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Final Report of NEEMO 14: Evaluation of a Space Exploration Vehicle, Cargo Lander, and Crew Lander during Simulated Partial-gravity Exploration and Construction Tasks

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Acronyms

ARC	Ames Research Center
BHP	behavioral health and performance
CAD	computer-aided design
CAPCOM	capsule communicator
CG	center of gravity
CPHS	Committee for Protection of Human Subjects
DAC3	Design and Analysis Cycle 3
DRATS	Desert Research and Technology Studies
DTO	detailed test objective
EAMD	exploration analog and mission development
EPSP	EVA Physiology, Systems, and Performance
ESMD	Exploration Systems Mission Directorate
EV	extravehicular
EVA	extravehicular activity
FY	fiscal year
GCPS	Gravity Compensation and Performance Scale
GEN II	Generation II
GRC	Glenn Research Center
HHC	human health and countermeasures
HRP	Human Research Program
IDV	integrated diver vest
ISS	International Space Station
ITCD	Information Technology and Communications Directorate
IV	intravehicular
IVA	intravehicular activity
JSC	Johnson Space Center
KSC	Kennedy Space Center
LaRC	Langley Research Center
LSB	life support buoy
MCC	Mission Control Center
MD	mission day
MHMA	mid-high/mid-aft
MK-12	U.S. Navy Mark 12
MK-III	Mark-III spacesuit technology demonstrator
MMCC	Mobile Mission Control Center
NEEMO	NASA Extreme Environment Mission Operations
NBL	Neutral Buoyancy Laboratory
NEO	near-Earth object

NURC	National Undersea Research Center
PC	percent complete
PI	primary investigator
PLSS	Portable Life Support System
PVC	polyvinyl chloride
RPE	rating of perceived exertion
SAID	space-flight-associated immune dysregulation
SEV	space exploration vehicle
SPIFe	Scheduling and Planning Interface for Exploration
TBD	to be determined
TV	task value
WSCT	weighted sum of completed task

1 Introduction

The Space Exploration Vehicle (SEV) is regarded by the Exploration Systems Mission Directorate (ESMD) as an integral part of the current exploration architectures under consideration. The SEV offers numerous health and safety advantages that accrue from having a pressurized safe haven/radiation shelter in close proximity to the crew at all times during exploration operations. It also combines a comfortable shirtsleeve, sensor-augmented environment for gross translations and geological/mapping observations with the ability to rapidly place suited astronauts outside of the vehicle using suitports to take full advantage of the unique human talents of perception, judgment, and dexterity. Data from the Desert Research and Technology Studies (DRATS) 2008 field test demonstrated that this combination of features and capabilities increases the productivity of suited crew time by an average of 370% during exploration/mapping/geological operations using an SEV compared to suited crew time with an unpressurized rover.

The SEV concept is being developed through an aggressive process of designing, prototyping, and testing in close coordination with the development of other exploration systems including the extravehicular activity (EVA) suit. Different test objectives necessitate different test sites, and the objectives of the NASA Extreme Environment Mission Operations (NEEMO) 14 test required a simulated reduced-gravity environment. The ability to simulate microgravity and reduced gravity for extended durations during EVA tasks means that NEEMO missions represent a cost-effective opportunity to understand the operation and interaction of hardware and humans in these environments. The ultimate success of future exploration missions is dependent on the ability to perform EVA tasks efficiently and safely, whether those tasks represent a nominal mode of operation or a contingency capability; all systems must therefore be designed with EVA accessibility and operability as important considerations. During the 2-week NEEMO 14 mission, four crew members performed a series of EVA tasks under different simulated EVA-suit configurations and gravity levels and used full-scale mock-ups of an SEV and a cargo lander. Quantitative and qualitative data collected during NEEMO 14 will be used to directly inform ongoing hardware and operations concept development of the SEV, exploration EVA systems, and future EVA suits.

The next iteration of the SEV-rover development process was the conceptual design of a Generation II (Gen II) SEV rover, which began in early fiscal year (FY) 2010. The size of the SEV side-hatches was one of the most significant drivers for the cabin geometry; and a primary driver for the hatch dimensions is the ability to transfer an incapacitated EVA crew member into the SEV. Data regarding the adequacy of a 101.6 cm wide by 101.6 cm high (40 in. wide by 40 in. high) side-hatch for transferring an incapacitated EVA crew member into the SEV, described in this report, was used by the SEV team to finalize the SEV side-hatch dimensions.

EVA interfaces, task design, suit weight and suit center of gravity (CG), and hardware accessibility and operability were quantitatively and qualitatively evaluated in simulated reduced gravity during the following EVA tasks at NEEMO 14:

1. Unloading an SEV mock-up from the deck of a cargo-lander mock-up
2. Off-loading small payloads from the deck of a cargo-lander mock-up
3. Transferring small payloads from the surface onto the deck of a cargo-lander mock-up
4. Transferring an incapacitated crew member from the surface onto the deck of a crew-lander mock-up

5. Transferring an incapacitated crew member from the surface into an SEV-rover mock-up via a:
   a. mock-up suitport
   b. 101.6 cm wide by 101.6 cm high (40 in. wide by 40 in. high) side-hatch
   c. 101.6 cm wide by 152.4 cm high (40 in. wide by 60 in. high) side-hatch
6. Crew member translation through hatchways:
   a. 101.6 cm wide by 101.6 cm high (40 in. wide by 40 in. high) hatch
   b. 101.6 cm wide by 152.4 cm high (40 in. wide by 60 in. high) hatch
7. Transferring an incapacitated crew member from the crew-lander deck into an airlock and ascent module
8. Crew member translation into an airlock and ascent module

Each of the EVA tasks was performed a total of nine times by each of the four crew members to enable the combined effects of three different simulated suit weights and three different suit CG locations to be evaluated and compared. Data regarding the effects of suit weight and CG on task performance were systematically analyzed and will ensure that the implications of suit weight and CG location on EVA performance are adequately understood and considered during the development of exploration EVA suits. In addition to the EVA tasks listed above, crew members also completed a standard exploration EVA task protocol used during all EVA Physiology, Systems, and Performance (EPSP) Project tests, including previous NEEMO missions. The protocol consisted of ambulation, kneel/recover, fall/recover, shoveling, rock pick-up, and ladder climbing tasks, each of which was performed according to the EPSP protocol under each of the nine weight/CG configurations.

In addition to the EVA tasks performed outside the habitat, a number of other Human Research Program (HRP) objectives were assessed during the mission that relate to Behavioral Health and Performance (BHP) and Human Health and Countermeasures (HHC). All of these studies were approved through HRP merit review and by the NASA Johnson Space Center (JSC) Committee for Protection of Human Subjects (CPHS). The full titles and the study investigators are shown in Table 1. Additional detail on the objectives/hypotheses and results can be found in individual protocols and final reports for each study and are not further discussed in this report.

Table 1. Additional HRP Studies that Took Place During the Mission

Study Title	Investigators
Advanced Extravehicular Activity (EVA) Exploration Activities Study to Assess Human Performance Responses in Partial Gravity Environments	PI* – Michael L. Gernhardt Co-I** – Steven P. Chappell Co-I – Nickolas Skytland
Evaluation of Astronaut-SEV Interactions During Incapacitated Crew Ingress Tasks in Simulated Lunar Gravity	PI – Michael L. Gernhardt Co-I – Steven P. Chappell Co-I – Andrew Abercromby
Cognitive Performance and Stress in a Simulated Space Environment	PI – David Dinges Co-I – Daniel Mollicone
A Scheduling and Planning Tool in NEEMO 14 – A Simulated Space Environment	PI – Kathryn Keeton
Measures of Team Cohesion, Team Dynamics, and Leadership in a Simulated Environment	PI – Kathryn Keeton

Study Title	Investigators
Immune Assessment during a Short-Duration Spaceflight Analog Undersea Mission	PI – Brian Crucian Co-I – Clarence Sams Co-I – Raymond Stowe Co-I – Alexander Chouker Co-I – Satish Mehta Co-I – Heather Quiriarte
Characterization of Oxidative Damage during a Saturation Dive	PI – Sara Zwart Co-I – Scott Smith Co-I – J. Millborne Jessup Co-I – Joseph Tomaszewski Co-I – Juiping Ji
Cardiac Adapted Sleep Parameters Electrocardiogram Recorder Monitoring During NEEMO Expedition Aboard *Aquarius* Undersea Habitat	PI – Marc O Griofa Co-I – Kenneth Cohen Co-I – Rebecca Blue Co-I – Derek O'Keefe Co-I – Don Doerr Co-I – Robert Thomas
Continuous Real-Time Hemodynamic Non-Invasive Monitoring During NEEMO Expedition Aboard *Aquarius* Undersea Habitat	PI – Marc O Griofa Co-I – Kenneth Cohen Co-I – Rebecca Blue Co-I – Luis Moreno Co-I – Kevin Ferguson

*PI = principal investigator; **Co-I = co-investigator.

The high-fidelity EVA and intravehicular activity (IVA) mission operations during NEEMO 14 provided an opportunity to evaluate the extent to which continuous real-time voice communications between Earth (topside) and an exploration objective (e.g., the moon) (NEEMO crew) is necessary to maintain crew productivity. Objective data on the effects of noncontinuous voice communications coverage on productivity and performance were needed to help inform decisions regarding how many communications relay satellites – if any – are necessary to support a chosen exploration architecture.

A combination of objective and subjective crew productivity metrics was used during the NEEMO 14 mission to compare crew productivity under the continuous and twice-per-day communications modes. The first half of the NEEMO 14 mission used continuous real-time voice communications with the topside, and the topside provided crew members on EVA with procedural guidance as needed. The second half of the mission had the NEEMO crew performing activities in a self-guided manner in accordance with the timeline and the procedures; during this time communications with the topside was limited to twice a day. For safety reasons, continuous real-time communications were always available between the crew and the topside; the different communications modes were emulated procedurally. Crew performance and productivity under these varied voice communications conditions were quantified and compared using predefined metrics. These NEEMO 14 mission data were supplemented with data from preceding DRATS 2009 and 2010 studies in which the collected crew productivity data were quantitatively compared between continuous real-time "Earth-moon" communications and intermittent "Earth-moon" communications (8 hours real-time Earth-moon communications followed by 4 hours without Earth-moon communications), and between continuous communications and twice-per-day communications, respectively. In the DRATS 2009 study that emulated a single elliptical relay satellite, the small differences in measured crew productivity realized through quantitative comparison of productivity data collected during continuous real-time “Earth-moon” communications with productivity data collected during intermittent “Earth-moon” communications (8 hours real-time Earth-moon communications followed by 4 hours without Earth-moon communications) did not meet the prospectively defined level of practical significance. NEEMO 14 productivity and data quality findings were expected to mirror analysis results of DRATS 2010 productivity data, which revealed that significantly more time was spent on science activities during twice-per-day communications than during continuous communications. Analysis on the effect of communications modes on data quality data collected during DRATS 2010 is under way at the time of this writing.

Finally, the NEEMO analog provides an ideal environment in which to investigate techniques and equipment that may be used in the exploration of objects with very-low-gravity fields, such as near-Earth objects (NEOs) or asteroids, or the martian moon Phobos. Unique challenges exist as humans in spacesuits consider exploring these types of environments, such as the ability to anchor oneself to the surface in a way that allows meaningful work to be accomplished without drifting away from the area of interest. Time limitations precluded these exploration techniques being evaluated during NEEMO 14, but they are planned for future NEEMO missions.

The hypotheses of this study were tested with a combination of objective and subjective productivity and performance and human factors metrics, which are detailed in section 8.4 of this protocol. Where small sample sizes precluded the use of inferential statistics in the testing of hypotheses, practically significant differences in the relevant metrics were prospectively defined and used.

2 Hypotheses

Hypotheses for this study are detailed below. The statistical analysis and specific metrics associated with each hypothesis are detailed in section 8.4.

Hypothesis 1: A volumetric rover mock-up will be successfully unloaded from a full-scale cargo lander mock-up using a davit with EVA support in simulated lunar gravity.

Hypothesis 2: EVA astronauts in simulated lunar gravity will successfully translate with small payloads between the surface and the deck of a full-scale cargo-lander mock-up in simulated lunar gravity.

Hypothesis 3: A simulated incapacitated crew member will be successfully transferred from the surface to the deck of a full-scale cargo-lander mock-up in simulated lunar gravity.

Hypothesis 4: A simulated incapacitated crew member will be successfully transferred in simulated lunar gravity from the surface into an SEV mock-up via:

a. the mock-up suitport.
b. a 101.6 cm wide by 101.6 cm high (40 in. wide by 40 in. high) side-hatch.
c. a 101.6 cm wide by 152.4 cm high (40 in. wide by 60 in. high) side-hatch.

Hypothesis 5: Varying simulated EVA suit weight and CG location (based on suitport-compatible Portable Life Support System [PLSS] packaging) will affect the performance of exploration EVA tasks.

Hypothesis 6: Crew productivity will not be significantly affected by a communications mode in which real-time habitat-ground communications are available only twice per day as compared with continuous real-time communications.

Hypothesis 7: A crew member will successfully translate through a hatchway in simulated lunar gravity, weighed out to IVA weight, via:

a. a 101.6 cm wide by 101.6 cm high (40 in. wide by 40 in. high) side-hatch with no tunnel.
b. a 101.6 cm wide by 152.4 cm high (40 in. wide by 60 in. high) side-hatch with no tunnel.

Hypothesis 8: A simulated incapacitated crew member will be successfully transferred from the crew-lander deck into an airlock and ascent module in simulated lunar gravity.

Hypothesis 9: A crew member will successfully translate into an airlock and ascent module in simulated lunar gravity.

Hypothesis 10: A crew member will successfully establish anchors and will translate and perform tasks in a simulated microgravity field.

Hypothesis 11: Crew members will find it acceptable to translate through a 101.6 cm wide by 101.6 cm high (40 in. wide by 40 in. high) hatchway in 1*g* over a 14-day mission.

3 Background and Significance

Table 2 details the relevance, products, and impacts of testing of specified hypotheses.

Table 2. Relevance and Significance of Hypotheses

Hypothesis/Objective	ESMD/HRP Relevance	Products	Results Utility
A volumetric SEV mock-up will be successfully unloaded from a full-scale cargo-lander mock-up using a davit with EVA support in simulated lunar gravity	EVA will be required for nominal and/or contingency unloading of all critical lander payloads; implications of these EVA tasks on lander, EVA, and surface systems designs and operations are not yet understood	Recommendations for lander and payload EVA support hardware (e.g., arrestors vs. belays vs. safety tethers) and for lander off-loading system	Lander, EVA, and surface systems design teams will be provided with data and recommendations early enough to make necessary design decisions that will ensure safe and efficient unloading of lander payloads in nominal and/or contingency scenarios
EVA astronauts in simulated lunar gravity will successfully translate with small payloads between the surface and the deck of a full-scale cargo-lander mock-up in simulated lunar gravity	EVA will be required for nominal and/or contingency transfer of small payloads such as geological sample boxes between the surface and lander deck; implications of these EVA tasks on lander, EVA and surface systems designs and operations are not yet understood	Recommendations for lander and small payload EVA support hardware and for lander off-loading system; outfitting of the payloads with crew aids; standard interfaces	Lander, EVA, and surface systems design teams will be provided with data and recommendations early enough to make necessary design decisions that will ensure safe and efficient transfer of small payloads in nominal and/or contingency scenarios, thus informing the designs for outfitting of payloads with crew aids, handling provisions, and standard interfaces
A simulated incapacitated crew member will be successfully transferred from the surface to the deck of a full-scale cargo-lander mock-up in simulated lunar gravity	EVA may be required for transfer of incapacitated crew members from the surface to the lander deck; implications of these EVA tasks on lander, EVA, and surface systems designs and operations are not yet understood	Recommendations for lander EVA support hardware and lander off-loading system	Lander, EVA, and surface systems design teams will be provided with data and recommendations early enough to make necessary design decisions that will ensure safe and efficient transfer of incapacitated crew members from surface to lander deck

Hypothesis/Objective	ESMD/HRP Relevance	Products	Results Utility
A simulated incapacitated crew member will be successfully transferred in simulated lunar gravity from surface into an SEV-rover mock-up via: a. the mock-up suitport b. a 101.6 cm wide by 101.6 cm high (40 in. wide by 40 in. high) side-hatch with no tunnel c. a 101.6 cm wide by 101.6 cm high (40 in. wide by 40 in. high) side-hatch with tunnel d. a 101.6 cm wide by 152.4 cm high (40 in. wide by 60 in. high) side-hatch with no tunnel e. a 101.6 cm wide by 152.4 cm high (40 in. wide by 60 in. high) side-hatch with tunnel	EVA will be required for transfer of incapacitated EVA crew members into the SEV-rover cabin; implications of these EVA tasks on SEV and EVA systems designs and operations are not yet understood; the going-in plan is to transfer incapacitated crew members via the suitport; transfer of suited crew members via side-hatch is also being considered, which may drive side-hatch dimensions	Recommendations for SEV suitport and side-hatch EVA support hardware and side-hatch dimensions	SEV and EVA system design teams will be provided with data and recommendations early enough to make necessary design decisions that will ensure safe and efficient transfer of incapacitated crew members from surface to SEV cabin; hatch dimension recommendations have the potential to impact all pressurized surface system designs
Varying simulated EVA suit weight and CG location (based on suitport-compatible PLSS packaging) will affect performance of the following exploration EVA tasks: – SEV unloading from cargo lander (i.e., Hypothesis 1 task) – Small payload transfer between lander and surface (i.e., Hypothesis 2 task) – Incapacitated crew member transfer from surface to lander deck (i.e., Hypothesis 3 task) – Incapacitated crew member transfer from surface to SEV cabin (i.e., Hypothesis 4 task) – EVA EPSP Project exploration EVA task protocol (i.e., ambulation, kneel/recover, fall/ recover, shoveling, rock pick up, ladder climbing)	EVA will be required for transfer of incapacitated EVA crew members into the SEV-rover cabin; implications of these EVA tasks on SEV and EVA systems designs and operations are not yet understood; nominal plan is to transfer incapacitated crew members via the suitport; transfer of suited crew members via side-hatch is also being considered, which may drive side-hatch dimensions	Recommendations for SEV suitport and side-hatch EVA support hardware and side-hatch dimensions	SEV and EVA system design teams will be provided with data and recommendations early enough to make necessary design decisions that will ensure safe and efficient transfer of incapacitated crew members from surface to SEV-rover cabin; hatch dimension recommendations potentially impact all pressurized surface systems

Hypothesis/Objective	ESMD/HRP Relevance	Products	Results Utility
Crew productivity will not be significantly affected by a voice communications mode in which real-time habitat-ground communications are available only twice per day as compared with continuous real-time voice communications	Significant cost savings can be realized if continuous moon-Earth voice communication is not required; little data exist on the impact of reduced voice communication coverage on crew productivity during lunar-like mission operations	Quantitative evaluation of crew productivity during NEEMO mission operations with and without reduced ground voice communications	Recommendations for lunar surface communications requirements
A crew member will successfully translate through a hatchway in simulated lunar gravity, weighed out to IVA weight, via: a. a 101.6 cm wide by 101.6 cm high (40 in. wide by 40 in. high) side-hatch with no tunnel b. a 101.6 cm wide by 152.4 cm high (40 in. wide by 60 in. high) side-hatch with no tunnel	IVA crew members will have the need to translate through hatchways between vehicles and habitats; implications of these tasks on SEV-rover and exploration systems designs and operations are not yet understood; translation of IVA crew members may drive side-hatch dimensions	Recommendations for SEV-rover side-hatch dimensions	SEV-rover and lunar surface system design teams will be provided with data and recommendations early enough to make necessary design decisions that will ensure safe and efficient translation of incapacitated crew members from between vehicles and habitats; hatch dimension recommendations potentially impact all pressurized surface systems
A simulated incapacitated crew member will be successfully transferred from the crew-lander deck into an airlock and ascent module in simulated lunar gravity	EVA will be required for transfer of incapacitated EVA crew members into an airlock and ascent module; implications of these EVA tasks on systems designs and operations are not yet understood; transfer of suited crew members through airlock may drive hatch and airlock dimensions	Recommendations for hatch and airlock dimension as well as for EVA support hardware	EVA system design teams will be provided with data and recommendations early enough to make necessary design decisions that will ensure safe and efficient transfer of incapacitated crew members from the lander deck into the ascent module through the airlock

Hypothesis/Objective	ESMD/HRP Relevance	Products	Results Utility
A crew member will successfully translate into an airlock and ascent module in simulated lunar gravity	EVA crew members may have the need to translate an airlock on entering and exiting an ascent module; implications of these tasks on exploration systems designs and operations are not yet understood; translation of EVA crew members may drive hatch and airlock dimensions	Recommendations for hatch and airlock dimensions	Lunar surface system design teams will be provided with data and recommendations early enough to make necessary design decisions that will ensure safe and efficient translation of crew members through airlocks
A crew member will successfully establish anchors, translate, and perform tasks in a simulated very-low-gravity field.	NEOs and low-gravity moons are potential targets for human exploration	Recommendations for techniques and equipment that will be necessary to work on NEOs and low-gravity moons	EVA and surface systems design teams will be provided with data and recommendations early enough to make necessary design decisions that will ensure safe and efficient operations in a nominal and/or contingency scenario
A crew member will find it acceptable to translate through a 101.6 cm wide by 101.6 cm high (40 in. wide by 40 in. high) hatchway in 1*g*	IVA crew members will have the need to translate through hatchways between vehicles and habitats; implications of these tasks on SEV-rover and exploration systems designs and operations are not yet understood; translation of IVA crew members may drive side-hatch dimensions	Recommendations for SEV side-hatch dimensions	SEV and lunar surface system design teams will be provided with data and recommendations early enough to make necessary design decisions that will ensure safe and efficient translation of incapacitated crew members from between vehicles and habitats; hatch dimension recommendations potentially impact all pressurized surface systems

Hypothesis/Objective	ESMD/HRP Relevance	Products	Results Utility
Cognitive performance and stress in a simulated space environment: 1. To determine the best measures and tools to use for assessing decrements in cognitive function due to fatigue and other aspects of space flight 2. To provide data collected to other BHP investigators to fulfill their research objective 3. To build a normative database for astronaut populations 4. To characterize astronauts' sleep duration in analogs and under normal conditions	BHP associated with space exploration	Objective and subjective data products and analysis (see section 4 for further details)	Insight on objectives relevant to the advancement of BHP research and knowledge
A scheduling and planning tool in NEEMO 14 – a simulated space environment in which: 1. NEEMO 14 mission will serve as a test bed (proof of concept) for development, deployment, and evaluation of the scheduling and planning tool 2. Overarching goal is to develop a technology to assist with scheduling, planning, and training of astronauts when they are working and living during long-duration space flight missions.	BHP associated with space exploration	Subjective data products and analysis (see section 4 for further details)	Insight on objectives relevant to the advancement of scheduling and planning tools for space exploration
Measures of team cohesion, team dynamics, and leadership in a simulated environment: 1. To assess crew performance, crew cohesion, and crew-ground interaction 2. To develop a normative database of team measures that may be generalizable to space flight and the astronaut population	BHP associated with space exploration	Subjective data products and analysis (see section 4 for further details)	Insight on objectives relevant to the advancement of BHP research and knowledge

Hypothesis/Objective	ESMD/HRP Relevance	Products	Results Utility
Immune assessment during a short-duration space flight analog undersea mission: 1. To measure immune function changes, physiological stress, viral reactivation, and viral-specific immunity 2. To further characterize any aspects of SAID (space-flight-associated immune dysregulation) 3. To compare this ground-based space flight analog to actual flight data	HHC associated with space exploration	Objective and subjective data products and analysis (see section 4 for further details)	Insight on objectives relevant to the advancement of BHP research and knowledge
Characterization of oxidative damage during a saturation dive: 1. To expand measurements of oxidative damage to include more markers to better characterize the type of damage 2. To measure markers of hemolysis (haptoglobin and hemopexin) to better understand the increase in iron storage during NEEMO missions 3. To measure markers of folate status to better understand the effect of an oxidative stress on folate metabolism	HHC associated with space exploration	Objective data products and analysis (see section 4 for further details)	Insight on objectives relevant to the advancement of BHP research and knowledge
Cardiac adapted sleep parameters electrocardiogram recorder monitoring during NEEMO expedition aboard *Aquarius* undersea habitat: 1. To use cardiac autonomic activity to detect sleep instability and circadian rhythm disruption in a space analog extreme environment	HHC associated with space exploration	Objective data products and analysis (see section 4 for further details)	Insight on objectives relevant to the advancement of BHP research and knowledge

Hypothesis/Objective	ESMD/HRP Relevance	Products	Results Utility
Continuous real-time hemodynamic noninvasive monitoring during NEEMO expedition aboard *Aquarius* undersea habitat: 1. To obtain daily 15-min "resting" hemodynamic data on each crew member 2. To obtain real-time transmission of hemodynamic data from *Aquarius* to the NASA Kennedy Space Center (KSC) on two separate occasions	HHC associated with space exploration	Objective data products and analysis (see section 4 for further details)	Insight on objectives relevant to the advancement of BHP research and knowledge

4 Methods

4.1 Crew subjects

Subjects were recruited from the active astronaut corps as well as through a space life sciences selection process. Through this selection, 4 male astronaut subjects (Table 3), consisting of 2 active astronauts and 2 space life sciences investigators, participated in the mission.

Table 3. Subject Characteristics

n = 4	Height (cm [in.])	Body Mass (kg [lbs])	Age (years)
Average	181.5 (71.5)	77.0 (169.8)	42.3
SD*	0.8 (0.3)	5.1 (11.2)	9.3
Max	182.4 (71.8)	82.6 (182.1)	50.0
Min	180.3 (71.0)	70.3 (155.0)	30.0

*SD = standard deviation

All subjects successfully passed a modified Air Force Class III Physical or equivalent examination. Each subject was provided verbal and written explanations of the testing protocols and the potential risks and hazards involved in the testing, and signed NASA JSC Human Research documentation indicating his/her understanding and consent. All testing protocols were reviewed and approved by the NASA JSC CPHS, and appropriate test readiness reviews were conducted before testing began.

4.2 Crew subject training

Crew members were briefed on the objectives and methods of the study before departure for the field test site, and participated in a comprehensive training program that included review and practice of the following:

- Study hypotheses
- Metrics and data collection procedures
- Mission rules
- Task procedures
- CG rig familiarization
- Mock-up familiarization
- *Aquarius* familiarization
- Communications protocols

On deployment to the field test site, all crew members completed a brief refresher course before the start of the mission.

4.3 Equipment

4.3.1 Aquarius Habitat

Aquarius is the only operational undersea research habitat in the world (Figure 1). It is operated through the National Undersea Research Center (NURC) by the University of North Carolina at Wilmington. It is highly sophisticated in its logistical infrastructure, and has not required major modifications to support unique NASA needs.

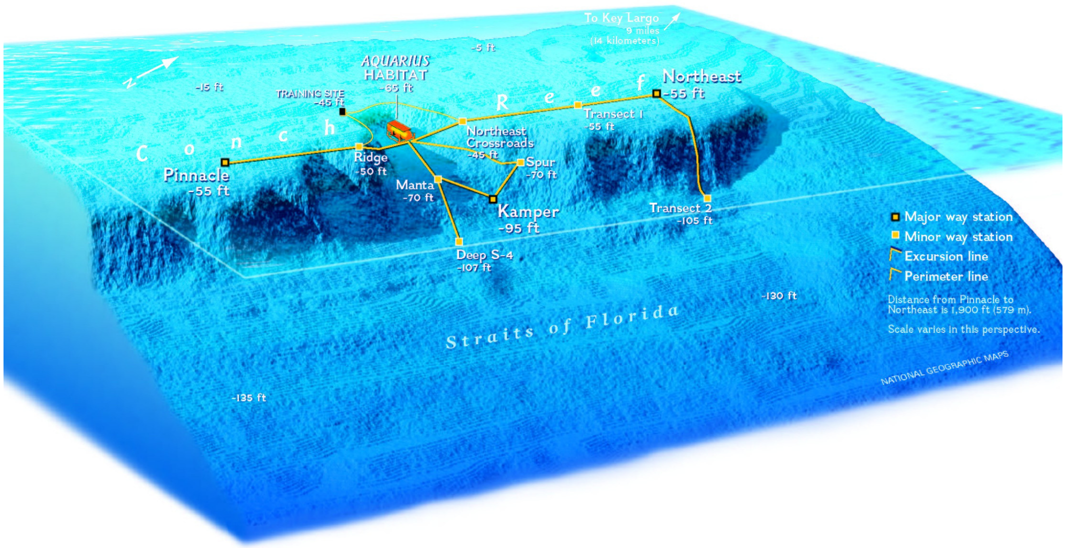


Figure 1. Location of *Aquarius* habitat off the coast of Key Largo, Fla.

Aquarius was built in the mid-1980s, and was previously located in Saint Croix (U.S. Virgin Islands) before moving to the reef line 19.3 km (12 miles) off Key Largo, Fla, in 1990. In these two locations, *Aquarius* has supported dozens of missions to study the undersea realm for several hundred marine research scientists from around the world (Figure 2).

Figure 2. A diver descends to the world's only undersea research habitat, *Aquarius*, in 18.9 m (62 ft) of seawater off Key Largo, Fla.

