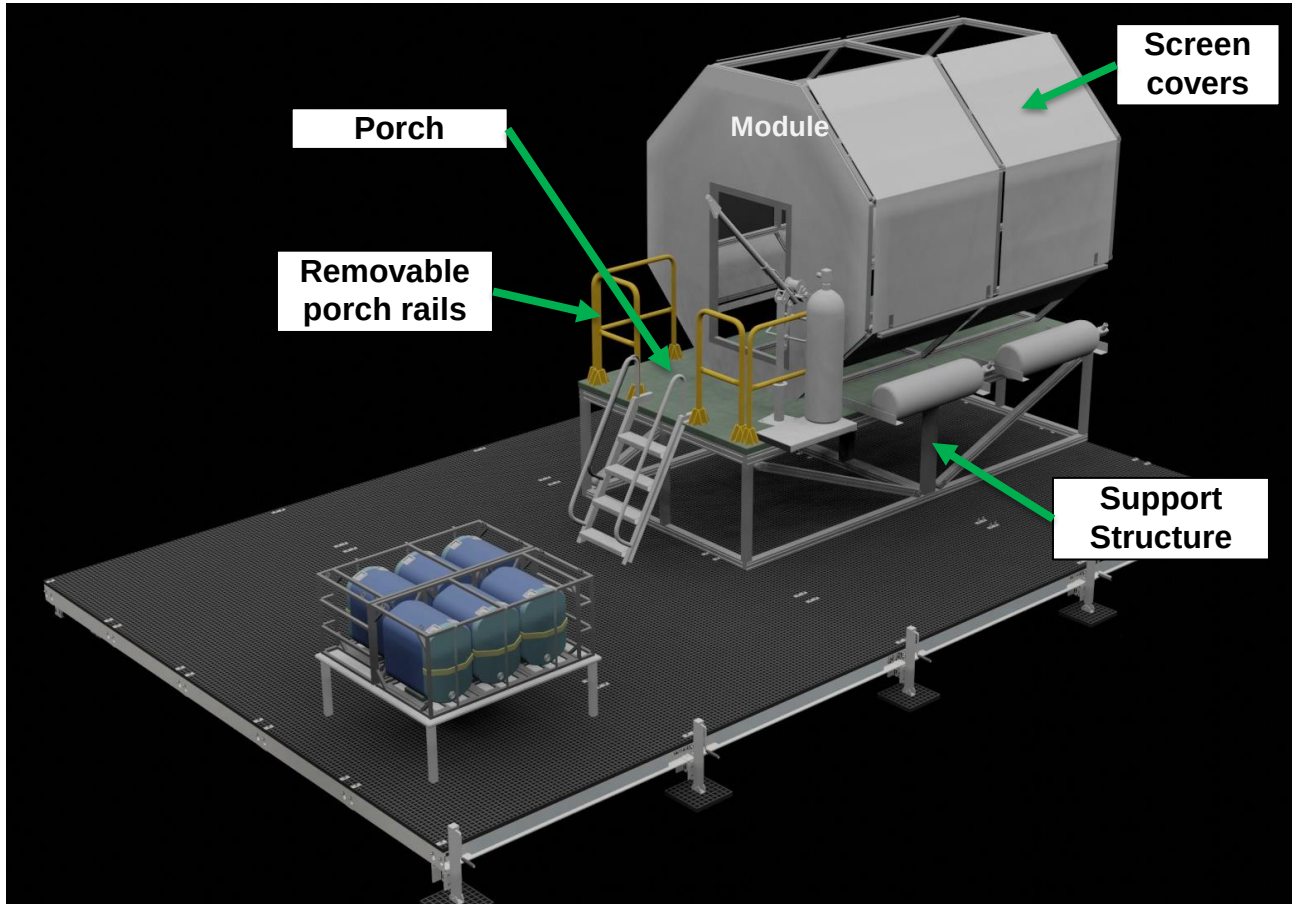
- Octagon shaped section to represent the first 2 bays of the cylindrical module – the airlock and the first part of the hab section
- Support structure to elevate the MPH hatch height above the surface
- Both side and porch mount locations for comparison for O2/N2 tanks
- An external hatch
- An Airlock section 2.1m long with an internal hatchway separating the airlock and hab sections
- Lifting mechanisms (davit and side hoist)



Artist rendering of SEATEST 7 Mockups

2.3.2 MPH (cont.)

SEATEST 7 MPH Mockup



SEATEST MPH Mockup consisted of multiple pieces:

- Module dimensions
  - Length = 3.66 m
  - Diameter = 3.05 m
- Porch dimensions =
  - 1.22 x 2.44 m
  - Porch height = 1.22 m
- Fibergrate flooring
- Airlock length = 2.1 m
- Airlock Outer hatch
  - Swing and roll hinge mechanism opening inwards
  - A/L hatch dimensions
    - Width = 102 cm
    - Height = 152 cm
    - Threshold height = 41 cm
- Airlock Inner hatch/bulkhead

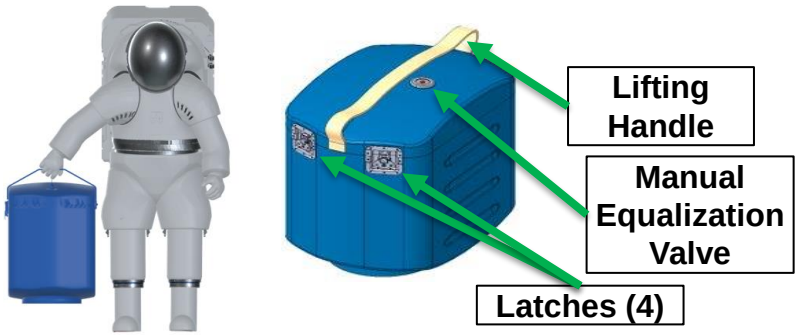
Note: *Mockup dimensions do not reflect the actual current design of the MPH*

2.3.3 Crew Portable Carriers

CPC Concept

The current concept for pressurized logistic containers is Crew Portable Carriers (CPC)

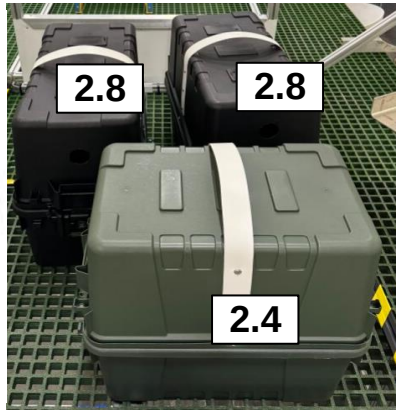
- A CPC is a small, conditioned pressure vessel intended to deliver pre-supplied logistics for Lunar Missions
- 2 sizes are under consideration: 2.4 and 2.8 CTB Equivalent (CTBE)
  - 2.8 measures: 68x61x43 cm, ~0.15m^3 pressurized volume
  - 2.4 measures: 54x61x45 cm, ~ 0.127m^3 pressurized volume
- **Total loaded CPC: 75kg (27.6lbs, lunar weight)**
  - Total max carry per EHP-10028 xEVA Compatibility Standards: 75.7kg (27.8lbs lunar weight)

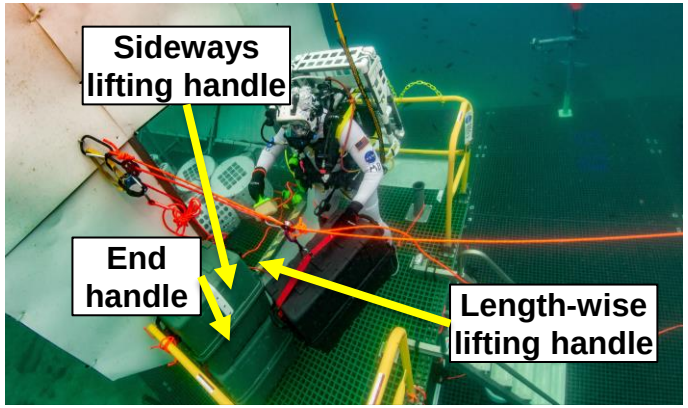


SEATEST 7 CPC Mockups

SEATEST CPCs were fabricated from COTS containers and were approximately the same total size and weight as the conceptual design

- Sizes approximated 2.8 and 2.4 sized CPCs – outer dimensions were:
  - 2.8: 76x36x61 cm
  - 2.4: 61x38x61 cm
- Each CPC was loaded to ~ 28 lbs in-water weight
- Two main carrying strap designs
  - White sideways handles were made of rigid polywall
  - Red length-wise handles were made of soft fabric
- Although not part of the conceptual design, handles were added at each end as well in the mockup versions
- Some cylindrical CPCs (1.0 and 2.0 CTBE in volume) from a previous design were used at times to represent larger volumes of CPCs

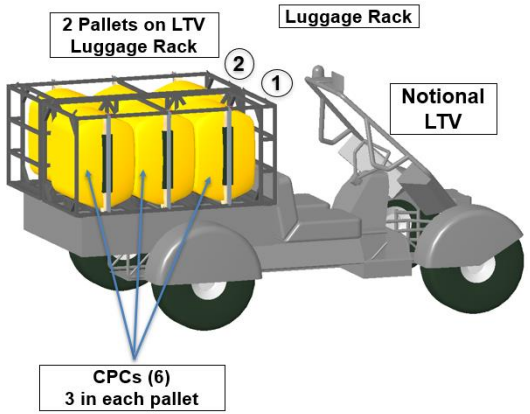




2.3.4 LTV Luggage Rack

Luggage Rack Concept

- **LTV volume requirement for carrying 2 cargo containers is 80x80x160 cm each**
  - Not necessarily in one contiguous area as shown in the conceptual rendering
- **LTVS contractor concepts for how it shows up vary considerably**
  - From ground level to perhaps as much as 1m off the ground
  - Maybe or maybe not touching regolith when crew starts the transfer

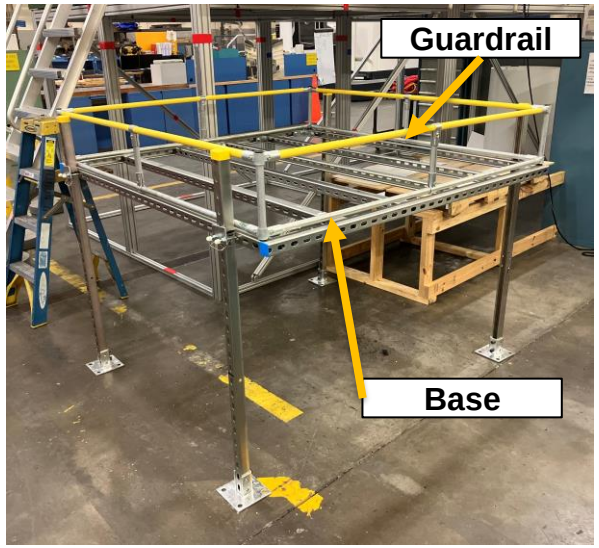


Conceptual rendering of LTV with Luggage Rack

SEATEST 7 Luggage Rack

- **Base adjustable to varying heights to account for possible LTVS contractor variability: surface, 0.5m, ~1m**
  - Guardrails extended around all 4 sides are 0.25m high
  - No ability to lower a side like a “tailgate”

Luggage Rack loaded with 2 air tanks + 1 pallet



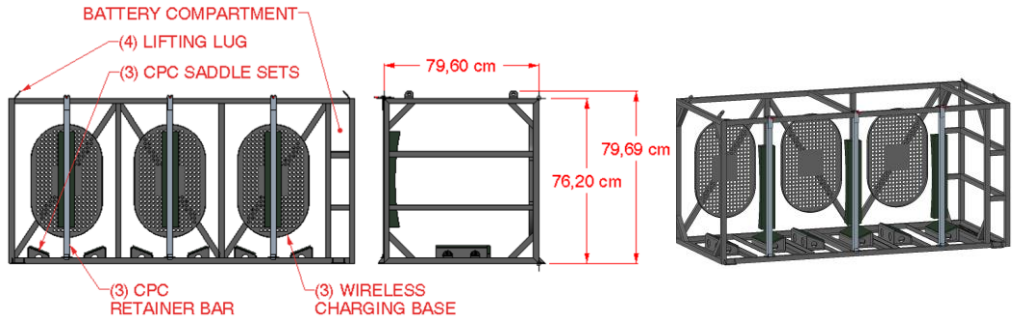
LTV Luggage Rack mockup

Note: *Luggage Rack mockup does not reflect any specific current vendor design and is based on publicly available vendor concept details*

2.3.5 CPC Pallet

CPC Pallet Concept

- **A CPC Pallet is a frame that holds 3 small CPCs. It is intended to deliver pre-supplied logistics for Sustained Lunar missions to the lunar surface**
  - Each has room for batteries and electronics for “keep alive” power to facilitate a conditioned environment from Earth launch until unloaded on the Moon
  - Each CPC slides into a unique slot and is held in place by a retaining bar
- **Each pallet is 160x80x80 cm**
  - Up to 2 could fit on an LTV per requirements
- **Lunar weight ~ 18 lbs**



SEATEST 7 CPC Pallet

- **Construction**
  - Maker Pipe and stainless steel nuts and bolts
  - Dimensions: 160x80x80 cm
  - ~ 20 lbs in-water weight to approximate lunar weight
  - Lift point on top to allow davit lifts
  - Retaining straps used in place of a bar

2.3.6 O_2/N_2 Tanks

MPH O2/N2 Tank Concept

- **Air tanks provide O_2/N_2 consumables for MPH cabin atmosphere and xEVA suit O_2 recharge**
- Dimensions
  - Length = 1.13 m
  - Diameter = 0.35m
- Lunar weight ~ 20 lbs
- Each tank has electrical and fluid (O_2/N_2) connectors

Tank mockup

SEATEST 7 Air Tanks

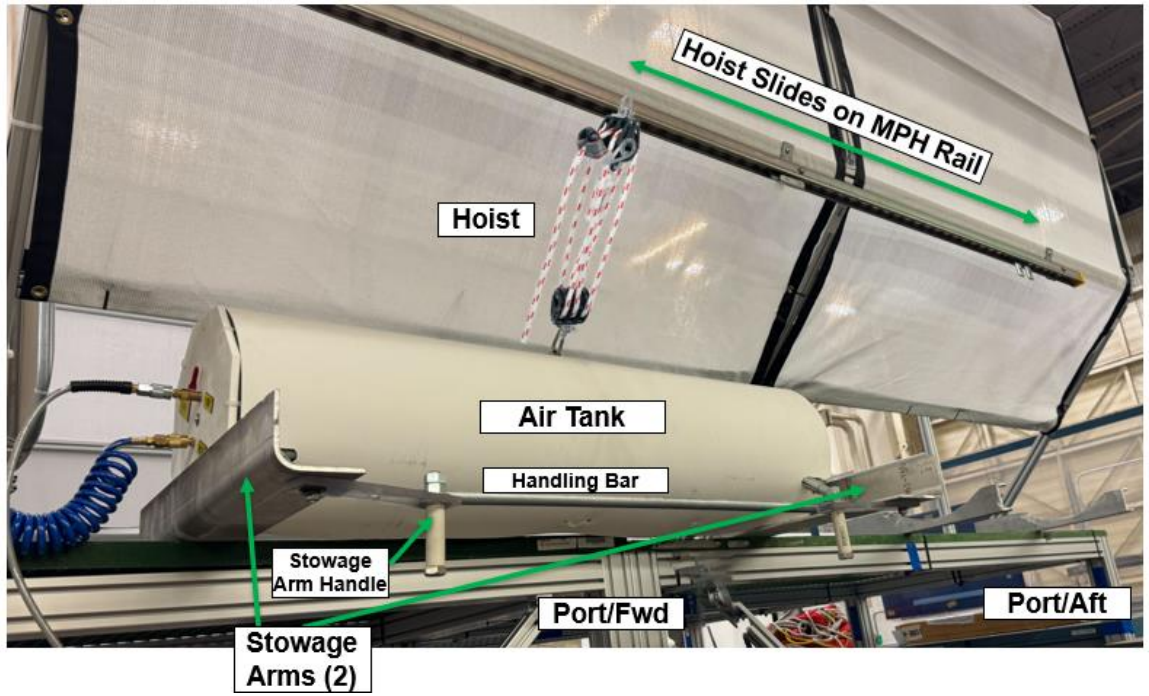
- Dimensions
  - L = 1.3 m
  - D = 0.4m
- In-water weight ~ 25 lbs
- Fake Utility Control Panel and fake fluid and electrical connectors are for timing purposes only (not representative of a current design or lunar surface EVA connectors)
- Handling bar
- Tether point

Tank mockup connectors

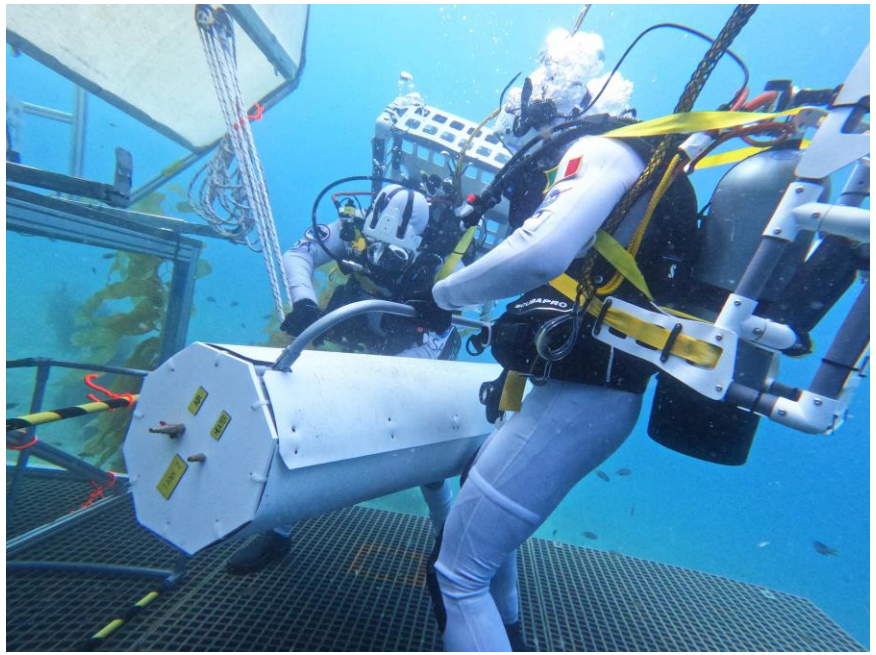
Notional Tank Utility Control Panel on Habitat

2.3.7 Conceptual Offloading Concepts – Air Tank Hoist

- Two air tank stowage design concepts along port side of MPH:
  - One deployable with stowage arms (port/fwd)
  - One a permanently deployed cradle (port/aft)



Air Tank Hoist

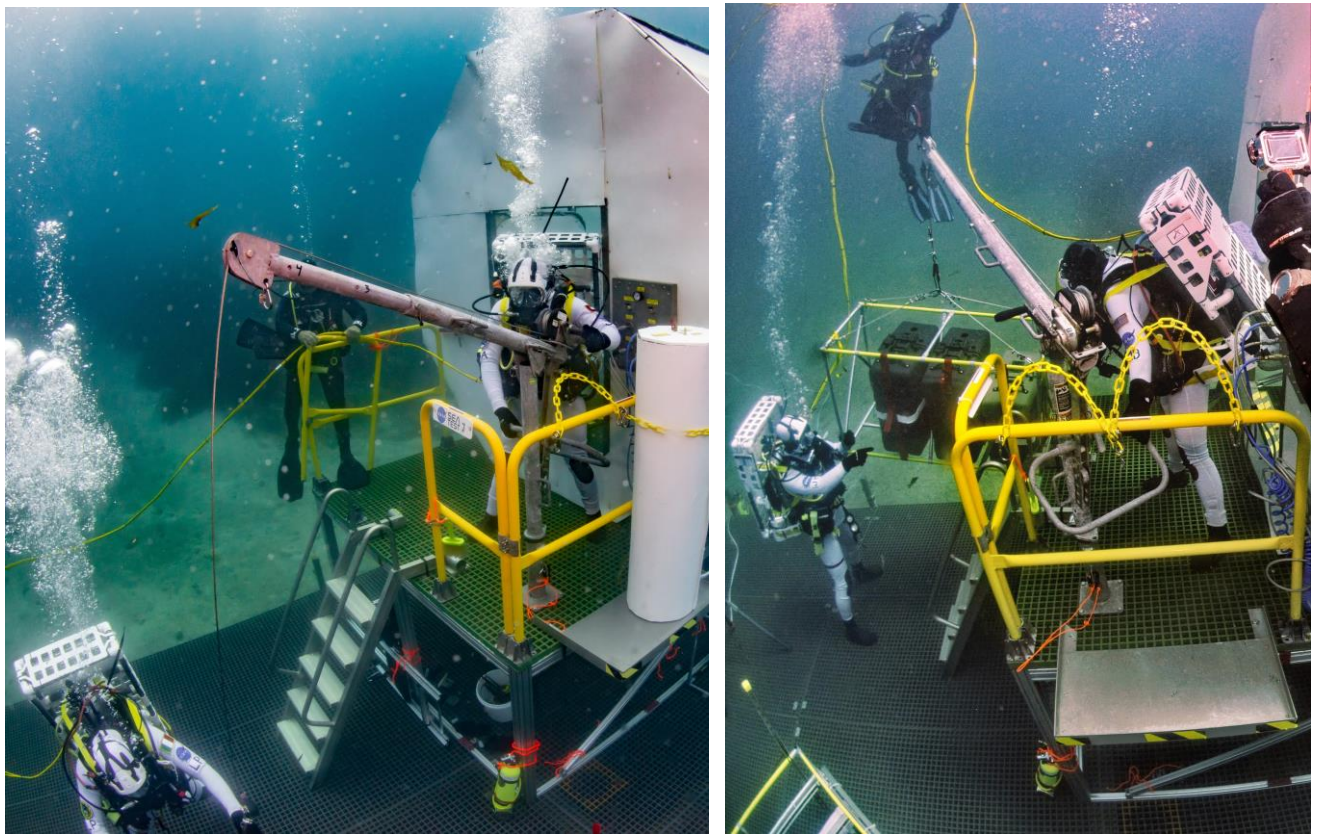


Tank hoist in use for a side mount

2.3.8 Conceptual Offloading Concepts – Davit

- **Davit is used to reposition large cargo, such as CPC Pallets and Air Tanks** (if the storage concept looked more like the porch shelf shown here)

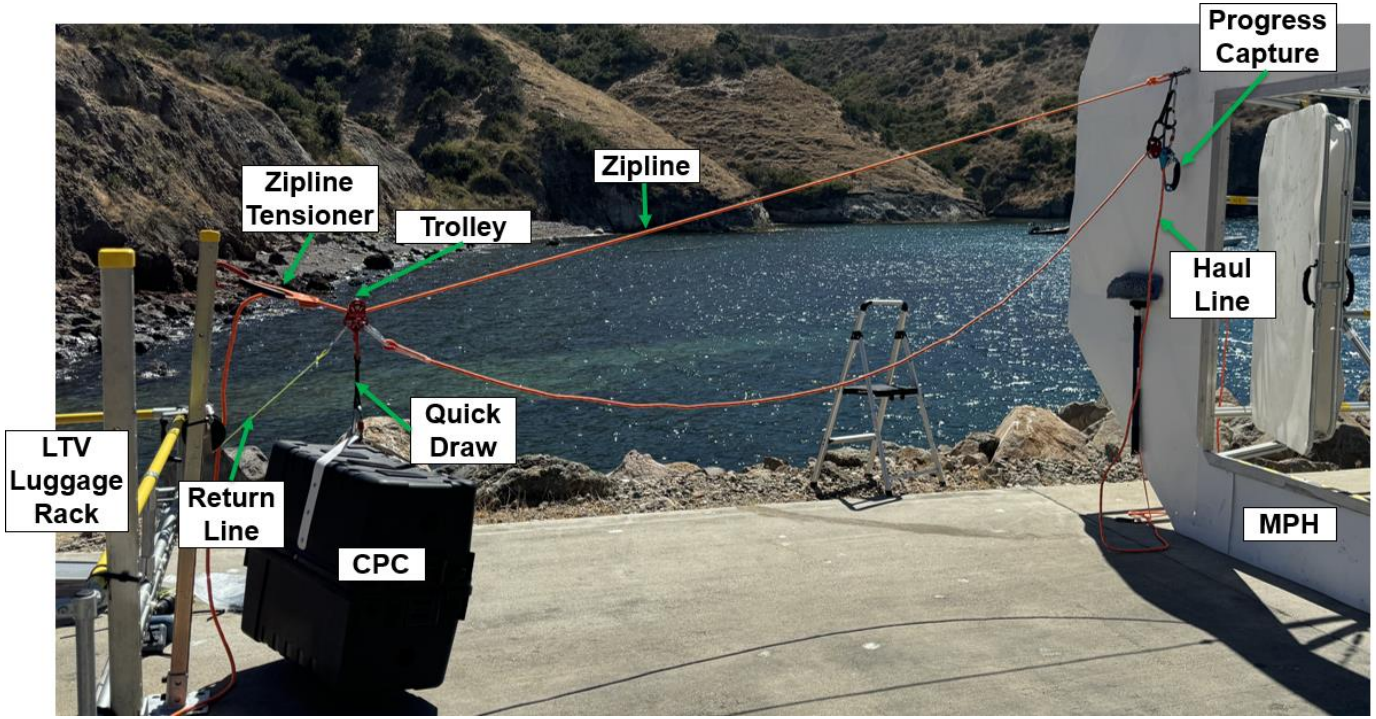
- **Davit Construction**
  - Stainless Steel
  - Fully extended arm = 153.6 cm
  - Height from Deck = 247.2 cm
  - Lift Below Deck Height = 8.02 to 9.7 m
  - Cable is galvanized aircraft cable at 6 mm diameter
    - Total length = 13.7 m
  - Arm Load Rating = 300 kg
  - Arm Rotation Range = 360º
  - Swivel hook, swaged ball fitting and quick disconnect
  - Adjustable hand crank length; left side of davit only