Aquarius is similar in size to the U.S. Laboratory module on the International Space Station (ISS) (~15 m [49.2 ft] long × 4.5 m [14.8 ft] diameter). It is firmly secured to a sand patch surrounded by large spur and groove coral reefs on three sides. It sits in water that is 18.3 m (60 ft) deep, but the entrance level is actually closer to 15.2 m (50 ft) deep, which corresponds to an internal pressure of approximately 2.5 atmospheres. At this depth, aquanauts living and working in the habitat are exposed to excessive levels of nitrogen within the first few hours, and must commit to staying in the habitat and undergoing "decompression" before returning to the surface. This type of diving is called "saturation" diving, which refers to the complete saturation of the body tissues by nitrogen. A diver in this condition will quickly experience the onset of the "bends" if he or she returns to the surface without going through decompression, and would most likely experience injury and even death if not treated. The danger is real and the environment is truly extreme, which is one of the key reasons it makes such a good analog to living in space. Aquanauts participating in these missions must use their training, skills, knowledge, and teamwork to ensure their safety and mission success.

Permanently anchored above *Aquarius* is a 10-m (32.8-ft) life support buoy (LSB) (Figure 3). On board the LSB are redundant generators and compressors that provide electrical power and fresh air to the habitat via umbilical. Separate umbilicals provide communications connectivity. The signal is relayed via microwave from the LSB to NURC headquarters in Key Largo, Fla. This allows *Aquarius* to have real-time voice communication (radio and telephone) and internet connectivity. It also allows the "watch desk" at NURC to monitor video and systems telemetry in real time, which they do 24 hours per day, 7 days per week during a mission.

Figure 3. The LSB moored directly above *Aquarius* provides electrical power and communications to shore.

A simulated reduced-gravity environment was necessary for the ESMD and EPSP studies to assess the ability of crew members to perform mission-critical tasks. The *Aquarius* facility provided an isolated and confined environment from which realistic EVAs could be performed.

With the addition of the SEV-rover and lander mock-ups near the habitat (see sections 4.3.2 and 4.3.3), EVAs could be performed to assess operations concepts in a way that will inform suit and vehicle requirements to maximize crew performance. Since crew members on EVA can be out for extended periods and weighed out to simulate reduced gravity, the *Aquarius* site was the most effective way with which to accurately test these operations concepts.

4.3.2 Space Exploration Vehicle Mock-up

The SEV mock-up used in this study is based on the cabin 1B prototype that was developed as a collaborative effort among JSC, NASA Langley Research Center (LaRC), NASA Ames Research Center (ARC), and NASA Glenn Research Center (GRC) (Figure 4). The SEV mock-up also incorporated the features necessary to achieve mission objectives, as shown in the detailed mock-up development drawings in section 8.1.

Figure 4. SEV rover cabin 1B integrated with Chariot chassis.

A full-scale mock-up of the SEV (Figure 5) was constructed near the *Aquarius* habitat to achieve the rover-based test objectives. This SEV mock-up had side-hatches that were 101.6 cm (40 in.) wide and an adjustable height from 101.6 cm (40 in.) to 152.4 cm (60 in.). The aft bulkhead of the mock-up featured suitport simulators. The height of the door thresholds, suitport thresholds, and aft deck accurately simulated the expected lowest possible heights based on prototypes. The SEV interior was minimally simulated by employing fold-up benches and side-hatch doors.

Figure 5. Full-scale SEV mock-up on seafloor during mission.

4.3.3 Lander Mock-up

The cargo-lander mock-up used for this study was based on the Design and Analysis Cycle 3 (DAC3) Altair concepts that were developed as a collaborative effort among multiple NASA centers.

A full-scale mock-up of a lander (Figure 6) was constructed next to the *Aquarius* habitat so that simulated EVAs could be performed to achieve the lander-based objectives of the test. There were two configurations for the lander: as a cargo lander designed to test on/off load of small and large payloads, and as a crew lander with an airlock and ascent module. The objectives were: off-loading of the SEV mock-up, on/off load of a small payload, on load of a simulated incapacitated crew member to the deck and ingress to the airlock, and airlock and ascent module ingress/egress. The crew's ability to safely, effectively, and efficiently climb/descend a full-scale ladder and move around the deck while using tethers and arrestors was also assessed. Further details of the lander mock-ups can be found in the mock-up development drawings in section 8.2.

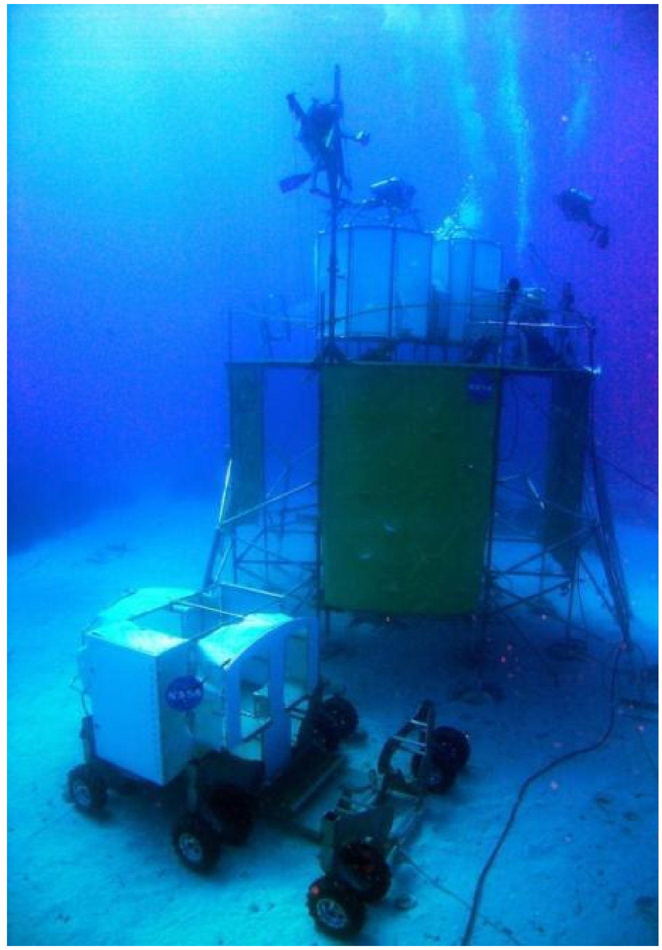


Figure 6. Full-scale cargo lander with airlock and ascent module in place on its deck and the SEV mock-up in the foreground.

4.3.4 Center-of-gravity Rigs

The EPSP Project developed a custom rig to be worn by a diver to allow different CGs to be simulated (Figure 7) while performing tasks underwater. These rigs were used to support NEEMO missions 9-13 (Figure 8) in addition to support NEEMO 14 mission objectives.

The CG rig was used in conjunction with U.S. Navy Mark 12 (MK-12) dive suits that allowed the subjects to be weighed out to 1/6*g* so that tasks could be performed in simulated reduced gravity. Three different CGs were assessed during NEEMO 14. The mid-high/mid-aft (MHMA) CG simulates wearing a PLSS that is consistent with the latest design concepts for use of a suitport. The "0,0,0" CG was coincident with the location of the CG of a 81.6-kg (180-lb), 1.83-m (6-ft) male (the standard subject used to calculate settings of the rig). The POGO CG, which was a high and aft CG representing a CG consistent with the use of a suitport PLSS, also crosses over to tests performed in the partial-gravity simulator (nicknamed POGO) at JSC so that cross-environmental comparisons could be made. The CG rigs were worn for the EPSP and cargo lander-based portions of the protocol (see section 4.6.1).

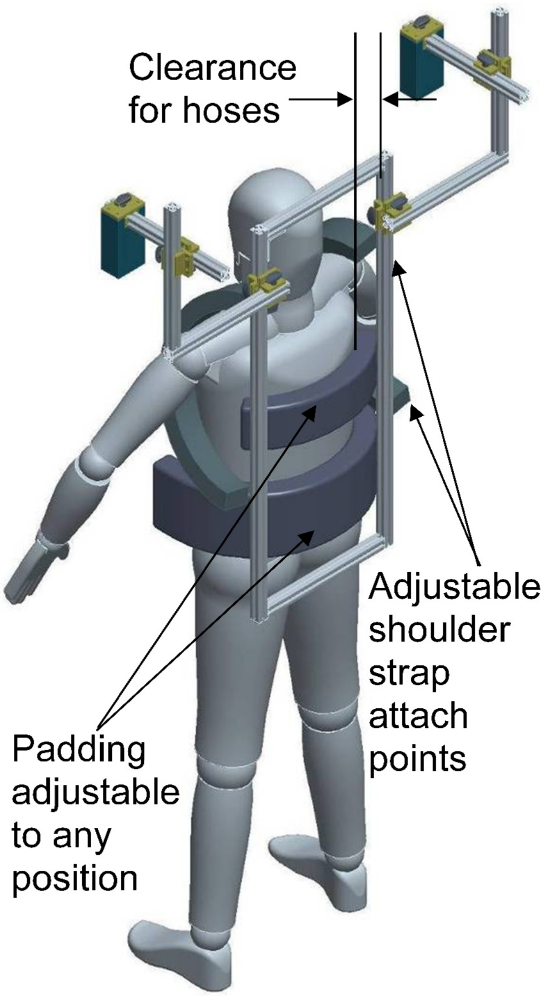


Figure 7. CG rig showing major features of design.

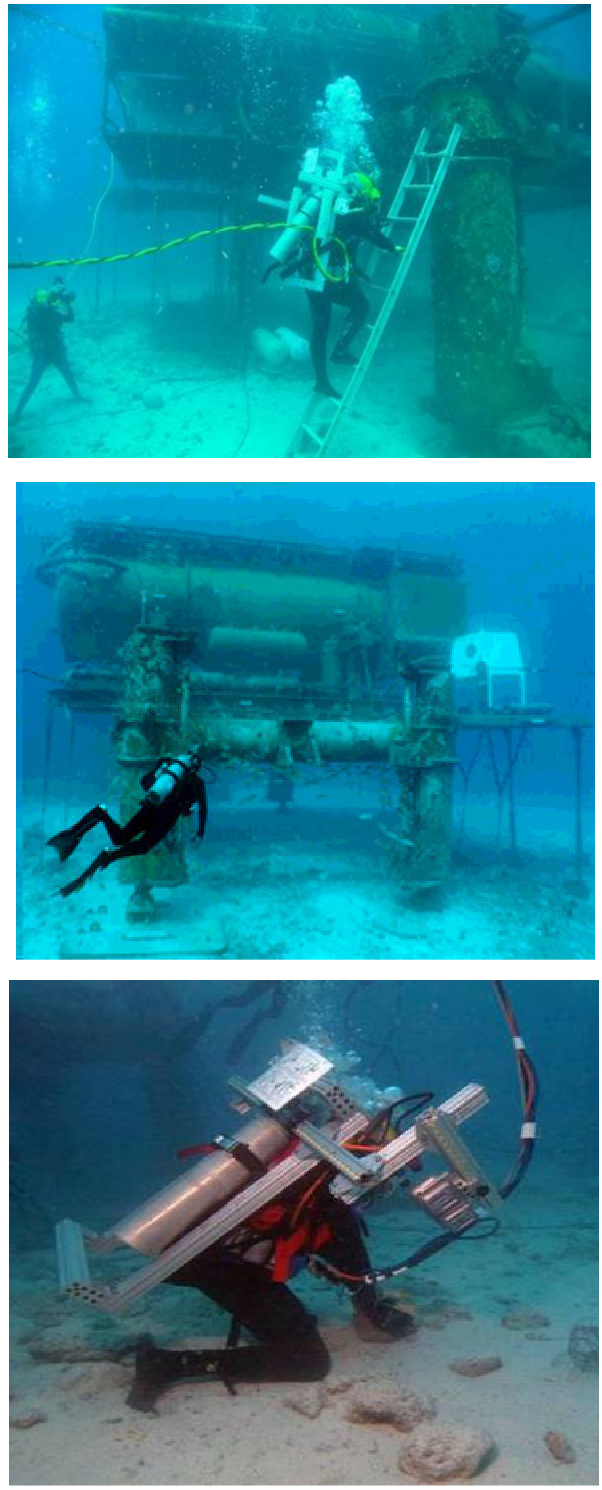


Figure 8. CG rig in use during previous NEEMO missions.

4.3.5 Mobile Mission Control Center

The Information Technology and Communications Directorate (ITCD) at KSC provided a Mobile Mission Control Center (MMCC), which accommodated test support personnel including the Science Backroom Team, CAPCOM [capsule communicator]/ Test Director, and data collection personnel. The MMCC is shown in Figure 9.

Figure 9. Interior of MMCC during mission, and the MMCC parked outside the *Aquarius* reef base.

4.3.6 Haul System

A haul system was designed to assist the crew in lifting and maneuvering the simulated incapacitated crew member through hatchways and up to the SEV suitport. Figure 10 and Figure 11 show the haul system and a component diagram, respectively.

Figure 10. Haul system.

The system, which was designed to provide crew members with a 4-to-1 mechanical advantage, was used during the incapacitated crew member SEV-suitport and side-hatch ingress tasks as well as the incapacitated crew member airlock/ascent module ingress task. Components for the haul system included carabiners (OK screw-lock, Petzl, Crolles, France), pulleys (Mini Double PMP, Seattle Manufacturing Corporation, Ferndale, Wash), rope (BlueWater II Plus™, BlueWater Ropes, Carrollton, Ga), self-ratcheting pulley (Mini Traxion self-ratcheting pulley, Petzl, Crolles, France), and 8-mm (0.3-in.) nylon cord (Sterling Rope Company, Inc, Biddeford, Me).

Figure 11. Haul system with explanation of components.

4.3.7 Fall Protection

Fall protection was provided to crew members to mitigate the risk of injury due to a fall while they were working on the lander ladder and upper deck of the lander. The ladder-fall protection design used a rope that was fixed in place on the lander ladder and a rope-grab device (LadSaf®, DBI-Sala, Red Wing); see Figure 12.

Figure 12. Lander ladder fall protection.

While working on the deck of the lander, the crew members each carried two safety tether carabiners (MGO, Petzl, Crolles, France) so that 100% connection could be attained. All fall protection was provided to the crew members by D-rings attached on their integrated dive vests.

4.3.8 Rescue Manikin

An adult water rescue manikin (Simulaids, Saugerties, NY) was used to simulate the incapacitated crew member. The manikin was outfitted with a PLSS mock-up (see section 4.3.9) to better simulate the volume of a suited, incapacitated astronaut.

Figure 13. Crew member climbing onto the lander deck wearing PLSS mock-up.

4.3.9 Portable Life Support System Mock-ups

PLSS mock-ups (Figure 13) were designed to match the dimensions and volume of the Mark-III spacesuit technology demonstrator (MK-III) PLSS. The PLSS mock-ups were made of polyvinyl chloride (PVC) tubing covered with PVC mesh and attached to the crew members via a nylon webbing harness with quick-release buckles.

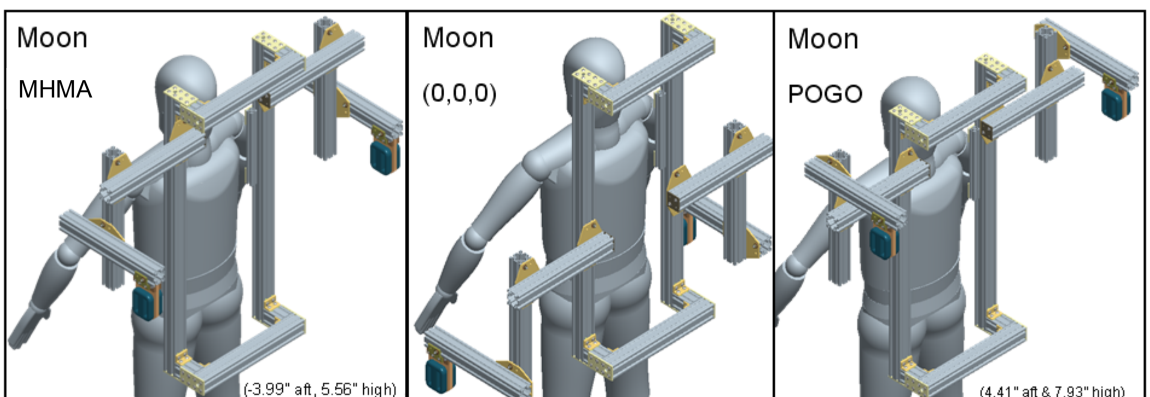
When not wearing the CG rig, subjects wore a mock-up that simulated the volume of a PLSS. The PLSS mock-up volume and dimensions were based on those of the MK-III.

4.4 Equipment layout

Figure 15 (shown on the following page) displays the layout of the *Aquarius* habitat, vehicle mock-ups, and exploration task area.

4.5 Test conditions

Three different 1*g* suit weights (90.7, 136.1, and 181.4 kg [200, 300, and 400 lbs]) were evaluated for each of the three CGs (Figure 14). To simulate these different suit weights, each subject was first weighed out in the water with his or her dive helmet and all dive equipment so that he or she was neutrally buoyant. The additional weight necessary was then computed by adding the subject weight to the CG-rig weight and multiplying by the 1/6*g* of lunar gravity. This weight was then added to the MK-12 dive suit or integrated-dive vest that supported the emergency gas supply system for each diver.



A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
3	53.5	90	81	99	85	19.5	53.5	90	88	104	72.25	5	53.5	94	78	90	84

Figure 14. CG rig showing different positions of weights and arms to achieve the three CGs to be used for NEEMO 14.

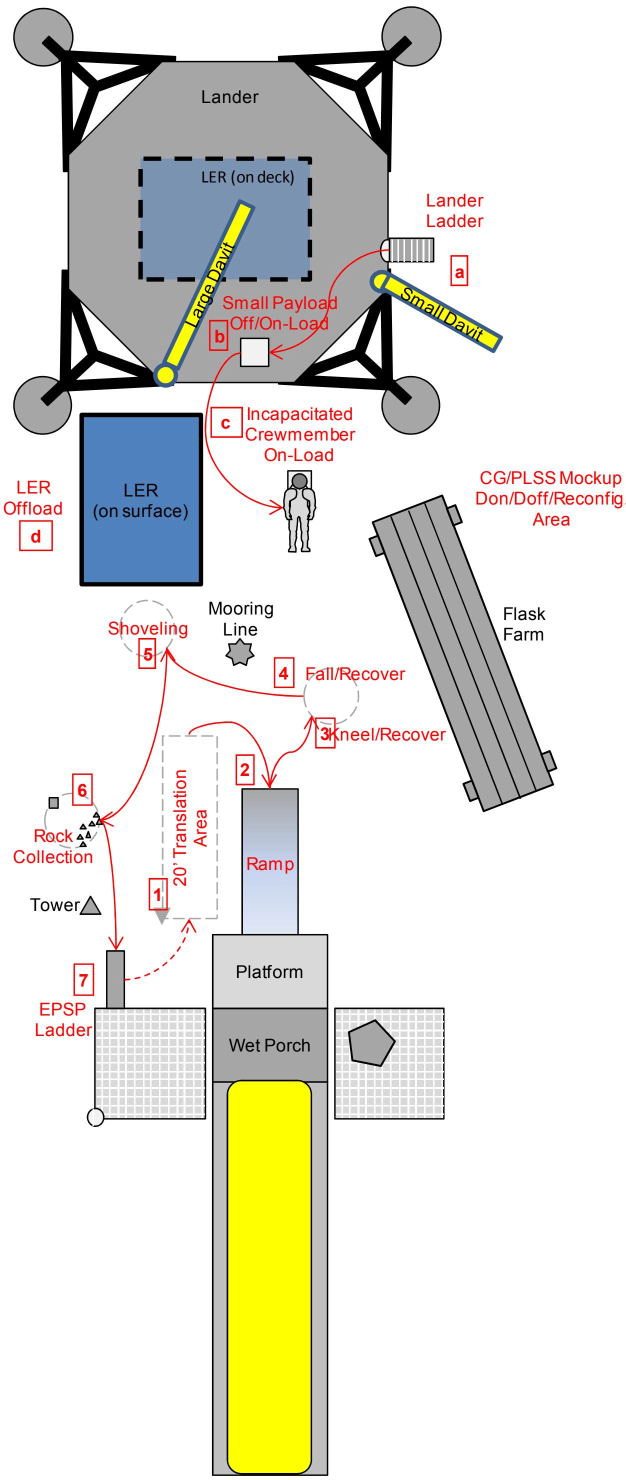


Figure 15. To-scale overhead layout of *Aquarius* habitat, vehicle mock-ups, and exploration task area.

While wearing the PLSS mock-ups (Figure 16), crew members performed weigh outs that are similar to those described for use of the CG rig, but simulated only the 1*g* suit weight of 136.1 kg

(300 lbs). The PLSS mock-ups were worn during the SEV and crew lander-based portions of the protocol (see section 4.5.2).

Figure 16. Crew members on lander deck wearing volumetric PLSS mock-ups.

4.6 Test protocols

The study hypotheses (section 2) were tested by planning and performing a 14-day mission at the *Aquarius* habitat during which productivity, human factors, and performance metrics for crew members and hardware were collected.

Preliminary data reduction and analysis began during the field test to enable verification of data quality. Comprehensive reduction and analysis of data, evaluating each study hypothesis, began immediately following completion of the field test.

An overview of the timeline showing the overall execution schedule for the protocol is included in section 8.3 (Figure 85 and Figure 86).

4.6.1 Extravehicular Activity Physiology Systems and Performance and Cargo Lander-based Center-of-gravity Test Protocol

Hypotheses 1, 2, 3, and 5, described in section 2, were evaluated during this portion of the test protocol. For this study, the purpose was to compare three different suitport-relevant CGs at three different suit weights while crew member teams performed a variety of tasks similar to those anticipated on lunar and/or Mars exploration missions. Measurements for this study were taken on a person wearing a wet suit with a PLSS-rig apparatus and a weighted overall suit, and performing a set of exploration and construction tasks to determine: (1) the best CG location for each task performance, (2) the EVA suit weight that best enables the subject to complete each of the tasks, and to collect, and (3) additional metrics as detailed in section 8.4. Exploration tasks took place on the seafloor outside the habitat and on or around the nearby mock-ups (i.e., cargo lander, SEV). Figure 14 shows a representation of the tasks and the physical layout of the test area around the habitat where the protocol was executed.

Fall protection equipment and methods were tested during the tasks that took place on the cargo-lander mock-up or its ladder. A rope-grab device to stop falls was used on ascent and descent of the ladder. While crew members were working on the cargo deck, tether systems, in combination with a safety rail system, were used that provided for 100% tie-off when a crew member was in danger of falling.

4.6.1.1 Extravehicular activity physiology systems and performance circuit protocol

The EPSP circuit consisted of the following exploration tasks: ambulation, incline ambulation, decline ambulation, kneel/recover, fall/recover, shoveling, rock pickup/transfer, and EPSP-ladder climb. The layout and order of the tasks are shown in Figure 14.

Ambulation consisted of a 6.1-m (20-ft) ambulation path on a level portion of seafloor over which the crew members took four passes at each test condition. The ramped incline/decline ambulation was performed on a 6.1-m (20-ft) ramp attached between the seafloor and the deck of *Aquarius*. One pass in each direction was performed. Kneel/recover consisted of the crew member performing one repetition of dropping to one knee and returning to a standing position. Fall/recover was similar to kneel/recover, with one repetition of falling to a prone position and returning to a standing position. Shoveling required placing 15 shovels of seafloor sand into a bucket using a standard, long-handled garden shovel. The rock pickup and transfer task used dive weights of differing sizes/weights that had to be transferred from one location to another location 3.05 m (10 ft) away, one at a time. The EPSP-ladder task had a single ascent and descent off a 3.05-m (10-ft) ladder placed at an approximately 10-deg incline. All tasks were performed once per CG and suit weight simulated.

4.6.2 Space Exploration Vehicle and Crew Lander-based Test Protocol

Hypotheses 4, 7, and 8, described in section 2, were evaluated during this portion of the test protocol. In dealing with the possibility of an incapacitated crew member on the lunar surface, EVA will be required to transfer that crew member to the ascent module for evacuation. If the crew is out on traverse in the SEV when the incapacitation occurs, methods for ingressing the SEV need to be developed and validated. This portion of the protocol compared the nominal plan of ingressing a simulated incapacitated crew member via a suitport with transfer via a side-hatch of differing sizes. A water rescue manikin, which was used to simulate an incapacitated crew member, was weighed out to approximate the weight of a suited astronaut on the moon (~36.3 kg [80 lbs]). To assist in lifting and manipulating the rescue manikin, the rescue manikin was outfitted with a harness to which a 4-to-1 mechanical advantage haul system was attached with the ability to capture the hauling progress. The haul system allowed crew member teams to move more easily and position the manikin properly in the suitport or through the side-hatch. Attachment points on the SEV mock-up assisted in using the haul system to maneuver the crew member either through the side-hatch or up to the suitport, as depicted in Figure 17 through Figure 21. Hypothesis 8 was tested similarly except with ingress of an incapacitated crew member through an airlock and ascent module hatch. Section 11.3 provides details on tasks performed in this portion of the protocol. A limitation of these evaluations was that the volume associated with the crew wearing a pressurized spacesuit was not in place; thus, additional fidelity testing may be needed beyond this study before finalizing design recommendations.

Hypothesis 7 was tested by weighing out the EVA crew members to the lunar weight they would have if they were performing an IVA (i.e., without a suit) inside the SEV. The crew members then translated through hatchways of different sizes to simulate moving between vehicles and habitats. Metrics were collected to inform vehicle and habitat hatchway requirements. A limitation of these evaluations was that the volume associated with the crew wearing a pressurized spacesuit was not in place; additional fidelity testing may therefore be needed beyond this study before finalizing design recommendations.

4.6.3 Lander and Space Exploration Vehicle Reduced Communication Operations Test Protocol

Hypothesis 6, described in section 2, was evaluated during this portion of the test protocol. Crew members were able to communicate with the test safety and support personnel as well as with each other during all test operations. However, the effect of reduced voice communications on crew productivity and performance was evaluated by intentionally varying voice communications capabilities between the crew members and the support team in the MMCC (see section 8.3.5).

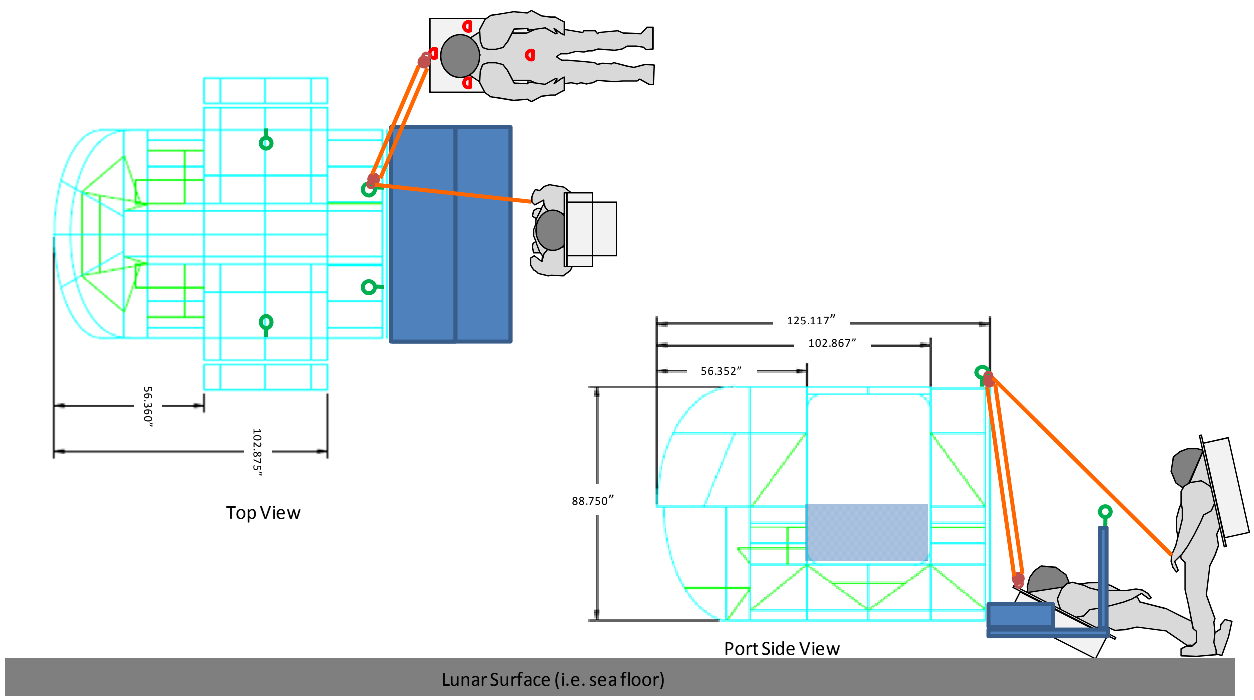


Figure 17. Suitport rescue protocol – crew member in initial position.

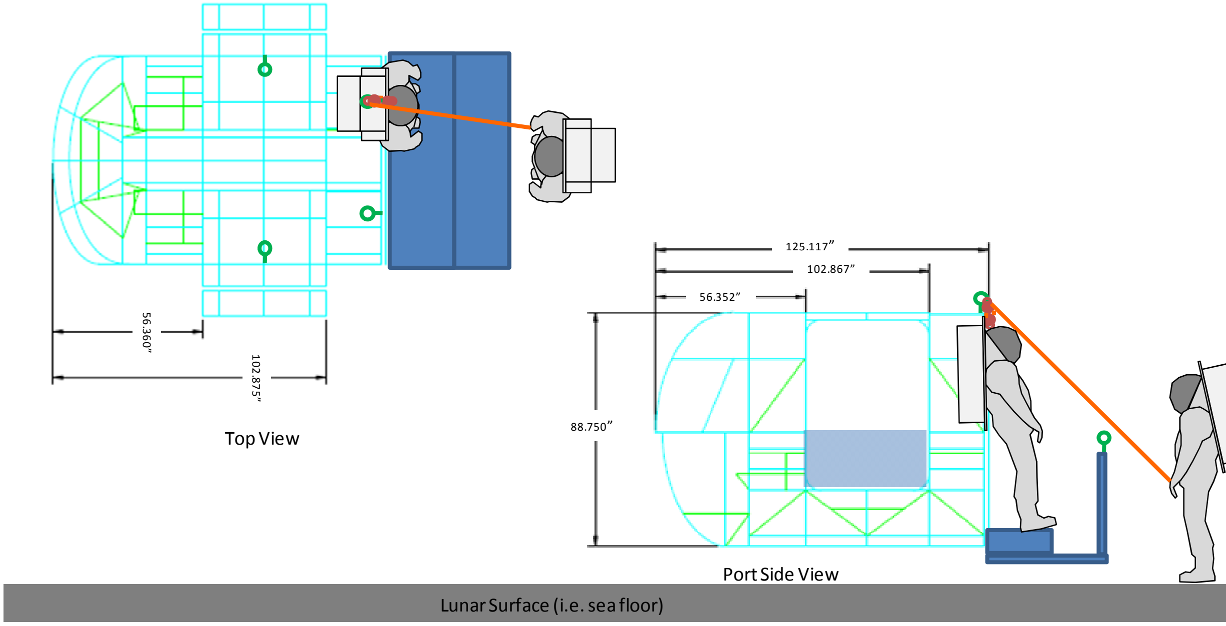


Figure 18. Suitport rescue protocol – crew member lifted to suitport.

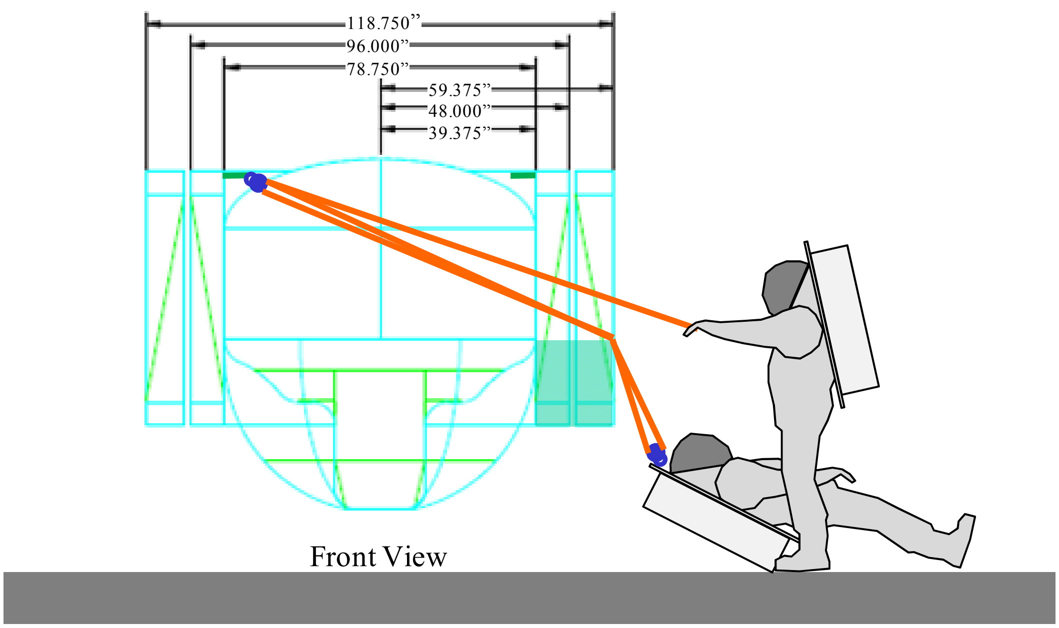


Figure 19. Side-hatch rescue protocol – crew member in initial position.

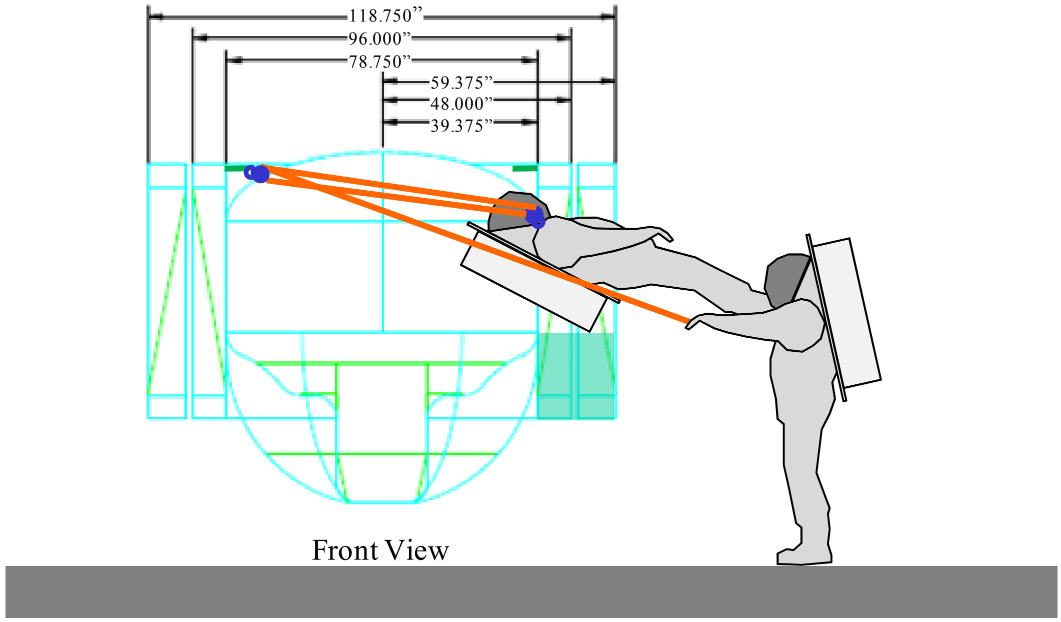


Figure 20. Side-hatch rescue protocol – crew member lifted to entryway of hatch.

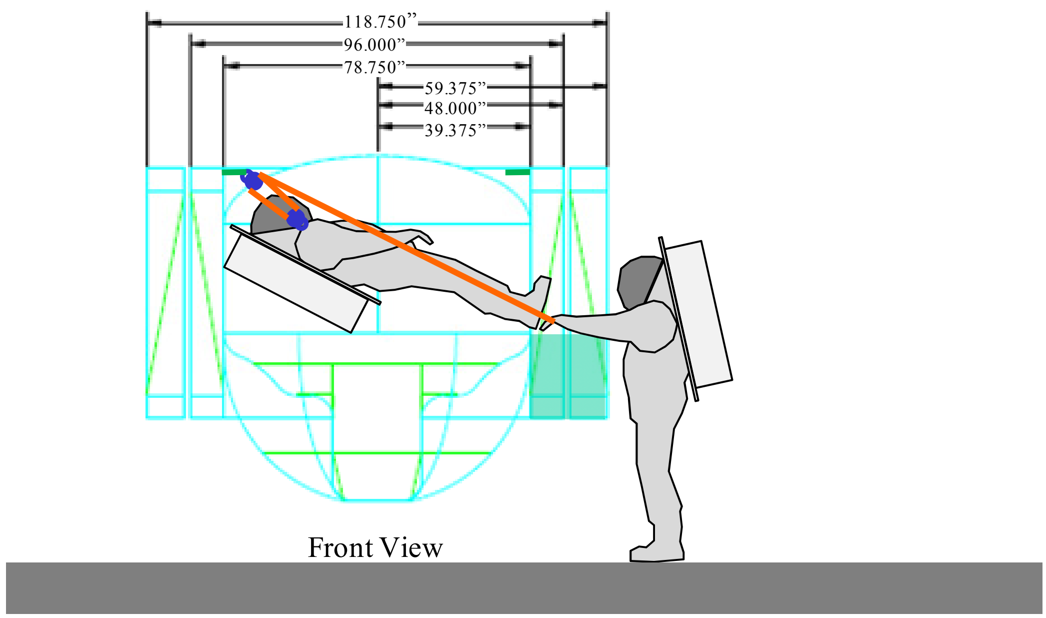


Figure 21. Side-hatch rescue protocol – crew member ingressed through hatch.

The hypothesis was evaluated by using measures of crew performance and productivity (section 8.4) that were previously used during DRATS and Pavilion Lake Research Program field tests. Metrics were collected during operations performed under at least two different voice communications conditions. As indicated in the summary mission timeline (Figure 85 and Figure 86), half of the 14-day mission was conducted with continuous real-time voice communications available between the crew members and the Test Director/CAPCOM and Science Team personnel in the MMCC.

During the last half of the mission, the communications philosophy was intentionally modified so that voice communications between the crew members and the MMCC were only available twice per day. Crew performance and productivity under these varied communications conditions were quantified and compared using the metrics described in section 8.4.

4.7 Timelines and procedures

4.7.1 Timelines

The 14-day mission had a detailed timeline that balanced the capabilities of the facility with the mission objectives. This timeline shows the objectives detailed or referred to in this protocol. Each task in the timeline was further detailed in task-specific timelines/procedures, as appropriate (see section 8.4). "Get-ahead" tasks were also included that were secondary tasks to be accomplished if the nominal tasks were completed and the crew members were ahead of the timeline by a predefined amount of time.

The overall mission timeline was managed using the Scheduling and Planning Interface for Exploration (SPIFe) mission operations planning software (ARC); examples of the overall timeline in the SPIFe software are shown in section 8.4.1. For the full pre-mission detailed timeline, see section 8.4.2 in which Figure 87 shows an example of a detailed task timeline for CG studies. These timelines were based on those under development for use as reference tasks by the EAMD team, an example of which is shown in section 8.4.2 (Figure 88) for SEV off-loading.

4.7.2 Procedures

Detailed procedures, which were developed for this study based on EAMD timeline development, are included in section 8.5. These procedures detailed the tasks to be performed by both the IVA and the EVA crew members to achieve each portion of the timeline. Additionally, cue cards were developed for use by the topside support divers to assist in guiding the test activities; the cue cards can be found in section 8.6.

4.8 Data collection and analysis

4.8.1 Study Metrics

The specific metrics used to test each of the study hypotheses are described in this section. For comparative hypotheses, the difference value for each metric that is considered practically significant is defined and the rationale explained. the absolute value of each metric that accepts or rejects each hypothesis is defined and the rationale explained for non-comparative hypotheses. Table 4 provides an overview of the study metrics.

Table 4. Summary of NEEMO 14 Metrics

EVA Performance and Human Factors Metrics
Gravity Compensation and Performance Scale
Ratings of Perceived Exertion
EVA Task Acceptability
Productivity Metrics
Weighted Sum of Completed Tasks
Task Completion Times
Subjective Crew Health Metrics (for crew health purposes only)
Bedford Thermal Scale
Corlett and Bishop Discomfort Scale

4.8.2 Gravity Compensation and Performance Scale Ratings

The degree of operator compensation required to operate certain tasks was quantified. The Gravity Compensation and Performance Scale (GCPS) rating of operator compensation has been successfully employed during multiple JSC Integrated Suit Testing protocols and was used in the evaluation of EVA tasks during this study. Note that the ratings may not have been collected for tasks in which crew members could not do a familiarization with the task in 1*g*. The modified scale is shown in Figure 22.

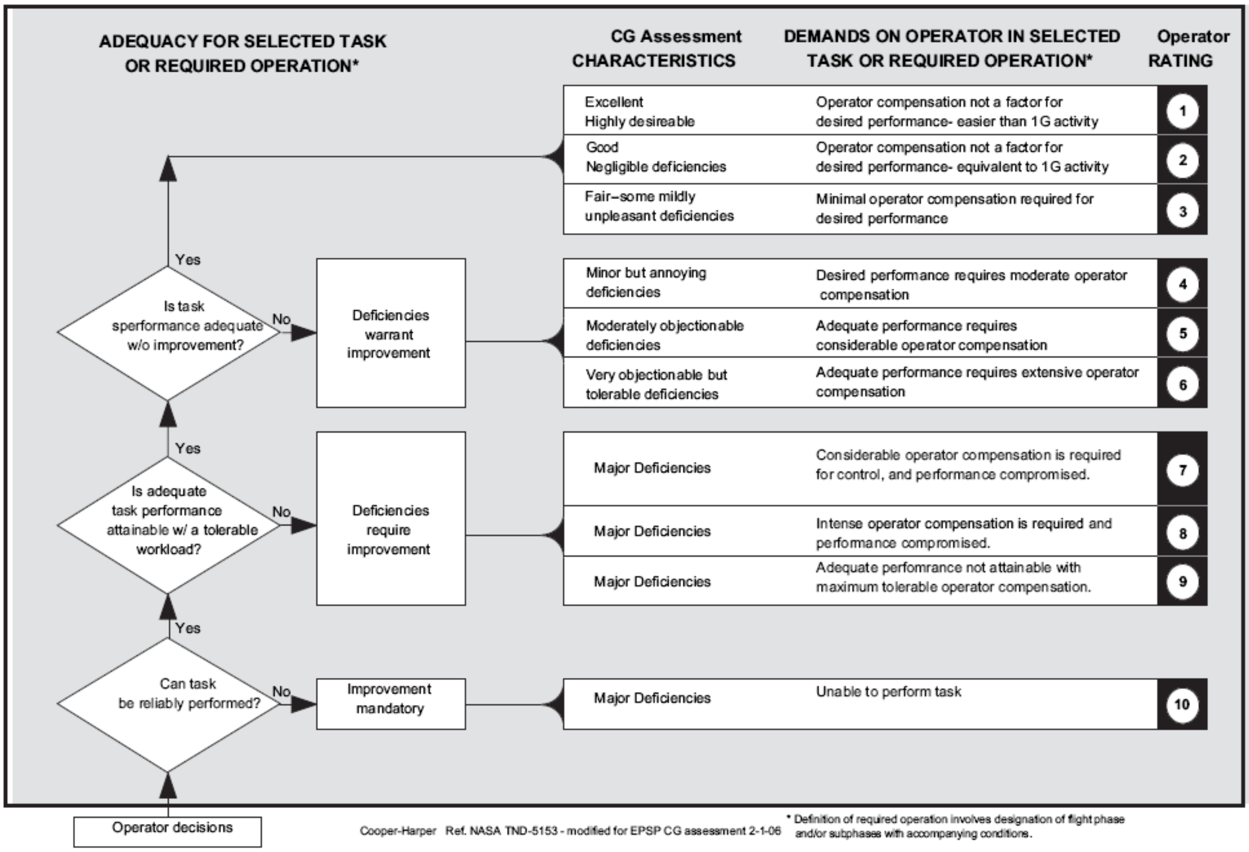


Figure 22. GCPS rating of operator compensation.

The study hypotheses require that the acceptability of human factors be assessed. For this purpose, a GCPS rating of ≤ 3 will be considered acceptable. As Figure 22 shows, a GCPS rating of 3 corresponds to "Satisfactory without improvements" with "minimal compensation required for desired performance." The full flow chart shown in Figure 22 was used to develop an abbreviated version for cue cards (see section 8.9) that was used by crew members in the field during the mission.

4.8.3 Ratings of Perceived Exertion

For each task, ratings based on the Borg Perceived Exertion Scale[1] were collected in lieu of direct metabolic energy expenditure, as measurement of direct metabolic energy expenditure in the marine environment is impossible. The rating of perceived exertion (RPE) scale is shown in section 8.9.

4.8.4 Extravehicular Activity Task Acceptability Ratings

Hypotheses 1 through 4 were tested using the following Likert scale, previously employed during DRATS field tests, to evaluate the acceptability of all aspects of the EVA tasks:

Totally Acceptable-no improvements necessary		Acceptable-minor improvements desired		Borderline-improvements warranted		Unacceptable-improvements required		Totally Unacceptable-major improvements required	
1	2	3	4	5	6	7	8	9	10

Crew members had the opportunity to evaluate aspects of the EVA tasks, including:

1) Accessibility
2) Interfaces
3) Task Design
4) Fall Restraint System
5) Overall Task Acceptability

By definition, ratings of ≤ 4 indicated acceptability. However, even where median values of ≤ 4 are measured, the reasons for any outlying data points > 4 (i.e., unacceptable EVA factors) will be recorded to help inform the redesign of the EVA tasks.

4.8.5 Weighted Sum of Completed Tasks

The weighted sum of completed tasks (WSCT) metric enables quantitative comparison of the crew productivity among different test conditions. This metric requires that all tasks performed by the crew are assigned task values (TVs) in a consistent manner; i.e., the same task performed on two different days should carry the same value. The extent to which crew members complete each task is reflected as a percent complete (PC). When crews completed tasks ahead of schedule get-ahead tasks were then performed, which will also have task values assigned.

$$\text{WSCT} = \sum \text{TV}(n) \times \text{PC}(n)$$

where: TV (n): Relative Value of Task *n*, on a 1 to 3 scale

1 = low value
2 = moderate value
3 = high value

PC (n): Percent Complete Quality of data collected at traverse waypoint objective *n*, from 0% to 100%.

Because the maximum achievable WSCT score often differs among mission days, a normalized version of this metric may also be employed wherein the WSCT metric as defined above will be divided by the sum of all *planned* task values.

The mean WSCT for each mission day under each communications condition may be calculated and compared. A difference in average daily WSCT of three points would reflect completion of one additional high value task per day and will be considered a practically significant difference in productivity for the purposes of this test. A difference in normalized WSCT of ≥ 10% will be considered practically significant.

4.8.6 Task Completion Times

Crew members verbally communicated to the IVA crew members when tasks were started and when they were finished. Times were recorded using data sheets, and the duration of each task was calculated. Reasons for large deviations from normal completion times (defined as ~25% or more deviation from normal task completion times) were documented; this was consistent with the procedures used during DRATS tests.

When comparing task completion times between communications conditions, a sustained increase of at least 10% in any crew member's average completion time for a series of EVA tasks may be considered practically significant and a non-negligible decrement in crew performance.

4.8.7 Subjective Crew Health Metrics

Crew members were prompted when warranted for subjective overall discomfort[2] and thermal comfort, the latter on the Bedford Thermal Comfort Scale.[3] The data were only used to ensure the health and safety of the crew members throughout the test, to identify deficiencies in test equipment, and as test termination criteria. The scales used are shown in section 8.9.

4.8.8 Statistical Analysis

Descriptive statistics were used to characterize the performance, productivity, and human factors metrics under all test conditions. Inferential statistics were not employed to test study hypotheses; however, practically significant differences in specific metrics were prospectively defined for the testing of study hypotheses and were described in the study protocol. This process has been used during previous EAMD protocols as well as during EVA suit testing protocols conducted by the EPSP in which small sample sizes precluded the use of inferential statistics. For example, a practically significant difference in metabolic rate has been defined as $\geq$ 3.5 mL/kg/min, which is approximately equal to an individual's resting metabolic rate and also corresponds to the difference in metabolic rate that is perceptible by a person.

5 Results

5.1 Center-of-gravity variation by subject

As was noted in the methods section, the settings for the CG rig to achieve the targeted CGs were based on the use of a computer-aided design (CAD) model of a “standard man” of height 1.83 m (6 ft) and weight 81.6 kg (180 lbs). Crew members posttest had anthropometric measures taken of their bodies and additional CAD models were created that matched each crew member’s anthropometric characteristics. The crew member CAD models were then used together with the CG-rig settings used during the mission (based on the “standard man” model) to determine the achieved CG locations. Posttest modeling also included the actual weight that was added to the MK-12 dive suits or integrated diver vests (IDVs) on a subject-by-subject and condition-by-condition basis. Figure 23 shows the results of this analysis. In the figure, the solid data points are targeted CG locations based on the pretest, standard-man model. The open data points represent the achieved CG locations based on the posttest, improved modeling. Several clusters seen in the figure represent differences in anthropometry and dive weights for different subjects and suit weight conditions, respectively.

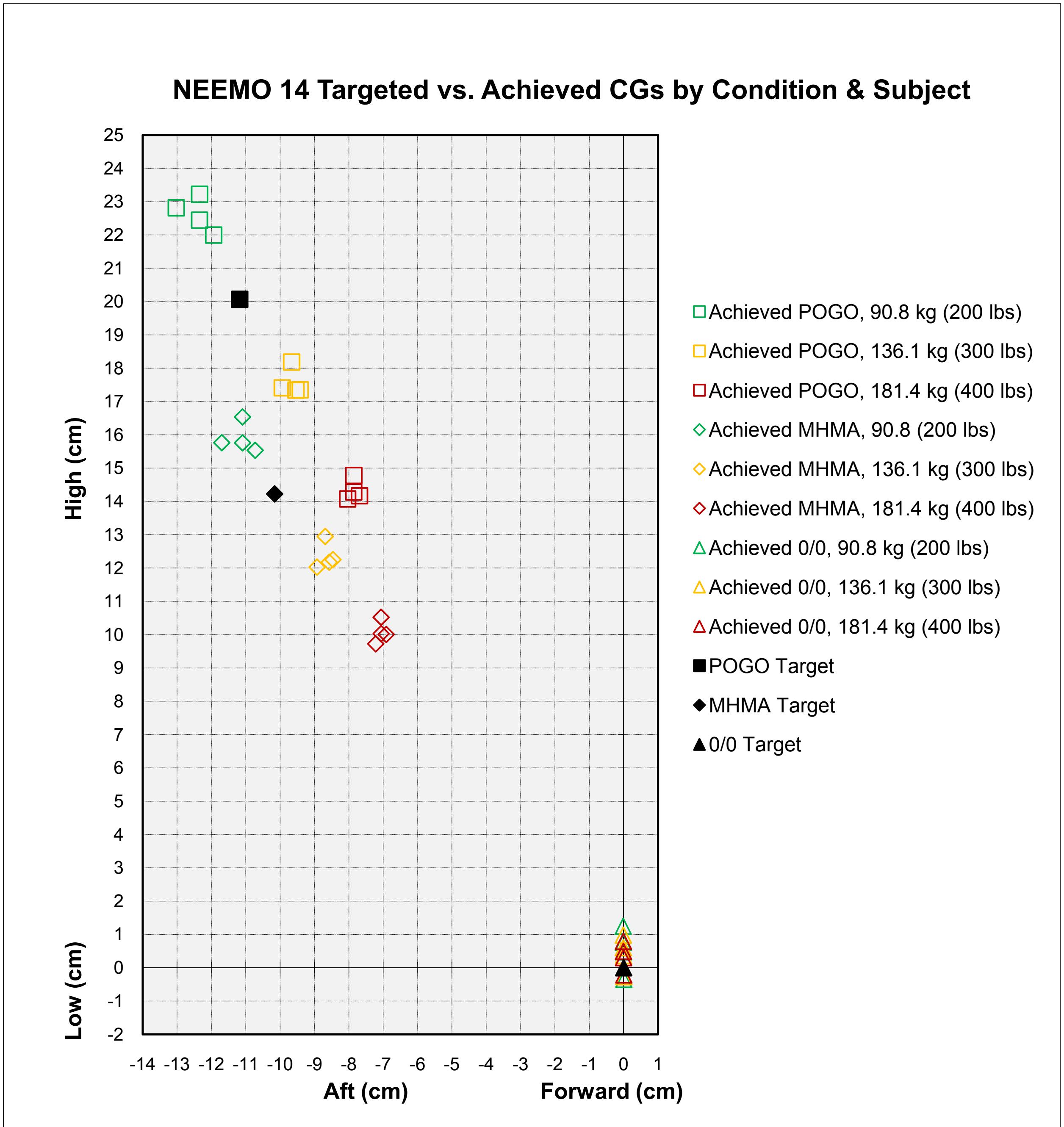


Figure 23. NEEMO 14 targeted vs. achieved CGs by condition and subject.

The following sections use the pretest, standard-man model targeted CG names (i.e., 0/0, MHMA, and POGO) when presenting results. In the 6 Discussion and Conclusions section, the possible effects of subject-by-subject and condition-by-condition changes in CG are analyzed further.

5.2 Space exploration vehicle off-load results

The SEV off-load task was performed by a pair of crew members who were working together (Figure 24). As described in section 4.6.1.2, one crew member operates the large davit and one crew member operates a tagline (Figure 25) to control the SEV rotation.

Figure 24. Crew members performing SEV off-load trial.

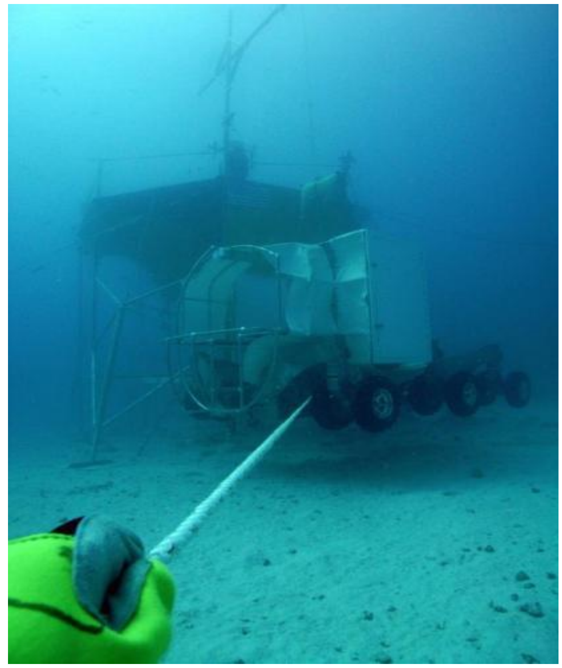


Figure 25. Crew member using belay line while performing the sand role of the SEV off-load.

Table 5 shows the mean and range of the GCPS ratings collected from crew members immediately following each test condition. GCPS ratings with means higher than 3 are shaded in red, and ranges (which denote the lowest and highest ratings given by crew members) are shown in orange if the upper end of the range exceeds 3. From the table it can be seen the 0/0 CG shows the largest number of acceptable conditions from a GCPS perspective for both roles.

Table 5. GCPS Means and Ranges for SEV Off-load Task

	Suit Weight (kg [lbs])	GCPS					
		0/0		MHMA		POGO	
		Mean	Range	Mean	Range	Mean	Range
SEV Off-load (deck role)	90.8 (200)	2.3	2,3	2.8	2,3	3.3	2,5
	136.1 (300)	2.5	2,3	3.3	2,5	2.5	1,4
	181.4 (400)	2.5	2,3	2.5	2,3	2.5	2,3
SEV Off-load (sand role)	90.8 (200)	2.7	1,4	3.0	2,5	3.5	2,4
	136.1 (300)	2.5	2,3	3.3	2,6	2.3	2,3
	181.4 (400)	3.8	3,5	3.3	2,5	4.0	3,5

Table 6 shows the mean and range of the RPE ratings collected from the crew members immediately following each test condition. While no acceptability standards were set for RPE ratings other than for test termination criteria, ratings greater than 13 (“somewhat hard” on the RPE scale) are highlighted in red, and ranges with a maximum higher than 13 are highlighted in orange. All means and most ranges had ratings less than or equal to 13.

Table 6. RPE Means and Ranges for SEV Off-load Task

	Suit Weight (kg [lbs])	RPE					
		0/0		MHMA		POGO	
		Mean	Range	Mean	Range	Mean	Range
SEV Off-load (deck role)	90.8 (200)	8.8	7,11	10.8	9,15	10.0	7,12
	136.1 (300)	10.3	9,12	10.3	8,11	11.3	11,12
	181.4 (400)	9.8	8,12	9.5	8,11	10.8	10,12
SEV Off-load (sand role)	90.8 (200)	11.0	9,13	8.5	7,10	8.5	7,10
	136.1 (300)	9.0	7,11	11.8	11,13	7.8	7,9
	181.4 (400)	9.3	8,11	8.8	8,9	9.5	8,11

Table 7 shows the mean and range of the task acceptability ratings collected from the crew members immediately following each test condition. Task acceptability ratings with means higher than 4 are shaded in red, and ranges (which denote the lowest and highest ratings given by crew members) are shown in orange if the upper end of the range exceeds 4. Most conditions show a mean task acceptability exceeding 4 for the deck portion of the task, and the sand portion of the task shows that all conditions are acceptable.