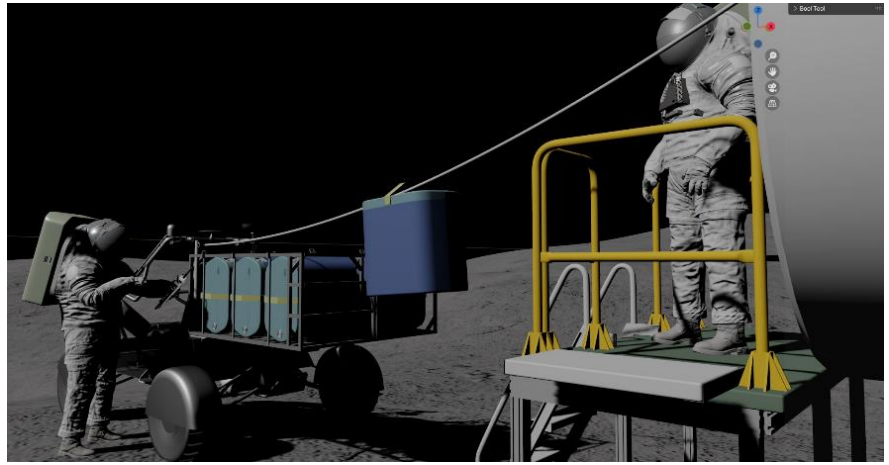
SEATEST 7 davit in use

2.3.9 Conceptual Offloading Concepts – Zipline

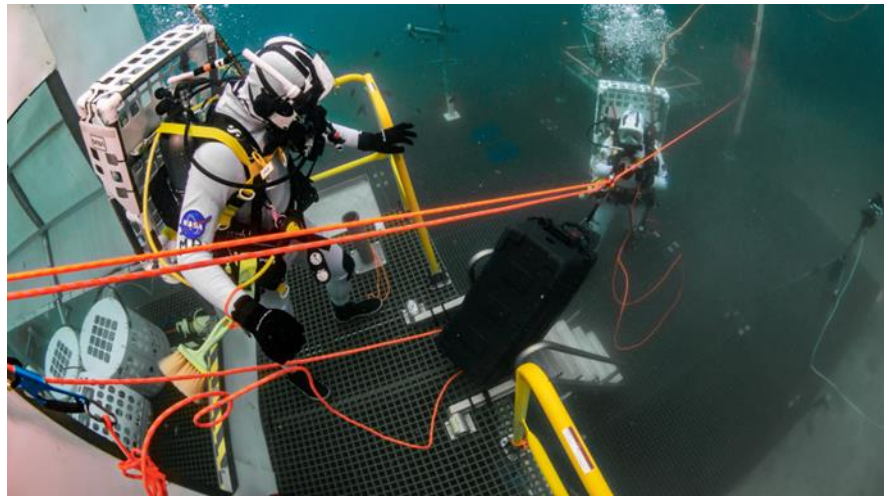
- **Zipline System**
  - MPH attach point ~ 3.2 m above deck
  - Ground side attach point ~ 1.5m above deck
  - Zipline and haul line were made of rope



SEATEST 7 zipline system



Rendering of zipline use to lift 1 CPC

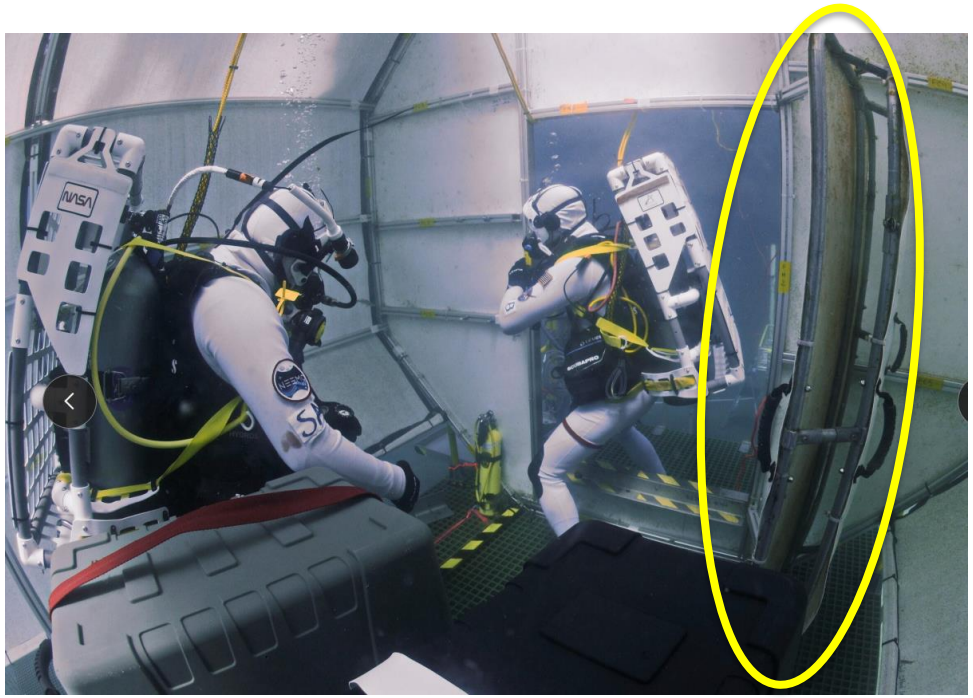


SEATEST 7 zipline in use

2.3.10 MPH Airlock Hatch

- Opens inward; swing and roll hinge mechanism
  - Seals always face away from crew when operating, similar to ISS EV hatch
- Mockup Hatch dimensions:
  - Width: 102 cm
  - Height: 152 cm
  - Thickness: 15 cm
- Threshold height: 41 cm

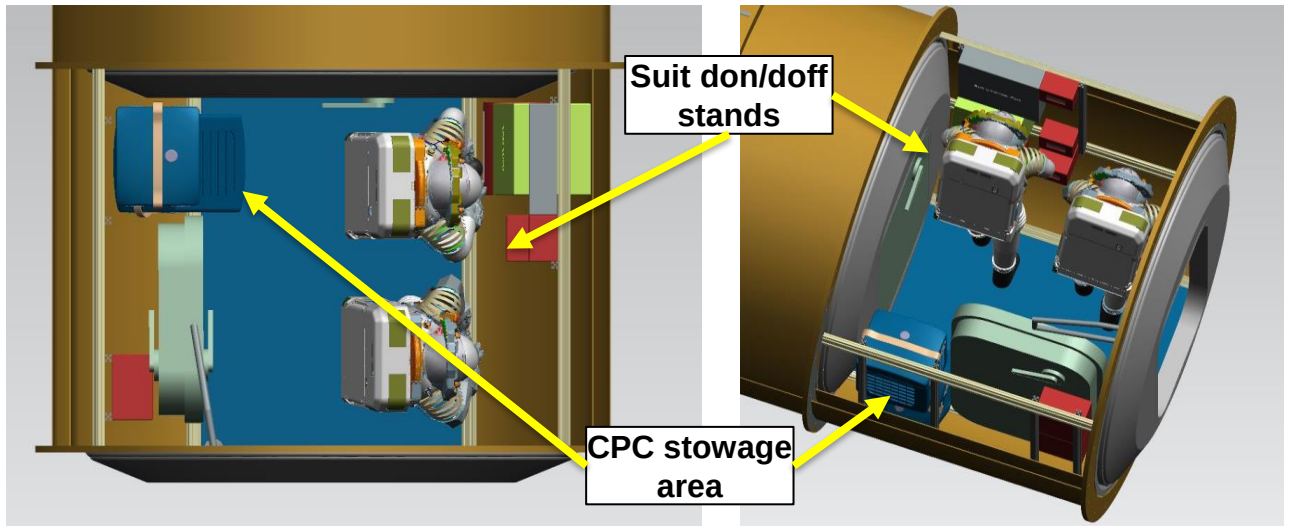
MPH Airlock Hatch closing views from within airlock



SEATEST 7 MPH Airlock Hatch

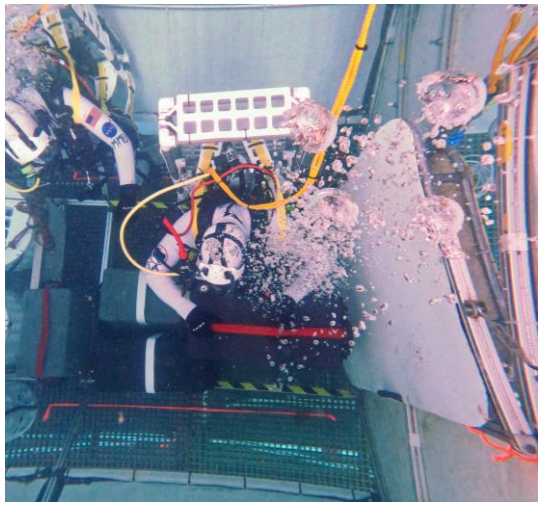
2.3.11 MPH Airlock

- Approximate Airlock Dimensions: 2.1m length x 3m diameter
- Would contain two donning stands + associated xEVA umbilicals, equipment, and hardware
  - Note: most EVA tools stowed externally
- Consider dust mitigation prior to entry, protection of hatch sealing surfaces, placement of CPCs, doffing volumes, EV1/EV2 choreography, hatchway mobility aids



Top view of Airlock volume

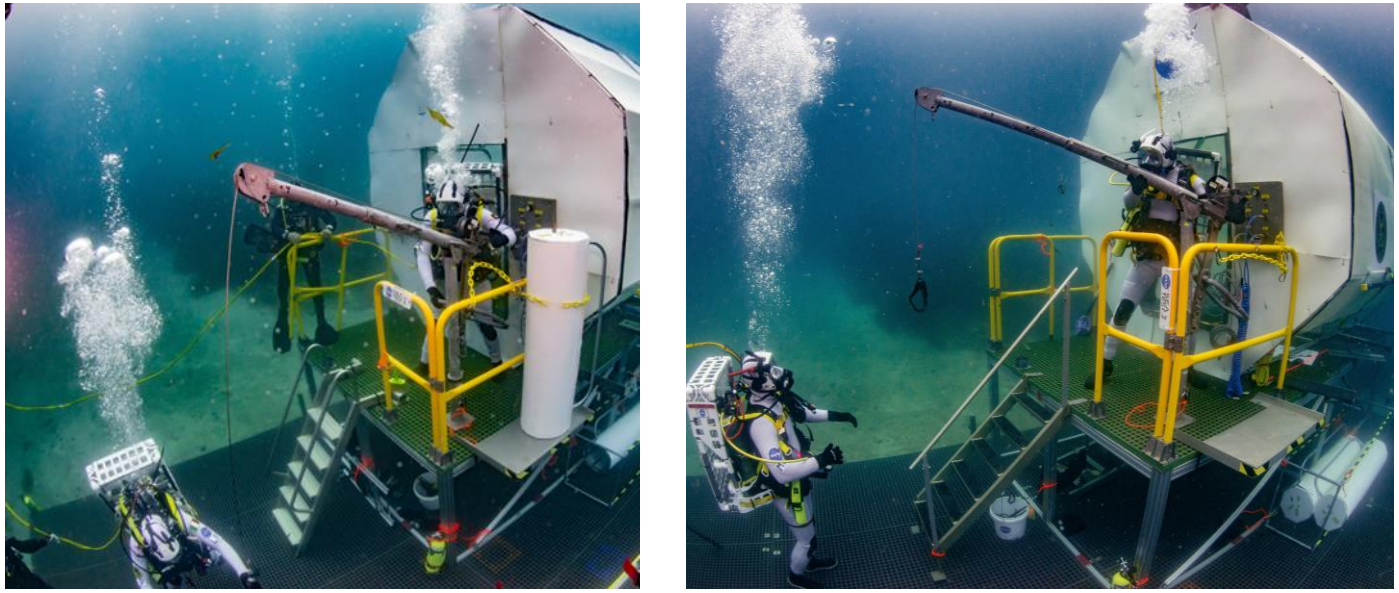
CPCs stowed within MPH Airlock



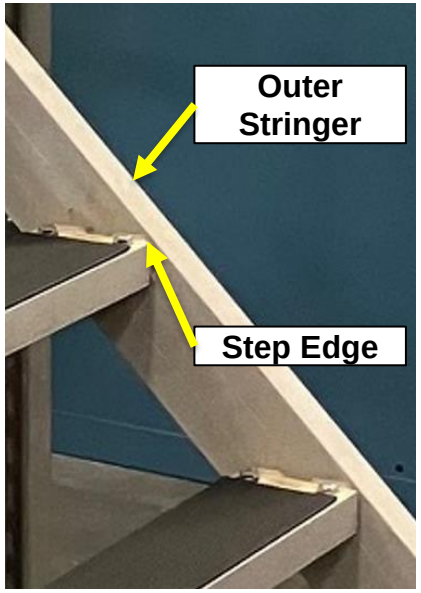
Top view of Airlock loading

2.3.12 Stairs/Ladder

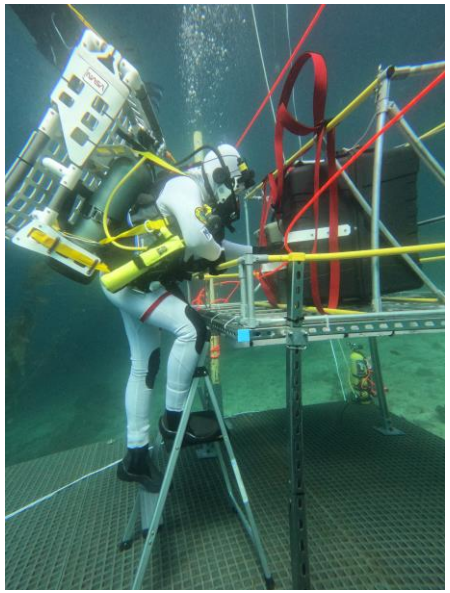
- **Two different methods for climbing to the MPH porch were provided for comparison/contrast**
  - **Ladder**
    - 55 deg climb angle
    - Easy to grip hand rails on both sides
    - Step Width: 20"
    - Step Depth: 6"
    - Distance Between Steps: 11
  - **Stairs**
    - 45 deg climb angle
    - Hand rail only on the right side
    - Step Width: 22"
    - Step Depth: 4"
    - Distance Between Steps: 12”
    - Outer stringer aligned with step edge
- **A step stool was also provided to enable high reaches**



Ladder (left) and stairs (right) for ascent/decent between MPH and mockup surface



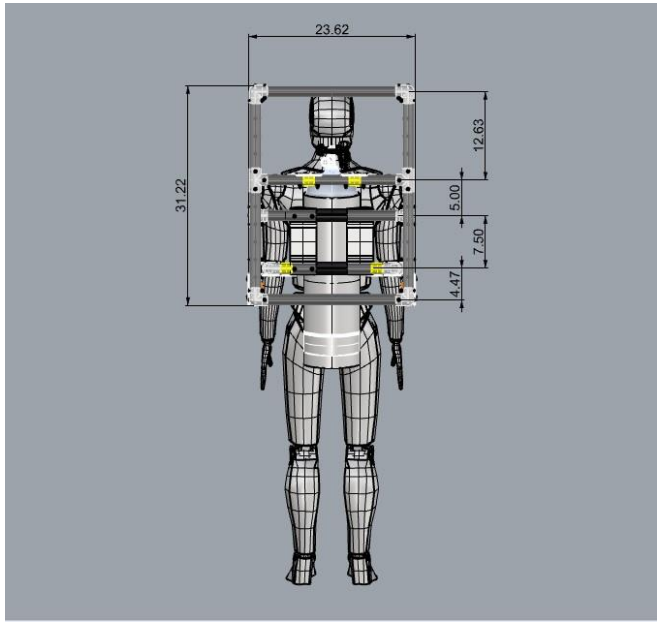
Close up of stairs

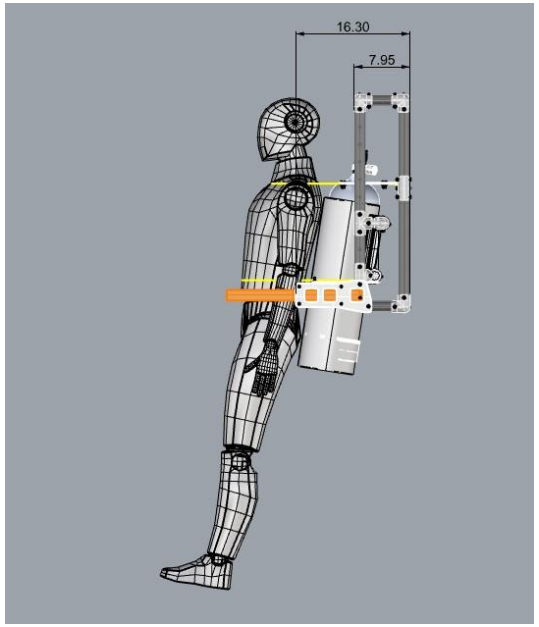


Step Stool

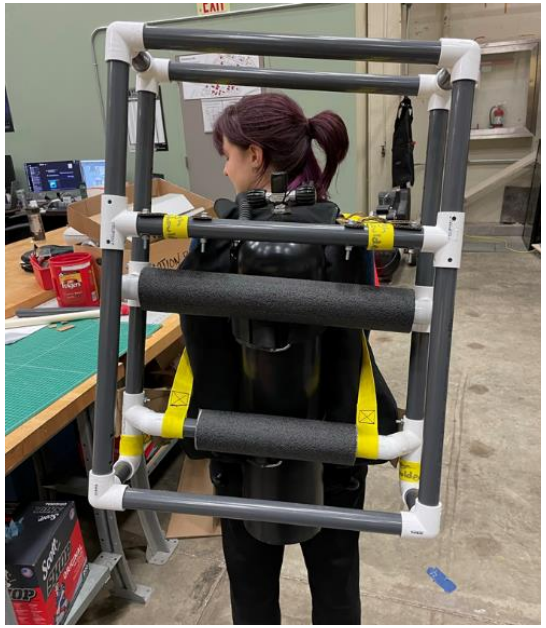
2.3.13 Portable Life Support System (PLSS) Mockup

- PLSS Mockup that are donned over air tanks to increase test fidelity
  - Construction = Polyvinyl Chloride (PVC), Kydex, Polypropylene straps
  - Dimensions = 79.3 x 59.9 x 20.2 cm
  - Weight = 9.07 kg on land; 3.17 kg underwater

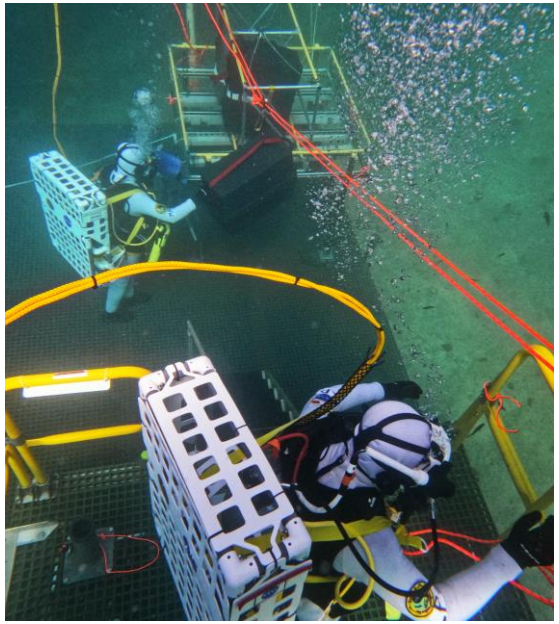




The PLSS mockup for SEATEST6 (Dimensions shown are in inches)



The PLSS mockup being tested on air tank

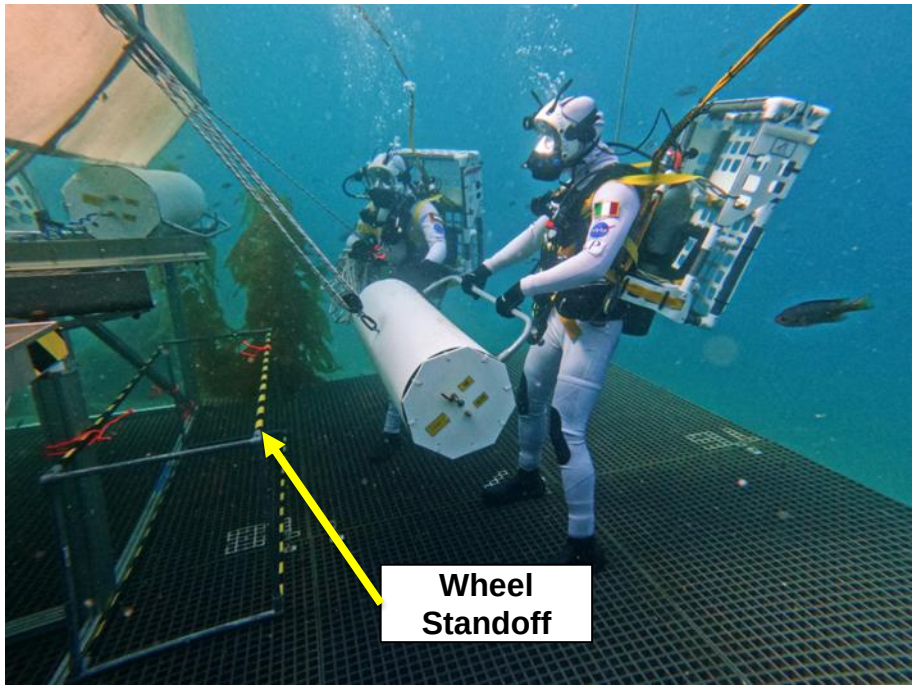


SEATEST 7 PLSS mockups

2.3.14 Ancillary Hardware

- Wheel standoff
  - A wheel standoff was built to represent the wheel/fender line of the MPH, and to remind the crew that other hardware and their suits need to stay clear
- HD 360 Video Camera
  - A 360-degree HD camera was used for real-time monitoring of scenarios, both dockside and in MCC

HD 360 video camera used during SEATEST 7 (left) and a crewmember (Parmitano) observing a run from MCC on a VR headset (right)



Wheel Standoff

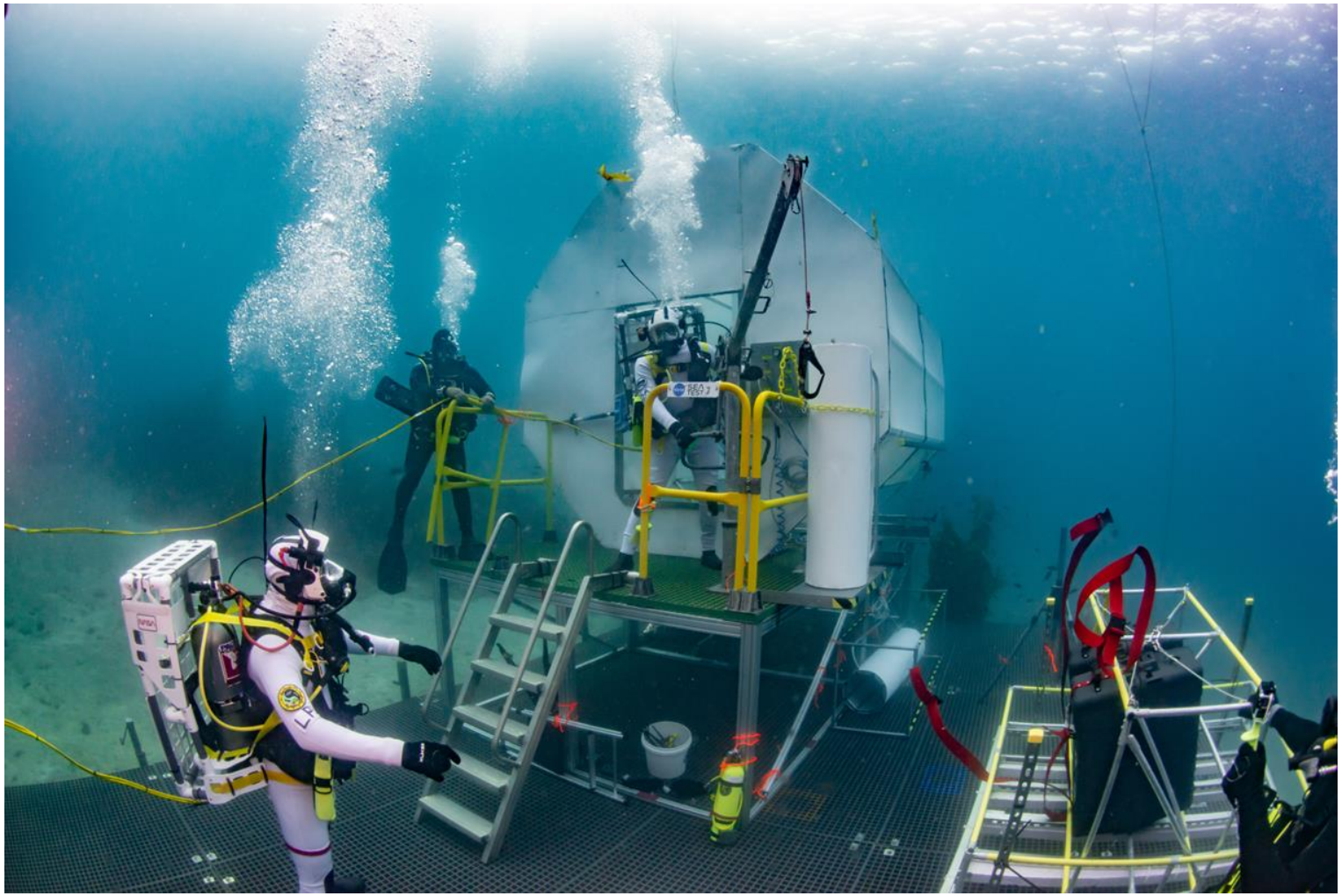
Section 2.4

Test Scenarios

2.4.3 Test Scenario Details

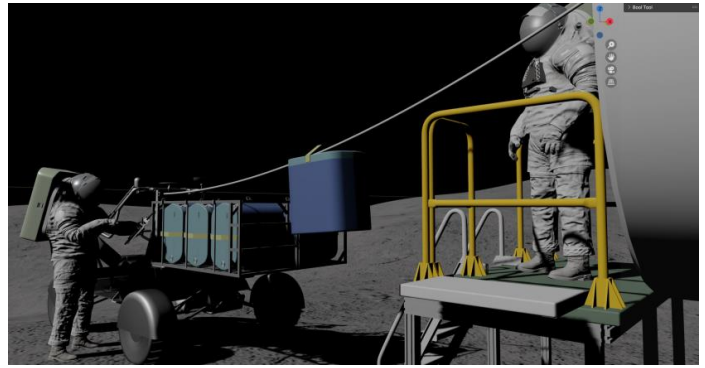
Test Scenarios:

1. CPC Transfer via Zipline
2. CPC Transfer via Davit
3. CPC Pallet Transfer via Davit
4. Air Tank Transfer via Hoist
5. Air Tank Transfer via Davit
6. Surface Habitat Airlock Cargo Transfer
7. BONUS: Team Choice for CPC Transfer
8. BONUS: Team Choice for Air Tank Transfer

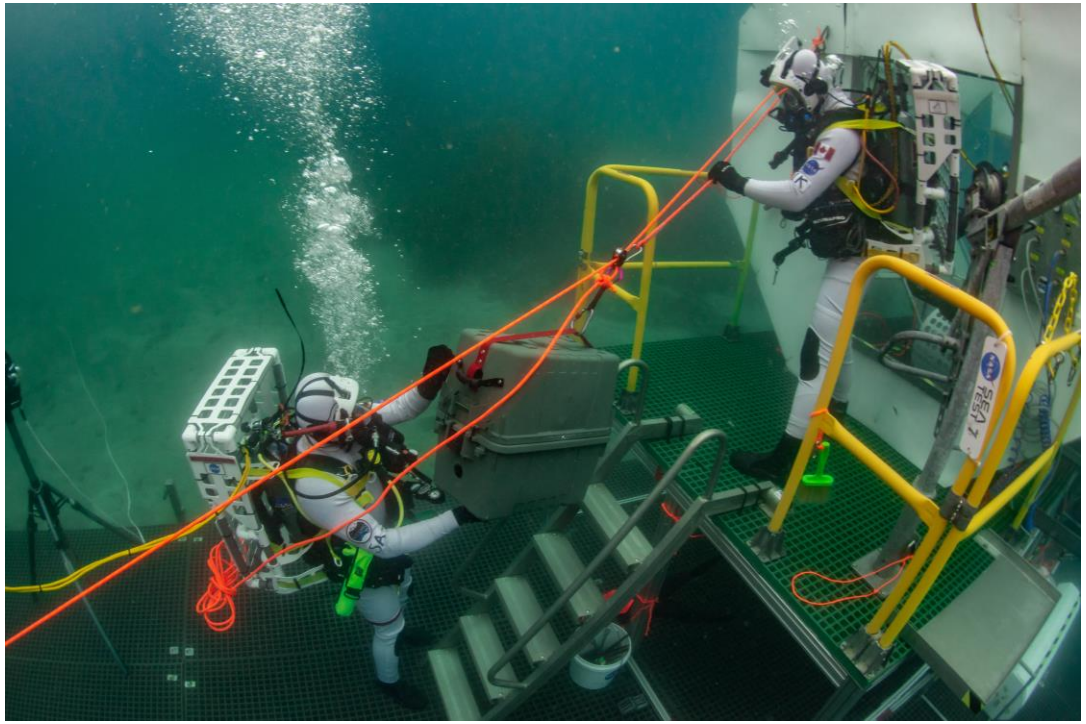


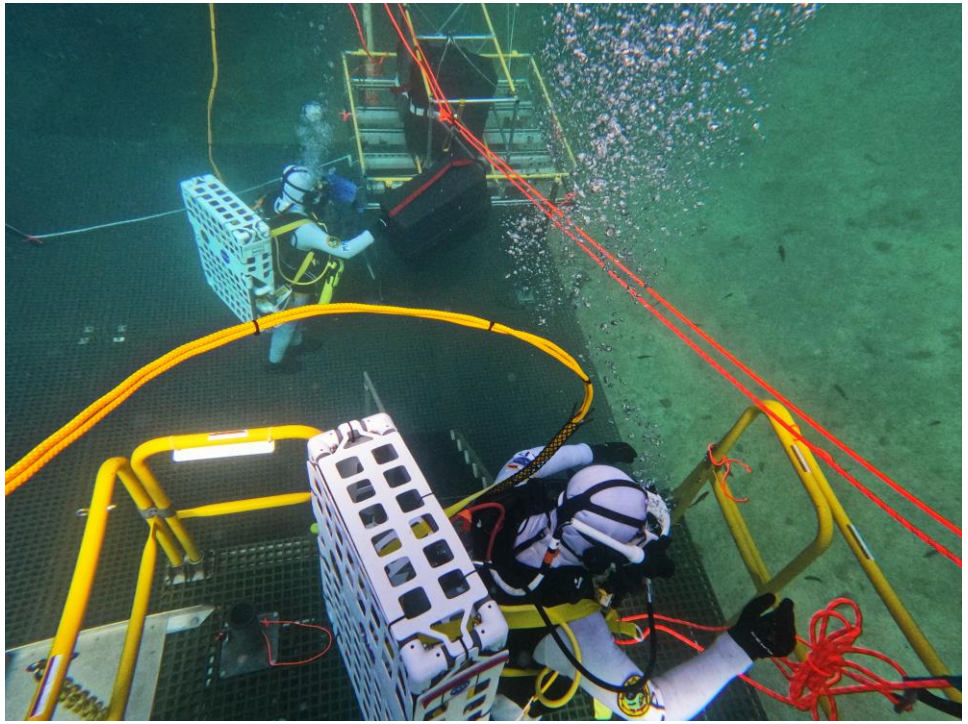
Scenario 1: CPC Transfer via Zipline

- EV1 attaches CPC to zipline hook, EV2 raises CPC, dusts it while still suspended, unhooks and stows on the porch
- Zipline hook returns to EV1 to load the next CPC
- Operations continue until all CPCs are dusted and on the porch



Rendering of zipline loading

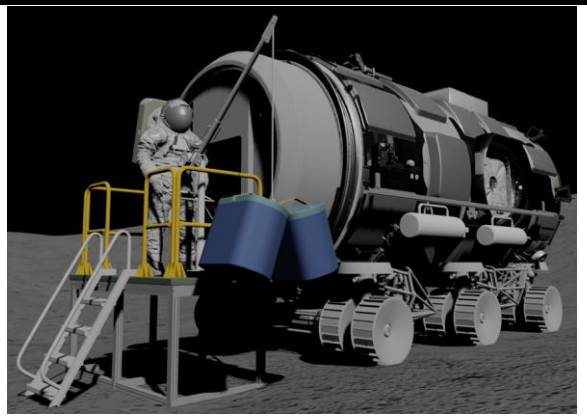




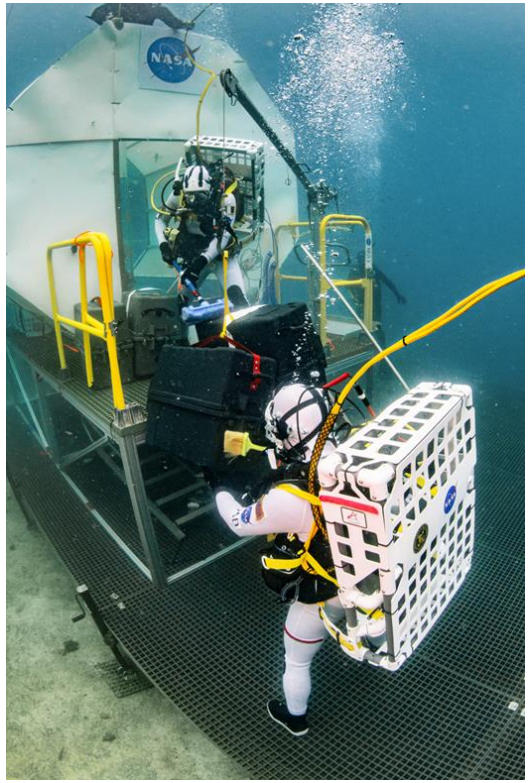
CPCs being loaded and lifted by Zipline

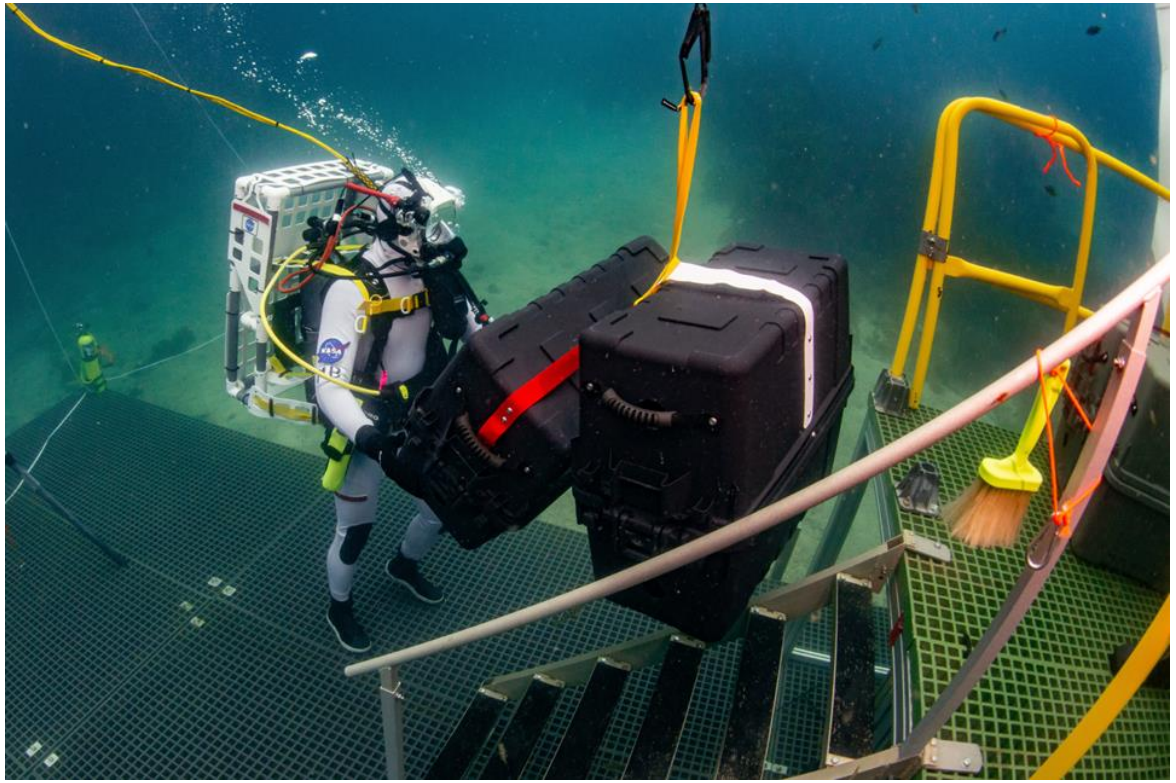
Scenario 2: CPC Transfer via Davit

- EV1 loads 2 CPCs at a time onto the davit hook
- EV2 raises them from the Luggage Rack, swings them to the porch, dusts, lowers them to the ground, and unhooks from the davit
- These steps are repeated for the remaining 2 CPCs



Rendering of CPC transfer by davit 2 at a time

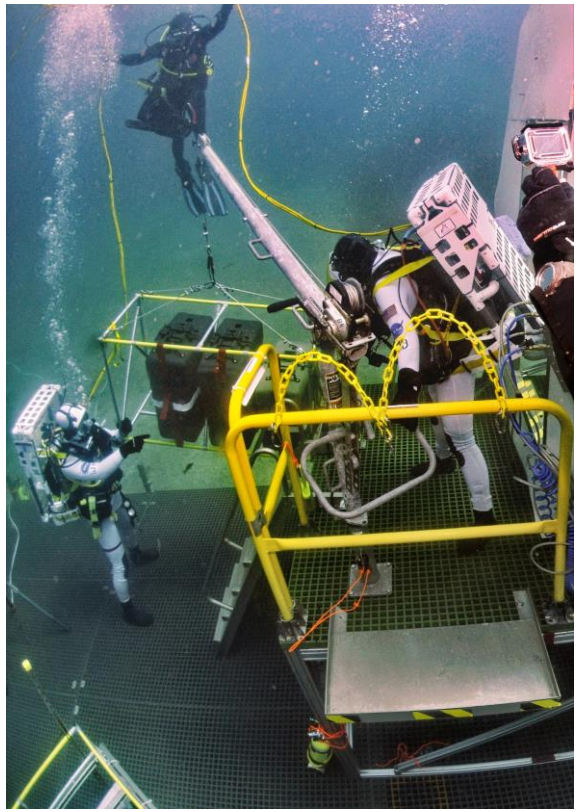


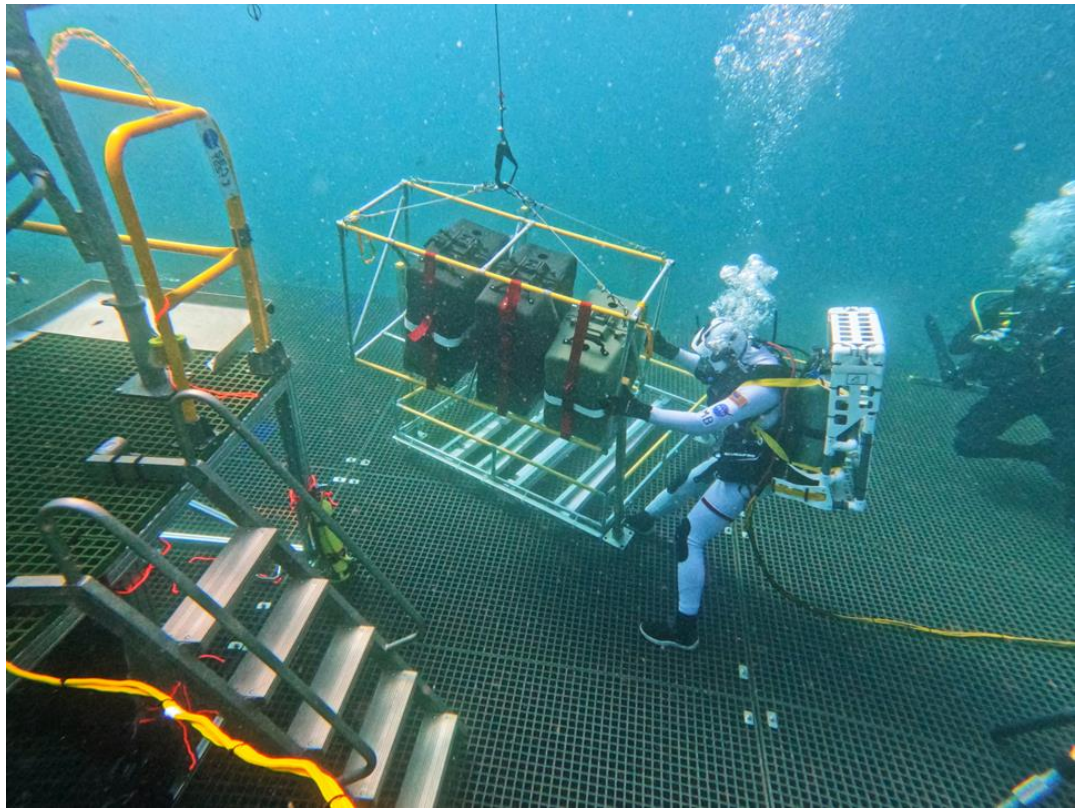


Transfer of CPCs 2 at a time via davit

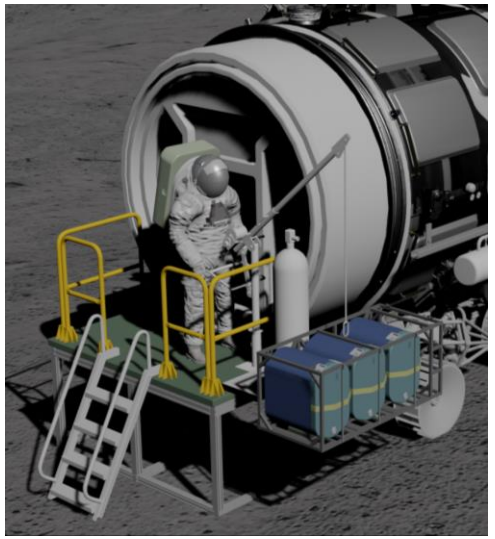
Scenario 3: CPC Pallet Transfer via Davit

- EV1 attaches pallet to davit hook
- EV 2 raises pallet out of Luggage Rack, swings it to starboard side of porch and lowers it

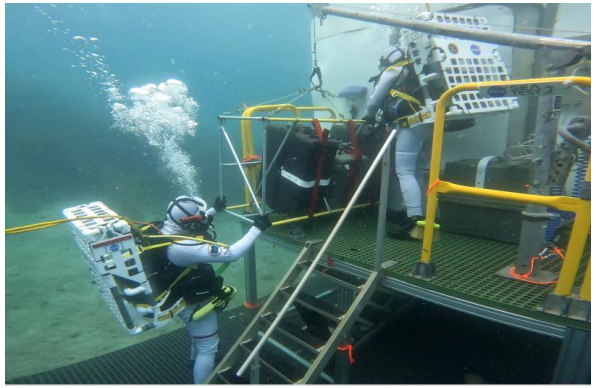




CPC Pallet being transferred by davit



Render of CPC pallet transfer by davit

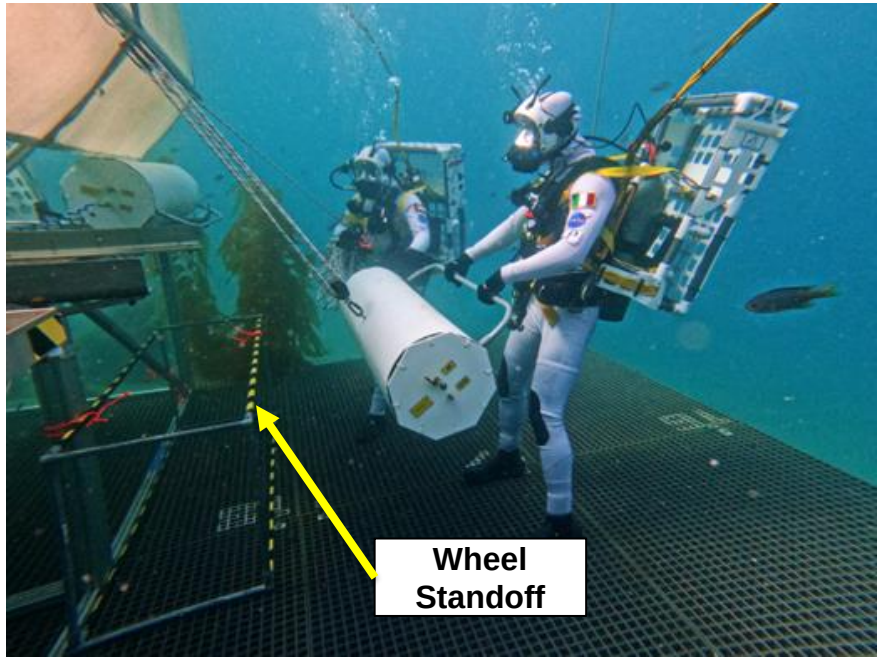


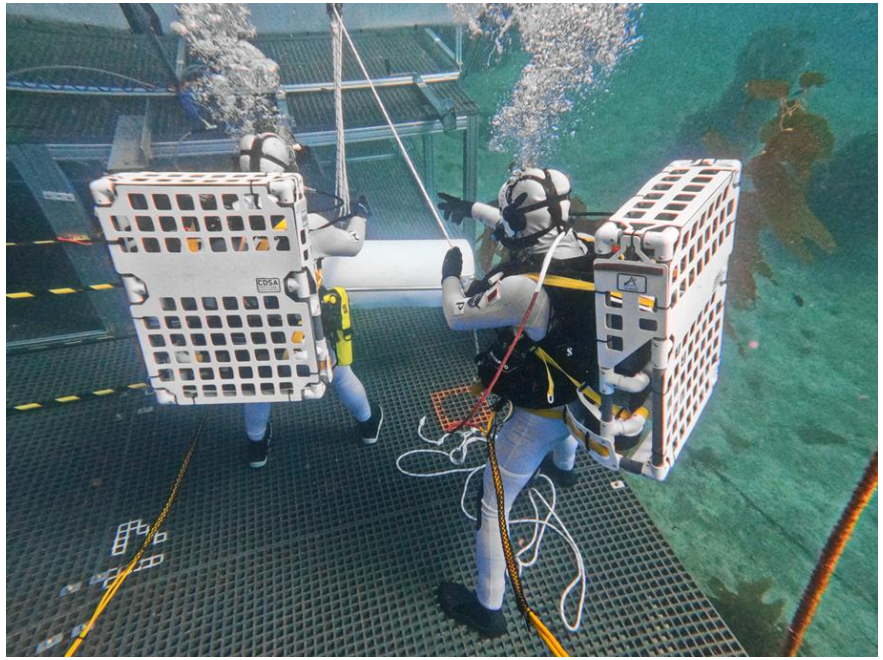
Loaded pallet positioned on porch.

Scenario 4: Air Tank Transfer via Hoist

- EV1/2 work together to transport air tanks to the lift point and attach the hoist hook
- EV1 pulls the hoist rope while EV2 controls the tank to ensure it clears the wheels and gets nestled into its mount

Render of side air tank installation by hoist

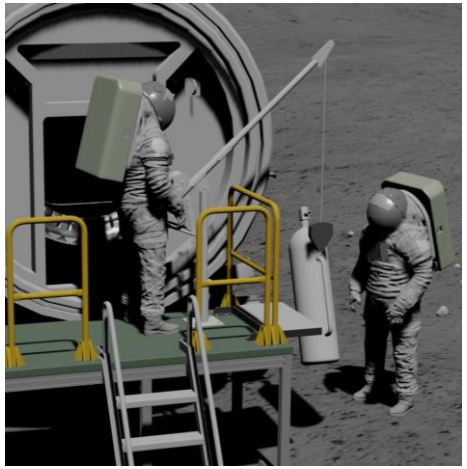




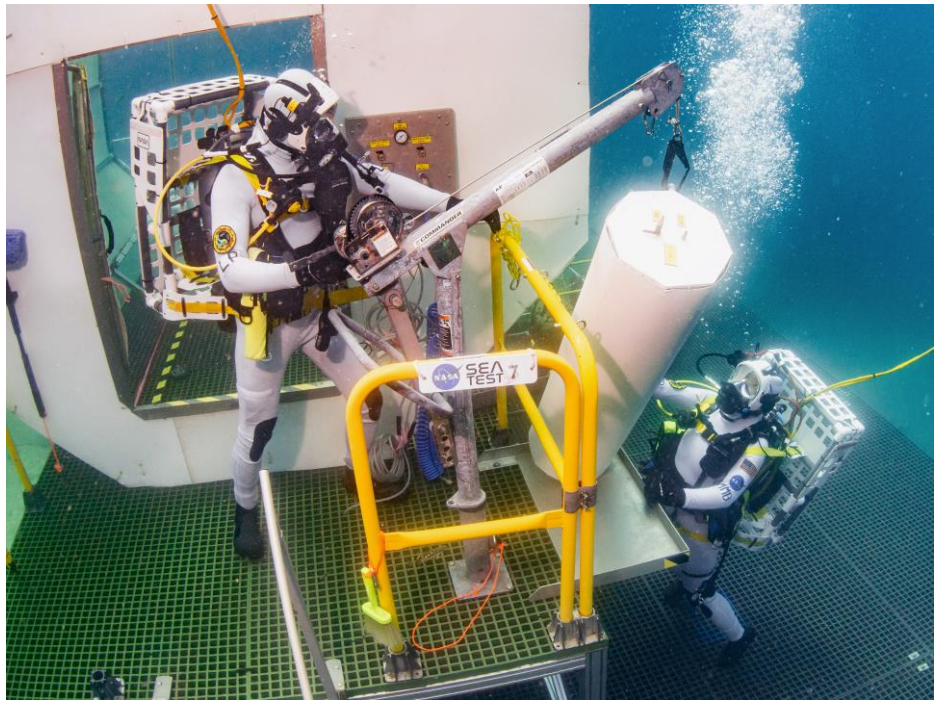
Hoist Operations for Air Tank Installation