Table 7. Task Acceptability Means and Ranges for SEV Off-load Task

	Suit Weight (kg [lbs])	Task Acceptability					
		0/0		MHMA		POGO	
		Mean	Range	Mean	Range	Mean	Range
SEV Off-load (deck role)	90.8 (200)	4.8	2,7	4.5	3,6	5.0	2,7
	136.1 (300)	4.0	3,5	4.8	1,7	4.0	2,7
	181.4 (400)	4.8	3,8	5.0	3,8	6.3	5,8
SEV Off-load (sand role)	90.8 (200)	2.7	2,4	3.3	2,4	4.0	2,7
	136.1 (300)	2.5	1,5	3.8	2,7	2.5	1,5
	181.4 (400)	3.3	2,6	2.3	2,3	2.3	2,3

5.2.1 Space Exploration Vehicle Off-load Deck Role Crew Comments

A major contributor to high ratings for task acceptability for the deck role of SEV off-load were due to the large, davit-winch handle being too high as the crew members felt it was quite difficult to keep their arms raised and work above shoulder level; this would be made even more difficult if the task were to be performed in a spacesuit. Crew members noted that heavier suit weights seemed better as they seemed to provide stability on the platform and allow them to generate more force on the winch handle. It was noted that handrails and/or footholds next to the winch might be helpful to generate more force on the winch handle and help with the stability. The crew consensus seemed to be that lowering the crank would make the task acceptability ratings lower. A crew member said that he felt as though he were working harder against the weight of the rig when it was set to 181.4 kg (400 lbs) and 0/0 CG. Another crew member felt as though the MHMA CG at 181.4 kg (400 lbs) was pulling back on his shoulders. With the high winch height at the POGO CG, 90.8-kg (200-lb) condition, two crew members feel as though they had to work to keep from falling backwards because they felt unbalanced.

5.2.2 Space Exploration Vehicle Off-load Sand Role Crew Comments

Two crew members felt as though a second tagline would have been helpful to perform the task of controlling SEV rotation. One crew member preferred that the taglines were longer so that he could get farther from the payload and not have to look up at such a steep angle. The main issue reported for this role of the task was looking up to monitor activities on the deck, especially for the POGO CG in which crew members felt unbalanced and some preferred to get down on one knee to hold a stable and more comfortable position.

5.3 Small payload transfer results

The small payload transfer task was performed by a pair of crew members working together, as described in section 4.6.1.2, with one crew member operating the small davit (Figure 26) and the other crew member attaching the davit line to the small payload.

Figure 26. Crew member operates the small davit to transfer the small payload.

Table 8 shows the mean and range of GCPS ratings collected from the crew members immediately following each test condition. GCPS ratings with means higher than 3 are shaded in red, and ranges (which denote the lowest and highest ratings given by crew members) are shown in orange if the upper end of the range exceeds 3. From the table it can be seen that most conditions show an acceptable mean from a GCPS perspective for both roles, with a tendency for more unacceptable ratings at higher simulated suit weights.

Table 8. GCPS Means and Ranges for Small Payload Transfer Task

	Suit Weight (kg [lbs])	GCPS					
		0/0		MHMA		POGO	
		Mean	Range	Mean	Range	Mean	Range
Small Payload Off-load (deck role)	90.8 (200)	2.0	2,2	2.0	2,2	2.0	2,2
	136.1 (300)	2.3	2,3	2.0	2,2	2.0	2,2
	181.4 (400)	3.3	2,5	2.3	2,3	2.0	2,2
Small Payload Off-load (sand role)	90.8 (200)	2.0	2,2	2.8	2,5	3.0	2,5
	136.1 (300)	2.7	2,3	2.0	2,2	2.5	1,4
	181.4 (400)	4.0	2,5	3.0	2,5	4.5	3,6
Small Payload On-load (deck role)	90.8 (200)	2.0	2,2	2.3	2,3	2.0	2,2
	136.1 (300)	2.5	2,3	2.0	2,2	2.0	2,2
	181.4 (400)	3.3	2,5	2.3	2,3	2.0	2,2
Small Payload On-load (sand role)	90.8 (200)	2.0	2,2	2.8	2,5	3.0	2,5
	136.1 (300)	2.7	2,3	2.7	2,4	2.8	1,4
	181.4 (400)	4.0	2,5	3.8	2,5	4.5	3,6

Table 9 shows the mean and range of the RPE ratings collected from crew members immediately following each test condition. While no acceptability standards were set for RPE ratings other than for test termination criteria, ratings greater than 13 ("somewhat hard" on the RPE scale) are highlighted in red, and ranges with a maximum higher than 13 are highlighted in orange. All means and most ranges had ratings less than or equal to 13.

Table 9. RPE Means and Ranges for Small Payload Transfer Task

	Suit Weight (kg [lbs])	RPE Mean					
		0/0		MHMA		POGO	
		Mean	Range	Mean	Range	Mean	Range
Small Payload Off-load (deck role)	90.8 (200)	8.8	7,10	8.5	7,11	8.5	7,11
	136.1 (300)	10.3	7,12	12.3	10,14	9.8	8,11
	181.4 (400)	8.0	7,9	10.0	8,12	8.8	7,10
Small Payload Off-load (sand role)	90.8 (200)	7.8	7,9	6.8	6,8	7.3	7,8
	136.1 (300)	7.7	7,9	7.5	7,8	7.0	7,7
	181.4 (400)	9.5	7,12	8.3	7,10	9.3	8,11
Small Payload On-load (deck role)	90.8 (200)	9.8	7,11	11.5	10,13	10.8	9,13
	136.1 (300)	12.0	11,13	11.5	11,13	9.8	8,11
	181.4 (400)	9.3	7,13	12.0	11,13	11.8	10,13
Small Payload On-load (sand role)	90.8 (200)	8.3	7,11	6.8	6,8	7.3	7,8
	136.1 (300)	7.7	7,9	7.0	6,8	7.0	7,7
	181.4 (400)	9.5	7,12	8.0	7,9	9.3	8,11

Table 10 shows the mean and range of the task acceptability ratings collected from the crew members immediately following each test condition. Task acceptability ratings with means higher than 4 are shaded in red, and ranges (which denote the lowest and highest ratings given by crew members) are shown in orange if the upper end of the range exceeds 4. Although all conditions show a mean task acceptability exceeding 4 for both roles, the range of ratings provided did exceed 4 for several conditions.

Table 10. Task Acceptability Means and Ranges for Small Payload Transfer Task

	Suit Weight (kg [lbs])	Task Acc. Mean					
		0/0		MHMA		POGO	
		Mean	Range	Mean	Range	Mean	Range
Small Payload Off-load (deck role)	90.8 (200)	1.5	1,2	1.0	1,1	2.0	1,3
	136.1 (300)	3.0	2,6	2.0	2,2	2.3	1,5
	181.4 (400)	1.5	1,2	2.3	2,3	1.8	1,3
Small Payload Off-load (sand role)	90.8 (200)	1.5	1,2	1.0	1,1	1.5	1,2
	136.1 (300)	1.3	1,2	1.0	1,1	1.5	1,2
	181.4 (400)	1.8	1,2	2.3	2,3	1.5	1,2
Small Payload On-load (deck role)	90.8 (200)	1.5	1,2	1.3	1,2	2.0	1,3
	136.1 (300)	3.8	2,7	1.8	1,2	2.3	1,5
	181.4 (400)	1.5	1,2	2.3	2,3	2.3	1,5
Small Payload On-load (sand role)	90.8 (200)	1.5	1,2	1.0	1,1	1.5	1,2
	136.1 (300)	1.3	1,2	1.7	1,3	1.5	1,2
	181.4 (400)	1.8	1,2	1.8	1,2	1.5	1,2

5.3.1 Small Payload Off-load Deck Role Crew Comments

A couple of crew members took short rest breaks at the MHMA CG, 181.4-kg (400-lb) condition. A crew member also felt that the workload was quite high at the POGO, 181.4-kg (400-lb) condition. The crew members stated that the challenging nature of these conditions after being on EVA for nearly 3 hours would require rest breaks to be factored into the EVA timeline. The winch height on the small davit was lower than the large davit winch used during the SEV off-load task, and crew members found it easier to use. The crew also noted that the gear ratio on the small davit winch could be improved as the winch had to be turned too many times to perform a full on- or off-load. There did not appear to be a noticeable CG effect for this task, likely due to the presence of a handhold on the small davit that provided for good stability while cranking the winch.

5.3.2 Small Payload Off-load Sand Role Crew Comments

Two crew members found it difficult to look up to deck height at the POGO, 181.4-kg (400-lb) condition, as may be necessary to ensure the payload is clear of all structure during a transfer.

5.3.3 Small Payload On-load Deck Role Crew Comments

The height of the upper-winch handle, which was more of an issue during the on-load task due to the need to exert more force, led to increased workload as well as instability during some of the CG and weight configurations.

5.3.4 Small Payload On-load Sand Role Crew Comments

The crew members had difficulty looking up at raised payloads using the POGO CG for all suit weights, as would be necessary to ensure the payload is clear of all structure during a transfer. They stated that looking up required a lot of energy to maintain balance, and that is also caused some crew members pain in the shoulders and back.

5.4 Incapacitated crew member upload results

Figure 27. Crew member connects simulated incapacitated crew member to small davit line for upload.

The incapacitated crew member upload task was performed by a pair of crew members working together, as described in section 4.6.1.2, with one crew member operating the small davit (Figure 27) and the other crew member attaching the davit line to the incapacitated crew member and managing a tagline to control rotation.

Table 11 shows the mean and range of the GCPS ratings collected from the crew members immediately following each test condition. GCPS ratings with means higher than 3 are shaded in red, and ranges (which denote the lowest and highest ratings given by crew members) are shown in orange if the upper end of the range exceeds 3. From the table it can be seen that most conditions show an acceptable mean from a GCPS perspective for both roles, with a tendency for more unacceptable ratings at higher simulated suit weights and more high and aft CG.

Table 11. GCPS Means and Ranges for Incapacitated Crew Member Upload Task

	Suit Weight (km [lbs])	GCPS					
		0/0	MHMA			POGO	
		Mean	Range	Mean	Range	Mean	Range
Incap. Crew On-load (deck role)	90.8 (200)	2.0	2,2	2.3	2,3	2.3	2,3
	136.1 (300)	2.5	2,3	2.0	2,2	2.3	2,3
	181.4 (400)	3.3	2,5	2.3	2,3	2.3	2,3
Incap. Crew On-load (sand role)	90.8 (200)	2.8	2,3	2.5	1,5	3.0	2,5
	136.1 (300)	2.3	2,3	2.8	1,4	2.0	1,4
	181.4 (400)	4.0	2,5	4.3	2,5	4.3	3,5

Table 12 shows the mean and range of the RPE ratings collected from crew members immediately following each test condition. While no acceptability standards were set for RPE ratings other than for test termination criteria, ratings greater than 13 ("somewhat hard" on the RPE scale) are highlighted in red; ranges with a maximum higher than 13 are highlighted in orange. The sand role means were all less than or equal to 13. However, the deck role means at the MHMA and the POGO CGs had higher workloads. Although the task was essentially the same as the small payload upload task for the deck role, the 36.3-kg (80-lb) load of the incapacitated crew member vs. the 9.1-kg (20-lb) load of the small payload could account for the higher RPE values.

Table 12. RPE Means and Ranges for Incapacitated Crew Member Upload Task

	Suit Weight (km [lbs])	RPE Mean					
		0/0		MHMA		POGO	
		Mean	Range	Mean	Range	Mean	Range
Incap. Crew On-load (deck role)	90.8 (200)	11.5	7,13	13.3	13,14	12.8	11,15
	136.1 (300)	11.0	7,13	13.0	11,15	10.8	8,12
	181.4 (400)	10.0	7,13	14.3	13,17	13.8	13,15
Incap. Crew On-load (sand role)	90.8 (200)	10.0	7,15	7.8	6,10	8.8	7,13
	136.1 (300)	9.0	7,11	7.8	7,9	7.0	7,7
	181.4 (400)	12.0	9,16	8.5	7,11	9.5	8,11

Table 13 shows the mean and range of the task acceptability ratings collected from crew members immediately following each test condition. Task acceptability ratings with means higher than 4 are shaded in red, and ranges (which denote the lowest and highest ratings given by crew members) are shown in orange if the upper end of the range exceeds 4. Although all conditions show a mean task acceptability less than 4 for both roles, the range of ratings provided did exceed 4 for a few conditions.

Table 13. Task Acceptability Means and Ranges for Incapacitated Crew Member Upload Task

	Suit Weight (kg [lbs])	Task Acceptability					
		0/0		MHMA		POGO	
		Mean	Range	Mean	Range	Mean	Range
Incap. Crew On-load (deck role)	90.8 (200)	2.0	2,2	1.8	1,3	2.3	2,3
	136.1 (300)	3.3	2,7	2.0	2,2	2.5	1,5
	181.4 (400)	2.0	1,3	3.0	2,4	3.0	2,5
Incap. Crew On-load (sand role)	90.8 (200)	2.8	2,4	2.5	1,4	2.5	2,3
	136.1 (300)	1.7	1,3	1.8	1,2	3.0	1,5
	181.4 (400)	2.3	2,3	2.3	2,3	2.3	2,3

5.4.1 Incapacitated Crew On-load Deck Role Crew Comments

It should be noted that all crew members rated the 0/0 CG, 90.8-kg (200-lb) condition with a GCPS of 2, which means that they all thought it was equivalent to performing the same task in shirtsleeves in 1*g*. The crew preferred to use the lower-winch handle as it did not require as much effort as did the upper-winch handle located at shoulder height. RPE ratings for the 0/0, 90.8-kg (200-lb) condition varied from 7 to 13, providing for a large range. GCPS ratings at the 0/0, 136.1-kg (300-lb) and the 0/0, 181.4-kg (400-lb) conditions were mixed, as some crew members had trouble looking up.

At the MHMA, 90.8-kg (200-lb) condition, with similar RPE ratings and GCPS to the 0/0, 90.8-kg (200-lb) condition, the crew again stated that the upper-winch handle was too high. At the MHMA, 136.1-kg (300-lb) condition, one crew member thought the condition was objectionable but another crew member thought that it did not require minimal compensation; as with the other conditions, one crew member stated that the upper winch was too high.

At the MHMA, 181.4-kg (400-lb) condition, the crew had to work harder because of the high winch, which was similar to other conditions. There were mixed comments for the POGO CG at the 90.8-, 136.1-, and 181.4-kg (200-, 300-, and 400-lb) conditions.

5.4.2 Incapacitated Crew On-load Sand Role Crew Comments

In general, looking up to monitor the raising of the crew member was noted as being more difficult at higher weights and as the CG moved away from 0/0. A crew member reported that the low, ground-reaction force associated with the 0/0, 90.8-kg (200-lb) condition made him more likely to slip on the sandy surface. Some crew members reported that the presences of either a second tagline or a tagline attachment point on the outer edge of the PLSS may provide easier access and better control of rotation.

5.5 Incapacitated crew member space exploration vehicle ingress results

The incapacitated crew member upload task was performed by a single crew member, as described in section 4.6.2, who was using different methods to perform the ingress; i.e., side-hatch (Figure 28) and suitport (Figure 29).

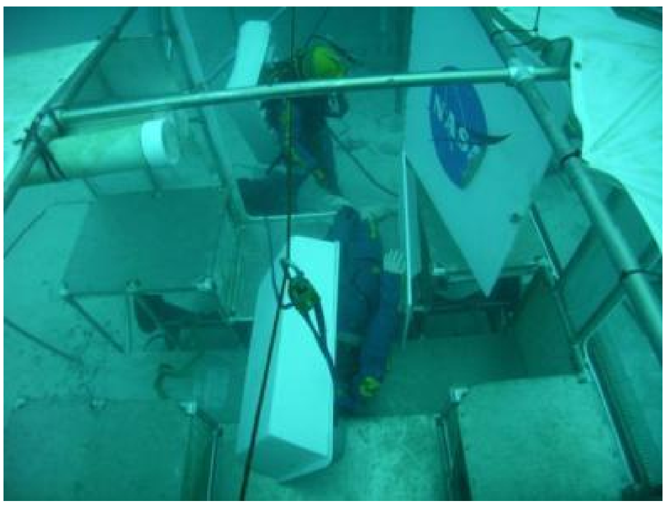


Figure 28. Crew member performing incapacitated crew member 101.6 cm by 152.4 cm (40 in. by 60 in.) side hatch ingress task.

Figure 29. Crew member performing incapacitated crew member suitport ingress task.

Table 14 shows the mean and range of the GCPS, RPE, and task acceptability ratings collected from the crew members immediately following each test condition. GCPS ratings with means higher than 3 are shaded in red, and ranges (which denote the lowest and highest ratings given by crew members) are shown in orange if the upper end of the range exceeds 3. While no acceptability standards were set for RPE ratings other than for test termination criteria, ratings greater than 13 ("somewhat hard" on the RPE scale) are highlighted in red, and ranges with a maximum higher than 13 are highlighted in orange. Task acceptability ratings with means higher than 4 are shaded in red, and ranges are shown in orange if the upper end of the range exceeds 4.

From the table it can be seen that all conditions had very good GCPS ratings. RPE rating means for side-hatch ingress were higher than for suit-port ingress. The task acceptability mean for the 101.6 cm by 101.6 cm (40 in. by 40 in.) side-hatch was higher than for the other two methods and was the only task acceptability mean that exceeded 4.

Table 14. GCPS, RPE, and Task Acceptability Means and Ranges for the Incapacitated Crew Member SEV Ingress Tasks

	GCPS		RPE		Task Acceptability	
	Mean	Range	Mean	Range	Mean	Range
Suit-port Incapacitated Crew Ingress	1.6	1,3	13.3	13,15	3.2	2,4
101.6 cm by 101.6 cm (40 in. by 40 in.) Incapacitated Crew Ingress	1.0	1,1	15.3	13,18	4.6	2,9
101.6 cm by 152.4 cm (40 in. by 60 in.) Incapacitated Crew Ingress	1.0	1,1	14.3	14,15	3.25	2,4

5.5.1 Incapacitated Crew Member Space Exploration Vehicle Ingress Crew Comments

Crew members reported that the haul system worked well to reduce the loads necessary to lift the incapacitated crew member up to the suitport. They stated that using the haul system to lift the crew member for ingress via the side-hatch was quite difficult when the attachment point for the haul system was above the opposite hatch from the ingress point. When the attachment point was moved to the inside of the near hatch, the haul system no longer bent sharply over the bottom of hatch, which had caused significant friction in the other configuration. The addition of the taught line on the ceiling between the doors of the SEV assisting in sliding the incapacitated crew member into the SEV after the crew member was lifted into the side-hatch also made the task easier. It was noted that more design work should go into the best configuration for the progress-capture device to ensure workability in an EVA suit, but the concept was good.

5.6 Simulated extravehicular activity suit weight and center-of-gravity location effects results

Table 15 shows the mean and range of GCPS ratings collected from the crew members immediately following each test condition. GCPS ratings with means higher than 3 are shaded in red, and ranges (which denote the lowest and highest ratings given by crew members) are shown in orange if the upper end of the range exceeds 3. From the table it can be seen that all but one of the tasks showed acceptable GCPS means for the 0/0 CG. The MHMA and POGO CGs show a substantially larger number of GCPS means and ranges above 4, with the largest number occurring at the MHMA CG, 136.1-kg (300-lb) conditions across the tasks.

Table 15. GCPS Means and Ranges for EPSP Circuit Tasks

	Suit Weight (kg [lbs])	GCPS					
		0/0		MHMA		POGO	
		Avg	Range	Avg	Range	Avg	Range
Ambulation	90.8 (200)	2.3	1,3	3.0	2,4	2.8	2,4
	136.1 (300)	3.3	2,4	4.0	3,5	3.0	2,4
	181.4 (400)	2.8	2,3	3.0	2,4	3.0	3,3
EPSP Ladder Up/Down (1×)	90.8 (200)	1.5	1,2	3.0	3,3	2.5	1,4
	136.1 (300)	1.5	1,2	2.3	1,4	2.5	2,3
	181.4 (400)	3.0	2,4	3.0	2,4	3.5	3,4
Forward Fall and Recovery	90.8 (200)	1.5	1,3	1.8	1,3	2.3	1,3

	Suit Weight (kg [lbs])	GCPS					
		0/0		MHMA		POGO	
		Avg	Range	Avg	Range	Avg	Range
(1×)	136.1 (300)	1.5	1,2	2.3	1,4	1.8	1,4
	181.4 (400)	2.5	2,3	2.3	2,3	3.0	1,4
Kneel and recovery (1×)	90.8 (200)	1.5	1,3	1.5	1,3	1.5	1,3
	136.1 (300)	1.5	1,3	1.8	1,4	1.5	1,3
	181.4 (400)	2.5	2,3	2.0	1,3	2.3	1,3
Ramp (Ascending) (1×)	90.8 (200)	2.3	1,3	3.8	3,4	2.8	1,4
	136.1 (300)	2.3	1,4	3.8	2,5	2.8	1,4
	181.4 (400)	2.3	1,3	2.5	1,3	2.3	1,3
Ramp (Descending) (1×)	90.8 (200)	2.0	1,3	2.5	2,3	1.8	1,3
	136.1 (300)	2.0	1,3	3.3	2,4	2.5	1,4
	181.4 (400)	2.3	1,4	2.5	2,3	2.8	2,3
Rock Pickup (all)	90.8 (200)	2.0	1,4	2.8	2,3	3.3	1,5
	136.1 (300)	2.0	1,3	3.5	2,5	3.3	2,4
	181.4 (400)	3.0	2,4	2.5	1,4	4.0	3,5
Shoveling (15× into bucket)	90.8 (200)	2.5	1,3	2.8	2,3	3.0	2,4
	136.1 (300)	2.3	1,4	4.0	2,5	3.0	1,5
	181.4 (400)	2.0	1,3	2.0	1,3	2.3	2,3

Table 16 shows the mean and range of RPE ratings collected from the crew members immediately following each test condition. While no acceptability standards were set for RPE ratings other than for test termination criteria, ratings greater than 13 ("somewhat hard" on the RPE scale) are highlighted in red, and ranges with a maximum higher than 13 are highlighted in orange. Nearly all tasks at all conditions showed RPE means and ranges below 13, except for the rock pickup and shoveling tasks and particularly at the higher suit weights.

Table 16. RPE Means and Ranges for EPSP Circuit Tasks

	Suit Weight (kg [lbs])	RPE					
		0/0		MHMA		POGO	
		Avg	Range	Avg	Range	Avg	Range
Ambulation	90.8 (200)	8.8	8,9	9.3	7,12	9.0	7,11
	136.1 (300)	10.0	9,12	10.0	9,11	9.3	7,11
	181.4 (400)	11.0	10,12	10.3	8,12	10.3	8,12
EPSP Ladder Up/Down (1×)	90.8 (200)	9.0	9,9	9.5	7,12	9.0	9,9
	136.1 (300)	8.0	7,9	9.8	8,12	8.5	6,11
	181.4 (400)	12.3	10,15	11.8	10,13	11.8	11,13

	Suit Weight (kg [lbs])	RPE					
		0/0		MHMA		POGO	
		Avg	Range	Avg	Range	Avg	Range
Fwd Fall and Recovery (1×)	90.8 (200)	7.5	7,9	9.0	8,11	9.0	9,9
	136.1 (300)	8.8	7,10	9.3	8,11	8.3	7,10
	181.4 (400)	9.5	8,11	9.3	8,12	9.5	8,11
Kneel and recovery (1×)	90.8 (200)	7.5	7,9	7.5	7,8	7.3	7,8
	136.1 (300)	9.3	7,13	8.0	7,11	7.5	7,9
	181.4 (400)	10.0	8,12	9.0	7,12	9.0	7,11
Ramp (Ascending) (1×)	90.8 (200)	9.0	9,9	10.3	9,12	9.8	8,11
	136.1 (300)	8.8	6,11	11.0	9,12	8.5	6,10
	181.4 (400)	11.0	8,13	11.0	10,12	10.5	9,11
Ramp (Descending) (1×)	90.8 (200)	7.5	7,9	7.8	7,9	7.5	6,9
	136.1 (300)	7.8	7,9	8.0	7,9	7.3	6,9
	181.4 (400)	8.3	7,9	9.0	7,11	9.0	7,11
Rock Pickup (all)	90.8 (200)	12.3	11,13	11.0	10,12	11.3	9,13
	136.1 (300)	11.0	10,12	11.8	9,13	11.3	9,13
	181.4 (400)	14.3	13,15	13.8	11,16	13.5	12,15
Shoveling (15× into bucket)	90.8 (200)	11.5	10,12	12.5	10,15	12.0	10,14
	136.1 (300)	11.5	11,12	11.8	9,13	10.5	9,11
	181.4 (400)	13.8	13,15	13.5	11,15	12.8	11,15

Table 17 shows the mean and range of the task acceptability ratings collected from the crew members immediately following each test condition. Task acceptability ratings with means higher than 4 are shaded in red, and ranges (which denote the lowest and highest ratings given by crew members) are shown in orange if the upper end of the range exceeds 4. All conditions show a mean task acceptability that is less than 4, with only a couple of conditions having a range that exceeded 4.

Table 17. Task Acceptability Means and Ranges for EPSP Circuit Tasks

	Suit Weight (kg [lbs])	Task Acc					
		0/0		MHMA		POGO	
		Avg	Range	Avg	Range	Avg	Range
Ambulation	90.8 (200)	1.3	1,2	1.5	1,2	1.3	1,2
	136.1 (300)	1.5	1,2	1.5	1,2	1.8	1,2
	181.4 (400)	2.0	1,3	1.8	1,2	1.5	1,2
EPSP Ladder Up/Down (1×)	90.8 (200)	2.3	1,3	2.3	2,3	1.8	1,3
	136.1 (300)	1.8	1,2	2.0	1,4	1.5	1,2
	181.4 (400)	2.3	2,3	3.0	2,4	3.3	2,4

	Suit Weight (kg [lbs])	Task Acc					
		0/0		MHMA		POGO	
		Avg	Range	Avg	Range	Avg	Range
Forward Fall and Recovery (1×)	90.8 (200)	1.3	1,2	1.5	1,2	1.8	1,2
	136.1 (300)	1.8	1,2	2.3	1,4	1.8	1,3
	181.4 (400)	1.8	1,2	1.8	1,2	2.5	1,5
Kneel and recovery (1×)	90.8 (200)	1.3	1,2	1.3	1,2	1.3	1,2
	136.1 (300)	1.5	1,3	2.0	1,3	1.3	1,2
	181.4 (400)	1.5	1,2	1.5	1,2	1.5	1,2
Ramp (Ascending) (1×)	90.8 (200)	1.5	1,2	2.5	2,3	2.3	1,3
	136.1 (300)	1.3	1,2	2.5	2,4	1.5	1,2
	181.4 (400)	1.8	1,2	2.0	2,2	1.8	1,2
Ramp (Descending) (1×)	90.8 (200)	1.5	1,2	1.5	1,2	1.3	1,2
	136.1 (300)	1.8	1,3	2.5	1,4	1.8	1,2
	181.4 (400)	2.0	1,4	2.5	2,3	2.0	1,3
Rock Pickup (all)	90.8 (200)	1.8	1,2	1.8	1,2	2.0	1,3
	136.1 (300)	1.5	1,2	3.0	2,5	2.3	1,3
	181.4 (400)	2.0	1,3	2.0	1,3	2.0	2,2
Shoveling (15× into bucket)	90.8 (200)	1.5	1,2	1.8	1,2	2.3	2,3
	136.1 (300)	1.8	1,2	2.8	2,4	1.5	1,2
	181.4 (400)	1.8	1,2	1.8	1,2	1.8	1,2

5.6.1 Ambulation Results

Figure 30. Crew member performing an ambulation trial.

The ambulation task (Figure 30) was performed as described in section 4.6.1.1, with a crew member making four passes over a 6.1-m (20-ft) ambulation path and providing GCPS, RPE, and task acceptability ratings at the completion of all four passes. The GCPS, RPE, and task acceptability ratings for this task are shown in Table 15, Table 16, and Table 17, respectively.

5.6.1.1 Ambulation crew comments

The crew reported that water drag did affect the fidelity of the simulation as some crew members had to lean forward to compensate for a strong current at some points during the study. The 0/0, 90.8-kg (200-lb) condition received positive comments from all crew members. According to crew comments, the strong current may have had the greatest impact to the 0/0, 136.1-kg (300-lb) condition although efforts were made by the crew to discount the effect. For the 0/0, 181.4-kg (400-lb) condition, all crew members felt the workload was quite high and contributed to their higher RPE ratings.

At the MHMA, 90.8-kg (200-lb) condition, a couple of crew members commented that their ground reaction forces felt lower. One crew member felt as though he had to lean forward to compensate, and another crew member reported that he felt that his CG was farther aft than some other conditions. At the MHMA, 136.1-kg (300-lb) condition, three crew members stated that they had to lean forward quite a lot to walk. For the MHMA, 181.4-kg (400-lb) condition, one crew member again felt he had to lean forward a lot to make progress, and another crew member stated that the extra weight was evident.

At the POGO, 90.8-kg (200-lb) condition, the crew had mixed comments. One crew member felt good and reported no instability. However, another crew member felt that this condition caused instability, especially when turning and stopping. For the POGO, 136.1-kg (300-lb) condition, all crew members felt as though they had to lean forward a fair amount to walk. One crew member stated that he could feel that the CG seemed high and aft. At the POGO, 181.4-kg (400-lb) condition, two crew members stated that they could feel the extra weight, and that the extra weight seemed to accentuate the instability. It was clear the crew felt the workload go up at higher suit weights, as is evidenced in Figure 31, which shows the relative change in RPE from a 136.1-kg (300-lb) reference point.

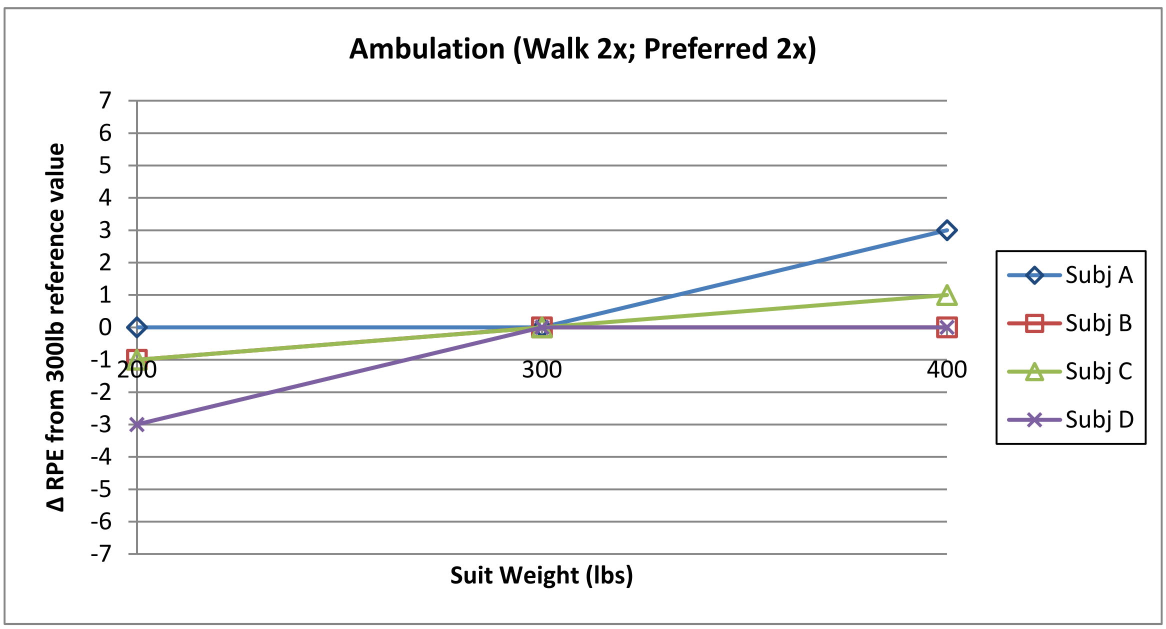


Figure 31. Change in RPE from a 136.1-kg (300-lb) suit for ambulation.

5.6.2 Ramp Ascent and Descent Results

The ramp ascent and descent task (Figure 32) was performed as described in section 4.6.1.1, with a crew member making a single pass up the ramp and a single pass down the ramp, providing GCPS, RPE, and task acceptability ratings at the completion of each phase. The GCPS, RPE, and task acceptability ratings for this task are shown in Table 15, Table 16, and Table 17, respectively.

Figure 32. Crew member performing a ramp descent trial.

5.6.2.1 Ramp ascent: crew comments

At the 90.8-kg (200-lb) condition across all CGs, the crew reported that the ramp felt slippery due to lower ground reaction forces. Conversely, at the181.4-kg (400-lb) condition across all CGs, the crew reported better traction and stability but a higher workload.

The crew reported that the MHMA and POGO CGs required them to lean forward further and walk more on their toes during ascent.

5.6.2.2 Ramp descent crew comments

Overall, the crew reported lower RPE scores for descending the ramp than for ascending the ramp. They felt they had more control at lower weights, and would have preferred a less-steep ramp at the 181.4-kg (400-lb) condition to help them control their momentum.

5.6.3 Kneel and Recover Results

The kneel and recover task was performed as described in section 4.6.1.1, with a crew member dropping to a single knee and returning to a standing position, providing GCPS, RPE, and task acceptability ratings after returning to the standing position. The GCPS, RPE, and task acceptability ratings for this task are shown in Table 15, Table 16, and Table 17, respectively.

5.6.3.1 Kneel and recover crew comments

The crew generally reported all conditions were relatively easy but some crew members reported that the added weight at the 181.4-kg (400-lb) condition made the task more difficult.

5.6.4 Forward Fall and Recover Results

The fall and recover task (Figure 33) was performed as described in section 4.6.1.1,with a crew member dropping to a prone position and returning to a standing position, providing GCPS, RPE, and task acceptability ratings after returning to the standing position.

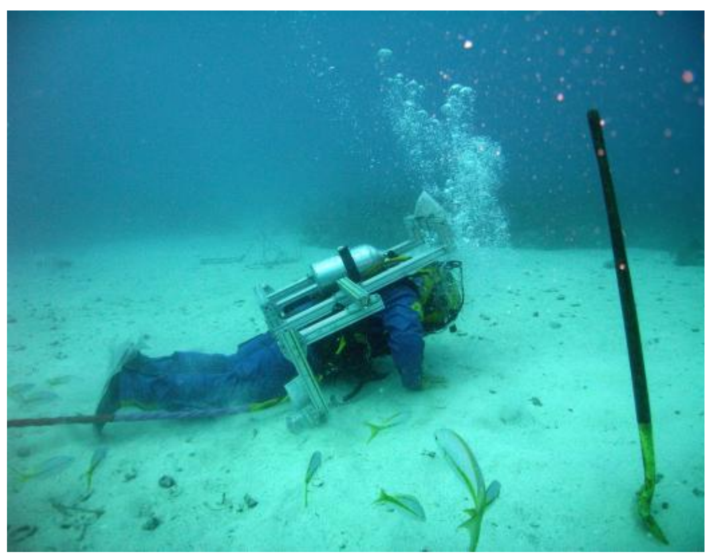


Figure 33. Crew member performing forward fall and recover trial.

The GCPS, RPE, and task acceptability ratings for this task are shown in Table 15, Table 16, and Table 17, respectively.

5.6.4.1 Fall and recover crew comments

The crew generally reported all conditions were relatively easy, but some crew members reported that the added weight at the 181.4-kg (400-lb) condition made the task more difficult. Some crew members also reported that at the POGO CG, it felt more unstable to get up and felt as though they were being pulled forward as they tried to rise to the standing position.

Figure 34. Crew member performing shoveling trial.

5.6.5 Shoveling Results

The shoveling task (Figure 34) was performed as described in section 4.6.1.1, with a crew member shoveling 15 scoops of sand into a bucket, thereby providing GCPS, RPE, and task acceptability ratings after all repetitions were completed. The GCPS, RPE, and task acceptability ratings for this task are shown in Table 15, Table 16, and Table 17, respectively.

5.6.5.1 Shoveling crew comments

At the 0/0 CG, some crew members felt that it was a bit more difficult to push the shovel into the sand at the 90.8-kg (200-lb) condition, and most preferred the heavier weights as they thought it made them feel more stable.

At the MHMA CG, the lower ground reaction forces at 90.8 kg (200 lbs) made the task a bit more difficult for the crew; at 181.4 kg (400 lbs), the crew felt more stable. For the MHMA, 136.1-kg (300-lb) condition, none of the crew found the task desirable; additionally, one crew member felt that the rig may have been incorrectly attached, possibly contributing to altered ratings.

The POGO CG provided for mixed comments from the crew across the weight conditions, but all crew members liked the 181.4-kg (400-lb) weight condition the best for the task. In general, the crew preferred the 181.4-kg (400-lb) condition across all CGs for this task.

5.6.6 Rock Pickup Results

The rock pickup task (Figure 35) was performed as described in section 4.6.1.1, with a crew member moving simulated rocks of different size/weight from one location to another, providing GCPS, RPE, and task acceptability ratings after completing all repetitions. The GCPS, RPE, and task acceptability ratings for this task are shown in Table 15, Table 16, and Table 17, respectively.

Figure 35. Crew member performing rock pickup trial.

5.6.6.1 Rock pickup crew comments

Crew members reported general instability at the POGO CG for this task, and thus reported higher GCPS scores. The crew reported higher workloads at 181.4 kg (400 lbs) and at MHMA and POGO CGs. In general, workload (RPE) was higher at 181.4 kg (400 lbs) across all CGs. There was a fair amount of inter-subject variability for GCPS ratings. For example, at the 0/0, 90.8-kg (200-lb) condition, one crew member felt that is was difficult to bend at waist and thus had to kneel for stability, but the rest of the crew appreciated the lightness.

All of the crew liked the 0/0, 136.1-kg (300-lb) condition and felt quite stable with little compensation required. Conversely, for the MHMA CG conditions, the crew reported feeling the CG and weight interactions more clearly and seemed to prefer the 181.4-kg (400-lb) condition better.

At the POGO, 90.8-kg (200-lb) condition, one crew member felt "spring-loaded" and liked the condition while all other crew members felt instability of different degrees. Although there were mixed comments at the POGO, 136.1-kg (300-lb) condition instability and little compensation required generally were reported. For the POGO, 181.4-kg (400-lb) condition, all crew members said that bending down on one knee was the best approach as this condition made it difficult to bend at the waist.

5.6.7 Extravehicular Activity Physiology, Systems, and Performance Ladder Climb Results

Figure 36. Crew member performing an EPSP ladder climb trial.

The EPSP ladder-climb task (Figure 36) was performed as depicted in section 4.6.1.1, with a crew member ascending the ladder to the top rung and descending to return to the seafloor, thus providing GCPS, RPE, and task acceptability ratings after the completion of the descent. The GCPS, RPE, and task acceptability ratings for this task are shown in Table 15, Table 16, and Table 17, respectively.

5.6.7.1 Extravehicular activity physiology, systems, and performance ladder-climb crew comments

Crew members felt that this ladder was too steep and often felt as if they were being pulled backward as they executed the task. For the 0/0 CG, the crew members felt the task was light work, but compensation jumped up at the 181.4-kg (400-lb) weight for this CG and they also felt they had to work hard to fight the feeling of being pulled back.

5.6.8 Cargo-lander Ladder Angle Results

The cargo-lander ladder tasks (Figure 37) were performed as described in section 4.6.1.2, with a crew member ascending the ladder to the deck, stepping off the ladder to the deck, stepping back onto the ladder, and descending to return to the seafloor, thereby providing GCPS, RPE, and task acceptability ratings after completion of the descent.

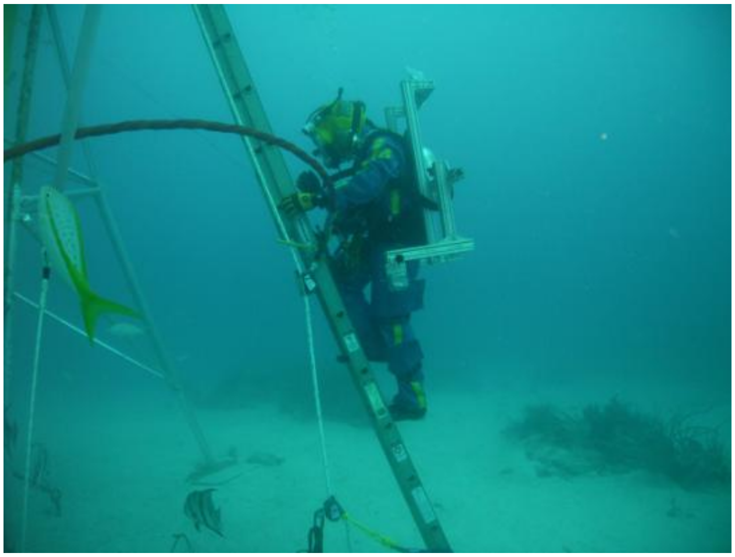


Figure 37. Crew member climbing the lander ladder.

Table 18 shows the mean and range of GCPS ratings collected from the crew members immediately following each test condition. The GCPS ratings with means higher than 3 are shaded in red, and ranges (which denote the lowest and highest ratings given by crew members) are shown in orange if the upper end of the range exceeds 3. From the table it can be seen that all conditions show an acceptable mean GCPS for the 20-deg ladder angle.

Table 19 shows the mean and range of RPE ratings collected from the crew members immediately following each test condition. While no acceptability standards were set for RPE ratings other than for test termination criteria, ratings greater than 13 ("somewhat hard" on the RPE scale) are highlighted in red, and ranges with a maximum higher than 13 are highlighted in orange. All conditions showed RPE means below 13, and all but one range had an RPE below 13 as well.

Table 18. GCPS Means and Ranges for Cargo-lander Ladder Tasks

	Suit Weight (kg [lbs])	GCPS					
		0/0		MHMA		POGO	
		Avg	Range	Avg	Range	Avg	Range
Ladder – 10 deg	90.8 (200)	2.0	1,3	2.0	1,3	2.0	1,3
	136.1 (300)	1.8	1,3	3.8	3,5	2.5	1,3
	181.4 (400)	2.8	2,4	3.5	2,5	3.3	3,4
Ladder – 20 deg	90.8 (200)	1.3	1,2	1.3	1,2	2.0	1,3
	136.1 (300)	1.5	1,2	2.8	1,4	2.0	1,3
	181.4 (400)	2.8	2,3	2.8	2,3	2.8	2,3
Ladder – 30 deg	90.8 (200)	2.0	1,3	3.0	1,4	2.5	1,4
	136.1 (300)	1.5	1,3	3.3	3,4	2.8	2,3
	181.4 (400)	3.3	2,4	3.3	3,4	2.8	1,4

Table 19. RPE Means and Ranges for Cargo-lander Ladder Tasks

	Suit Weight (kg [lbs])	RPE Mean					
		0/0		MHMA		POGO	
		Avg	Range	Avg	Range	Avg	Range
Ladder – 10 deg	90.8 (200)	9.0	8,10	10.3	9,11	10.0	8,11
	136.1 (300)	9.0	7,11	10.3	9,12	9.5	7,12
	181.4 (400)	12.3	11,13	12.3	12,13	11.8	11,13

	Suit Weight (kg [lbs])	RPE Mean					
		0/0		MHMA		POGO	
		Avg	Range	Avg	Range	Avg	Range
Ladder – 20 deg	90.8 (200)	9.3	8,11	9.5	7,11	10.0	8,11
	136.1 (300)	8.3	7,9	10.8	8,15	9.3	7,12
	181.4 (400)	12.3	11,15	12.0	12,12	11.8	11,13
Ladder – 30 deg	90.8 (200)	9.8	8,11	9.3	8,11	10.3	9,11
	136.1 (300)	8.5	7,9	10.3	8,11	9.0	7,11
	181.4 (400)	11.3	9,13	11.0	10,12	11.0	10,12

Table 20 shows the mean and range of task acceptability ratings collected from the crew members immediately following each test condition. Task acceptability ratings with means higher than 4 are shaded in red, and ranges (which denote the lowest and highest ratings given by crew members) are shown in orange if the upper end of the range exceeds 4. All conditions showed task acceptability means below 4, and all but four ranges had task acceptability below 4 as well.

Table 20. Task Acceptability Means and Ranges for Cargo-lander Ladder Tasks

	Suit Weight (kg [lbs])	Task Acc. Mean					
		0/0		MHMA		POGO	
		Avg	Range	Avg	Range	Avg	Range
Ladder – 10 deg	90.8 (200)	2.3	1,3	3.3	2,4	2.5	1,5
	136.1 (300)	2.3	1,3	4.0	3,6	2.5	2,4
	181.4 (400)	3.3	2,4	3.8	2,5	3.3	2,4
Ladder – 20 deg	90.8 (200)	1.3	1,2	2.0	1,3	1.5	1,2
	136.1 (300)	1.3	1,2	2.5	1,4	2.0	2,2
	181.4 (400)	2.0	1,3	2.3	2,3	2.3	2,3
Ladder – 30 deg	90.8 (200)	2.8	2,3	3.0	3,3	2.5	2,3
	136.1 (300)	2.0	1,3	3.8	3,5	2.3	1,3
	181.4 (400)	3.3	2,4	3.0	2,4	2.0	1,3

5.6.8.1 Cargo-lander Ladder Task Crew Comments

In general, the 10-deg ladder angle felt too steep and crew members felt they were being pulled backward as they climbed; this was especially true at the 181.4-kg (400-lb) suit weight across all CGs. The 20-deg ladder angle was a "sweet spot" according to the crew; crew members had favorable comments across all weights and CGs for this angle. The crew also reported a good balance of stability and workload at this angle and an easiness of foot placement. The 30-deg angle received the most negative comments. Crew members complained about lateral instability (i.e., a feeling that it would be easier to fall sideways) and issues with placing their feet properly to hit the next ladder rung, especially while descending. However, all crew members felt the 181.4-kg (400-lb) POGO configuration worked really well at this ladder angle, suggesting that the interactions between weight and CG deserve further exploration.

5.7 Crew productivity communications results

Table 21 shows the results of analyzing the number of exploration tasks completed and the total time to completion and compares the number for continuous vs. twice-per-day communications schemes. The continuous communications scheme was executed for the first week of the mission, and the twice-per-day communications scheme was executed for the second week of the mission. Note that for both weeks, all planned tasks were completed so that the number of planned tasks is equivalent to the number of completed tasks.

Table 21. Crew Productivity Comparison by Communications Type

	Communications Type	
	Continuous	Twice per Day
Total No. of Exploration Tasks Completed	341	343
Total Time to Complete Exploration Task	10:52:37	10:54:10
Average Time per Task Completed	00:01:55	00:01:54

5.8 Crew member hatchway size reduced-gravity results

The reduced-gravity hatchway translation tasks (Figure 38) were performed as described in section 4.6.2, with a crew member doffing his/her PLSS mock-up and shedding weight to go to lunar IVA weight before translating through the hatchway, thus providing GCPS, RPE, and task acceptability ratings after completing the translations in each direction.

Figure 38. Crew member negotiating 101.6 cm by 101.6 cm (40 in. by 40 in.) hatch mock-up.

Table 22 shows the mean and range of the GCPS, RPE, and task acceptability ratings collected from crew members immediately following each test condition. GCPS ratings with means higher than 3 are shaded in red, and ranges (which denote the lowest and highest ratings given by crew members) are shown in orange if the upper end of the range exceeds 3. While no acceptability standards were set for RPE ratings other than for test termination criteria, ratings greater than 13 (“somewhat hard” on the RPE scale) are highlighted in red; ranges with a maximum higher than 13 are highlighted in orange. Task acceptability ratings with means higher than 4 are shaded in red, and ranges are shown in orange if the upper end of the range exceeds 4.

From the table it can be seen that all conditions had very good GCPS, RPE, and task acceptability ratings that were well within the acceptable limits. In addition, crew comments collected stated that the task was trivial; however, it was noted that the addition of handholds on both sides of the tunnel and possibly in the tunnel would make the task design even better.

Table 22. GCPS, RPE, and Task Acceptability Means and Ranges for IVA 101.6 cm by 101.6 cm (40 in. by 40-in.) Hatch Translation

	GCPS		RPE		Task Acceptability	
	Mean	Range	Mean	Range	Mean	Range
101.6 cm by 101.6 cm (40 in. by 40 in.) Hatch Translation (IVA Weight)	1	1,1	6	6,6	1	1,1

5.9 Incapacitated crew member airlock and ascent module ingress results

The incapacitated crew member airlock and ascent module ingress task (see Figure 39, Figure 40, and Figure 41) was performed as described in section 4.6.2, with crew members working both together and solo to perform the task, thus providing GCPS, RPE, and task acceptability ratings after completion of the ingress.

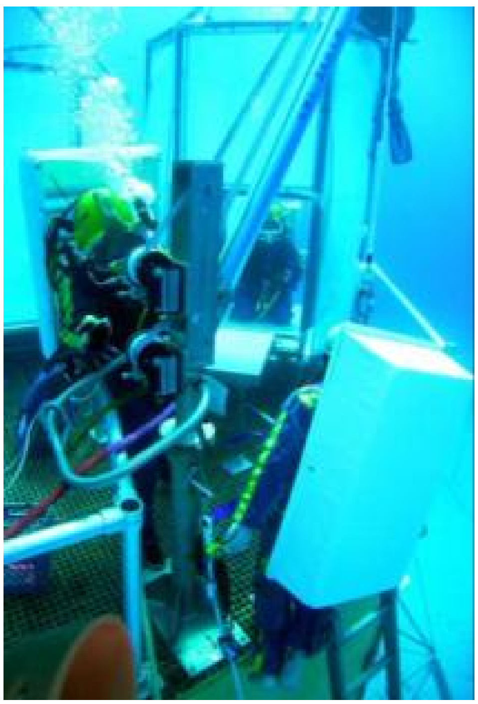


Figure 39. Crew member raising simulated incapacitated crew member to deck.

Figure 40. Crew member positioning simulated incapacitated crew member for ingress to airlock.

Table 23 shows the mean and range of the GCPS, RPE, and task acceptability ratings collected from crew members immediately following each test condition. GCPS ratings with means higher than 3 are shaded in red, and ranges (which denote the lowest and highest ratings given by crew members) are shown in orange if the upper end of the range exceeds 3. While no acceptability standards were set for RPE ratings other than for test termination criteria, ratings greater than 13 ("somewhat hard" on the RPE scale) are highlighted in red, and ranges with a maximum higher than 13 are highlighted in orange. Task acceptability ratings with a means higher than 4 are shaded in red, and ranges are shown in orange if the upper end of the range exceeds 4.

From Table 23 it can be seen that all conditions had good GCPS, RPE, and task acceptability ratings that were within the acceptable limits.

Table 23. GCPS, RPE, and Task Acceptability Means and Ranges for the Incapacitated Crew Member Airlock/Ascent Module Ingress Task

	GCPS		RPE		Task Acceptability	
	Mean	Range	Mean	Range	Mean	Range
Incapacitated Crew Airlock/Ascent Module Ingress	1.8	1,3	11.8	10,13	2.5	1,4

5.9.1 Incapacitated Crew Member Airlock and Ascent Module Ingress Crew Comments

Figure 41. Crew member closing outer hatch of airlock after ingressing simulated incapacitated crew member.

Crew members tried several different methods to complete the task, both acting as a two-person team and solo. When performing the task solo some crew members felt that "muscling" the incapacitated crew member into the airlock was the best solution while others felt that using the haul system was more effective, if slightly slower. Working as a team, it was noted that one person operating the small davit to maneuver the incapacitated crew member onto the diving board was effective while the other crew member was positioned inside the airlock to ingress the crew member the rest of the way. This same technique could be made to work with one crew member rather than a pair of crew members as well, but required pushing the incapacitated crew member into the airlock and following that crew member inside.

It was noted that other solutions could be investigated that use a powered winch (with a manual backup) within the airlock to draw the incapacitated crew member inside. It was also noted that having handholds on the suit itself and the PLSS would make maneuvering the incapacitated crew member easier.

5.10 Crew member airlock and ascent module ingress results

The crew member airlock and ascent module ingress task (see Figure 42 and Figure 43) was performed as described in section 4.6.2. Crew members provided GCPS, RPE, and task acceptability ratings after completing the ingress and the egress.

Table 24 shows the mean and range of the GCPS, RPE, and task acceptability ratings collected from crew members immediately following each test condition. GCPS ratings with means higher than 3 are shaded in red, and ranges (which denote the lowest and highest ratings given by crew members) are shown in orange if the upper end of the range exceeds 3. While no acceptability standards were set for RPE ratings other than for test termination criteria, ratings greater than 13 ("somewhat hard" on the RPE scale) are highlighted in red, and ranges with a maximum higher than 13 are highlighted in orange. Task acceptability ratings with a means higher than 4 are shaded in red, and ranges are shown in orange if the upper end of the range exceeds 4.

Figure 42. Crew member prepares to egress the outer airlock hatchway.

Figure 43. Crew member egressing the outer airlock hatchway.

Table 24. GCPS, RPE, and Task Acceptability Means and Ranges for the Airlock/Ascent Module Ingress Task

	GCPS		RPE		Task Acceptability	
	Mean	Range	Mean	Range	Mean	Range
Airlock/Ascent Module Ingress/Egress	1.3	1,2	7.7	7,9	3.0	1,5

From the table it can be seen that all conditions had good GCPS, RPE, and task acceptability ratings that were within the acceptable limits. The most variability occurred for task acceptability with the maximum of the range being above 4.

5.10.1 Airlock and Ascent Module Ingress Crew Comments

Crew members attempted this task with and without the diving board in place. It was noted that handholds above the inside and the outside of the hatchway would be necessary if ingress and egress were to be done in the supine position. Ingress and egress could be accomplished in the prone position as well. The diving board seemed to help for most crew members, although some crew members felt that it was more helpful for ingress and seemed to get in the way for egress.

5.11 Crew member anchor establishment, translation, and task performance in near-Earth object gravity results

This hypothesis, which was not fully tested during NEEMO 14 due to time limitations, shows some limited concept testing of a jetpack concept that were performed during NEEMO 14 dry runs. This hypothesis is planned to be tested during NEEMO 15, which is currently projected to take place in May 2011. Figure 44 shows an evaluation of jetpack concepts for maneuvering in very-low-gravity fields as performed by two crew members.

Figure 44. Evaluation of jetpack concepts for maneuvering in very-low-gravity fields.

5.12 Crew member interior hatchway size in 1*g* results

This hypothesis was not tested during NEEMO 14 because the interior hatchway width of *Aquarius* is approximately 70 cm (24 in.) (shown in Figure 45). It was deemed that a width of only 70 cm (24 in.) was insufficient to test the hypothesis appropriately.

Figure 45. Interior hatchways of *Aquarius* showing narrow width.

6 Discussion and Conclusions

6.1 Discussion of overall results

The consequences of test benefits from a high-level look at the results grouped the percentage of unacceptable GCPS ratings. Figure 46, Figure 47, and Figure 48 show the percentage across all tasks of GCPS ratings of > 3, 4, and 5-6, respectively. The figures show the largest percentage unacceptable ratings occurred with the MHMA CG and at the 136.1-kg (300-lb) suit weight.

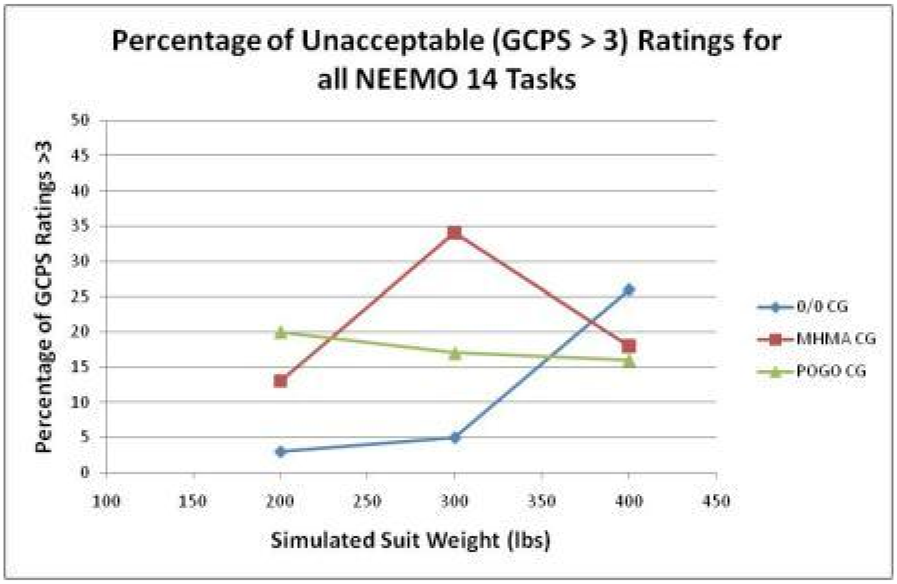


Figure 46. Percentage of unacceptable (GCPS > 3) ratings for all tasks.

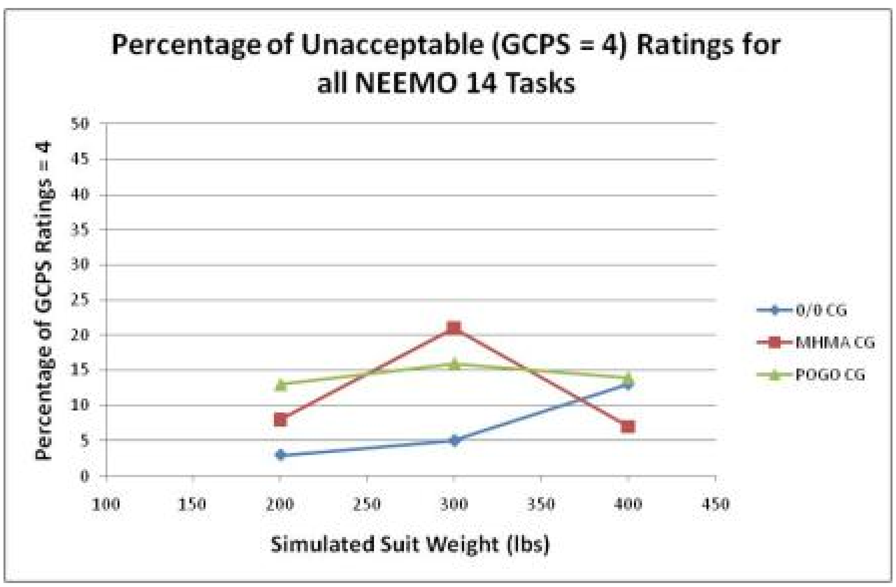


Figure 47. Percentage of unacceptable (GCPS > 4) ratings for all tasks.