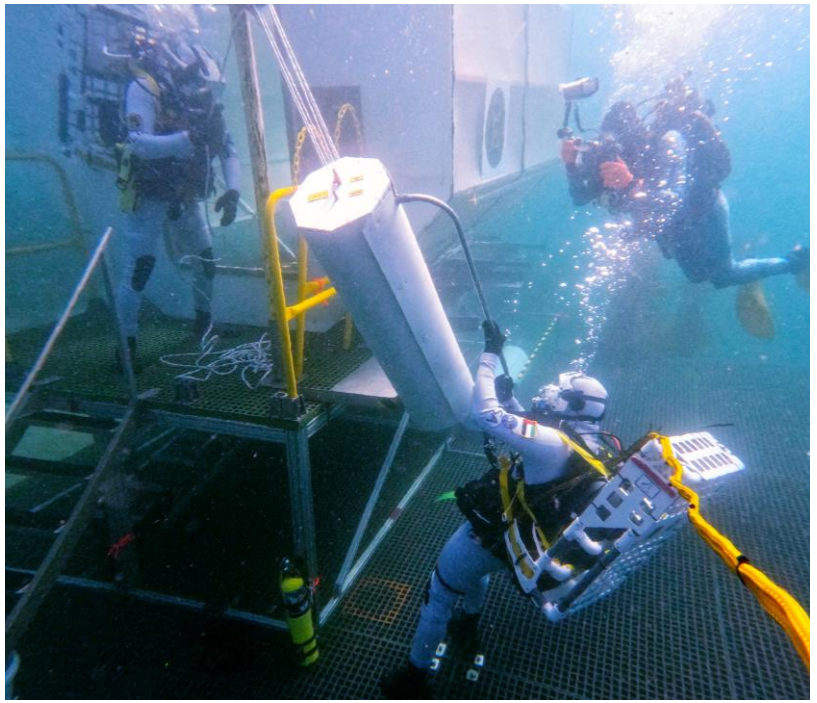
Scenario 5: Air Tank Transfer via Davit

- EV1/2 work together to transport air tanks to the lift point and attach the davit hook
- EV2 partially ascends stairs and gets dusted by EV1
- EV2 operates the davit to bring tank up to porch mount while EV1 provides control
- EV2 secures the tank so it won't fall
- Operation is repeated for the 2nd tank



Render of porch mount air tank installation by davit



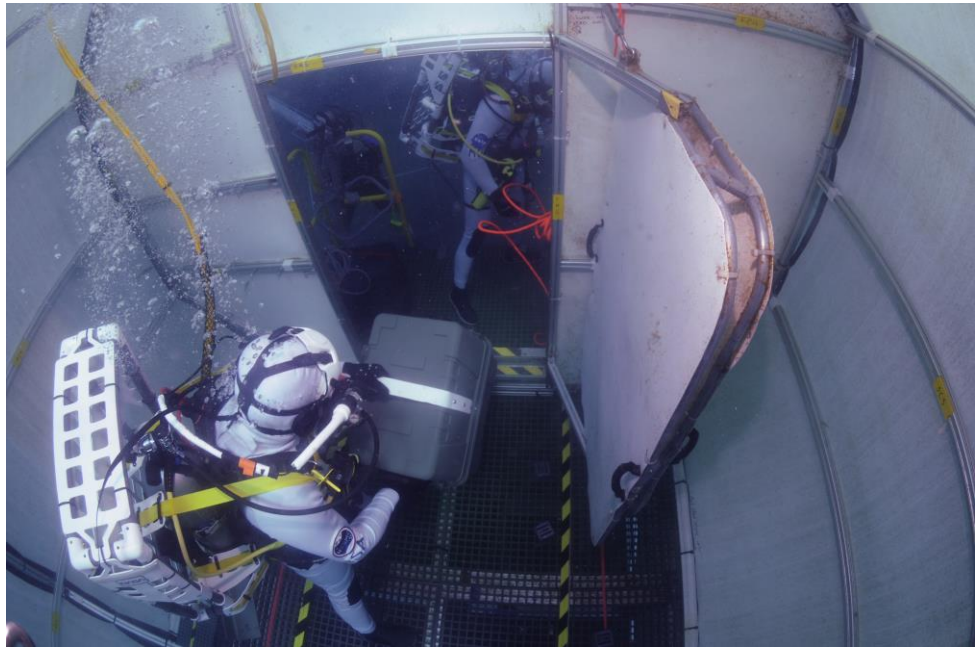


Davit Operations for Air Tank Installation

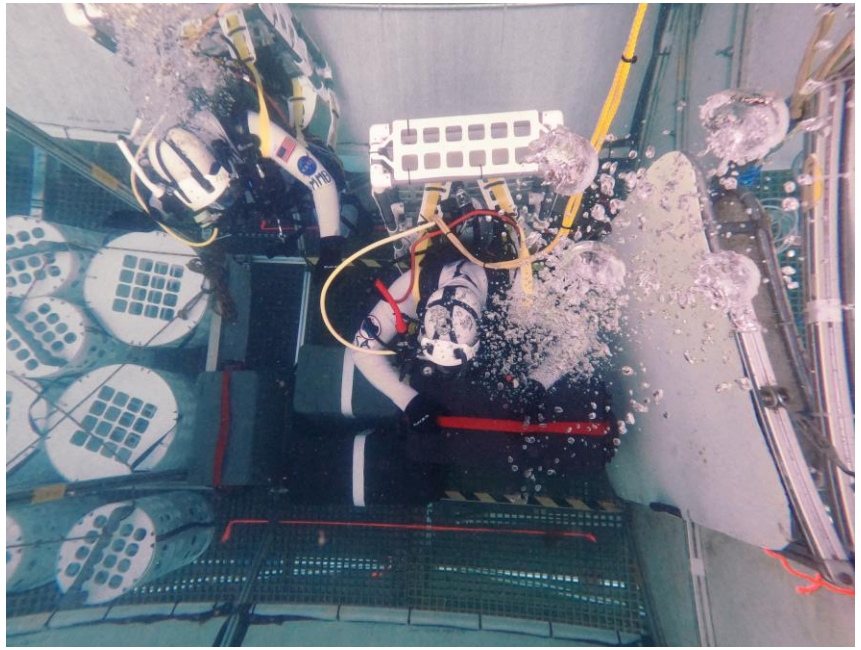
Scenario 6: Surface Habitat Airlock Cargo Transfer

- EV1 transfers CPCs across the A/L hatch to EV2
- EV2 stacks them, taking care to leave room for EV1 ingress, hatch closure, suit doffing stand access
- EV1 ingresses, hatch is closed
- EV1/2 ingress suit doffing stands, A/L is re-pressurized, suits are doffed
- Inner hatch to habitat is opened such that cargo can be transferred inside

Render of CPC transfer into Airlock



CPC being transferred into Airlock

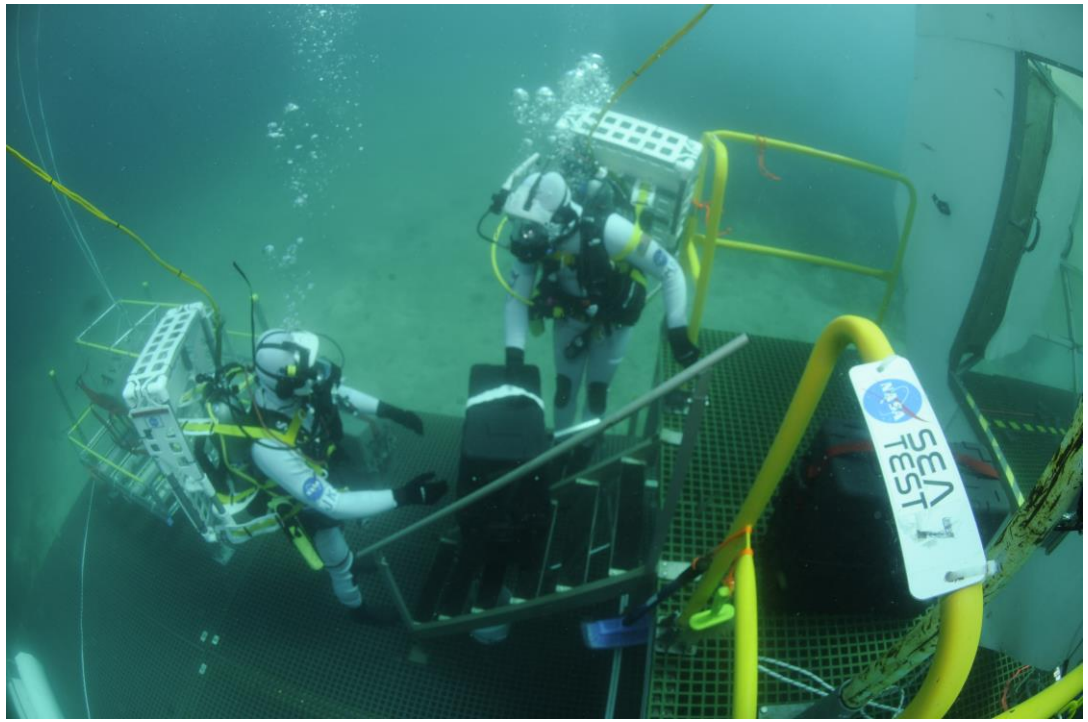


CPCs being arranged inside Airlock

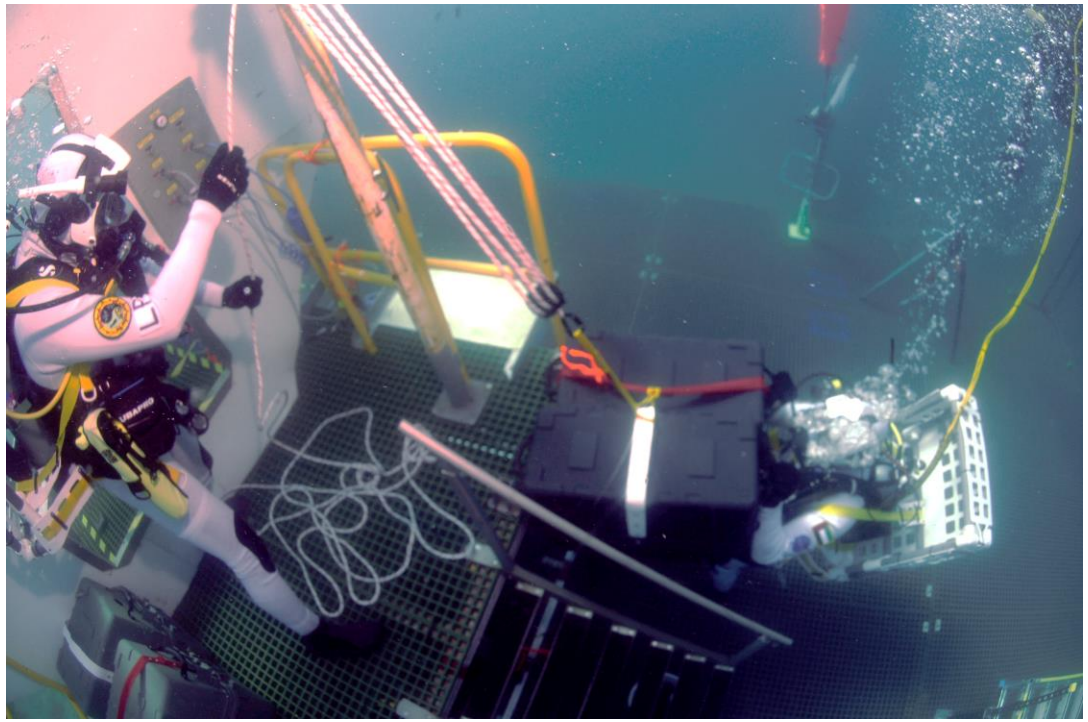
Bonus Scenario 7: Team Choice for CPC Transfer

<u>Objective</u>: Try different concepts for CPC transfer using minimal system support

1. Manually lifting and lowering
   a) Cascading CPCs upward to intermediate stops on the habitat stairs with and without use of supplemental stepstool
   b) Sliding CPCs down edge of steps
2. Use (the much simpler) hoist to guide CPCs up and down stair outer stringer (edge of steps) with other EV supporting CPC for balance



Cascading a CPC up a few steps at a time with use of a step stool

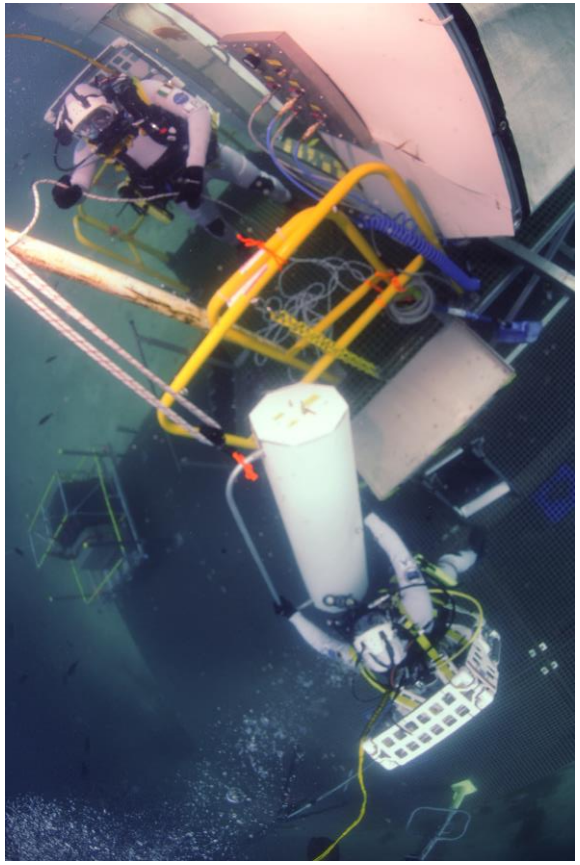


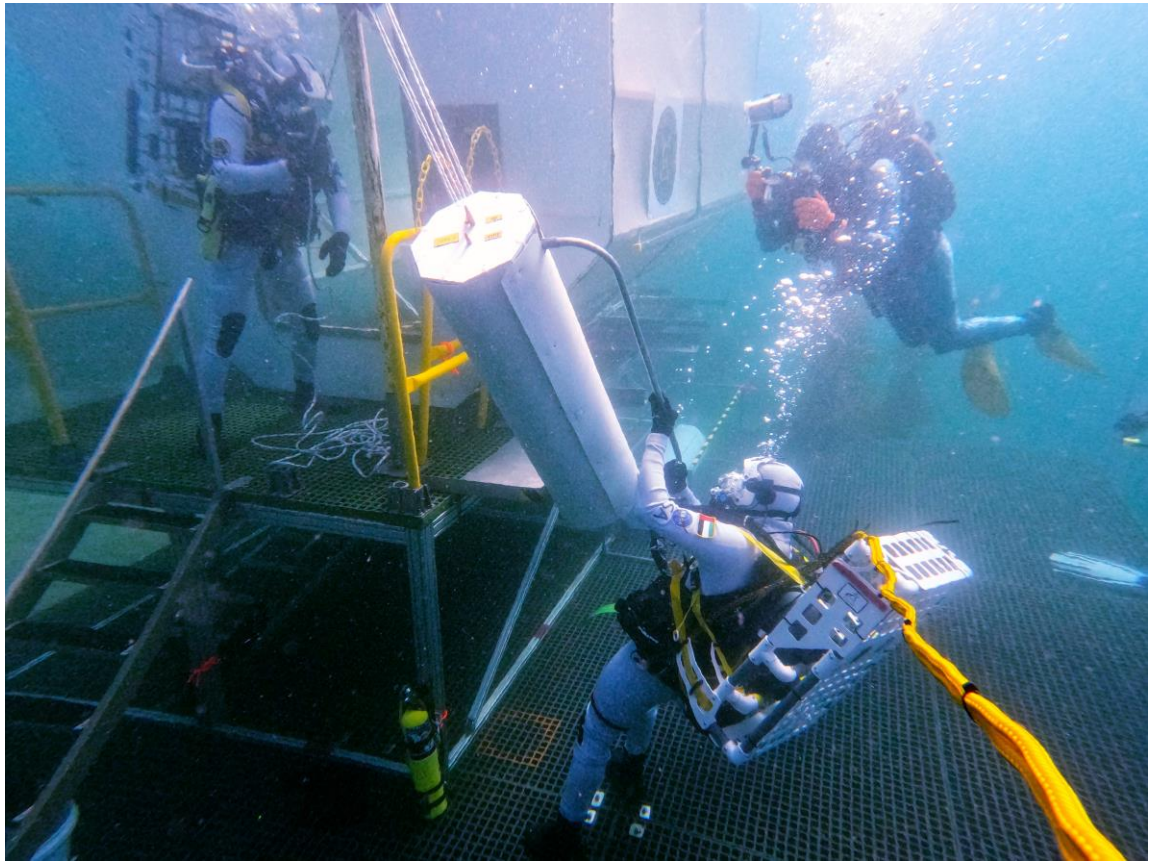
Lifting a CPC with a simple hoist

Bonus Scenario 8: Team Choice for Air Tank Transfer

<u>Objective</u>: Try different concepts for air tank transfer using minimal system support

1. Lift air tanks to the porch mount position using a hoist instead of a davit





Lifting an Air Tank with a simple hoist

Section 2.5

Data Collection

2.5.1 Data Collection

- **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:** task timing and collisions/hang-up events recorded by data collectors seated in MCC observing scenario runs in real-time:
    1. Event markers to record time durations of scenario subtasks
    2. Collision (“dings”) count/location
    3. Hang-up event count/location
    4. Handhold aid count/location

    Footage and raw data from test scenarios is included in the test deliverables for future analysis/reference
  - **Subjective data:** 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

SEATEST 7 crew debrief discussion

SEATEST 7 crew consensus data collection

2.5.2 Objective Data

- **Timing:**
  - Total task time and time duration (mm:ss) for major intervals of the task (e.g., remove CPCs/Tanks from luggage rack, transfer CPCs/Tanks to porch, ingress/egress crew/CPCs), as well as selected high-resolution samples (e.g., single CPC/Tank transfer, single CPC dusting, EV1 and EV2 dusting, ascend/descend ladder/stairs)
- **Hang-Ups:** Count and location of occurrences in the scenario where the crew got hung up and burned unnecessary time
- **Hand-Holds:** Count and location of occurrences where crew uses the hatchway (or other pieces of the mockups) as a stability handhold
- **Collisions ("Dings"):** Count and location of occurrences of any collisions on the vehicle with CPCs, PLSSs, or crew limbs

2.5.3 Subjective Data: Simulation Quality

- **Simulation quality ratings were collected to reflect the extent to which the simulation itself allowed for meaningful evaluation of the logistic offloading and transfer operations**
  - Justifications for why a particular simulation quality numerical rating was chosen were provided to explain what the simulation quality limitations were and what could have been done (if anything) to improve the simulation quality
  - A simulation quality rating of 4 or 5 indicates the hummus simulation quality was too poor to enable meaningful evaluation of the test objectives

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
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).

2.5.4 Subjective Data: Capability Assessment

- **Capability assessment ratings reflect the level of mission enhancement a capability might have**
  - Justifications were provided for each numerical rating

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 rare occasions		Capabilities are not useful under any reasonably foreseeable circumstances.	
1	2	3	4	5	6	7	8	9	10

2.5.5 Subjective Data: Acceptability

- **Acceptability ratings were used to describe how acceptable or unacceptable a task (or portion of a task) was for each scenario**
  - For numerical ratings of 3 or higher, comments were solicited regarding specific desired/warranted/ required improvements, and/or minor/moderate/significant deficiencies

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

2.5.6 Subjective Data: Additional Notes

- It is important to assess simulation quality and acceptability when evaluating ConOps and capabilities, as each metric addresses unique features important to the design decision making process
  - Without adequate simulation quality, corresponding acceptability data hold little merit
  - Capability assessment ratings can help prioritize limited resources to implement and improve upon those capabilities that have the potential to provide the highest level of mission enhancement
  - Acceptability ratings help bin the level of criticality w.r.t. recommended improvements, e.g., required vs. desired
    - Required (i.e., “I can't do this task without this improvement”)
    - Desired (i.e., “This would be nice to have, but I can manage OK without it”)

Section 2.6

Test Execution

2.6.1 Test Team Training and Qualifications

- **All support divers and crew**
  - Obtained Diver Qualification by the University of Southern California (USC)/Wrigley Marine Science Center (WMSC)
  - Trained on all mockups and test equipment
- **All crew completed Neptune Full Face Mask training and checkouts including out of air emergency drills**

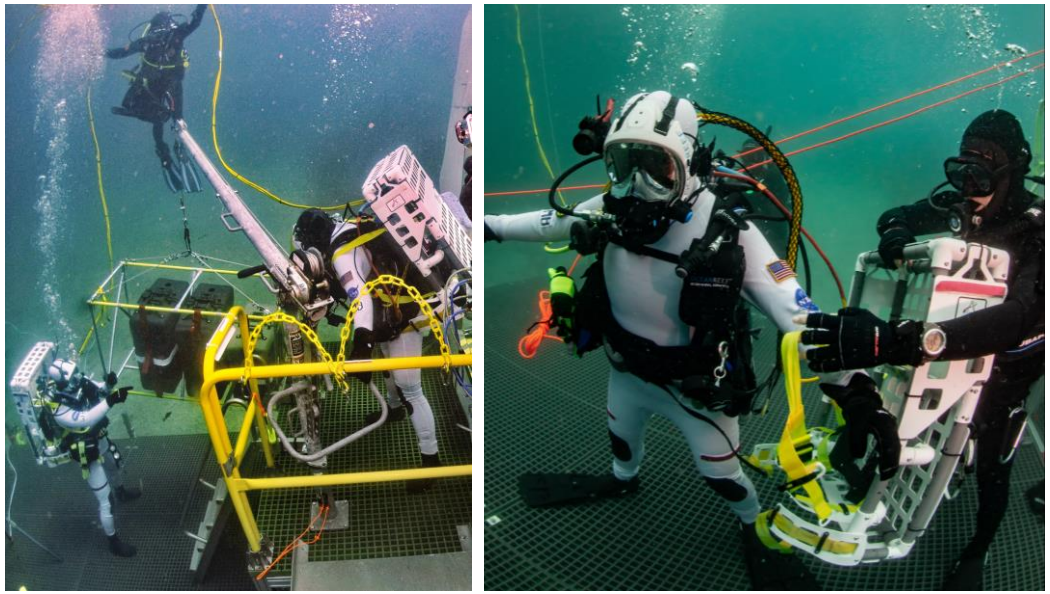
Crew dive training with USC Dive Safety Officer

Crew full-face mask training

2.6.2 Diving ConOps: Test Scenario Execution

- **Crew**
  - Crews worked as a team of 2 for approximately 1 hour per scenario
  - Performed various cargo transfer scenarios as a 2-person team
    - Crewmembers not currently conducting the scenarios underwater observed from MCC so that all crew could participate in consensus discussions
  - 5 Crewmembers rotated through EV1, EV2, and MCC observation roles and experienced each scenario type
  - 4 test scenarios tested per day
- **Support divers**
  - One support diver buddied with one Crewmember, with primary role of ops support
  - Also provided configuration support (e.g., PLSS and extra weight donning for partial-g config), communication umbilical management, and photo documentation
  - Re-configured hardware between dives

MCC test observations



Support Divers providing ops support

2.6.3 MCC/Crew Comm Protocol

- Crewmembers referred to as EV1/EV2
- CapCom referred to as Houston
- 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)
- When interacting with suspended or unsecured loads:
  - Overcommunication was encouraged.
  - Explicit with diver locations and who has eyes-on vs. who has control of load
  - Verified diver locations prior to motion

Section 3.0

Results

Section 3.1

Objective Data

3.1.1 Timing Results (Example)

Landmark START Def.	*Landmark STOP Def.*	Timing interval description	Δ T (hh:mm:ss)	NOTES
CAPCOM "Go"	*End of CPC 2-fer via davit*	CPC TRANSFER VIA DAVIT TOTAL [LOAD]	0:12:02	Support diver finished lowering cpc pair to porch.
Approach LTV	*Connect CPC* to transfer mechanism - first CPC pair*	Clear CPCs from LR	0:05:37	
EV1 begin dusting EV2	*EV1 end dusting EV2*	High resolution sample: EV2 Dusting	0:00:41	
First CPC connected to davit hook	*Removal of last CPC from hook/end of dusting, pair on porch*	Transfer all CPCs/pallet [to porch] - single CPC pair	0:06:17	Transferred first pair only in this dive
Start dust single CPC pair	*End dusting single CPC pair*	High resolution sample: Single CPC PAIR dusting	0:01:41	EV2 had difficulty accessing bottom of cpc for dusting.
CAPCOM "Go"	*End of Air tank transfer via davit*	AIRTANK TRANSFER TOTAL	0:08:26	
Approach LTV	*Tank cleared from LR* (en route to davit staging area)*	Clear Tank from LR	0:00:35	Single tank only cleared from LR in this dive
First tank leaves LR	*Tank secured to porch/holder (yellow chain) (single tank)*	Tank installation [davit]	0:07:43	Davit did not allow tank to clear porch mount. Crew needed to lift and place diagonally. Crew were then unable lower hook to release tank.

Example table of objective timing data collected per dive, representative for each scenario .Full set of raw data provided separately upon request. Start/Stop event markers are included for each event. ∆t indicates the time duration of each subtask (hh:mm:ss). Notes were provided for added event context when appropriate.