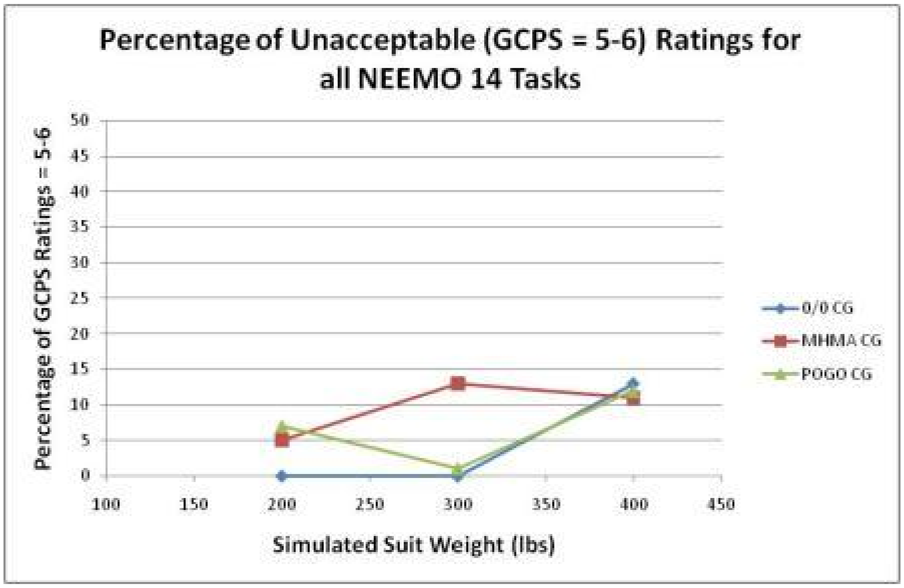


Figure 48. Percentage of unacceptable (GCPS = 5-6) for all tasks.

When the percentage of GCPS ratings > 3 are broken down on a subject-by-subject basis (Figure 49, Figure 50, Figure 51, and Figure 52), we observed that the majority of unacceptable ratings were provided by one crew member (Subject D, Figure 52), indicating that there are subject-to-subject differences yet to be understood as CG and weight interact for the tasks performed.

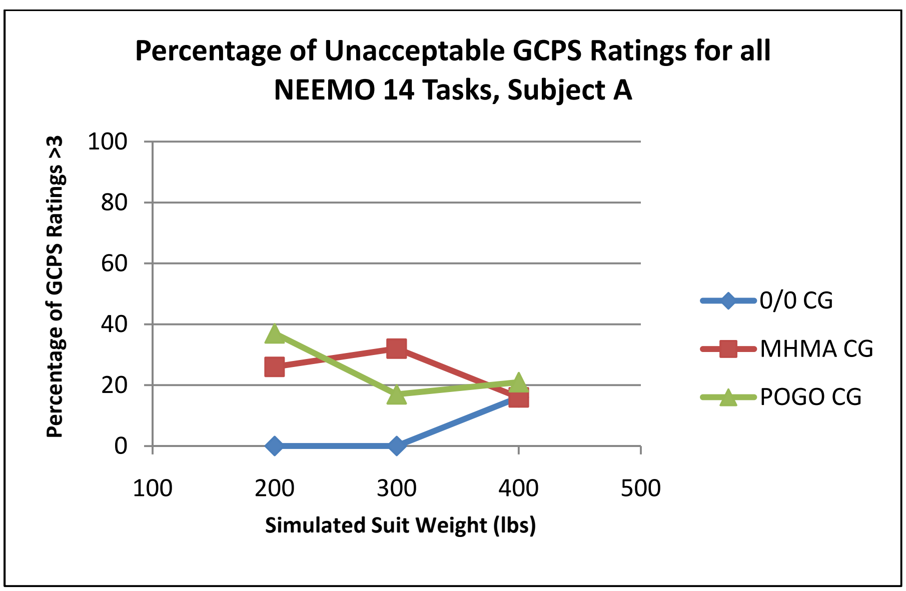


Figure 49. Percentage of unacceptable GCPS ratings for all tasks, Subject A.

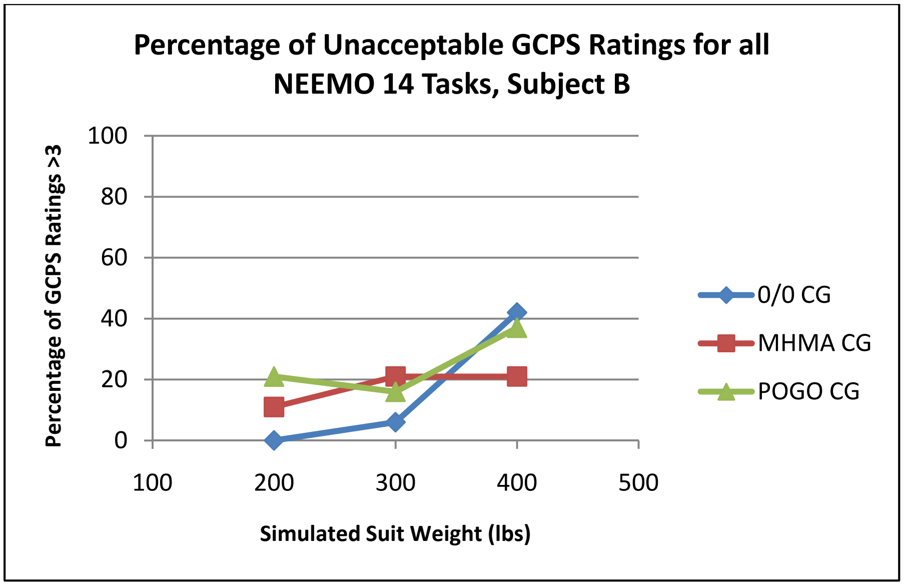


Figure 50. Percentage of unacceptable GCPS ratings for all tasks, Subject B.

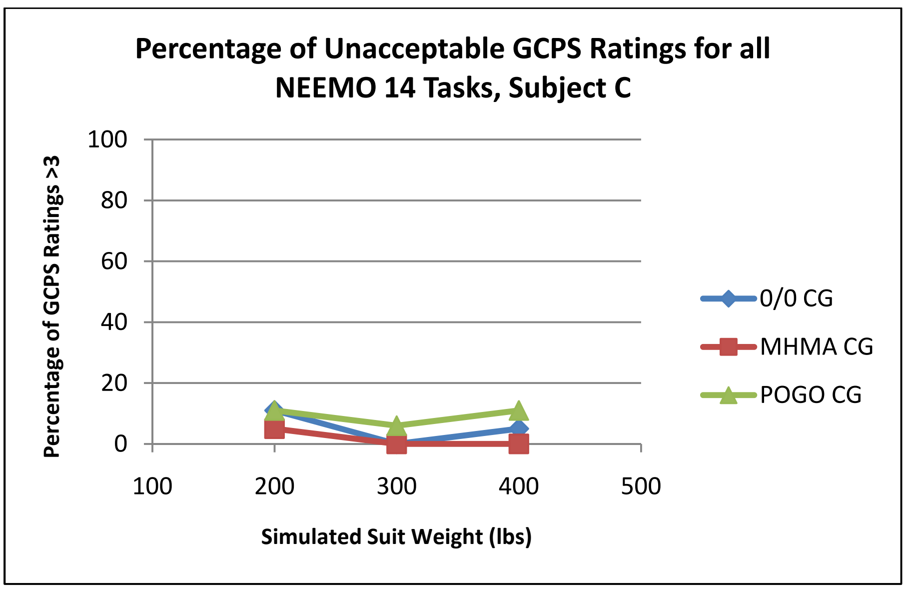


Figure 51. Percentage of unacceptable GCPS ratings for all tasks, Subject C.

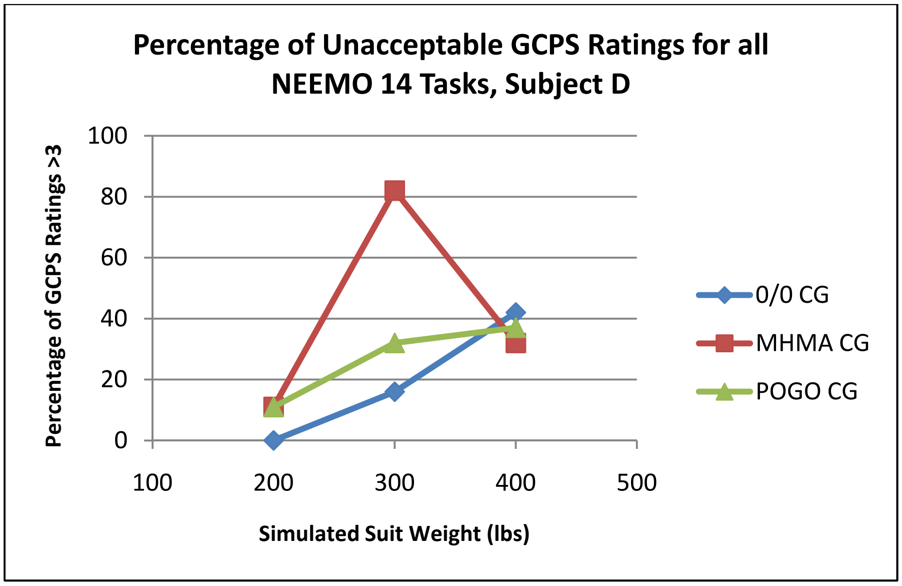


Figure 52. Percentage of unacceptable GCPS ratings for all tasks, Subject D.

Breaking down the tasks by cargo-lander-based tasks (Figure 53) and exploration tasks (Figure 54) provides further insight in that the majority of the GCPS > 3 ratings occurred during the exploration tasks using the MHMA CG and at the 136.1-kg (300-lb) suit weight.

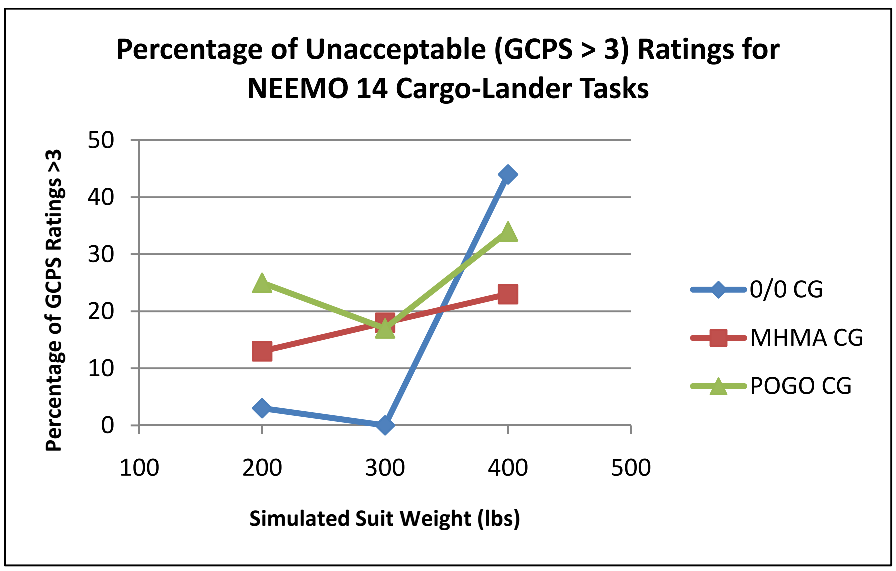


Figure 53. Percentage of unacceptable (GCPS > 3) ratings for cargo-lander-based tasks.

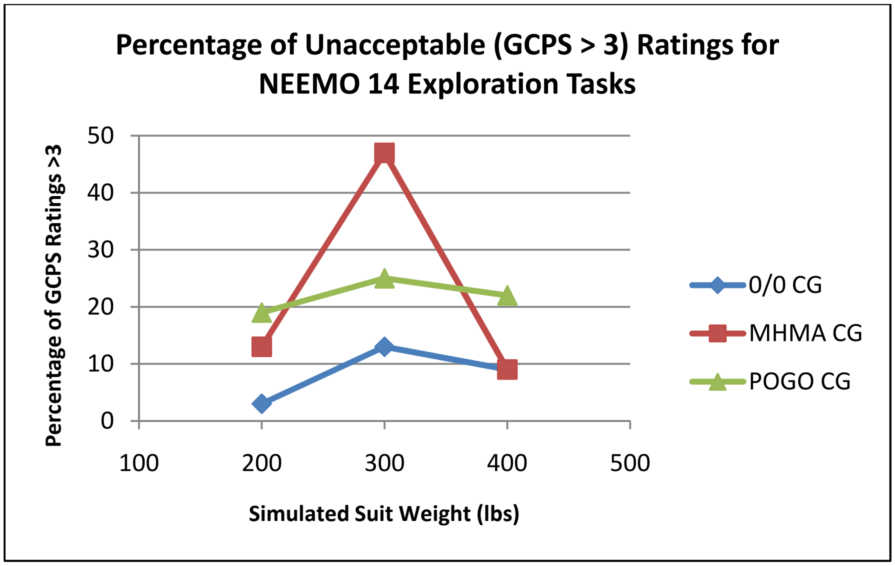


Figure 54. Percentage of unacceptable (GCPS > 3) ratings for EPSP exploration tasks.

Looking at the exploration tasks on a subject-by-subject basis further shows intersubject variation in acceptability of different conditions as Subject A and Subject D (Figure 55 and Figure 58) had issues with the MHMA, 136.1-kg (300-lb) condition while Subject B and Subject C (Figure 56 and Figure 57) did not. Similarly for the cargo-lander tasks (Figure 59, Figure 60, Figure 61, and Figure 62) show variation in acceptability with Subject D having the greatest number of unacceptable ratings for the MHMA condition.

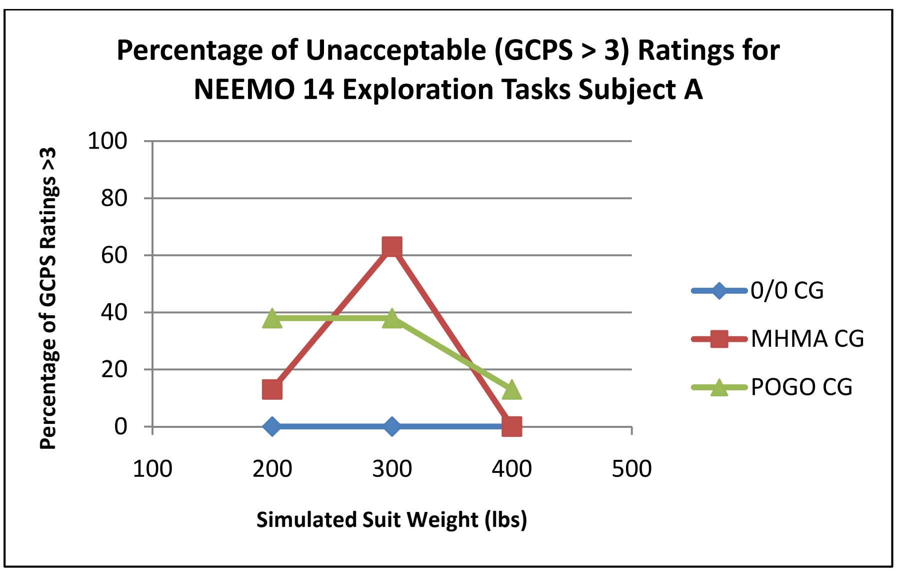


Figure 55. Percentage of unacceptable (GCPS > 3) ratings for exploration tasks, Subject A.

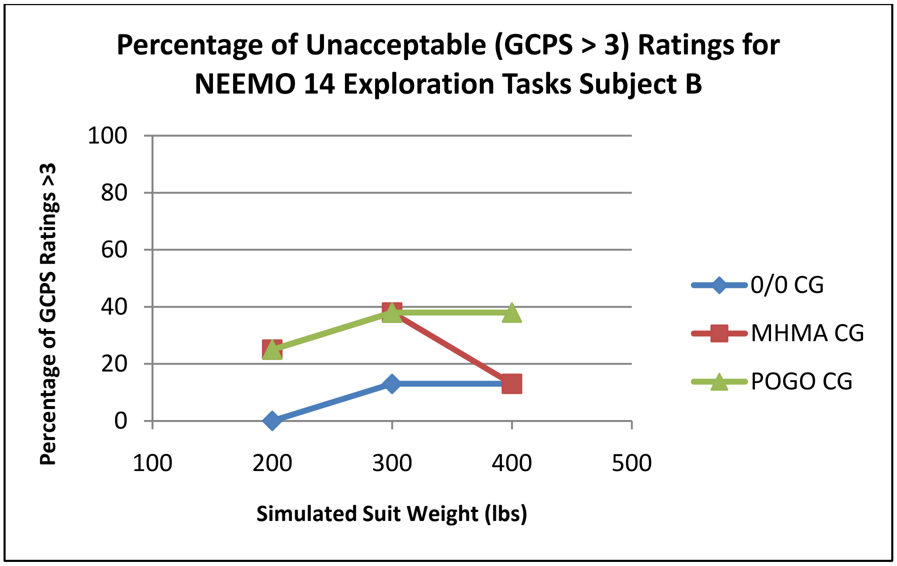


Figure 56. Percentage of unacceptable (GCPS > 3) ratings for exploration tasks, Subject B.

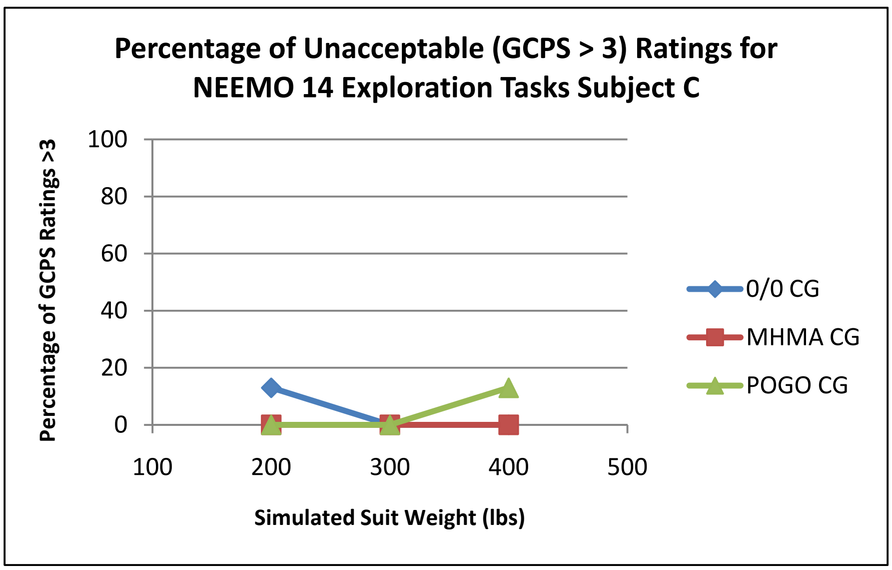


Figure 57. Percentage of unacceptable (GCPS > 3) ratings for exploration tasks, Subject C.

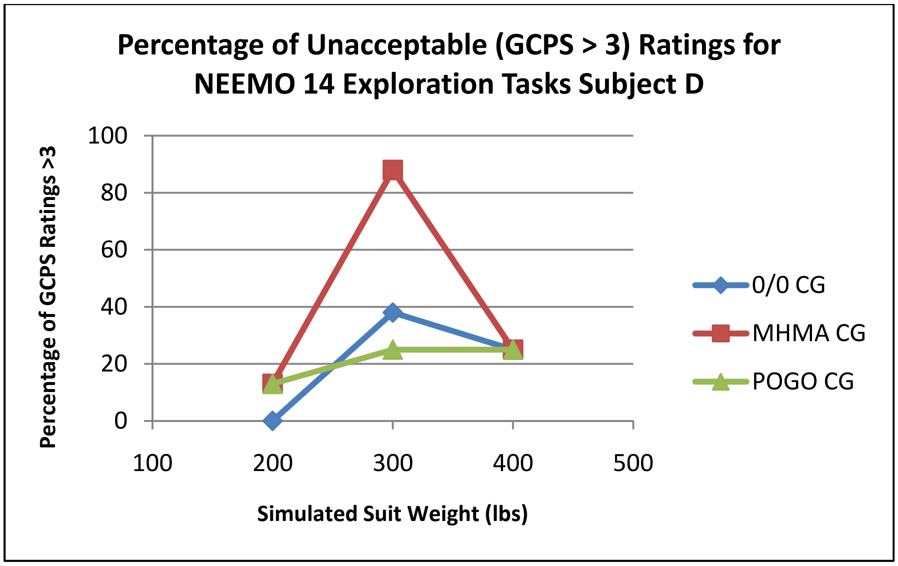


Figure 58. Percentage of unacceptable (GCPS > 3) ratings for exploration tasks, Subject D.

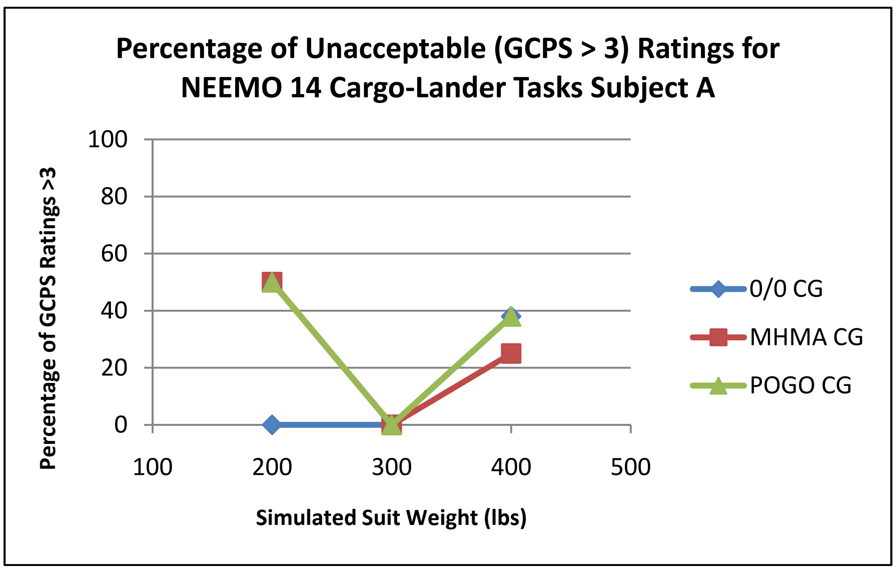


Figure 59. Percentage of unacceptable (GCPS > 3) ratings for cargo-lander tasks, Subject A.

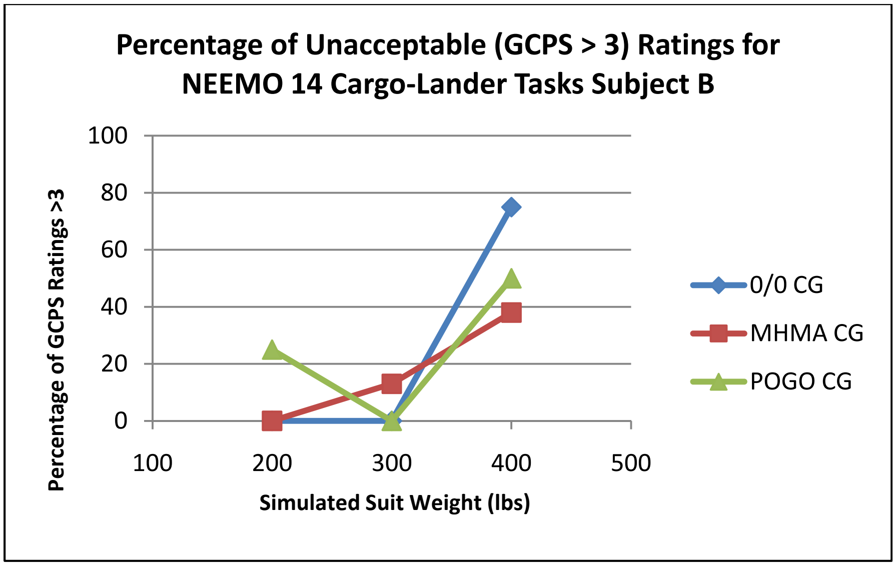


Figure 60. Percentage of unacceptable (GCPS > 3) ratings for cargo-lander tasks, Subject B.

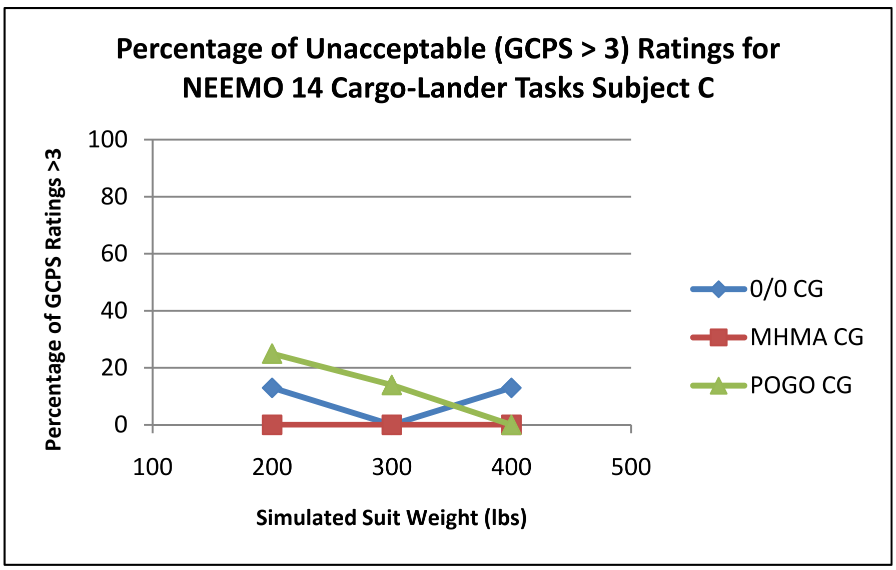


Figure 61. Percentage of unacceptable (GCPS > 3) ratings for cargo-lander tasks, Subject C.

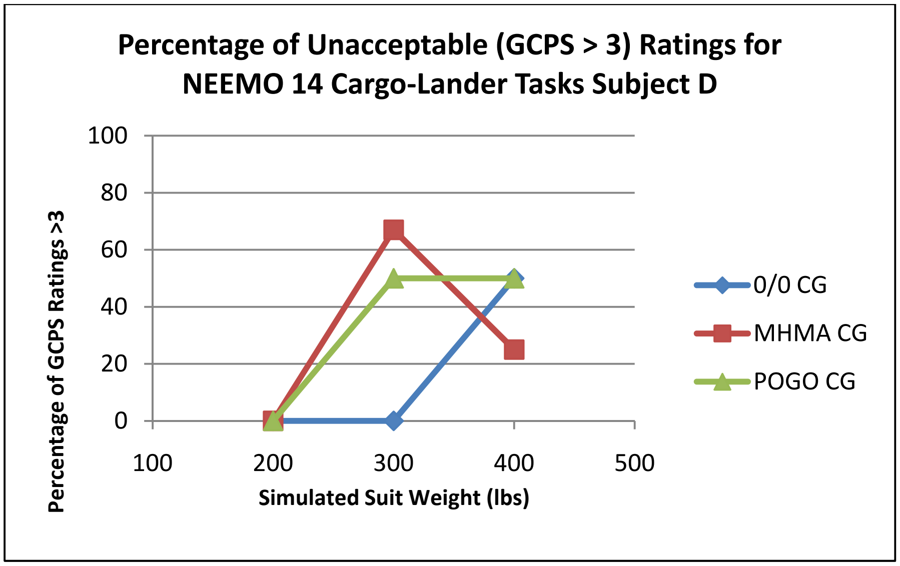


Figure 62. Percentage of unacceptable (GCPS > 3) ratings for cargo-lander tasks, Subject D.

These data show that the 0/0 CG at the 90.8-kg (200-lb) total suit weight had the lowest number of unacceptable ratings across all tasks and appear to be a good target for suit and PLSS designs. However, current projections for combined suit and PLSS weights are more in the neighborhood of 136.1 kg (300 lbs), and the data show that more work needs to be done to understand the interactions between CG and weight in this mid-weight region.

6.2 Actual center-of-gravity locations vs. acceptable gravity compensation and performance scale ratings

Figure 63 shows a plot of GCPS ratings vs. the actual CG location for each crew member and test condition (see section 5.1 for further details on actual CG location computation). The plot contains a linear fit of the GCPS ratings that are less than or equal to 3. When this plot is compared to similar data from a parabolic flight test using the MK-III Space Suit Technology Demonstrator,[4] it is consistent with the findings that it is important to provide upward CG movement if the CG is moved to the aft to allow the crew member to maintain more control over the task performance with less compensation.

Continued analysis of all CG study data from previous NEEMO and Neutral Buoyancy Laboratory (NBL) studies will be performed and combined with the data presented here to provide a more complete picture. This will provide guidance to future spacesuit designers that will help to optimize human performance in next-generation EVA systems.