3.1.2 Hang-Up Results Summary

Summary of Hang-Up Data

HANG-UPS		
Location	Count	Key Takeaways Summary
Porch - General	5	Dust brush management (attach/disconnect from mount), CPC configuration on porch for pallet operations; spin pallet orientation while suspended;
Porch - Tanks	6	Chain management/configuration: crew had difficulty wrapping around tanks and securing to porch, need to maneufer tanks for chain connection
Porch - Davit	7	Need to reach around davit to crank (sometimes resulting in second crew needing to assist and/or move to outside of porch rail to access); davit getting stuck and/or not raising high enough; crew maneuvering under davit arm.
Porch - Airlock	6	Discussion between crew to coordinate how to configure CPCs in airlock, (to ingress, to access suit don/doff and IV hatch; discussion between crew and MCC on aligning cargo on yellow vs pink mockup lines, changing hatch door orientation when opening/closing (hatch was "backwards")
Porch - Utility Panel	2	MCC and Crew discussion to communicate panel valve configuration for open vs closed; EV descended from porch after completing utility panel procedure, but was asked by MCC to return to porch to verify panel status
Luggage Rack	7	Two people required for moving CPCs/Pallet to/from luggage rack; While moving the free CPC to luggage rack, EV1 tried to set CPC on top of stool while to climb onto stool but it didn't work, so EV2 came down to the ground to hold the CPC while EV1 got onto step stool, then EV2 handed the CPC back to EV1 to place in luggage rack;
Surface - Tank Ops	2	Coordinate two-person carry (MCC communication; one crew directing other crew walking backward)
Surface - Hoist Ops	8	Needing to reach arms above shoulders to release hoist from tank (use of step stool); hoist getting stuck; hoist not lifting tank high enough to clear stowage arms; managing hoist cables; support divers required to move hoist mount between tanks; improvising lift point on tank (in crew choice scenario to lift tank vertically using hoist)
Surface - Zipline Ops	9	Re-tensioning zipline (including MCC communication and need for divers to assist in re-tensioning); managing zipline cable; difficulty attaching/disconnect CPC to/from zipline hook (specifically with the white CPC strap) [also occurred at Luggage Rack]; As EV2 climbed stairs after being dusted, he was on left side of zipline but realized he wanted to be on right side of zipline so had to come back down the stairs to go under the zipline to switch sides. EV1 pushed zipline up so EV2 could go under it and go back up steps (EV1 stated she would not have been able to raise arms high enough to lift line in a pressure suit)
Misc.	1	Managing Comms umbilical

3.1.3 Hand-Hold Results

Summary of Hand-Hold Data

HAND-HOLDS - Summary		
Location	Count	**NOTES**
Hatch: Top	0	
Hatch: Bottom	0	
Hatch: Left	1	Use of hatchway when ingressing/egressing through hatch
Hatch: Right	18	Use of hatchway when ingressing/egressing through hatch; for leverage when maneuvering CPCs
Other: Porch Rail	2	Use of porch hand rail for stability when ascending/descending from porch; Use of porch hand rail for stability when maneuvering to outside of hand rail to operate davit;
Other: Hatch handle	3	Use of hatch handle for stability while ingressing/egressing

3.1.4 Collisions Results

Summary of Collision Data

COLLISION ("DINGS") SUMMARY				
Description			Count	**NOTES**
CPC	dinged ->	Stair Handrail	3+	Contact while lifting (davit, zipline)
CPC	dinged ->	Stairs	7	CPC impacting and being rested on stairs during load/offload
CPC	dinged ->	Porch	4	Sliding over porch/agains edge when lifting and dusting
CPC	dinged ->	Porch Handrail	3	During zipline operations; While suspended for dusting
CPC	dinged ->	Surface	7	At bottom of zipline for offload/load; dragged on floor when being lifted by davit
CPC	dinged ->	Luggage Rack	8	When clearing LR for offload/load with davit and zipline; when dusing while suspended from zipine
CPC	dinged ->	Rail, Stairs, Porch Edge (undifferentiated reporting)	8	CPC contacted rail, steps and front edge of porch during load and/or offload.
CPC	dinged ->	Hatch	4+	While preparing CPCs for transfer (positioning on porch near hatch); impact with stacks of CPCs when opening/closing hatch
CPC	dinged ->	CPC	1	While CPC was being raised to porch on zipline, contact with CPC that was already on the porch.
Pallet	dinged ->	Stair Handrail	4	While lifting and maneuvering/swinging onto porch
Pallet	dinged ->	Stairs	2	While lifting
Pallet	dinged ->	Luggage Rack	3	When lowering pallet for LTV loading
Air Tank	dinged ->	Porch Mount	5	Tank contact porch mount as tank being lowered
Air Tank	dinged ->	Stowage Arm	3	While maneuvering tank into stowage arm
Air Tank	dinged ->	Porch rail	3+	While lifting tank to porch
Air Tank	dinged ->	Luggage Rack	4	Sliding against LR during offload/load
Air Tank	dinged ->	Wheels	1	
Air Tank	dinged ->	Air Tank	1	Tanks impacting each other when clearing from LR
Air Tank	dinged ->	Wheels	1	Impact while hoisting tank to fwd install location

3.1.4 Collisions Results (cont.)

Summary of Collision Data (Cont.)

COLLISION ("DINGS") SUMMARY				
Description			Count	**NOTES**
Crew	dinged ->	Porch rail	1	When maneuvering between rail and davit for davit operation
Crew	dinged ->	Wheels	~1	Potential impact with wheels while operating hoist
Hoist Hook	dinged ->	Wheels	1	Hoist hook impacted wheels when left free after loading CPCs
PLSS	dinged ->	Hatch	2	PLSS impact hatch opering/hatch door during traverse
Crew	dinged ->	Zipline	7	Intentional contact with zipline (hand) to raise zipline to move under line between LR and zipline loading position
PLSS	dinged ->	Luggage Rack	2	While guiding CPC pallet back down; while bending over to retreive trank
PLSS	dinged ->	Zipline Rope	4	PLSS contacted zipline as EV1 moved under it as he moved between luggage rack and zipline loading position.

Section 3.2

Subjective (Crew Consensus) Data

3.2.1 Simulation Quality Results – Key Takeaways

Simulation quality reflects the extent to which the simulation allows meaningful evaluation of test objectives

- Ratings were collected each test day prior to acceptability/capability ratings

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
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).

- **Q1. Rate the simulation quality of the environment as compared to expected lunar environment**
  - Ratings:
    - 2 for scenarios that do not involve Airlock
    - 3 for scenarios involving Airlock
  - Comment Summary:
    - (2) Overall good simulation of the environment but lacking certain fidelity items associated with known test limitations (such as the geometry of a real space suit, drag due to water, 1/6g bodyweight accuracy)
    - (3) Fidelity limited for a full airlock evaluation – for a volumetric evaluation, volumetrically accurate airlock (system standoffs represented, shelving, umbilicals) and representative suit mockups (size-representative PLSS and donning stands, etc.) would be required. A size-adjustable airlock mockup would enable crew to assess minimal required airlock size

- **Q2. Rate the simulation quality of the environment's ability to provoke relative operational considerations**
  - Ratings:
    - Ranged from 2 to 3
  - Comment Summary:
    - (3) Hoist "too light" which limits simulation fidelity and fidelity limitations of the airlock for volumetric assessment (see Q1 Comment Summary)

Simulation quality was sufficient to support meaningful evaluation of all test objectives

3.2.1 Simulation Quality Results – Raw Data

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

Day 1 (Scenarios 2, 3, 4, 5)		
Question	**Rating**	**Comments**
The environment as compared to expected lunar environment (1/6 g effects, mass management, offloading concept fidelity, etc.)	**2**	Water provides "unrealistic" drag Some crew members "weight" is not 1/6 g… some "heavier" and some "lighter".
The environment's ability to provoke relevant operational considerations (dusting requirements, suit maneuverability, mechanism and system fidelity, etc.)	**3**	Wetsuits do not provide the mobility that we expect to have in the lunar space suits. Mechanical constraints are different on the sea floor than on the moon. Hoist was "too" light and that simulation feature is at the limit of fidelity.

Day 2 (Scenarios 1, 6)		
Question	**Rating**	**Comments**
The environment as compared to expected lunar environment (1/6 g effects, mass management, offloading concept fidelity, etc.)	**2: Zipline**	In general, good fidelity for zip line development and evaluation. Fidelity limited for a full airlock evaluation, in that for a volumetric evaluation (the task) we require a volumetrically accurate airlock Similarly, volumetrically representative suits would be required. More realistic airlock evaluation requires accurate volume representation (system standoffs represented), shelving, umbilicals, size-representative PLSs and donning stands, etc. Ideally, airlock would have a size-adjustable construction, permitting test crews to move the aft wall/IV hatch longitudinally while assessing minimal required airlock size.
	3: Airlock	
The environment's ability to provoke relevant operational considerations (dusting requirements, suit maneuverability, mechanism and system fidelity, etc.)	**2: Zipline + Airlock**	

3.2.1 Simulation Quality Results – Raw Data (cont.)

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

Day 3 (Scenarios 2, 5)		
Question	**Rating**	**Comments**
The environment as compared to expected lunar environment (1/6 g effects, mass management, offloading concept fidelity, etc.)	2	Mostly the same comments as day [1] overall good simulation of the environment, but lacking certain fidelity items (such as the geometry of a real space suit).
The environment's ability to provoke relevant operational considerations (dusting requirements, suit maneuverability, mechanism and system fidelity, etc.)	2	Same comments as day 1

Day 4 (Scenarios 3, 1)		
Question	**Rating**	**Comments**
The environment as compared to expected lunar environment (1/6 g effects, mass management, offloading concept fidelity, etc.)	2	Same comments as day 3
The environment's ability to provoke relevant operational considerations (dusting requirements, suit maneuverability, mechanism and system fidelity, etc.)	2	Same comments as days 2/3

Day 5 (Scenarios 4, 7)		
Question	**Rating**	**Comments**
The environment as compared to expected lunar environment (1/6 g effects, mass management, offloading concept fidelity, etc.)	2 3 (for airlock)	Airlock needs to be higher fidelity with respect to useable volume, and representative suits must be worn, for accurate airlock assessments.
The environment's ability to provoke relevant operational considerations (dusting requirements, suit maneuverability, mechanism and system fidelity, etc.)	2 3 (for airlock)	Airlock needs to be higher fidelity with respect to useable volume, and representative suits must be worn, for accurate airlock assessments.

3.2.2 Capability Assessment Results – Key Takeaways

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 rare occasions		Capabilities are not useful under any reasonably foreseeable circumstances.	
1	2	3	4	5	6	7	8	9	10

Capability assessment ratings reflect the level of mission enhancement a capability might have

- Prompt: Provide a capability assessment for the following operations/tools:

Q1: Davit (Two CPCs vs Pallet vs Air tank)

- Ratings:
  - **2-Pallet**
  - **5-Tank**
  - **10-Two CPCs**
- Comment Summary: If pallet is required, then the davit is enhancing and required. However, crew could visualize easier solutions (a simple hoist mounted high above the tank mount location) rather than the davit

Q2: Zipline

- Rating: **3**
- Comment Summary: The zipline allows for dusting suspended CPCs away from the porch, which is advantageous.

Q3: Hoist (Tanks vs CPC 2fer)

- Rating: **2 (Tanks and CPC 2fer)**
- Comment Summary:
  - Tanks: Hoist was required and generally elegant for mounting the tanks horizontally on the port side of the surface habitat
  - CPCs: Good concept for raising/lowering CPCs, more efficient/effective than zipline and davit. Advantageous that it allowed CPCs to be dusted while suspended. Future hoist needs be adjustable for appropriate positioning, depending on the task, to prevent the CPCs or tanks from impacting the habitat during raising/lowering. This improved hoist design should be tested for the pallet case.

Q4: Step Stool

- Rating: **1**
- Comment Summary: Essential

Q5: Ladder from lunar surface to surface habitat

- Rating: **2**

Q6: Stairs from lunar surface to MPH

- Rating: **1**
- Comment Summary: Stairs (with only one handrail) were better suited for manually transporting CPCs up and down.

Essential/Enabling: Davit (Pallet), Hoist, Step Stool, Ladder, Stairs
Significantly Enhancing: Zipline
Moderately Enhancing: Davit (Tank)
Little or No Enhancement: Davit (2 CPCs)

3.2.2 Capability Assessment Results – Raw Data

Capability assessment ratings reflect the level of mission enhancement a capability might have

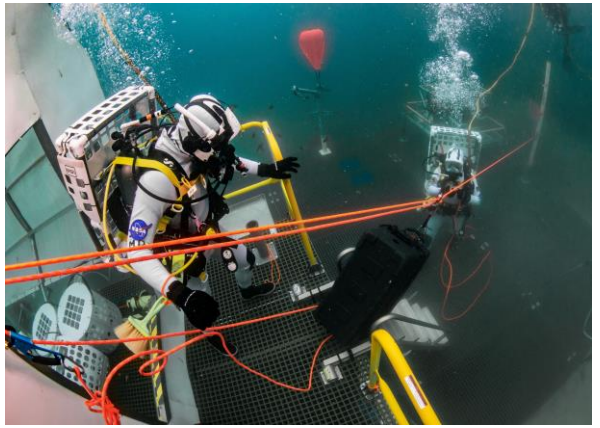
- Prompt: Provide a capability assessment for the following operations/tools:

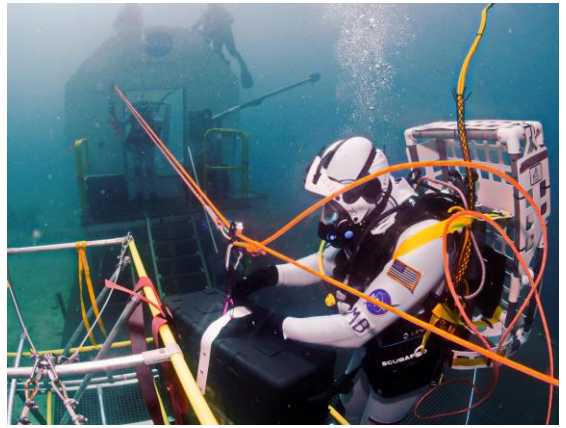
Essential / Enabling		Significantly Enhancing		Moderately Enhancing		Marginally Enhancing		Little or No Enhancement	
Impossible or highly inadvisable to perform mission without capability		Capabilities are likely to significantly enhance one or more aspects of the mission		Capabilities likely to moderately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

Question	Rating	Comments
Davit (2 CPCs vs Pallet vs Air Tank)	**Pallet-2** **Tank-5** **2 CPCs-10**	If there are reasons for why the pallet has to be used, then the davit is enhancing (and required). Crew commented that although the davit was the only mechanism available during testing to raise the tanks, they could visualize easier solutions (a simple hoist mounted high above the tank mount location)
Zipline (CPCs)	**3**	The zipline allows for dusting suspended CPCs away from the porch, which is advantageous.
Hoist (Tanks vs CPC 2fer)	**Tanks & 2 CPCs (Small/ Large) -2**	Hoist was required for mounting the tanks horizontally on the port side of MPH, and was generally an elegant way of doing this task. Hoist was also good, as a concept, for raising and lowering CPCs to the porch, and was assessed as more efficient and effective than the other CPC transporting mechanisms (zip line and Davit). Another advantage was that it allowed the CPCs to be dusted while suspended. This assumes that the hoist would be adjustable such that it could be appropriately positioned, depending on the task, to prevent the CPCs or tanks from impacting the MPH during raising/lowering.
Step Stool	**1**	Essential
Ladder from lunar surface to MPH	**2**	
Stairs from lunar surface to MPH	**1**	Stairs (with only one handrail) were better suited for manually transporting CPCs up and down.
Additional Comments?		It'd be worth investigating using an improved design of the hoist (with more adjustments capability) to lift an entire pallet out of the LTV

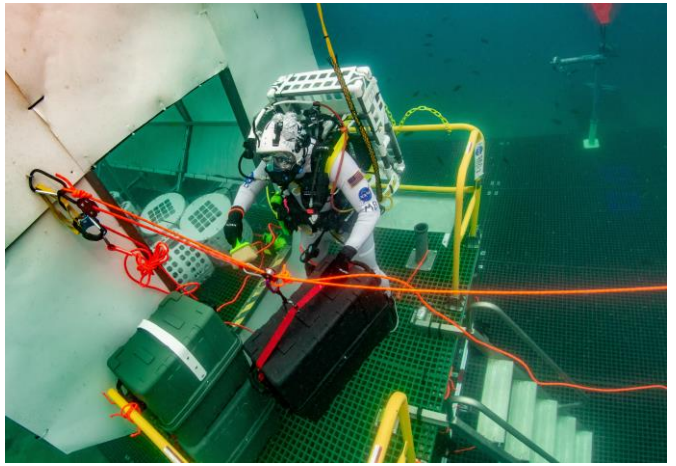
3.2.3.1 Results: CPC Transfer via Zipline – Key Takeaways

- More flexible setup compared to the davit, LTV parking less constrained (though line path should not intersect with stairs/ladder)
  - Flexibility would be further increased if the surface habitat and LTV included an adjustable height feature to secure the zipline
- Low mass and simple CPC transfer solution
- Zipline allowed CPC dusting while suspended from line – porch packing more easily configurable when CPC is dusted before lifting to porch
- A small elevation aid (e.g., stepstool) is beneficial for temporary stowage of CPC without placing on Lunar surface
- Porch crewmember would benefit from a load alleviating feature to control CPC descent
- Need for a rope management design feature
- Zipline hook must be compatible with all CPCs

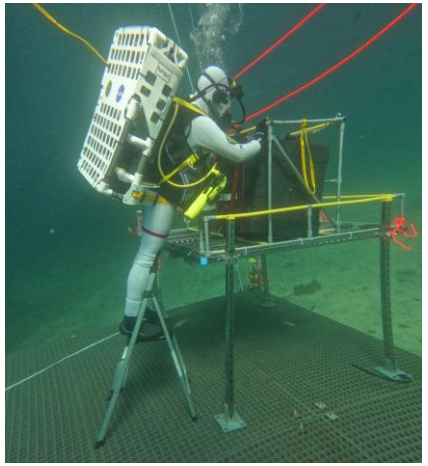




Left: Zipline path crossing ladder. Right: Zipline path avoiding crossing stairs.



Porch crew dusting CPC while suspended on zipline above porch



Use of step stool with LR at 1m

A zipline is a promising simple and lightweight solution for CPC transfer

3.2.3.1 Acceptability Results: CPC Transfer via Zipline – Raw Data

- Day 2
- Luggage Rack: 0m & 0.5m
- Luggage Rack Misalign: N/A

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

Question	Rating	Comments
Using the Zipline for loading [to MPH] transfer operations (reach, attachments, loading containers, haul line, return line, tensioner, trolley, etc.)	4	[LOAD Scenario]: In general, crew found the zipline to be a better solution for CPC transfer than the davit. The zipline affords more flexibility (for example, with respect to where you park the LTV), and is a lower mass, simpler solution to the problem of lifting CPCs up to the porch. The load line for the porch crewmember can be significant. Some sort of load alleviating device/assist (a kin to a block and tackle) would reduce workload for the porch based crew. Some complications/shortcomings observed: for example, LTV placement is important - certain positions lead to the zip line itself blocking the staircase from use by the surface based crewmember. A feature allowing crew to adjust the height of the zip line, at either end, would increase efficiency in certain cases. Dusting operations with zipline were achievable but constrained: easy to dust the sides (as CPC hangs in free space), but second crewmember was better positioned to dust the bottom. Certain crew wrapped the dust brush tethers around their hand. Important to have multiple dust brushes, with tethers, that are easily accessible to both crew. Thought should be given to rope management, and where to place the excess (coil, reels, hooks?). Although not used in the test, the footstool may make CPC loading (and dusting operation) easier for the surface based crewmember (potentially, loading can be done without placing the CPC on the lunar surface, thereby reducing dust collection). [OFFLOAD Scenario]: All comments in lines 1 through 5 [Load Scenario], above, apply [for OFFLOAD Scenario]. Additionally, the porch crewmember's job would be easier with some sort of load alleviating device on the porch end of the zipline, allowing them to control (with ease) the rate of descent of the CPC.
Two crew (ground level + porch level) for this transfer method	2	Acceptable - considerations mentioned above apply.
The cargo packing (i.e., layout of CPCs) on the porch for loading transfer operations	3	Acceptable, however, may be easier and more effective (from an access, space point of view), to dust each CPC as it is suspended beside the zipline, before hauling it up to the porch. Limited porch space made operations on the porch possible but constrained. Porch railings (or some equivalent restraint/handhold/net) is required to assist the porch crewmember.
ICR Access (ability to access buddy)	8	Zip line over the stairs/main access path lends itself to crew entanglement if the crew is required to expeditiously transit to or from the porch. Nominal operations should not occlude the main crew access path (there are operational work arounds that would fix this, such as restricting the relative azimuths on which the LTV can park with respect to the porch.
Overall acceptability of using this transfer method for loading from end-to-end (including risk to crew)	3	Acceptable - improvements and operational considerations captured above.

3.2.3.1 Acceptability Results: CPC Transfer via Zipline – Raw Data (cont.)

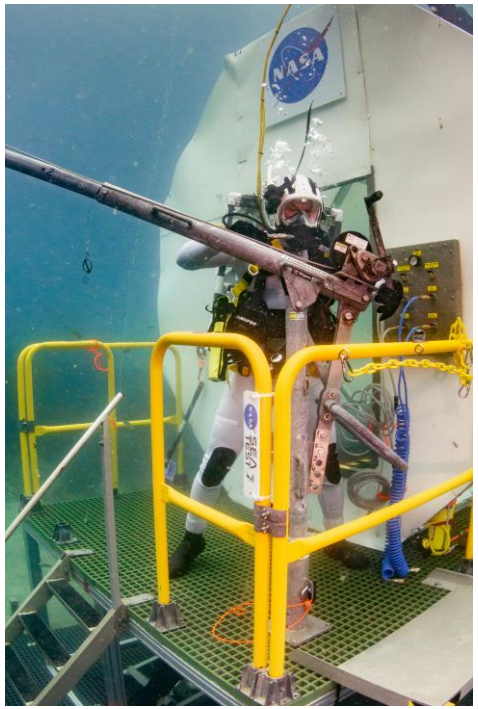
- Day 4
- Luggage Rack: 1m
- Luggage Rack Misalign: II & III
- Step Stool as initial condition

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

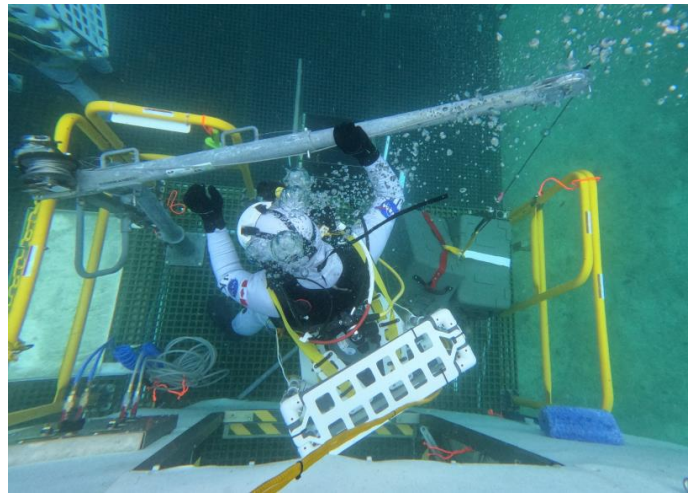
Question	Rating	Comments
Using the Zipline for loading [to MPH] transfer operations (reach, attachments, loading containers, haul line, return line, tensioner, trolley, etc.)	7	[LOAD Scenario]: Crewmember lift aid (step stool or equivalent), required for task completion. Unacceptable with out a stool (ie, rating of 9). Even with the provided stool, crew member compensation was required, with improvements required, due to the instability of the step stool (risk of fall), and the requirement to lift each CPC above the luggage rack side rails (Zip line was not rigged high enough, and would need to be rigged higher in order to alleviate the requirement of the crew to lift/guide each CPC up, over and out of the luggage rack. Ideally, the zip line should be fully adjustable in height (at both ends). Any step stool design needs to be stable on the surface, while accounting for the mass and mass distribution of the TBD space suit design. Additionally, the zip line hook was not compatible with the various straps on the different sized CPCs. The hook must be equally compatible with the top CPCs straps, and should not change between large and small CPCs. [OFFLOAD Scenario]: Important for the porch-based crewmember to control the rate of descent for the CPC during offloading (although this capability is provided for in the zipline design). All the same complications/challenges as loading existed due to the height of the 1.0 m luggage rack and its even higher hand rails (crew had to lift CPCs over this railing while standing on an unstable step stool, mostly because the height of the zip line could not be suitably adjusted).
Two crew (ground level + porch level) for this transfer method	2	2 crew was acceptable for this task.
The cargo packing (i.e., layout of CPCs) on the porch for loading transfer operations	2	Acceptable; however, and as previously mentioned, the Davit obstructs CPC movement and available options on the porch. Would be enhanced if the Davit either did not exist, or was mounted elsewhere (on a swing arm, for example, or directly on the surface).
ICR Access (ability to access buddy)	2	ICR access was acceptable throughout the task, given that the zip line was deliberately setup adjacent to the stairs (so as not to interfere with stairway access).
Overall acceptability of using this transfer method for loading from end-to-end (including risk to crew)	3	Crew generally felt that the zip line was a more acceptable solution than the Davit for this task. The height of the luggage rack complicated the operation, which was the main driver of assessed improvement requirements.

3.2.3.2 Results: CPC Transfer via Davit – Key Takeaways

- The lack of adjustability of the davit (boom length, pitch, crew access to crank) as well as significant porch space allocation led to low acceptability scores
  - Crew often needed to duck under boom, reach around davit and/or standing on the edge of porch outside of railing to access the crank, and boom often crossed airlock path restricting ICR access, which affect safety of davit operations
- Davit deemed too complex (high mass, porch area/volume penalty) for CPC lifting capability
- Simpler methods (Zipline, manual carry) were preferred for CPC lifting



Difficulty accessing davit crank.



Davit boom causing porch maneuverability issues.

The Davit was universally disliked as part of a lifting solution

3.2.3.2 Acceptability Results: CPC Transfer via Davit – Raw Data

- Day 1
- Luggage Rack: 0m & 0.5m
- Luggage Rack Misalign: I
- (did not perform OFFLOAD on Day 1)

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

Question	Rating	Comments
Using the davit for transfer operations to load [to MPH] a couple of CPCs at a time (reach, attachment/detachment, accessibility of containers, etc.)	7	Need ability to change davit configuration (boom length, pitch, etc.). The ability to "crank" the davit from all orientations with respect to the davit (for example a wheel). Davit that can be deployable and storable would be beneficial (e.g., on a swing arm to reposition into and out of the way). Davit concept is acceptable, but improvements required.
The porch size for loading transfer operations (deck volume, deck height, etc.)	5	Porch size was adequate to accommodate two CPCs for temp storage and to allow for dusting. We did not have all four CPCs on the porch, but initial thought is that the porch can accommodate . Porch size and layout results in unsafe condition when operating the davit in its current condition. Specifically having to duck under the davit and crank the crane from the forward section of the porch, while holding on to the railing with one hand and at times "dangling" off the edge. The boom location during/after transferring cargo would not allow for the rescue of an incapacitated crew member. Porch size contributes to inefficient operations, more time required moving/fitting cargo in small spaces and could lead to longer times dusting CPCs. With flight-like connections for air and heat, the operational volume would require additional porch volume. The current configuration and porch size would be unacceptable with the davit in its current location.
Ease of transferring CPCs from Luggage Rack	3	Half meter height was easier than the scenario with the rack on the floor. Luggage rack on floor required crew to bend down in order to grasp CPC. Not sure if bending motion is a realistic maneuver in the lunar suits.
The number of crew for this transfer method	2	
ICR Access (ability to access buddy)	7	ICR access was in question whenever the davit was in use and the boom was over the ladder and further starboard. Whenever the hook was crossing the airlock path. The crewmembers would have to move the davit out of the way before accessing incapacitated crew member. Ability to improve/gain accessibility quickly would be needed (e.g., a quick release to create access)
Overall acceptability of using this transfer method for loading from end-to-end (including risk to crew)	3	The davit as a concept has promise with all caveats above.