In summary, the best CG and weight combination seems to depend on the task that is being performed and, at least somewhat, on the subject. The 0/0 CG seems to be the most predictable in terms of fostering acceptable performance at a wide variety of tasks. Additional research needs to be performed to better understand the interactions between CG and weight as the CG moves up and aft and as the suit weight increases past 90.8 kg (200 lbs).

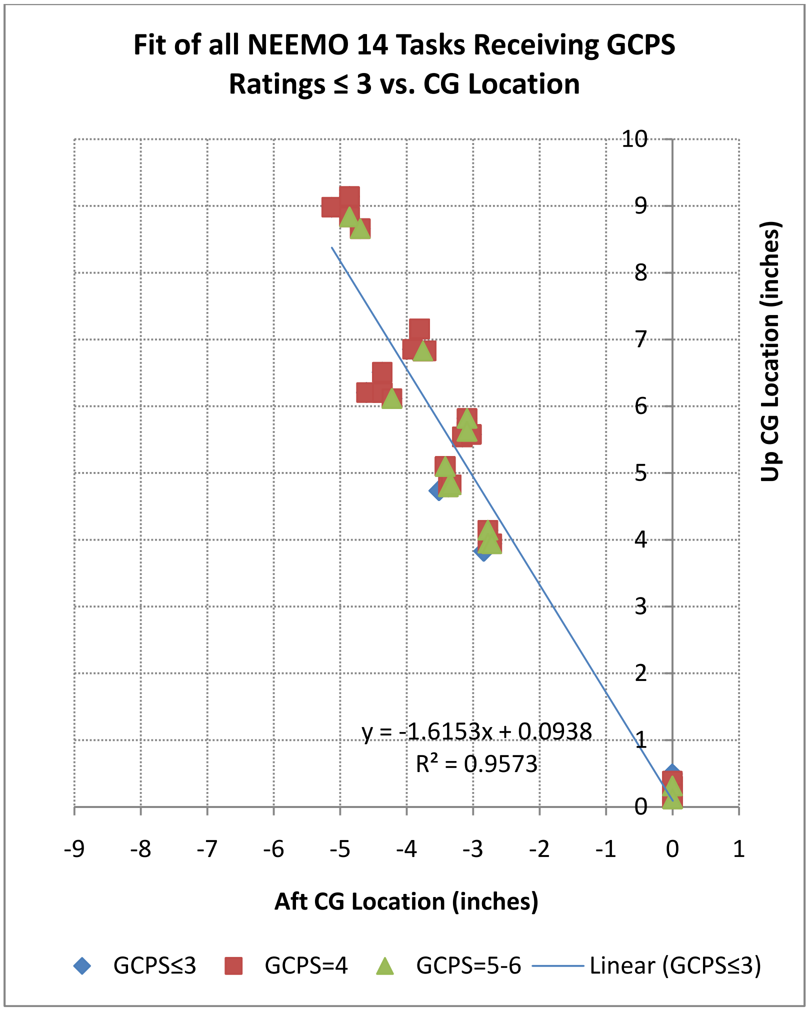


Figure 63. Fit of acceptable GCPS ratings vs. CG location.

6.3 Limitations of test conclusions

6.3.1 Reduced-gravity Environment

The reduced-gravity environment simulated via partial buoyancy is effective at producing accurate ground reaction forces for partial gravity and simulating zero-*g* conditions. However, water drag contributes additional forces that reduce the accuracy of the simulated gravity field for dynamic tasks, such as fast ambulation. Efforts were made to brief subjects in the proper use of subjective ratings scales to account for these extra forces. Additionally, testing is performed in multiple analog environments so that results can be compared and analog-specific adjustments can be made to the data as necessary.

6.3.2 Fidelity of Mock-ups

The fidelity of the lander and SEV mock-ups was low but volumetrically correct and provided sufficient detail to assess the hypotheses tested. The level of fidelity was meant to evaluate the ability for an EVA crew member to perform tasks, such as lifting and properly positioning an in-capacitated crew member for ingress to the SEV. Further testing with higher-fidelity latching and alignment mechanism, for instance, could be performed and results combined with those from this test to provide a more complete picture. Additionally, the low fidelity of the mock-ups did not allow for more detailed concepts of operations testing, such as the ability to extract an incapacitated crew member from a suit after attaching that crew member to the SEV suitport.

6.4 Future work

Continued research is needed to further understand the interactions of suit weight, CG, and inter-subject variations (e.g., anthropometry, strength, fitness, and experience). Collaborative, well-defined, hypothesis-driven research across multiple analogs will provide the best input to future EVA systems designers to ensure optimal human performance.

7 References

[1]Borg G. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*. 1982;14(5):377-381.

[2]Cortlett E, Bishop R. A technique for assessing postural discomfort. *Ergonomics*. 1976;19(2):47-51.

[3]Bedford T. The warmth factor in comfort at work. In: *MRC Industrial Health Board Report No 76*. London, England: H M. Stationery Office; 1936.

[4]Chappell S, Gernhardt M. *Final Report of the Integrated Parabolic Flight Test: Effects of Varying Gravity, Center of Gravity, and Mass on the Movement Biomechanics, and Operator Compensation of Ambulation and Exploration Tasks*. Houston, Tex: NASA Johnson Space Center. TP-2010-216137, 2010.

8 Appendices

8.1 Space exploration vehicle mock-up development drawings

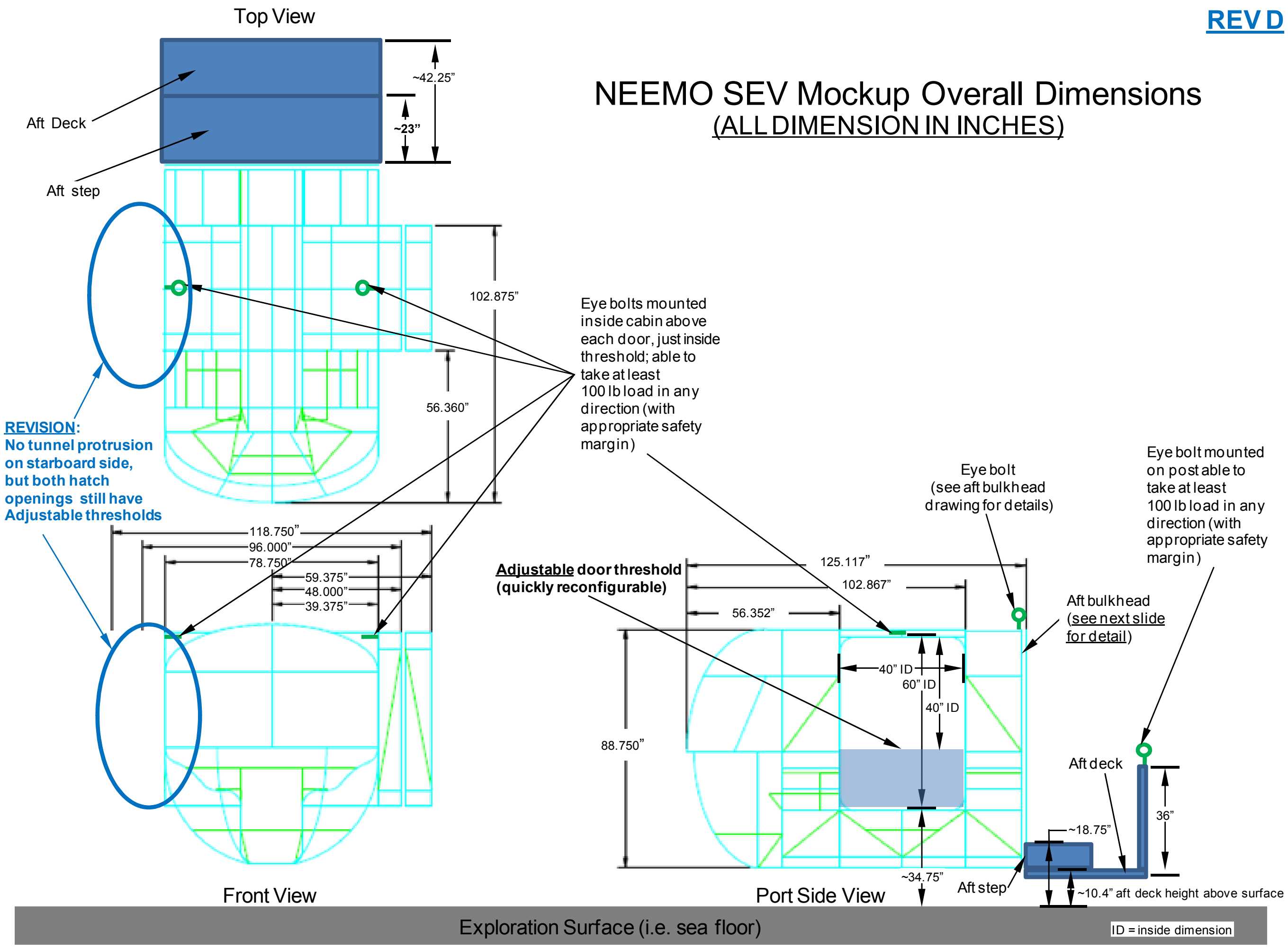


Figure 64. NEEMO SEV mock-up overall dimensions.

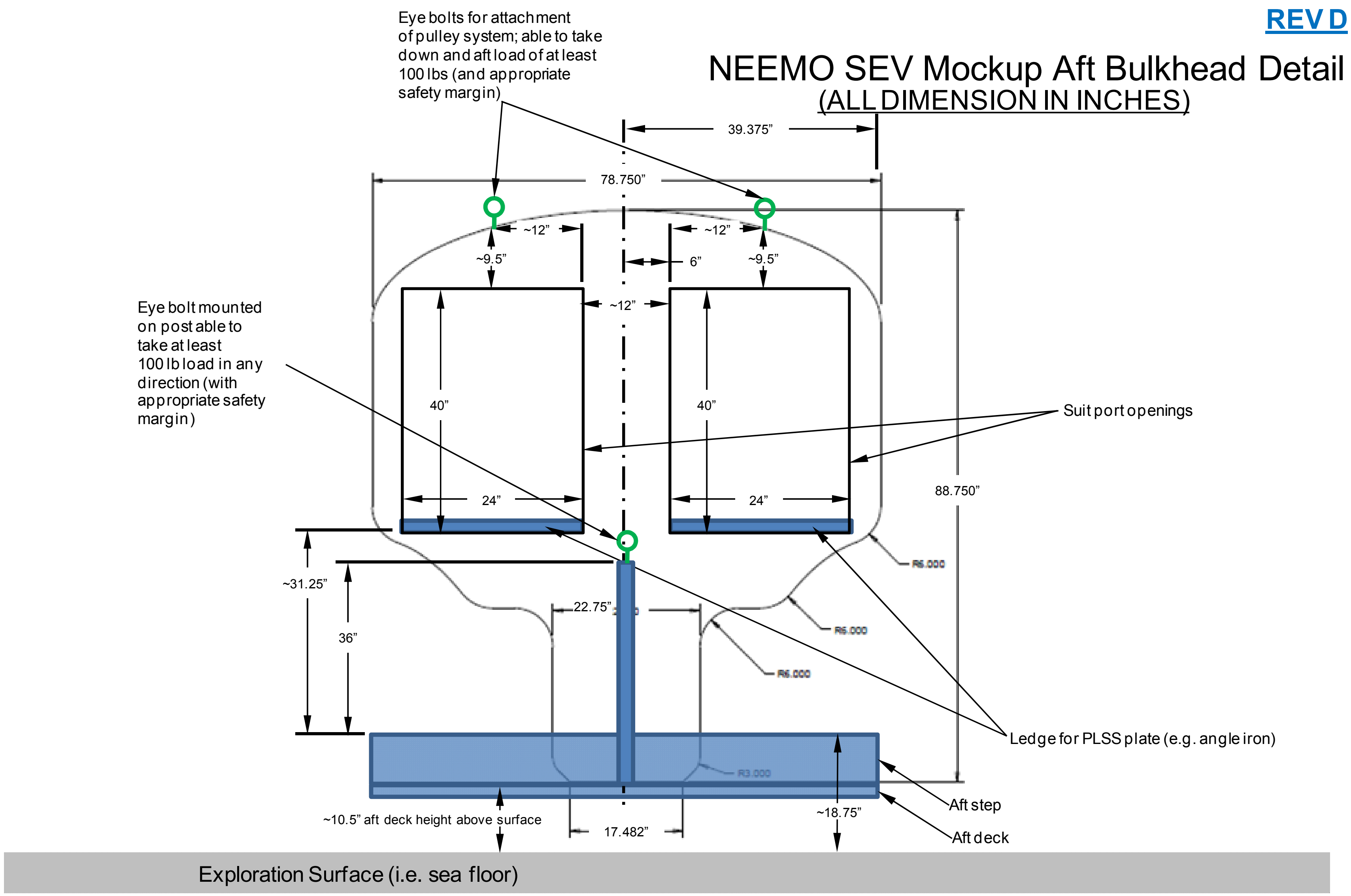


Figure 65. NEEMO SEV mock-up aft bulkhead detail.

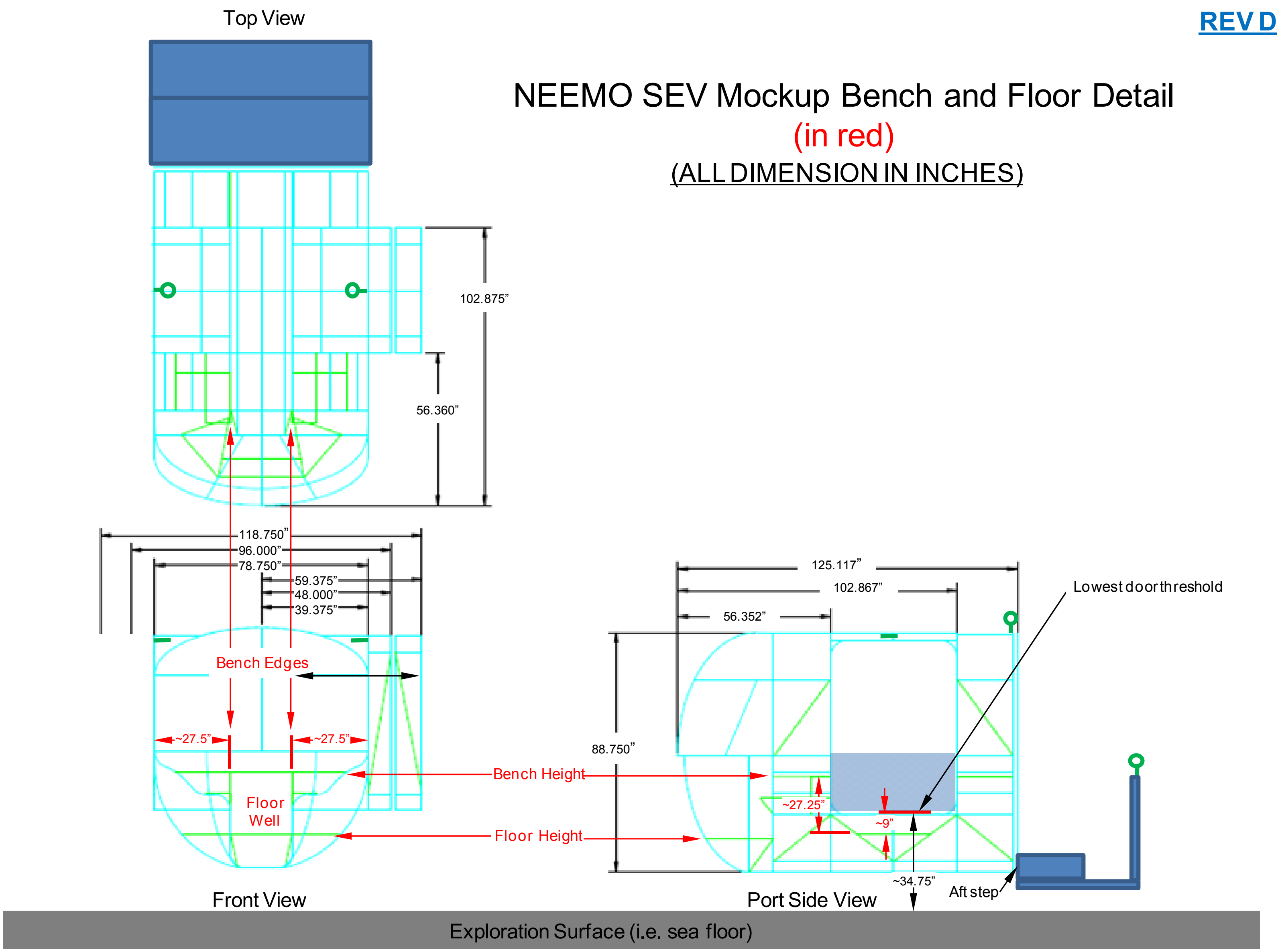


Figure 66. NEEMO SEV mock-up bench and floor detail.

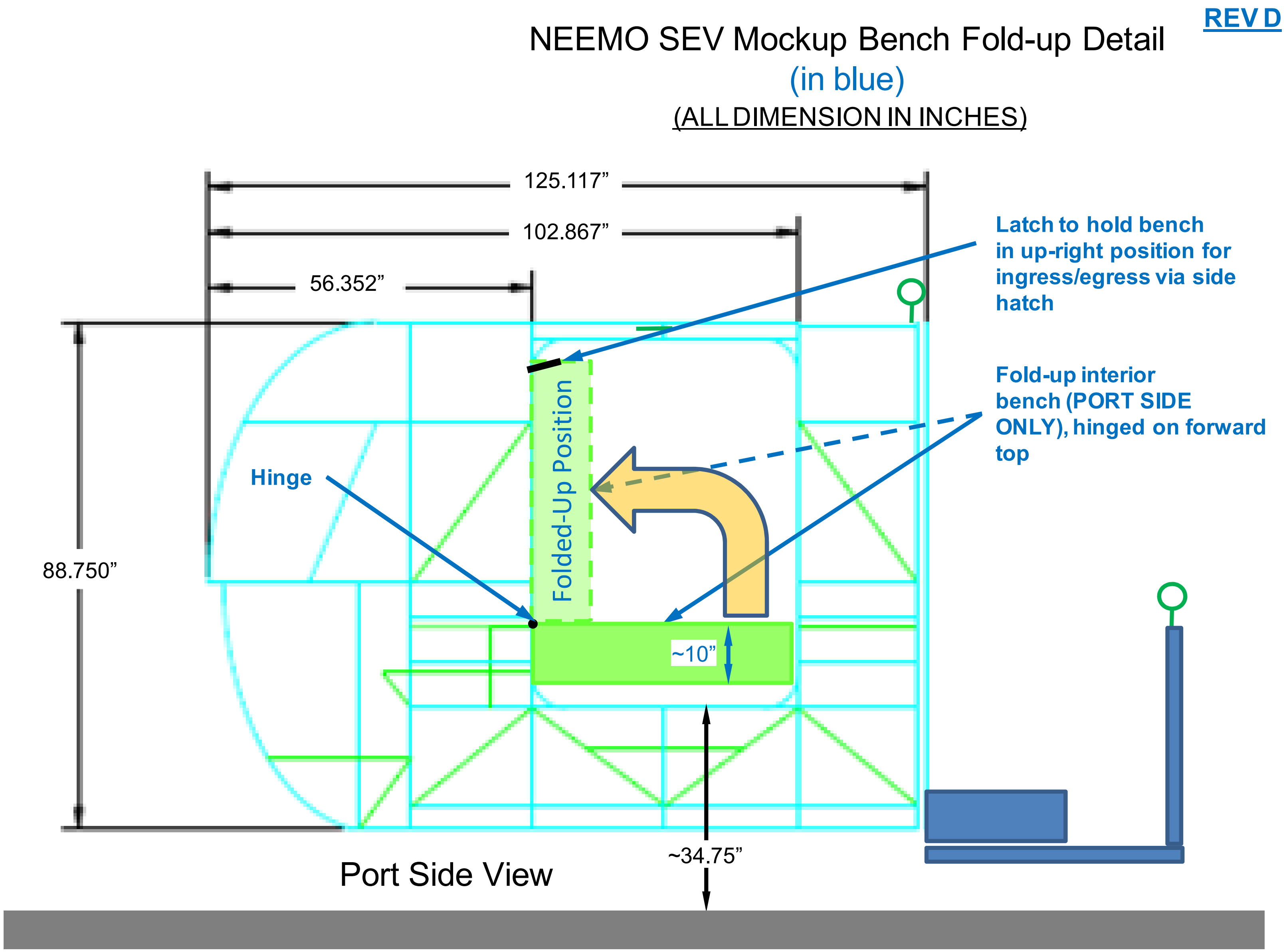


Figure 67. NEEMO SEV mock-up bench fold-up detail.

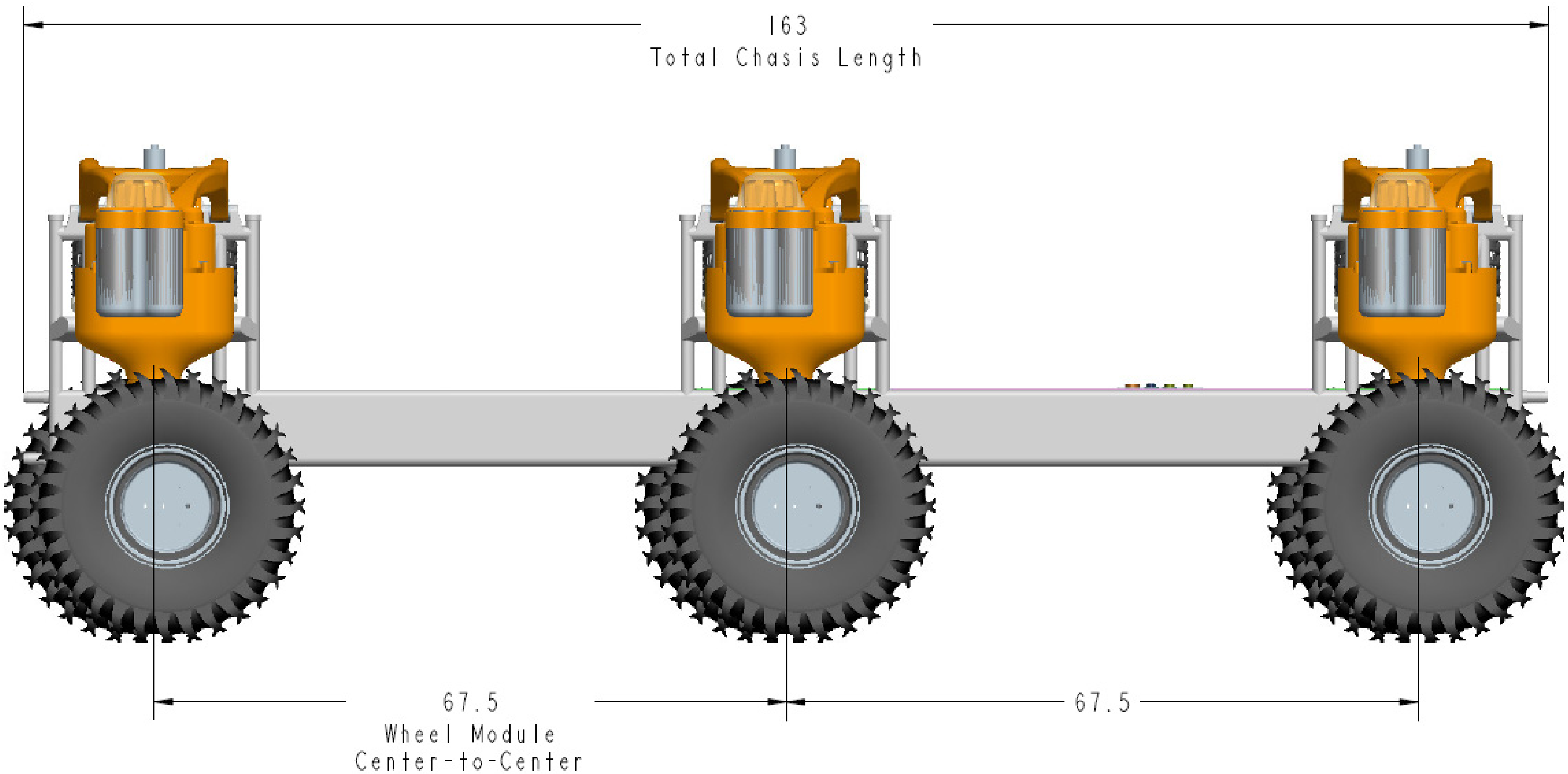


Figure 68. Total chassis length and center-to-center wheel distance used for SEV mock-up fabrication.

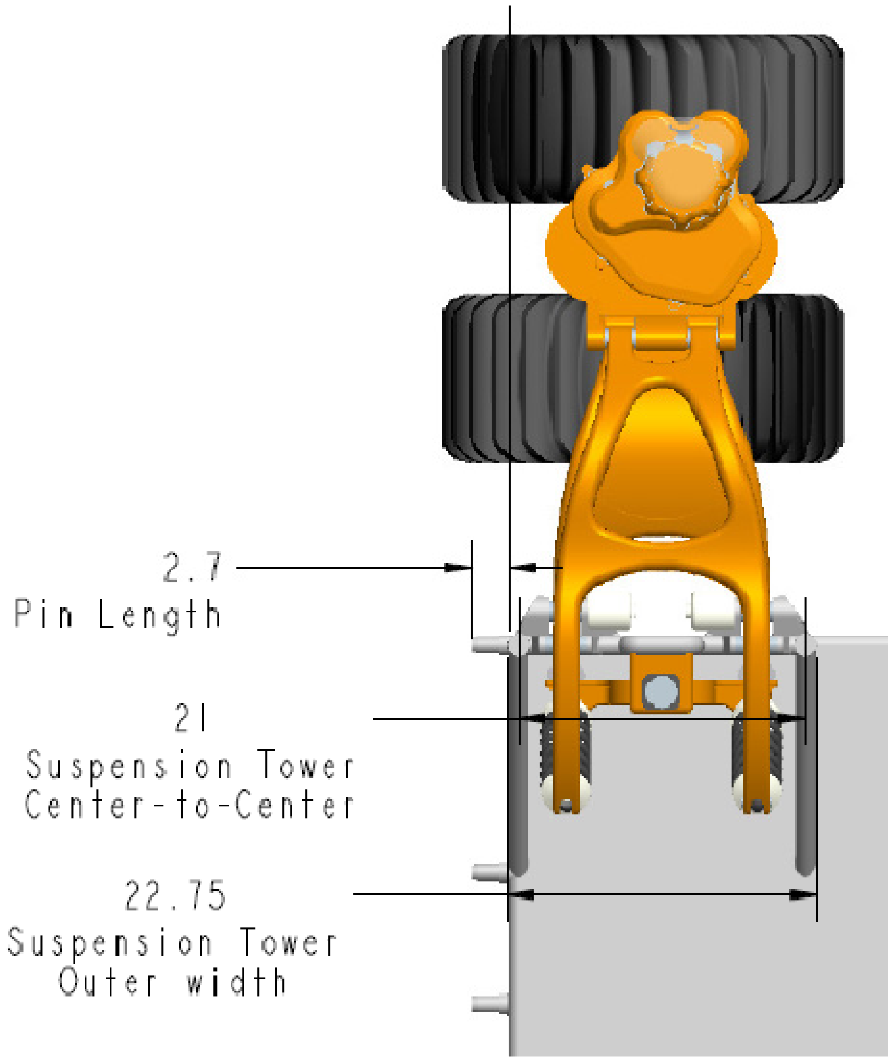


Figure 69. Suspension detail used for fabrication of SEV mock-up.