3.2.3.2 Acceptability Results: CPC Transfer via Davit – Raw Data (cont.)

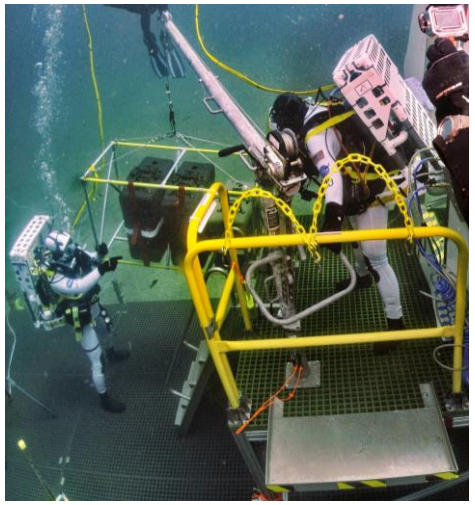
- Day 3
- Luggage Rack: 1m
- W/ & W/O Ambulation
- Luggage Rack Misalign: II & N/A (Ambulation)
- Step stool NOT included as initial condition

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

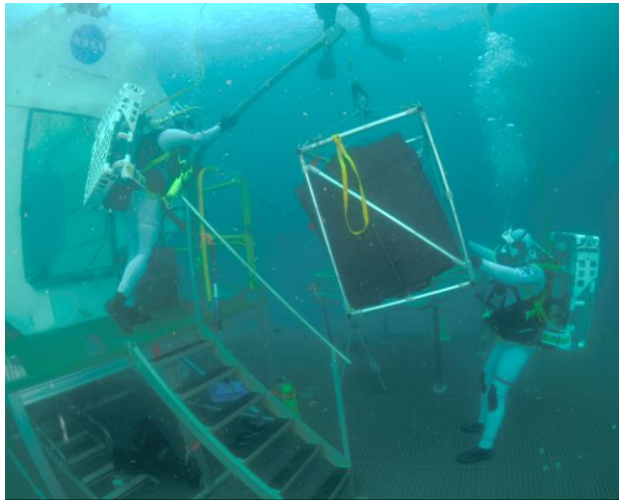
Question	Rating	Comments
Using the davit for transfer operations to load [to MPH] a couple of CPCs at a time (reach, attachment/detachment, accessibility of containers, etc.)	9	This task (lifting the CPCs from a 1.0m LTV, and then higher to clear the LTV railing) cannot be done without some sort of mechanism to elevate the crew. Some sort of step up assist was deemed essential - the step stool was suitable, but a simple step (perhaps integral to the LTV itself) could be more effective. Task was completed with Davit, but in general davit obstructed crew efficiency. When using the davit to raise CPCs to the porch, the porch-based crewmember has to constantly maneuver around the davit itself, using movements that (although not tested) are unlikely to be easy to do in a space suit. Crew made use of the step stool while accessing the luggage rack at 1.0 m. As mentioned on day 1, the Davit being positioned on the porch is highly undesirable, because it renders half the porch area as unusable. Crew observed that there are many alternative, easier ways to lift a CPC to the porch, including simply carrying them with one hand, while using the other hand to stabilize on the staircase railing (demonstrated).
The porch size for loading transfer operations (deck volume, deck height, etc.)	5	Same comments from day 1. porch size itself was sufficient for 4 CPCs, but the davit being located on the porch is highly undesirable because it is always in the way (and reduces the amount of useful porch area considerably).
Ease of transferring CPCs from Luggage Rack	9	Step stool (or alternative elevation gain for crew member) was assessed as essential for the 1.0 m LTV unless an alternative design was used, due to the requirement to lift the CPC above the LTV railing height.
The number of crew for this transfer method	2	2 crew required and sufficient for this task.
ICR Access (ability to access buddy)	7	Same as day 1. Davit's location on the porch means that it is frequently blocking the access (stairs) that one crew member has to the other.
Overall acceptability of using this transfer method for loading from end-to-end (including risk to crew) for mixed size CPCs	6	The davit is effective at lifting 2 CPCs to the porch; however, by day 3 the crew felt that in light of the multiple, simpler options for getting the CPs to the porch (just carry them), the davit was excessively ineffective and obstructive. The crew felt that they would not elect to use the davit for CPC transfer to the porch. The complexity, weight and area/volume penalty on the porch is too great when compared to the (very simple) task of lifting CPCs to the porch.
Additional Comments?		Given the task at hand, the davit is not a mission enhancing feature. The complexity of using the davit does not warrant the efforts required to design, build, and launch a davit when there are other easier and simpler concepts.

3.2.3.3 Results: CPC Pallet Transfer via Davit – Key Takeaways

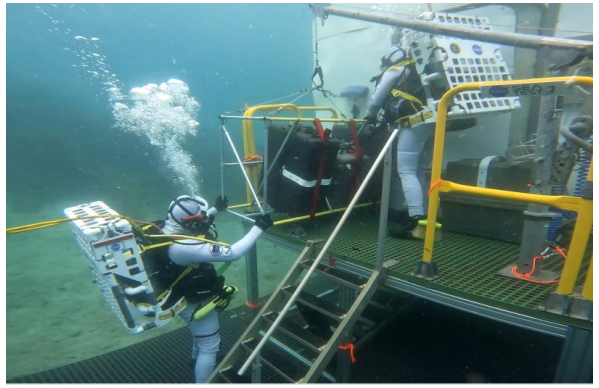
- LTV mis-align from davit is a problem when loading/offloading pallet and causes swing, requires precision when parking LTV
- Pallet occupies large footprint on porch (while still not completely fitting in 4 ft depth) in addition to space required to access/unpack CPCs
  - Porch space was less of an issue when the forward-facing porch rails were not in place
- If trying to transfer 4 CPCs, the complexities of transferring the entire pallet + 1 individual CPC outweigh perceived efficiencies. (If the pallet design evolved to provide dust protection, that calculation might change.)
- Same operating constraints for davit as 2 CPC case (porch unaccommodating of range-of-motion needs, safety impacts of davit access/operations



EV1 guiding pallet to porch during lift.



EV2 controlling pallet when pivoting to porch.



Loaded pallet positioned on porch.

Lifting the whole pallet held no obvious advantages (and numerous disadvantages) over other methods

3.3.3.3 Acceptability Results: CPC Pallet Transfer via Davit – Raw Data

- Day 1
- Luggage Rack: 0m & 0.5m
- Luggage Rack Misalign: II

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

Ratings unchanged from CPC-2-at-a-time using a davit LOAD case.

Question	Rating	Comments
Using the davit for transfer operations to load [to MPH] an entire pallet packed with 3 CPCs (reach, attachments, stability of pallet, accessibility of containers, etc.)	7	Same comments as CPC 2-at-a-time case.
The porch size for load transfer operations (deck volume, deck height, etc.)	5	The porch size did not allow for the pallet to be fully on the porch.
Ease of packing CPCs to pallet ***[N/A DAY 1]***		
The number of crew for this transfer method	2	Same comments as CPC 2-at-a-time case.
ICR Access (ability to access buddy)	7	Same comments as CPC 2-at-a-time case.
Overall acceptability of using this transfer method for loading from end-to-end (including risk to crew)	3	Same comments as CPC 2-at-a-time case.
Additional Comments?		[LOAD Scenario]: Crew felt comfortable with the ability to perform operations safely without the forward facing rails. In this scenario, a section of the forward facing rail (the gate) was opened to allow for the pallet to be placed on the porch. A lot of problems are solved with more porch volume.

3.2.3.3 Acceptability Results: CPC Pallet Transfer via Davit – Raw Data (cont.)

- Day 4
- Luggage Rack: 1m
- Luggage Rack Misalign: II & III
- Step Stool as initial condition

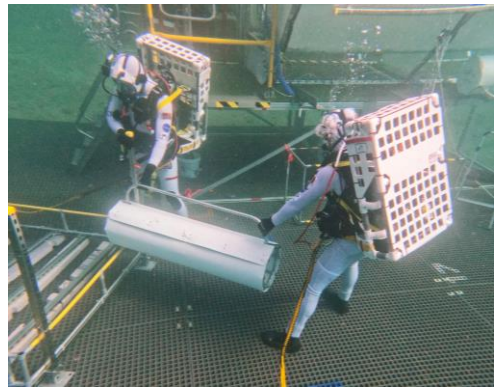
Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

Question	Rating	Comments
Using the davit for transfer operations to load [to MPH] an entire pallet packed with 3 CPCs (reach, attachments, stability of pallet, accessibility of containers, etc.)	7	[LOAD Scenario]: Task was acceptable assuming that a step stool (or similar aid) is available for the surface based crewmember, otherwise the task is impossible and unacceptable. Crew noted that the luggage rack was parked in "exactly the right place" and as such, all the previous comments pertaining to Davit improvements still apply (should be adjustable in length, boom height, boom angle, etc to allow for off-plumb line LTV locations). With a misaligned or off-axis LTV, crew would assess a score of 7 (as they did on day 1). In other words, the Davit only works (and is otherwise unacceptable) if and only if the pallet/LTV is positioned exactly below the Davit's plumb line. Crew commented that this operation was much easier due to the existence of a railing on only one side of the stair case. As per previous days' comments, having only one handrail on the staircase, with the other side open, is an enhancing feature and should be maintained. [OFFLOAD Scenario]: See above, loading - Crew assessed that all the operational comments/considerations from loading (above) applied equally to offloading.
The porch size for load transfer operations (deck volume, deck height, etc.)	5	Per day 1 comments, the porch is big enough to accommodate the pallet and CPCs with Davit, but it does not accommodate the range of motion required of the crew member to operate the davit. For example, crew had to duck under the boom in order to work the crank from the other side, while hanging off the forward rail. Again, ideally the davit would be located off the porch so as not to interfere with crew member ops.
Ease of unpacking CPCs from pallet	3	[LOAD Scenario]: Pallet had to be maneuvered so that it was close to an edge of the luggage rack. A "tailgate" on the luggage rack would enhance operations by preventing need to lift CPC over the railing. [OFFLOAD Scenario]: Pallet had to be maneuvered so that it was close to an edge of the luggage rack. A "tailgate" on the luggage rack would enhance operations by preventing need to lift CPC over the railing. CPC restraint straps should be integral to the pallet.
The number of crew for this transfer method	2	Acceptable with 2 crew.
ICR Access (ability to access buddy)	7	Per day 1 comments, Davit boom obstructs the ICR pathway/.access during loading and unloading operations (since, as tested, it is not adjustable in terms of boom height, angle, etc).
Overall acceptability of using this transfer method for loading from end-to-end (including risk to crew)	3	The concept has promise, but improvements to the davit are necessary so that it doesn't interfere with crew on the porch. Additionally, crew did not understand why they would (and would not nominally elect to) use such a complicated, heavy piece of equipment to move something so light (the CPCs), which could be easily lifted up the stairs individually, slid up the rail, hauled with a zipline, etc. Perhaps there is future utility for the davit - future requirements to lift heavy payloads to the porch? Dusting considerations (i.e., lifting an entire pallet, wrapped together in a dust covering, directly to the porch so as to avoid surface contamination)?

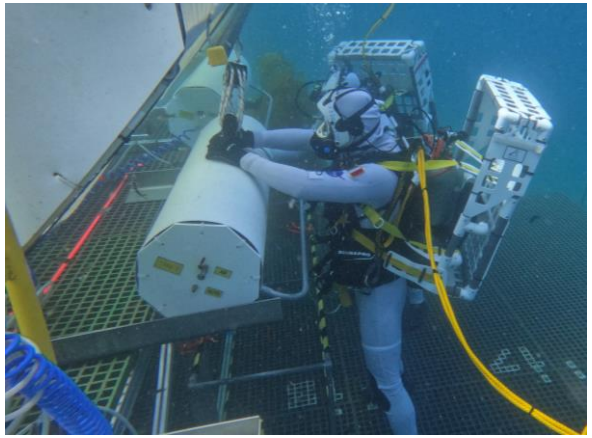
3.2.3.4 Results: Air Tank Transfer via Hoist – Key Takeaways

- Conceptually, hoist was preferred over davit for lifting tanks to high mount position
  - Higher anchor point is needed – current design was not tall enough for adequate clearance at highest point
- A temporary stow position desired when preparing to attach to hoist
- Lifting mechanism should lift directly upward to prevent swinging heavy payload
- Operational difficulties in lifting/installing tanks can also be addressed through tank design:
  - Multiple handling options accessible from different positions to maintain control (e.g., handholds on ends of tank in addition to horizontal handling bar)
  - Multiple lift point options to attach to the hoist
  - Given these design considerations, tanks controllable and maneuverable for 2 person carry

Placement of tanks on ground when connecting to hoist



Two-person carry for air tanks



High reach required to connect/disconnect tank to/from hoist on vehicle mount

Hoist is effective for lifting air tanks

3.2.3.4 Acceptability Results: Air Tank Transfer via Hoist – Raw Data

- Day 1
- Luggage Rack: 0m & 0.5m
- Luggage Rack Misalign: II
- Step stool NOT included as initial condition

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

Question	Rating	Comments
Ease of getting tank rigged for lift	4	[LOAD Scenario]: Place attach point on same side as carrying handle, desire temp stow location to set up rig to keep it out of dust [OFFLOAD Scenario]: A stool was required to access the hoist and tank anchor point to release the hook. The height was too high for the crew members to reach.
Controlling tank during lift (and avoiding contact w/ Keep Out Zone [KOZ])	3	Hoist mechanism at current height did not allow for adequate clearance to control the tank effectively at its highest point. Suggest a mechanism with a higher anchor point.
Shelf mechanism and securing options (for loading)	3	[LOAD Scenario]: See above comment. [OFFLOAD Scenario]: Aft shelf vertical lips did not allow crew member to lift the tank over the shelf due to limited arm mobility (can not move arms above shoulder). Crew member needed to use a stool to execute this action.
Fluid and electrical connections (placement and access)	3	[LOAD Scenario:] Access to tank was fine. Some kind of dummy port to keep fluid and electrical connections when not installed. [OFFLOAD Scenario: did not perform]
ICR Access (ability to access buddy)	2	
Overall acceptability using this lifting method for loading from end-to-end (including risk to crew)	3	*[Crew did not provide comment on Day 1]*
Additional Comments?		[LOAD Scenario]: Hoist release mechanism (flick rope upward) not feasible in spacesuit [OFFLOAD Scenario]: The 6-to-1 ratio worked well - the light weight would allow the crew member to grip the rope (and not squeeze) during hoisting operations.

3.2.3.4 Acceptability Results: Air Tank Transfer via Hoist – Raw Data

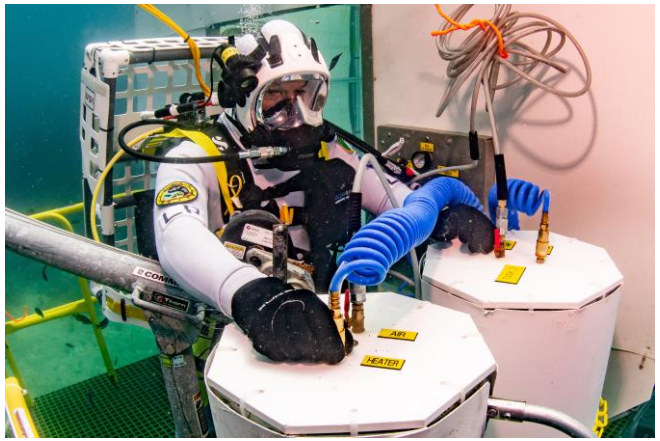
- Day 5
- Luggage Rack: 1m
- Step stool include in initial conditions
- Luggage Rack Misalign: N/A

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

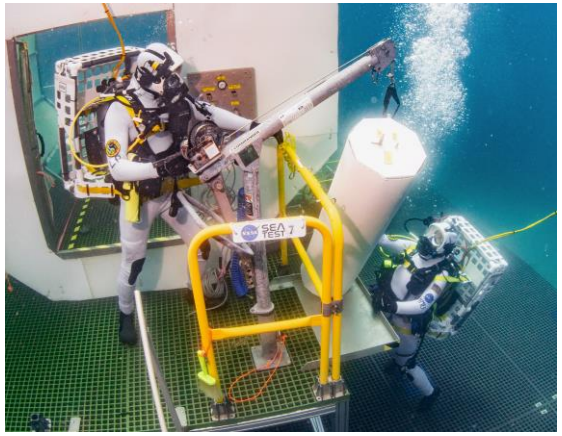
Question	Rating	Comments
Ease of getting tank rigged for lift	3	[LOAD Scenario]: Tether point is offset from handle bar. If it was closer to the tank's handle bar, this would be easier. [OFFLOAD Scenario]: Same comments as loading, above [for OFFLOAD Scenario]. Additionally, stool or crew lift aid required for rigging the hoist to the tanks when on the shelves.
Controlling tank during lift (and avoiding contact w/ Keep Out Zone [KOZ])	7	1.0 meter height of luggage rack is significant, and drives the requirement for a step stool. Tanks should have additional handling aids/straps in addition to the single bar (see previous days' comments). This is particularly true with a 1 m luggage rack.
Shelf mechanism and securing options (for loading)	3	Same as day 1's comments for this task. Higher hoist required.
Fluid and electrical connections (placement and access)	3	Same as day 1's comments for this task.
ICR Access (ability to access buddy)	2	
Overall acceptability using this lifting method for loading from end-to-end (including risk to crew)	3	Acceptable except for the challenge of lifting the tanks manually out of a 1 m height luggage rack. Some sort of crew assist should be incorporated here, be it more handling aids, integrated luggage rack steps, etc.

3.2.3.5 Results: Air Tank Transfer via Davit – Key Takeaways

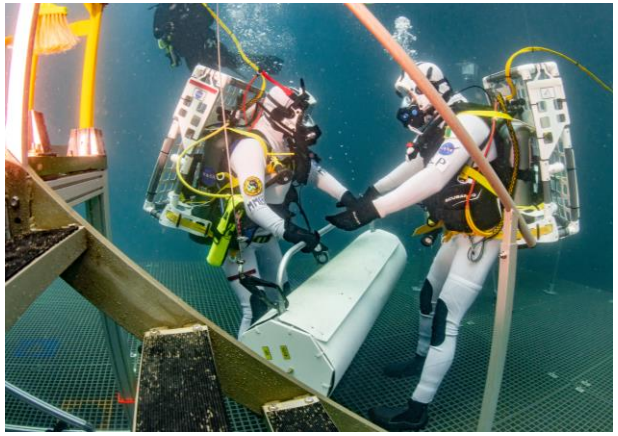
- Hoist system was preferred for lifting tanks
- Lift point on handling bar problematic:
  - Resulted in an angled lift - lifting mechanism should lift directly upward to prevent swinging heavy payload
  - Allowed undesired hook sliding along handling bar
- Reiteration of the importance of tank design: need additional hand holds on tank in addition to handling bar for better tank control during lift and loading/offloading from LTV
- Davit not high enough to allow tank to clear porch shelf
- Davit required too much porch space and significantly obstructed crewmember while securing tank, performing connections
- Difficulty reaching around tanks to secure on porch shelf (surface crew member contributed by using the step stool)
- Suggest a lower shelf position for tank storage



Davit obstructing tank connection procedure



Positioning air tank on porch mount with davit



Davit lift point on handling bar

A simple hoist would be sufficient for the lift, and the tank shelf should be lowered

3.2.3.5 Acceptability Results: Air Tank Transfer via Davit – Raw Data

- Day 1
- Luggage Rack: 0m & 0.5m
- Luggage Rack Misalign: I

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

Question	Rating	Comments
Ease of getting tank rigged for lift	2	
Controlling tank during lift (and avoiding contact w/ MPH)	3	Orientation of the tank needed to be controlled. Lifting the tank while starting in a vertical/upright location made it difficult to control the tank to avoid contact with the MPH. The lifting point on the handling bar/rail caused the tank to be lifted at an angle and required crew to control . Additional "straps" or handling mechanisms in addition to the handling bar would allow for better tank control during the lifting operation. Current davit design did not allow for the tank to be lifted high enough to clear the shelf.
Shelf mechanism and securing options [install]	7	Don't want the crew to reach around the tank while securing chains/straps or to feed through anything (in this case the handling bar). Crew members had to over extend in order to wrap the chain around the tank and to feed the chain through the handling bar. The tank orientation could have been changed to ease this operation (require less reach). Some ideas... soft capture with a pit-pin. If the tank has an MLI, perhaps an integral tether could be used to secure tank on shelf.
ICR Access (ability to access buddy)	2	
Overall acceptability using this lifting method for loading from end-to-end (including risk to crew)	3	*[Crew did not provide comment on Day 1]*

3.2.3.5 Acceptability Results: Air Tank Transfer via Davit – Raw Data

- Day 3
- W/ & W/O Ambulation
- Luggage Rack: 1m
- Luggage Rack Misalign: II & N/A (Ambulation)
- Step stool NOT included as initial condition

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

Question	Rating	Comments
Ease of accessing tank in luggage rack	5 9 (when LTV is significantly offset from davit plumb line)	[LOAD Scenario]: Accessing the tank (above the luggage rack with handrail, assuming the luggage rack itself was at 1.0 m) was not possible without the step stool (or some sort of equivalent crew elevation aid). The tank design requires some handling aid along the body and at the endcones, so that crewmembers can safely control motion.
Ease of getting tank rigged for lift [Loading to MPH]	6	Rigging the tank (above the luggage rack with handrail, assuming the luggage rack itself was at 1.0 m) was not possible without the step stool (or some sort of equivelant crew elevation aid). The tank had to be positively controlled. Although the rigging mechanism (to handrail) was very easy to connect, it introduces uncertainty because the hook can slide along the handrail. To prevent damage to the tank, it had to be controlled and guided by the surface based crewmember. The tank design requires some handling aid along the body and at the endcones, so that crewmembers can safely control motion. Alternatively, crew suggested using a single attachment point (metal loop) centered above the tank, such that it would always raise/lower vertically in the same geometry.
Controlling tank during lift (and avoiding contact w/ MPH)	6 – LOAD 7 – OFFLOAD	[LOAD Scenario]: Controlling the tank was possible, but difficult due to the lack of off-axis hand rails (there is one handrail, but aside from that there are few (none) places that the crew could use to import force or leverage to the tank. [OFFLOAD Scenario]: Due to the limitations of the davit (inability to lift high enough) the tank must be manually maneuvered to clear the shelf which may result in uncontrolled descent; the off-load case is worse than load.
Shelf mechanism and securing options [install]	7	The davit unacceptably obstructed the porch crew member while working with the tank and its securing mechanisms (chains, in the test). Although the point has been made numerous times in previous comments, the Davit, if it has to exist, really does need to be positioned off the porch (lunar surface, on a swing arm, etc). Additionally, crew commented numerous times that this task would be much more efficient and safer if the tanks did not have to be positioned that high above the surface - i.e., why is the tank shelf so high? Why can the tanks not rest on a lower shelf, or even on the lunar surface? As tested, the davit being in the way prevented the porch based crewmember from being able to reliably work with the chain restraint for the forward tank (because of reach). Crew had to use step stool and access the chain from the lunar surface (or, one crewmember chose to climb on the outside of the railing to reach the chain).
Fluid and electrical connections (connector access)	10	The height of the connections above the porch floor meant that crew would require (again) a step stool or some sort of elevation aid. Even with elevating the crewmember, only the aft tank connections could be reasonably accessed by the crew. The Davit prevents access to the forward tank connections, even with elevation, after you account for the general restrictions and body forward volume (DCM on the EMU) of a spacesuit.
ICR Access (ability to access buddy)	2	No significant issues.
Overall acceptability using this lifting method for loading from end-to-end (including risk to crew)	6	Given the height of the LTV and its railings, a raising mechanism/step is required. Crew considered this to be a "warranted" (and easy to achieve improvement. The more significant issue, leading to the overall score of 6, was the location of the davit and its interference with most aspects of the tank lifting and install operation

3.2.3.6 Results: Surface Habitat Airlock Cargo Transfer – Key Takeaways

- Successful Airlock Operations would encompass loading of required number of CPCs, placed to enable
  - Ingress of both EVs
  - Closure of outer A/L hatch
  - Access to suit don/doff stands for both EVs
- Fully acceptable for 4 CPC case (~10 CTBE)
- 9 CPC (~19 CTBE) case achieved successfully but with low confidence
- Insufficient room for ICR access with 9 CPCs in the A/L
- **Crew Recommendation:** More study required to understand whether this size (2.1m) is adequate for the task or not. Fidelity and design maturity not sufficient to fully understand primary unknowns
  - Limitations and space requirements of a pressurized suit
  - Airlock floorplan
  - Airlock volume constraints

Airlock configuration with 4 CPCs with clear access to suit donning stands on port side

Airlock configuration with 9 CPCs with clear access to suit donning stands on port side

Airlock size assessment should continue as design and requirements mature

3.2.3.6 Acceptability Results: Surface Habitat Airlock Cargo Transfer – Raw Data

- Day 2
- Luggage Rack: N/A
- Luggage Rack Misalign: N/A
- **5 CPCs (four 2.0 and one 1.0) pre-staged,**
- **4 CPCs transferred in during the scenario**

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

Question	Rating	Comments
Sufficient volume for reconfiguring and stacking all containers (4 transferred + 5 pre-staged CPCs)	9	For the context of suited crewmembers, combined with 9 CPCs, the accessible volume available made it highly unlikely (/impossible?) for 2 crewmembers to maneuver to the doffing position while preserving enough space behind their PLS (MPH starboard) to open the suits and egress.
Sufficient volume to operate the hatch and access suit don/doff stands	9	Same comments as above.
Sufficient space to position buddy to perform an ICR if required	9	There is not sufficient room in the airlock to drag in and reconfigure a completely incapacitated crewmember with this amount of cargo. (Obviously, cargo could be jettisoned as the first workaround).
Overall acceptability of loading CPCs into airlock from end-to-end (including risk to crew)	9	See lines 1 through 3, above.
Additional Comments?		The current A/L dimensions allow enough volume for 2 CM for donning and doffing operations, plus a relatively small number of crewlock-type bags for mission support tools.

3.2.3.6 Acceptability Results: Surface Habitat Airlock Cargo Transfer – Raw Data

- Day 4
- Luggage Rack: N/A
- Luggage Rack Misalign: N/A
- **Ingress with 4 CPCs**

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

Question	Rating	Comments
Sufficient volume for reconfiguring and stacking CPCs	2	Acceptable for the case of 4 CPCs. Of note, crew assumed that space port of the crewmembers when in the don/doff position was not available (assuming this space would be taken up by UIAs, don/doff structure, etc.). Various configurations of the 4 CPCs were used while still preserving space for the crewmembers to position themselves in the don/doff locations following hatch closure. (One crew demonstrated acceptable airlock Ops with 4 CPCs + 2 CPCs pre-staged in the airlock).
Sufficient volume to operate the hatch and access suit don/doff stands	2	Acceptable. A floor marking to display the arc of motion taken by the hatch during opening and closing ops would enhance crew awareness during airlock ops (so that they don't have to guess how close CPCs can be placed).
Sufficient space to position buddy to perform an ICR if required	-	*N/A – crew did not evaluate ICR*
Overall acceptability of loading CPCs into airlock from end-to-end (including risk to crew)	2	(for 4 CPCs)
Additional Comments?		For future evaluation, it's indispensable that the A/L volume and outfit be more closely represented.

3.2.3.6 Acceptability Results: Surface Habitat Airlock Cargo Transfer – Raw Data

- Day 5
- Luggage Rack: N/A
- Luggage Rack Misalign: N/A
- **Ingress with Transfer of 4 CPCs, with additional CPC volumetric evaluation**

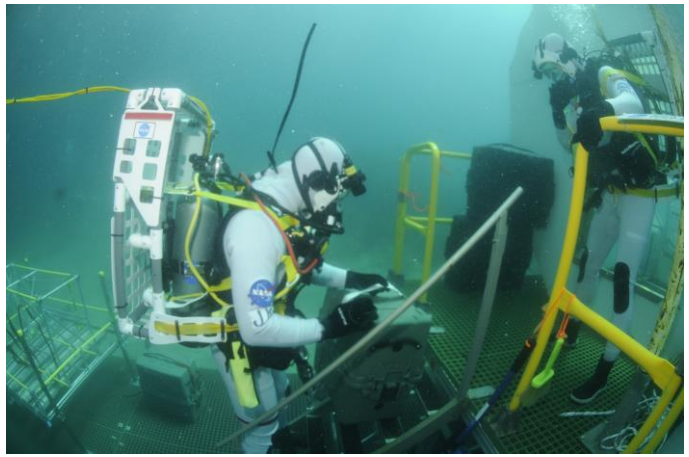
Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

Question	Rating	Comments
Sufficient volume for reconfiguring and stacking containers	3	Crew re-attempted airlock entry/exit ops with 4 CPCs (2 large, 2 small) and 5 additional CPCs, after talking to designers about the envisioned useable volume. By stacking containers partly up the starboard wall, airlock don/doff tasks could be acceptably performed. This task was assessed as unacceptable on Day 1 for 9 containers (but acceptable for 4 CPCs), but during that testing crew was assuming that the only useable space in the airlock was above the rectangular, flat floor - in other words, that there would be racks/systems consuming all the space out to the outer mold line. It should be emphasized that this evaluation really required a higher fidelity airlock that is accurate in terms of useable volume, as well as accurate space suits with accurate don/doff stations. Markings on the floor to outline space that must be left clear for PLS fold-down ops would, in all cases, assist the crew.
Sufficient volume to operate the hatch and access suit don/doff stands	3	Acceptable for the case of 4 CPCs. Above comments (line 1) apply.
Sufficient space to position buddy to perform an ICR if required	-	*N/A – crew did not evaluate ICR*
Overall acceptability of loading CPCs into airlock from end-to-end (including risk to crew)	3	Acceptable, with the above comments.

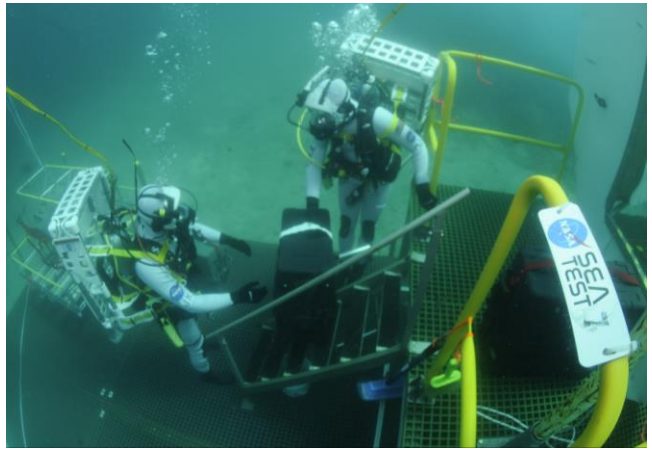
3.2.3.7 Results: Alternative Transfer Methods – Key Takeaways

- Manual transfer of 4 CPCs without mechanical assistance:
  - Crew preferred manual transfer of CPCs over zipline or davit
  - Carried CPCs up/down stairs*, only possible due to stairs with single-sided rail
  - Utilized non-mechanical aids (sliding CPC up/down stair edge, temporary stow on stair or step stool to transfer between surface crewmember and porch crewmember)
- Feedback may be affected by known sim limitations (suit mobility, difficulty in climbing/descending stairs for each CPC, drag, support of water column) – Seeing footage of a suited carry of a CPC for a representative distance would help crew understand carrying capability of suited person

Manual carry of CPC up stairs



CPC temporary stow on stairs for handoff between EV1 and EV2



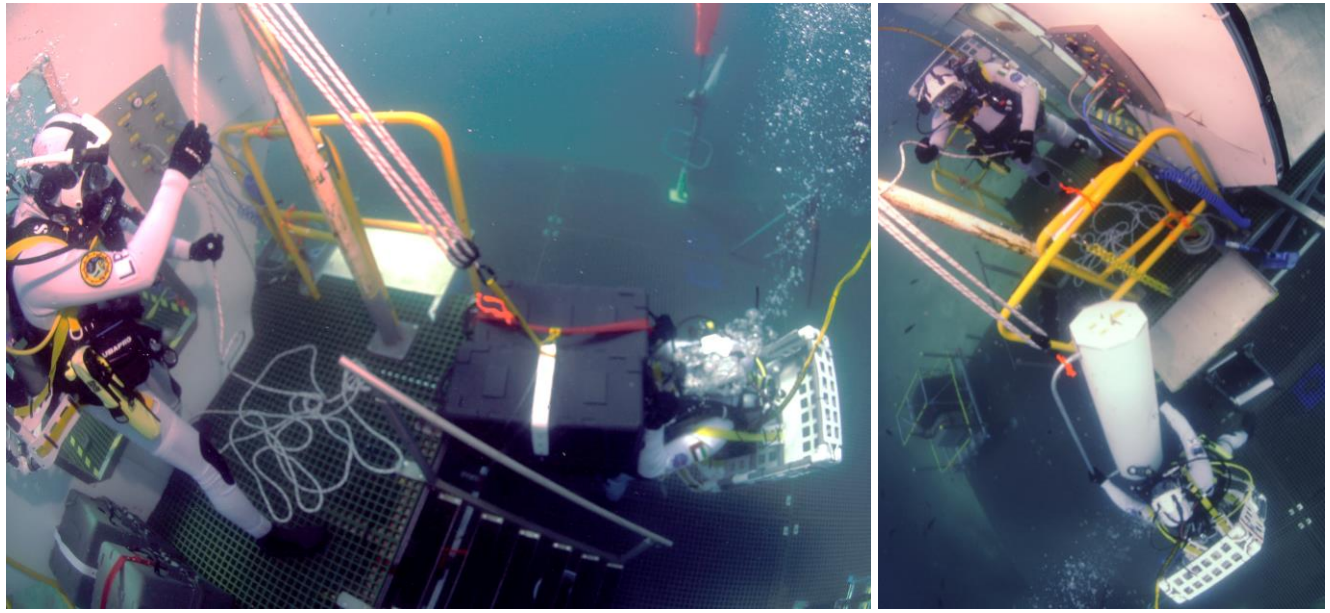
Use of step stool to transfer CPC from stair position to porch.

* Note that this did violate assumption #5, that only a single trip up the stairs would be assumed for an entire loading operation

It should be possible to lift a small number of CPCs manually or with only very simple aids

3.2.3.7 Results: Alternative Transfer Methods – Key Takeaways

- Transfer of CPCs/Tanks using simple pulley system:
  - Simplicity of pulley system superior to davit for lifting (lighter, smaller, leaves porch open, no cranking)
  - Configurability design improvements required for such a system (to be tested): anchor point mounted off habitat, extendable boom, rotatable. These features would also address mis-alignment challenges
  - For CPCs, still prefer manual transfer over simple pulley, but for larger payloads simple pulley system would be preferred



Use of simply pulley (hoist) to lift 2 CPCs (left) and air tank to porch mount (right)

- **Crew Recommendation:** continue to explore a simple swivel boom with adjustable reach that can be easily placed directly over a lift point, and uses a simple system like a hoist to perform the lift

- **Team Recommendation:** Investigate hoist mount above the A/L hatch to lift CPCs. EV2 would stand inside the A/L, EV1 would lift, dust, and guide the CPC as it rises. EV2 would unhook and lower the CPC to the A/L floor and repeat.

A simple Hoist is effective and versatile for a wide range of lifting tasks

3.2.3.7 Acceptability Results: Alternative Transfer Methods – Raw Data

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

Crew choice Alternative CPC Transfer

- Luggage Rack: 0.5m
- Luggage Rack Misalign: N/A

Question	Rating	Comments
Overall acceptability of manually transferring CPCs from 0.5m LR to porch without mechanical assistance (note if different for offload)	1 – Offload	Crew found manual transfer of CPCs to be the easiest transfer method, and simpler/more efficient than using the zip line or davit. Methods demonstrated included carrying the CPCs, sliding them up the staircase side (side without the handrail), and using the step stool to hand CPCs up to a porch-based crew member. Score of 1 for manual offloading (Offloading was easier due gravity assist with sliding CPCs down the staircase).
	2 – Load	
Overall acceptability of manually transferring CPCs from 0.5m LR to porch with simple pulley system (note if different for offload)	4	Method has promise, so long as the pulley is appropriately positioned (otherwise, you risk bumping the CPCs against MPH equipment as they are raised and lowered). Crew suggested that this method be further explored and developed, as it might be a simpler and more flexible solution for all the other applications that are currently done by the Davit and/or zipline.
ICR Access (ability to access buddy)	2	With manual or pulley transfer of CPCs, porch area and access to other crewmember remain fully clear.

3.2.3.7 Acceptability Results: Alternative Transfer Methods – Raw Data (cont.)

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

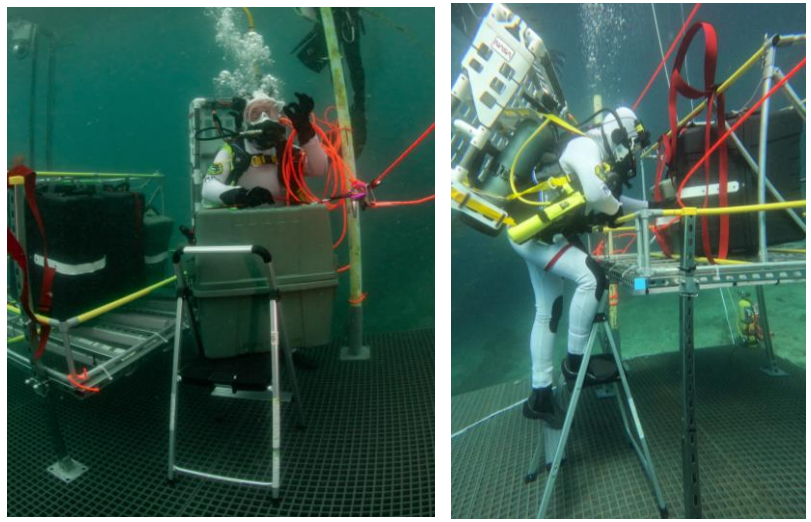
Crew choice Alternative Air Tank Hoist

- Luggage Rack: 0.5m
- Luggage Rack Misalign: N/A

Question	Rating	Comments
Overall acceptability using this lifting method for loading from end-to-end (including risk to crew) (note if different for offload)	2	Assessed as significantly more effective and efficient than using the Davit for this same task.
ICR Access (ability to access buddy)	2	

3.2.3.8 Results: Step Stool – Key Takeaways

- Step stool added crucial capability for numerous operations
  - Required to accomplish loading/offloading cargo from Luggage Rack @ 1m height
  - Used as an aid for temporary stowage for CPC dusting, CPC/tank attachment to lifting mechanisms, air tank electrical/air connections
  - Used as an aid for a couple of variations of manual CPC lift options
- Portability enabled versatile use in many scenarios
- Design changes needed:
  - Stability: both when freely placing on lunar surface, as well as including hardware interfacing with vehicles in strategic locations with high step stool traffic to leverage stability of larger structures
  - Convenient stowage location



Step Stool use when Luggage Rack @ 1m. While attaching CPC to zipline (left) and to remove CPC from pallet (right)

Use of step stool to unload CPCs from 1m LR (required 2 crew members)

Use of step stool to manually transfer CPC from stair position to porch.

Use of step stool for tank hoist connection/disconnection at vehicle mount.

A lightweight portable stepstool aids/enables numerous operations

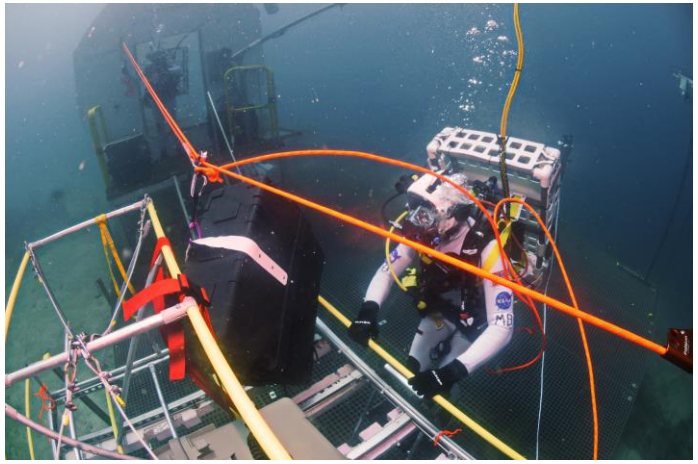
3.2.3.8 Acceptability Results: Step Stool – Raw Data

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

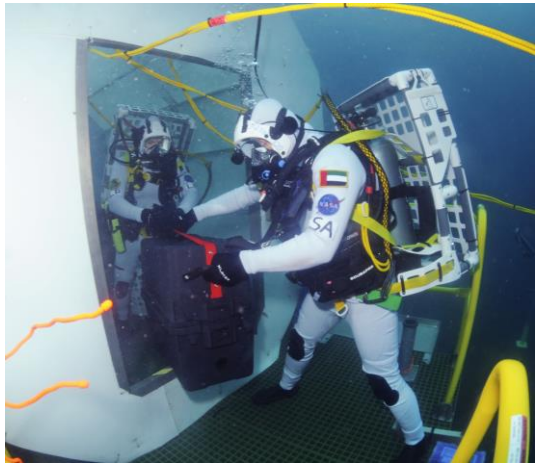
Question	Rating	Comments
Overall acceptability of the step stool	2	2 for an ideally designed, stable stool (8 for the stool that was provided in the scenario). As an idea the step stool is acceptable and essential. The stool used, however, was not acceptable because it was unstable and subject to tipping over.
Portability of step stool	2	Portability was acceptable and required to facilitate flexible applications. Assuming interoperable interfaces on different systems (e.g.: MPH, LTV) the stool should be designed so that it can be attached to the structure itself in strategic locations, as to improve its stability. It should also be capable of being a stable surface for a suited subject while on the lunar soil.

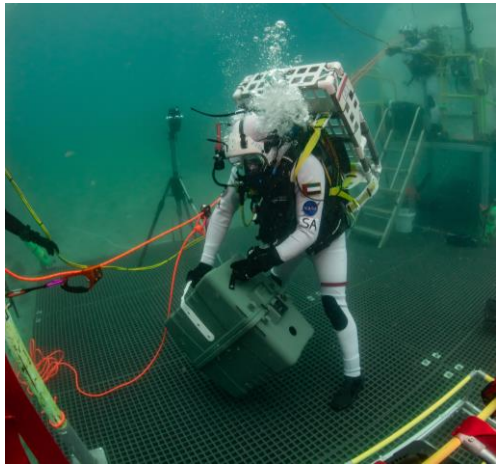
3.2.3.9 Results: CPCs – Key Takeaways

- The smaller CPC size (2.4 CTBE) is preferred over the larger size (2.8 CTBE) for EVA handling
- Usability feedback:
  - Additional handholds on sides of CPC are essential
  - CPCs should fit together cleanly, both stacking vertically and aligning horizontally
  - Long axis strap preferred over short axis for ambulating with CPC to prevent wrist rotation
  - No difference noted between side vs lengthwise strap for manual handling (given that there were side handles in both cases)
  - Flexible/fabric straps preferred to rigid strap
  - If lifting by hook, a lift point should be available that keeps the CPC centered (rather than sliding down a strap and hanging awkwardly)
- **Crew recommendation:** Pursue hi-fi testing with CTBs in a pressurized suit

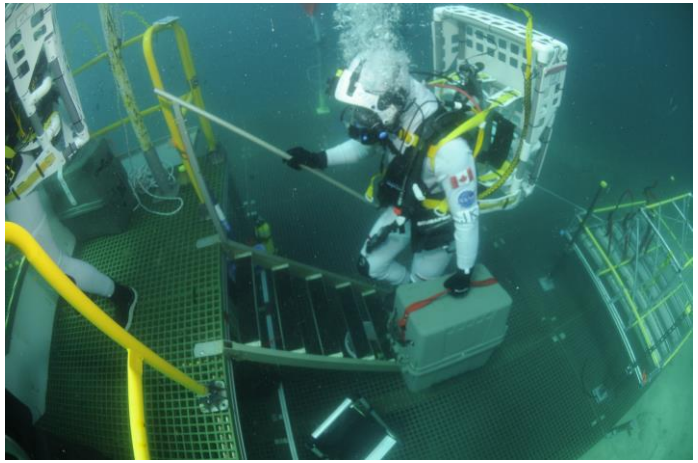


Lift point unbalanced on CPC





Use of top and side handles of CPC



Long axis strap use during ambulation

The smaller CPC size is preferred for EVA handling

3.2.3.9 Acceptability Results: CPCs – Raw Data

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

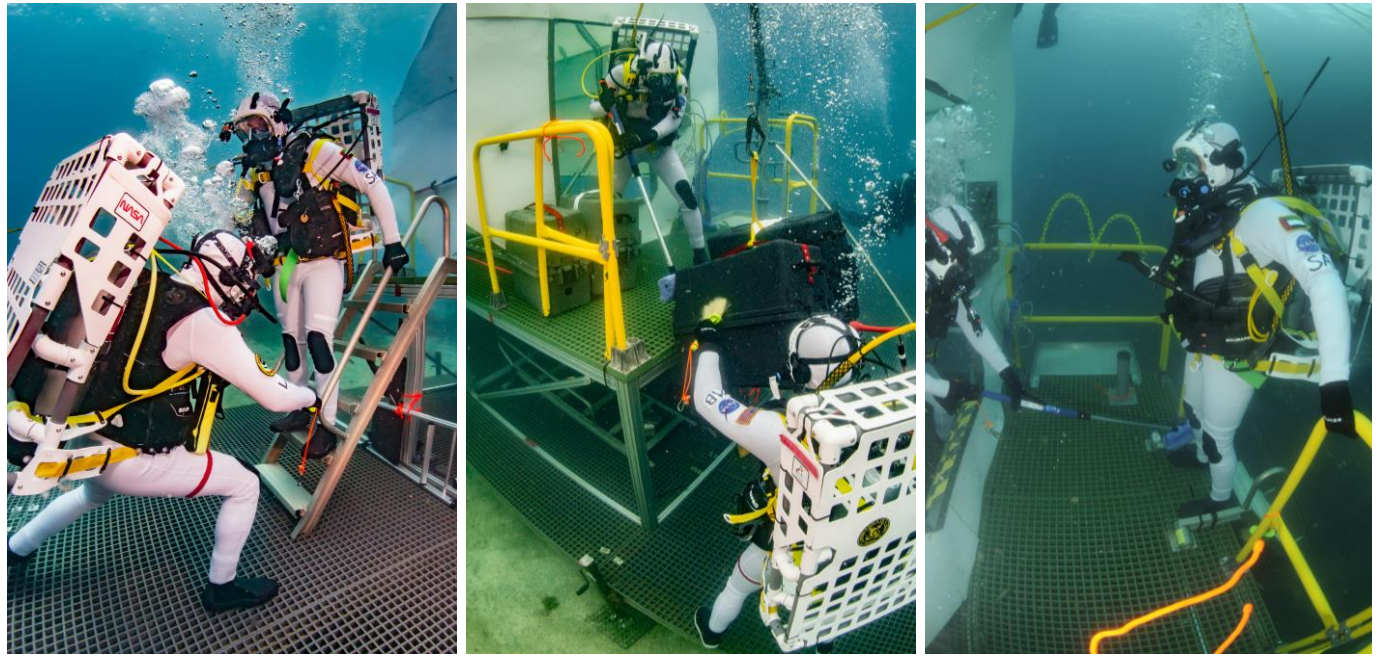
Question	Rating	Comments
Ease of unloading/loading CPCs to/from Luggage Rack	4	Ease of loading/unloading depends on height of luggage rack and placement/number of handholds.
The conceptual small CPC container when handling by yourself or passing to buddy (handholds, size, shape, weight, etc.)	7	Additional handholds on the sides were essential for carrying and maneuvering, but not part of current design. Top straps are useful for pulling from pallet and carrying at side. This (smaller) size preferred by smaller crewmember.
The conceptual large CPC container when handling by yourself or passing to buddy (handholds, size, shape, weight, etc.)	7	Additional handholds on the sides were essential for carrying and maneuvering, but not part of current design. Top straps are useful for pulling from pallet and carrying at side.
CPC connection to hoist mechanism	3	Minor improvements desired to make the 2 CPCs symmetrical, together, without risk of the strap shifting during raising, lowering.
Ease of unloading/loading CPCs to/from Pallet	3	External curves & edges get caught on structure.
Additional Comments?		Stackable CPCs are desired; stackable on all sides

3.2.3.10 Results: Dusting Operations – Key Takeaways

- Without knowledge of dust behavior and anticipated dusting technology limits, we are unable to determine the efficacy of dust removal (or time required). However, dusting operations were simulated for all scenarios to ensure that the potential overhead was factored into each scenario

- Performed dusting motion with brush and broom on EV1/2 and on CPCs prior to airlock ingress

- Demonstrated reach of "dusty" surfaces and extrapolation for logical dusting locations and operational feasibility associated with different transfer solutions
  - Preference for solutions that allowed CPC to be suspended while on surface, to minimize dusting requirements on small porch
  - Telescoping broom improved reach for dust mitigation procedures when dusting crew



Left: crew dusting on stairs. Center: crew dusting CPC while suspended from zipline. Right: crew dusting on porch.

Dusting operations can significantly impact transfer method efficacy

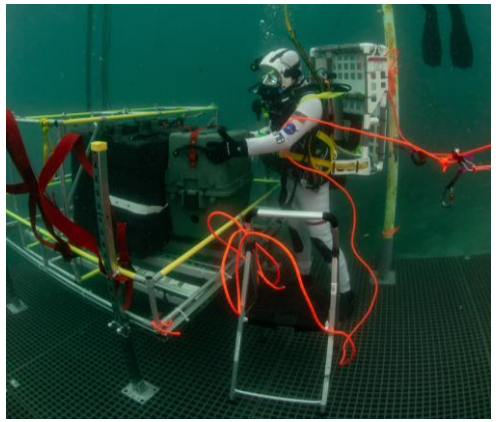
3.2.3.10 Acceptability Results: Dusting Operations – Raw Data

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

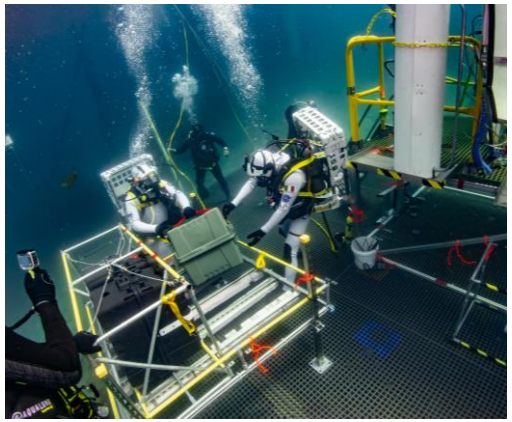
Question	Rating	Comments
Conceptual dust mitigation procedures (dusting through the hatch?)	7	Dusting through the hatch seemed like a bad idea, because doing so would run a high(er) risk of dispersing regolith into the airlock. There are additional risks, such as damaging the hatch seal with the dusting device.
Conceptual dust mitigation procedures (dusting each other while on steps)	3	Fully adjustable (telescopic broom) enhanced this operation.
Conceptual dust mitigation procedures (dusting while both on porch)	3	More porch space would enhance., Even as is, this was an acceptable operation.
Conceptual dust mitigation procedures (dusting suspended CPCs)	2	Easy to dust suspended CPCs (due to the ability to swivel them, while controlling where the dust would fall).,
Overall acceptability of dusting everything prior to A/L ingress (including risk to crew)	3	Overall acceptable, however it seems that dust will, inevitably, end up accumulating in the airlock, and as such some sort of airlock dust evacuation system will be required. Dust covers, for the airlock itself but also for individual items (CPCs) should be considered.
Is manual dusting sufficient? (manual dusting of CPCs, other crew)		We could touch all surfaces that needed to be dusted (CPCs, crewmembers). The amount of time it took to touch these surfaces is hard to estimate. However, if you touch a surface does that mean all of the dust is gone? This simulation allowed us to go through the motion of manual dusting, but we don't know if that motion removes dust effectively. In any case, the airlock will get dusty. Countermeasures like positive pressure can help prevent the dust from coming inside the habitat.
Additional Comments?		These scores assume that a brushing system will be developed that effectively captures/removes lunar dust without generating a dust cloud.

3.2.3.11 Results: Luggage Rack – Key Takeaways

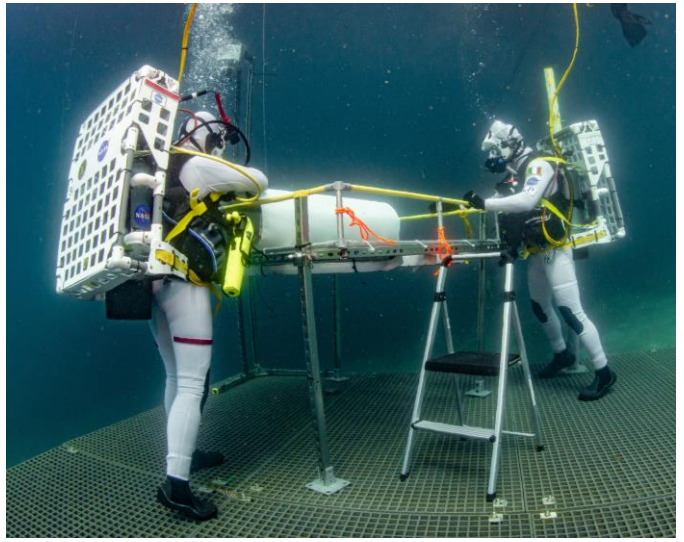
- Height
  - 1m height is too high for loading/offloading cargo without the use of a step stool
  - 0m and 0.5m heights are about equally difficult to access
  - A “tailgate” that opens could allow cargo to be more easily slid from the LR and should be considered especially for higher LRs
- Mis-alignment
  - All operations, especially lateral control, are more difficult at a 1m height than at the lower heights
  - Lifting in mis-aligned case was unacceptable for all LR heights (due to lateral motion control of payload) without better handling aids
  - As parking directly under a lift point is considered operationally infeasible, two options remain:
    1. Ability to adjust the position of the lifting device (such that plumb line is directly over payload)
    2. Ability to easily remove cargo by hand and carry directly under the lift point
- **Crew recommendation:** Continue to explore both options 1 and 2 above



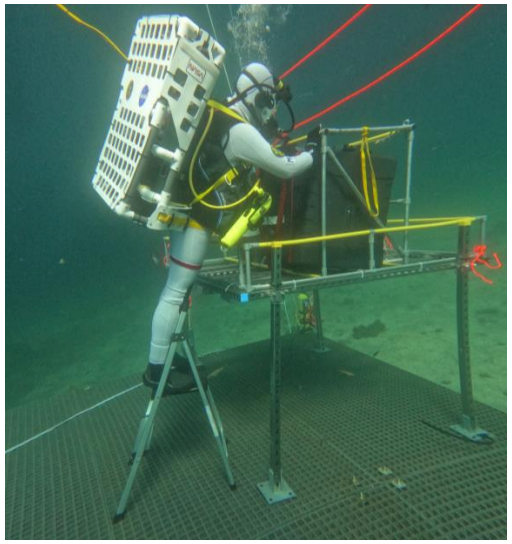
Accessing CPCs with LTV at 0.5m



Accessing CPCs with LTV at 0m



Tank out of expected suit reach on 1m LTV



Step stool required for accessing LTV at 1m

Luggage rack height and alignment with lift point significantly impact operational complexity

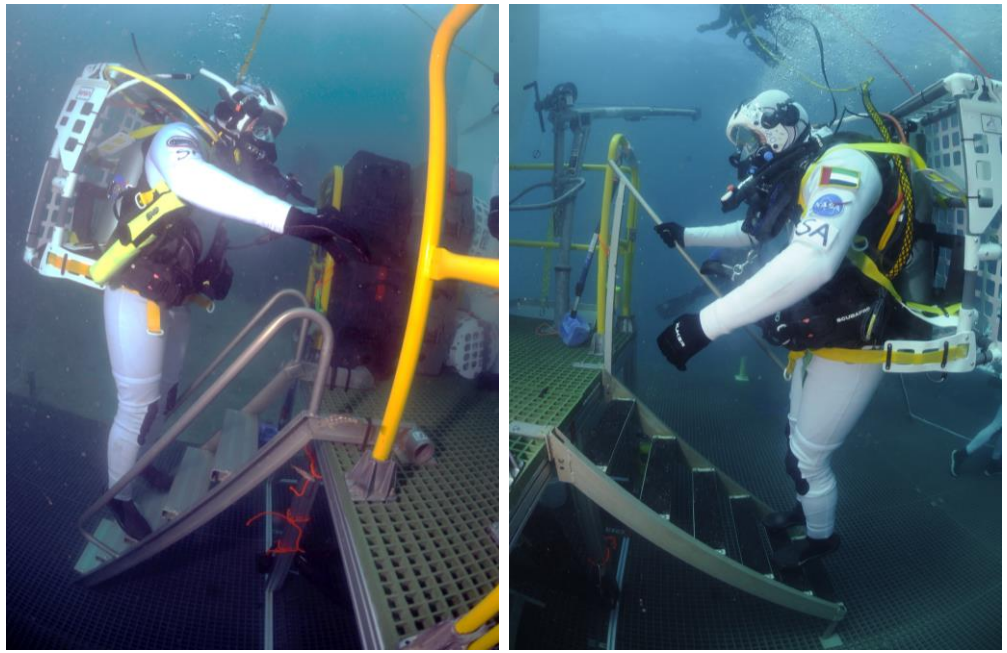
3.2.3.11 Acceptability Results: Luggage Rack – Raw Data

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

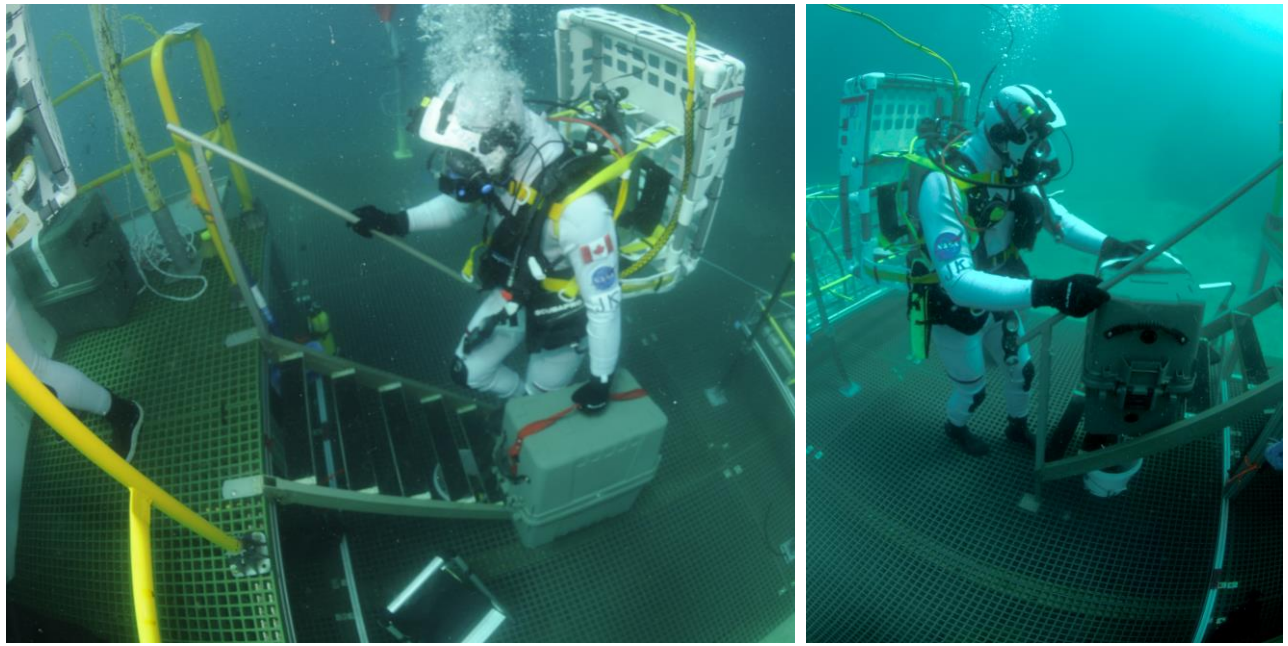
Question		Rating	Comments
Ease of cargo access	0m	2	
	0.5m	2	
	1m	3	Improvement desired, such as a tail gate, integral step stool, etc.
Ease of pallet lift point access	0m	2	
	0.5m	2	
	1m	6	The top of the pallet is too high to reach by a suited crewmember when mounted on a 1.0 m high luggage rack.
Payload control in mis-aligned case (lift point not centered)	0m	4	As mentioned in previous tests, lift devices that are adjustable are required, such that the plumb line of the cable can always be positioned generally right above the item being lifted, in order to minimize crewmember input. Additional handling aids on the items (specifically when considering the air tanks) would help.
	0.5m	4	
	1m	6	All operations, but especially lateral control, are more difficult off of the 1.0 me high luggage rack as opposed to lower starting points.
System tolerance to mis-alignment	0m	4	Same comments as above.
	0.5m	4	Same comments as above.
	1m	6	Same comments as above.

3.2.3.12 Results: Climbing Aids – Key Takeaways

- Stairs preferred over ladder:
  - Smaller spacing between steps
  - Lower pitch angle
  - Handrail on one side only (allows possibility to hand carry a CPC)
  - Ability to slide CPC up stair edge (though widening edge would improve this feature) or temporarily stow on stairs to hand up to porch crewmember



Crew ascending to porch using ladder (left) and stairs (right)



Use of stairs to hand carry CPC (left) and for temporary storing CPC to hand up to porch crewmember (right)

Stair design with handrail on one side (only) was preferred to the ladder

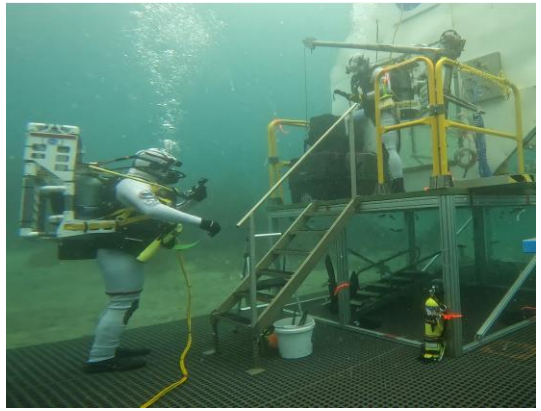
3.2.3.12 Acceptability Results: Climbing Aids – Raw Data

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

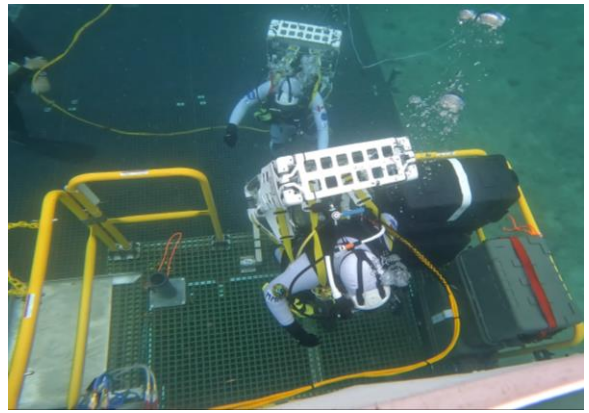
Question		Rating	Comments
Step placement (pitch, spacing)	Ladder	2	Stairs had less spacing between steps, and a lower pitch angle. Stairs also only had one hand rail, compared with 2 on the ladder. All these features made the stairs more useable for carrying cargo.
	Stairs	1	
Width of steps (possibility of 2 crewmembers side by side?)	Ladder	2	No possibility of 2 crewmembers side by side
	Stairs	1	2 crew were able to work beside each other (one on the stairs, on e on the surface or step stool).
Usefulness and placement of handrails	Ladder	2	Ladder felt narrower and more constrained than the stairs, perhaps because it incorporated handrails on each side, as opposed to the stairs which just used one handrail.
	Stairs	1	
Need for other restraints	Ladder	2	Crew did not think additional restraints were necessary.
	Stairs	1	Crew did not think additional restraints were necessary.
Overall acceptability of using this climbing aid from end-to-end (including risk to crew)	Ladder	2	Both methods worked, and facilitated an easy method of crew locomotion up and down (hopping).
	Stairs	1	Making the stair surface a grate (as was done) was assessed as good for traction, balance and dust.
Additional Comments?			It'd be worth investigating a ladder with just one handrail (on the right side) because one major advantage of the stairs was that we could remove the left handrail.

3.2.3.13 Results: Porch – Key Takeaways

- Porch size (~1.2m x 2.4m) was adequate for task (elevating 4 CPCs, dusting, A/L ingress)
  - With or without footprint of davit (which effectively took 0.6m of width out of play)
  - However, space limited for dusting both crew on porch and would nominally avoid
  - Can continue looking at shape and width, but 1.2m depth is a minimum for operations exercised, which did NOT include a method for bringing a CPC directly into the airlock
- Able to configure two stacks of CPCs (2 high), could also fit 1 CPC under davit
- Porch railings (or some equivalent restraint/handhold/net) necessary to contain CPCs as they accumulate on the porch during zipline operations
- Forward rails are not required for fall protection and functionality should prioritize hand-hold aids, rather than mitigating risk of fall
- **Crew Recommendation:** Explore the option of removing forward rails or making them removable to create more functional space



Porch with 4 CPCs and davit in place



Porch with 4 CPCs and no davit

Porch with 9 CPCs (~19 CTBE) and 1 crewmember without davit

Porch depth of 1.2m is a minimum for operations evaluated

3.2.3.13 Acceptability Results: Porch – Raw Data

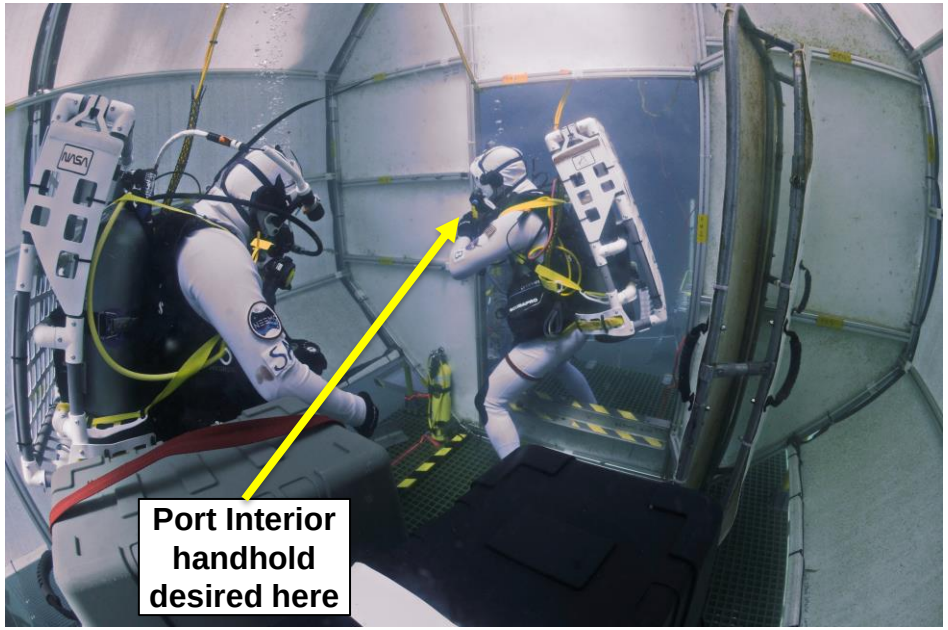
Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

Question	Rating	Comments
Suitability of size with davit installed (considering loose CPCs, pallet, transfer mechanism operation, ICR)	4	Porch suitability more acceptable without the davit installed.
Suitability of size without davit installed (considering loose CPCs, pallet, transfer mechanism operation, ICR)	2	
Suitability of size with hoist installed (considering loose CPCs, pallet, transfer mechanism operation, ICR)	3	The functional porch space available is reduced if there is a hoist hanging from the space above, even if minimally.
Conceptual dust mitigation procedures (dusting through the hatch?)	2	Porch size is acceptable for dusting operation, with all the above comments applying (dual dusting of both crewmembers, together, on the porch is difficult and likely would not be chosen as a nominal method)
Stability and risk of falling	2	Acceptable. The perception is that risk of falling is relatively low, and recommend exploring the option of removing the fwd rails or make them removable. Crew felt that additional mitigations against falling (such as tethers, additional railings, flight rules, etc) would be overly constraining and complicating, to the point of inducing more risk than they would mitigate.

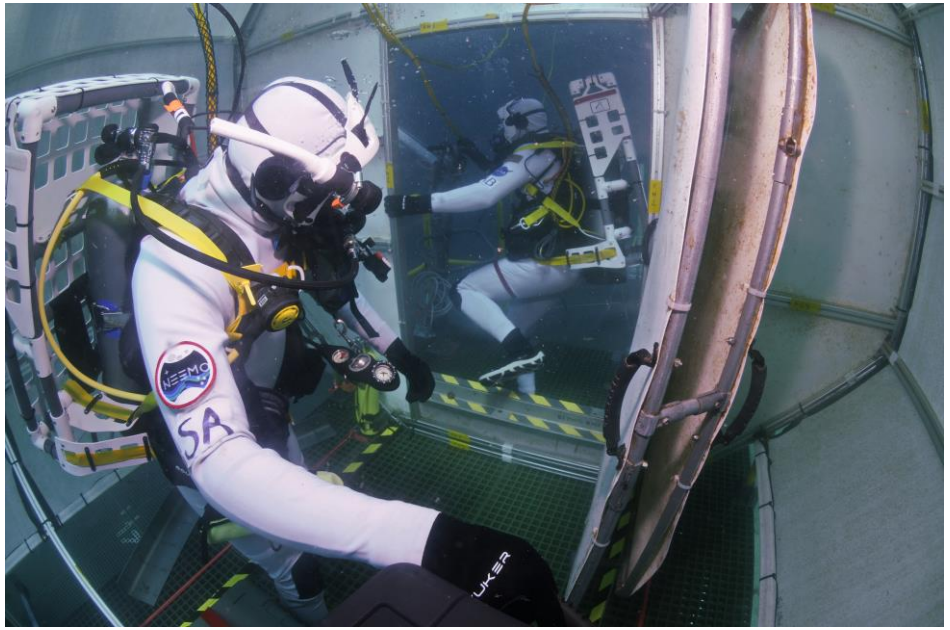
3.2.3.14 Results: Transfer Through Hatch – Key Takeaways

- Essential to include long vertical stability handhold aids for ingress/egress
  - Port and starboard side exterior
  - Port side (non hinged side) interior

- Stepover: high but manageable*
  - *Note that the threshold height was 41cm for this test; the standard is converging to 30.5cm since it was designed



Use of hatch as hand hold for egress



Stepover height for egress

EVA handholds required to aid ingress/egress

3.2.3.14 Acceptability Results: Transfer Through Hatch – Raw Data

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No Improvements Necessary		Minor Improvements Desired		Improvements Warranted		Improvements Required		Major Improvements Required	
1	2	3	4	5	6	7	8	9	10

Question	Rating	Comments
Overall acceptability of using this transfer method from end-to-end (including risk to crew) [Stepping thru the hatch (overall height, step-over height, step-over depth, opening dimensions (width, height)). Please comment on handholds (where should they be, how valuable would they be, what type)]	7	Additional handrails to assist ingress/egress are essential, even for the lateral ingress technique. Ideally, handholds would be port and stbd side of the hatch, half way between the bottom and top, with identical handrails on the EV and IV sides (except for the stbd IV side, where a hand rail wouldn't be practical because it would be behind the hinge's path of travel. Step-over height is high but manageable.

3.3 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:**
  - "High risk, high consequence environment" demanding:
    - Critical and challenging training
    - Good buddymanship
    - High individual and team performance
    - Operational risk management
  - Leadership/followership opportunities
  - Detailed procedures
  - Opportunity to learn from each other's experience
- **Crew comments included:**
  - *"This is a good environment for operational risk management. The complexity of tasks and equipment contribute."* – M. Behnken
  - *"This puts us in a high risk, high consequence environment…"* – J. Kutryk
  - *"What we're doing here is incredibly valuable. Not just for learning how we could do operations on the Moon one day, but also in quickly eliminating the ways we should NOT continue pursuing."* – L. Parmitano

Continuing discussions into the evening

Crew Dive Training

"When you have real-time operations that require a highly functioning team, risk management, and good decision making, you have the makings of good Expeditionary Training." – J. "Vegas" Kelly

3.4 Additional Objective: Educational Outreach

- **Megan McArthur Behnken gave a virtual and in-person educational outreach event with:**
  - Girls in STEM students at Space Center Houston (SCH)
  - Students from the University of Southern California (USC)
  - Students from California State University Northridge (CSUN)

Flyer for the event

Megan speaking to students in-person and virtually

Thank You!

A huge thank you to the SEATEST 7 stakeholders and test team!

SEATEST 7 Crew (pictured from left to right): Josh Kutryk/CSA, Sultan Alneyadi/UAE, Luca Parmitano/ESA, Megan McArthur Behnken/NASA, and Marcos Berrios/NASA

Marcos Berrios/NASA & Luca Parmitano/ESA by Surface Habitat Mockup

4.0 Appendices

Appendix A:

SEATEST 7
Safety and Management Reviews

SEATEST 7 Safety and Management Milestones

✓	February 26	Brief to full SAO Management and leadership Team (approval to proceed)
✓	May 14	NEEMO/SEATEST DSB Approval
✓	June 24	USC Dive Safety Board Approval
✓	July 8	Crew assignments
✓	July 9	Mockup TRR Approval
✓	July 9	IRB “Not Human Subjects Research” Determination
✓	July 24	JSC DSB Approval
✓	July 25	Integrated TRR
✓	August 5, 6, 19	Crew qual training
✓	August 14	Exploration Forum
✓	August 24-25	Engineering Week (new Topside diver quals)
✓	September 16	Mission Week (Crew and new Topside diver quals)

Appendix B
Acronyms

Acronyms

A/L	–	Airlock
ACR	–	Architecture Concept Review
ADD	–	Architecture Definition Document
APFR	–	Articulating Portable Foot Restraint
CapCom	–	Capsule Communicator (communicates with crew)
CAVES	–	Cooperative Adventure for Valuing and Exercising
CG	–	Center of Gravity
Comm	–	Communications
ConOps	–	Concept of Operations
CSA	–	Canadian Space Agency
CTBE	–	Crew Transfer Bag Equivalent
CWC	–	Contingency Water Containers (CWC)
D-RATS	–	Desert Research And Technology Studies
DSB	–	Dive Safety Board
EHP	–	Extravehicular Activity and Human Surface Mobility Program
ESA	–	European Space Agency
ESDMD	–	Exploration Systems Development Mission Directorate
EV1/EV2	–	Extra Vehicular crew number 1 or 2
EVA	–	Extra-Vehicular Activity
FOD	–	Flight Operations Directorate
FRP	–	Fiber-Reinforced Polymer
Hab	–	Habitat
HITL	–	Human in the Loop
HQ	–	NASA Headquarters
HUT	–	Hard Upper Torso
ISS	–	International Space Station
IV	–	Intra-Vehicular
JSC	–	Johnson Space Center
KSC	–	Kennedy Space Center
LAT	–	Lunar Architecture Team
LR	–	Luggage Rack
M2M	–	Moon to Mars
MCC	–	Mission Control Center
MMT	–	Mission Management Team
MPH	–	Multi-Purpose Habitat
NASA	–	National Aeronautics & Space Administration
NEEMO	–	NASA Extreme Environment Mission Operations
NOLS	–	National Outdoors Leadership School
Ops	–	Operations
PANGAEA	–	Planetary Analogue Geological and Astrobiological Exercise for Astronauts
PAO	–	Public Affairs Office
PLSS	–	Portable Life Support System
PR	–	Pressurized Rover
SAC	–	Strategic Analysis Cycle
SAO	–	Strategy & Architecture Office
SCUBA	–	Self-Contained Underwater Breathing Apparatus
SEATEST	–	Space Environment Analog for Training, Engineering, Science, and Technology
Sim	–	Simulation
ST7	–	SEATEST 7
TRR	–	Test Readiness Review
UAE	–	United Arab Emirates
USC	–	University of Southern California
VR	–	Virtual Reality
w.r.t.	–	with respect to
WMSC	–	Wrigley Marine Science Center
xEMU	–	exploration EVA Mobility Unit