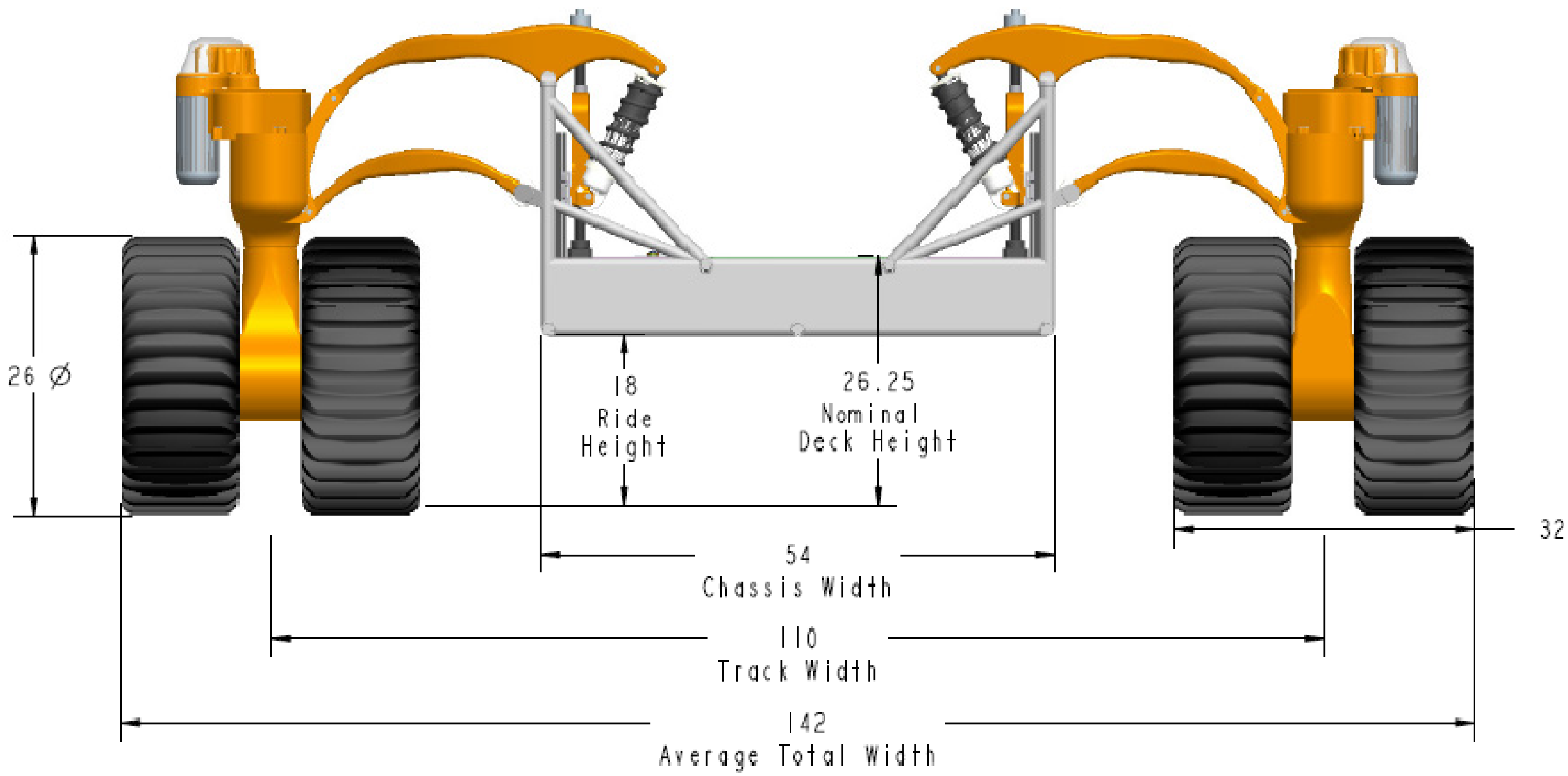


Figure 70. Total chassis width and wheel track width used for SEV mock-up fabrication.

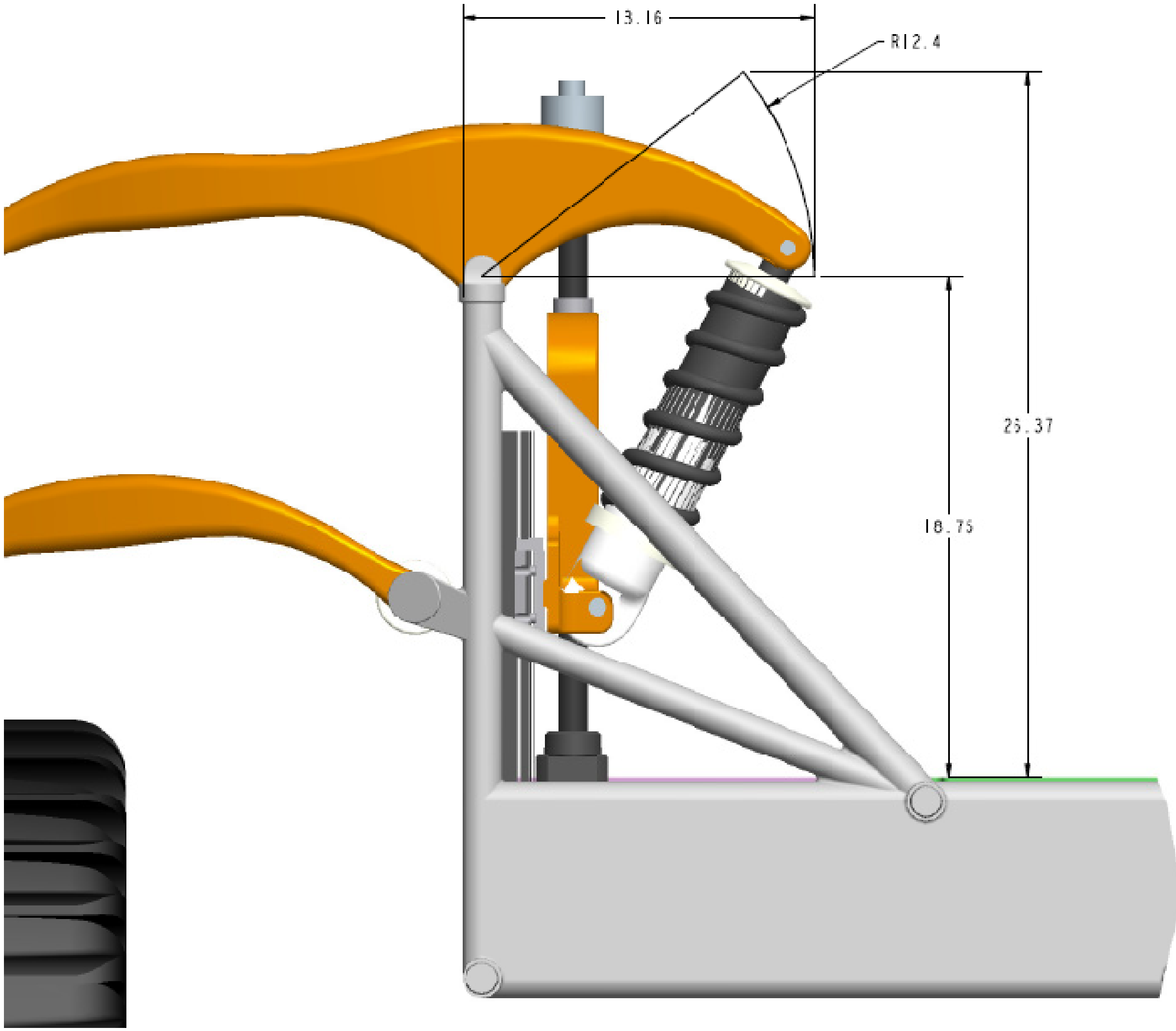


Figure 71. General suspension height and angles used for SEV mock-up fabrication.

8.2 Lander mock-up development drawings

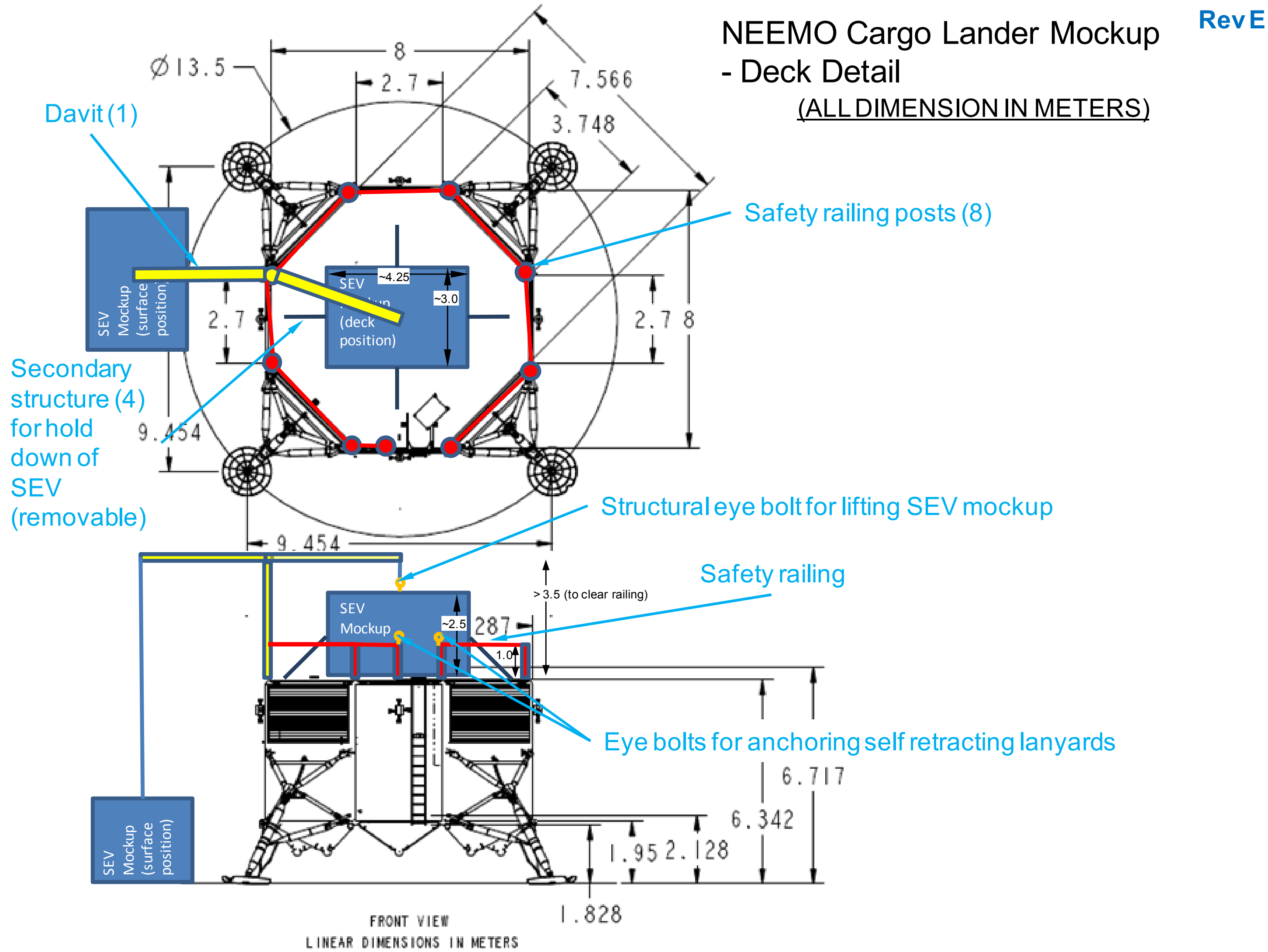


Figure 72. NEEMO lander mock-up deck detail.

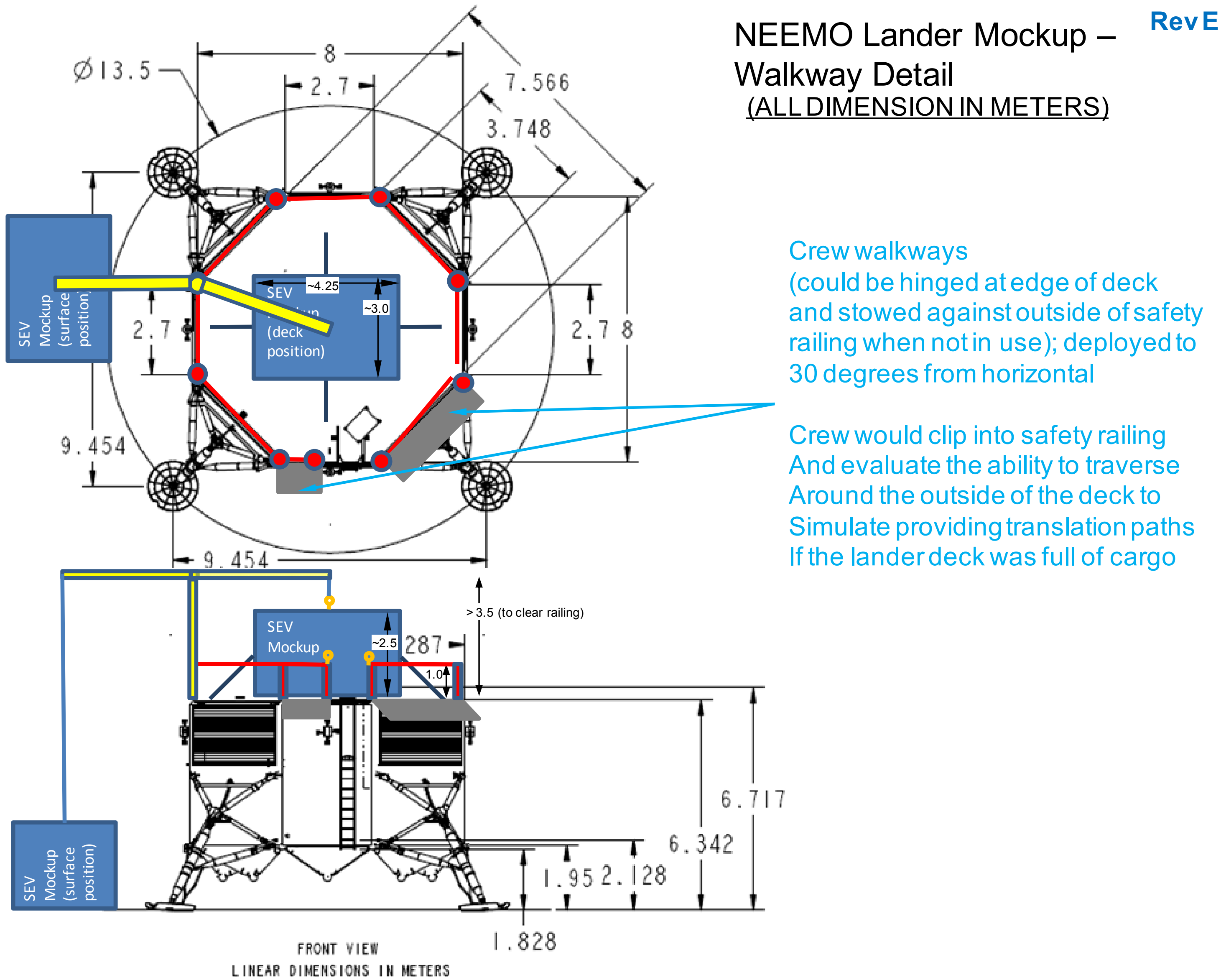


Figure 73. NEEMO lander mock-up walkway detail.

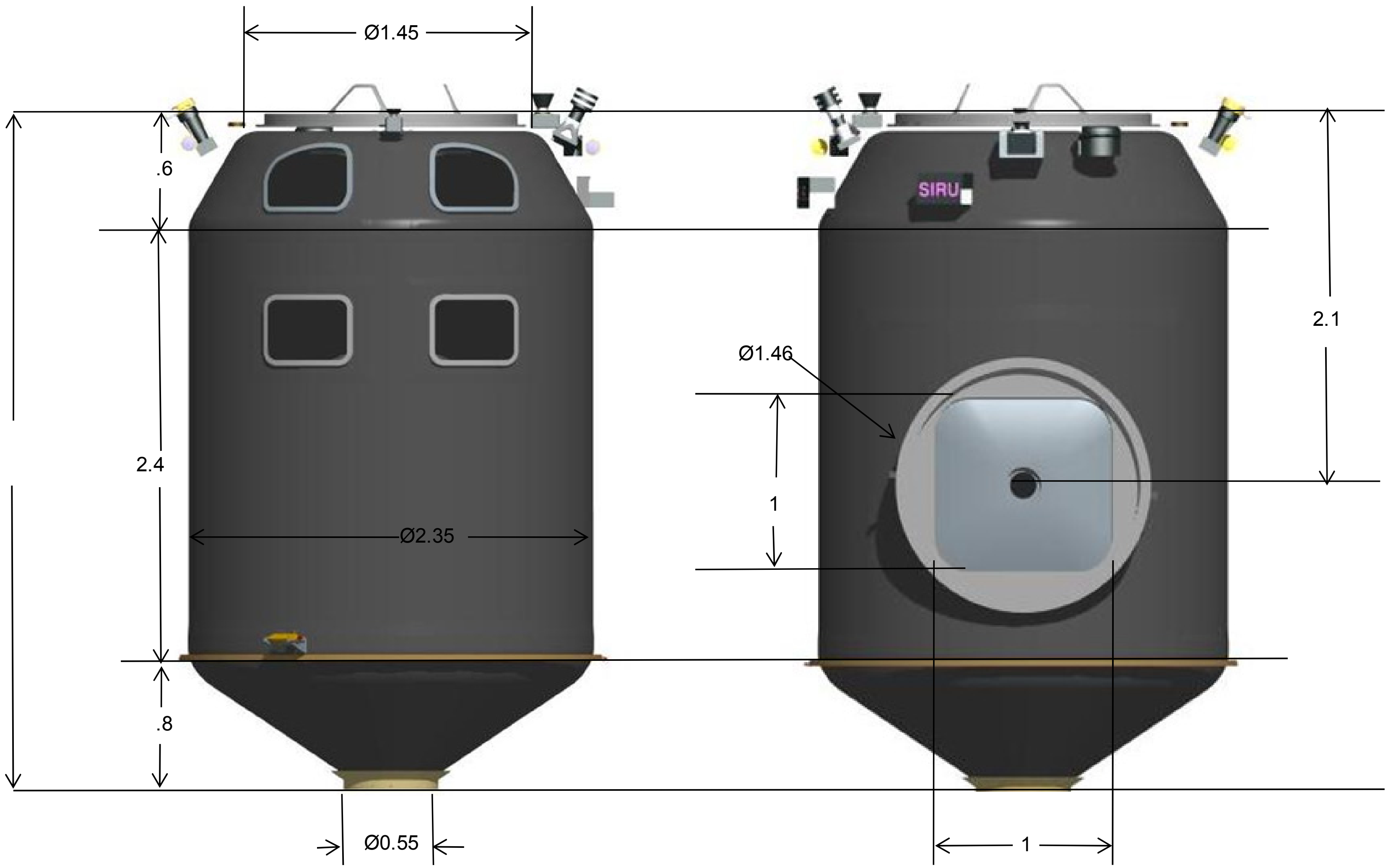


Figure 74. Overall dimensions of ascent module used in mock-up fabrication (dimensions in meters).

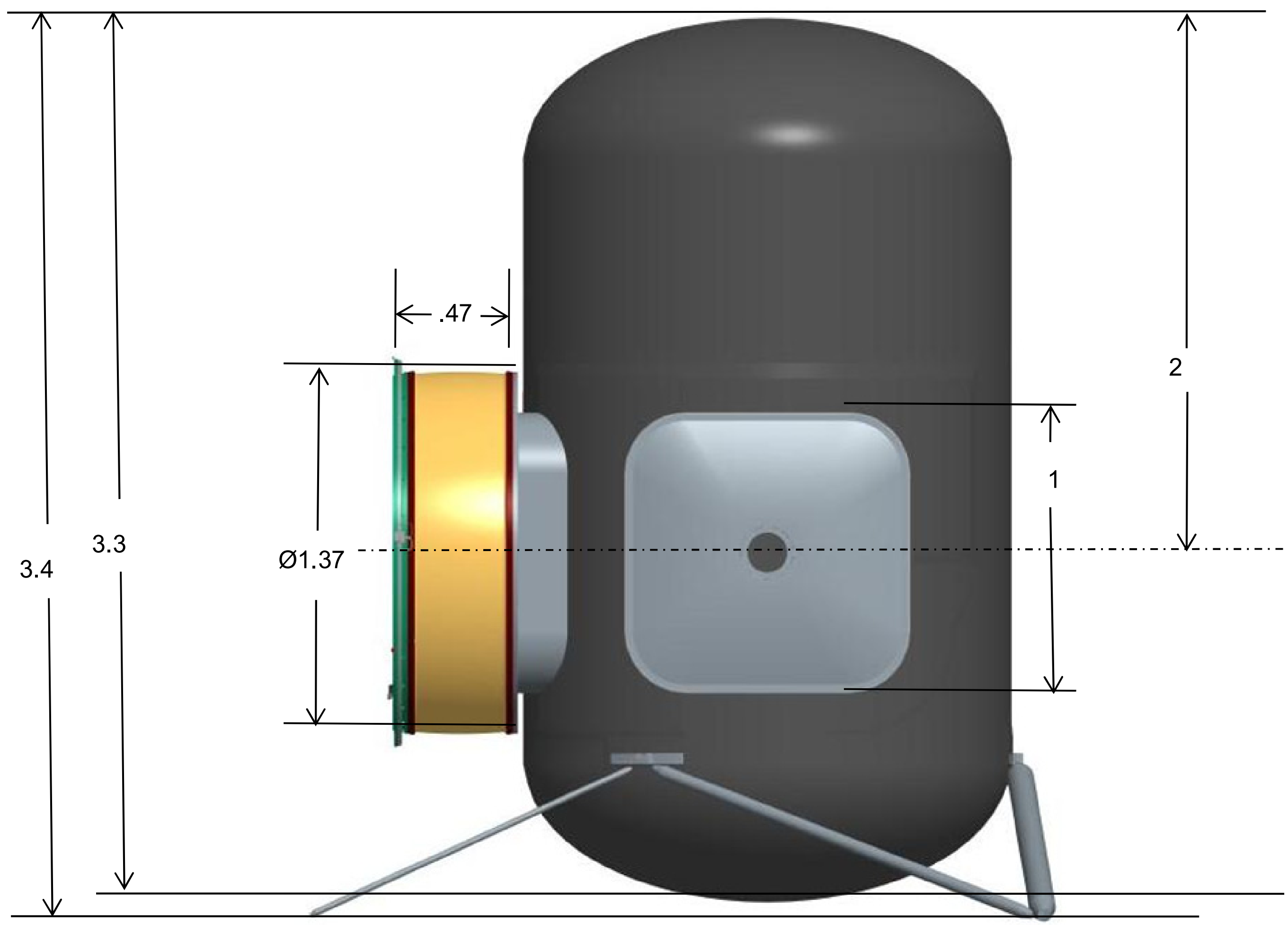


Figure 75. Overall dimensions of airlock used in mock-up fabrication (dimensions in meters).

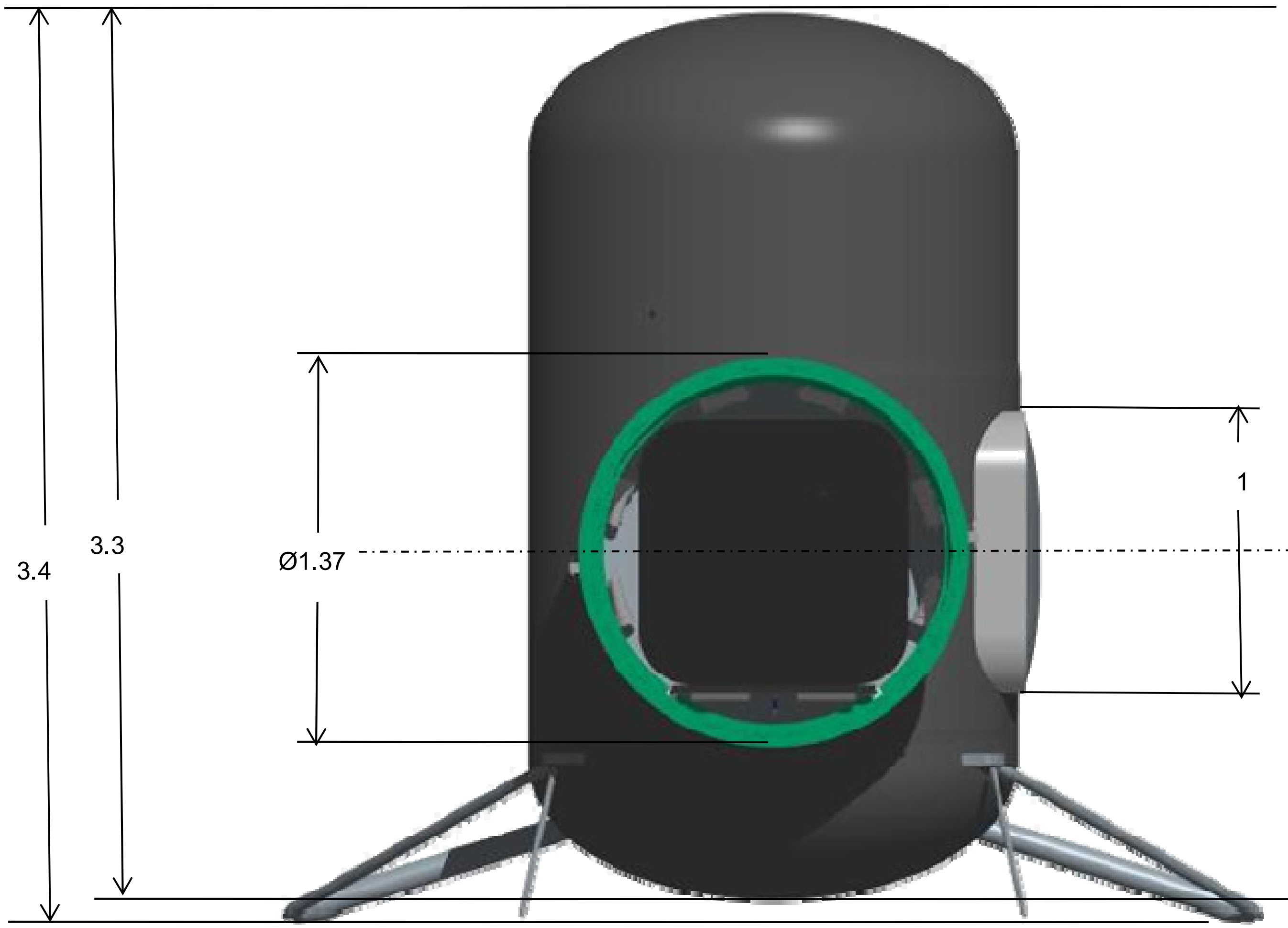


Figure 76. Tunnel view of overall dimensions of airlock used in mock-up fabrication (dimensions in meters).

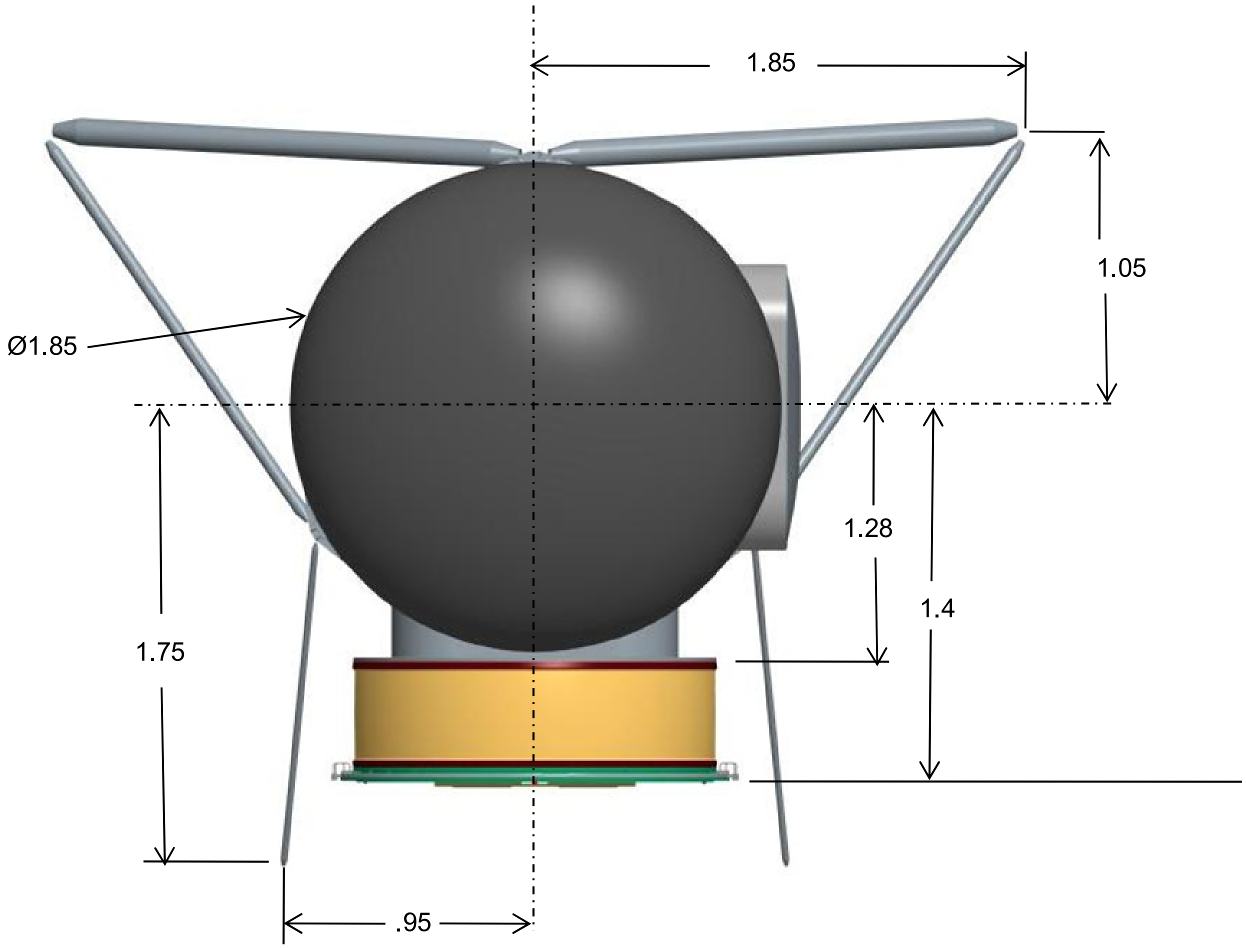


Figure 77. Top view of overall dimensions of airlock used in mock-up fabrication (dimensions in meters).

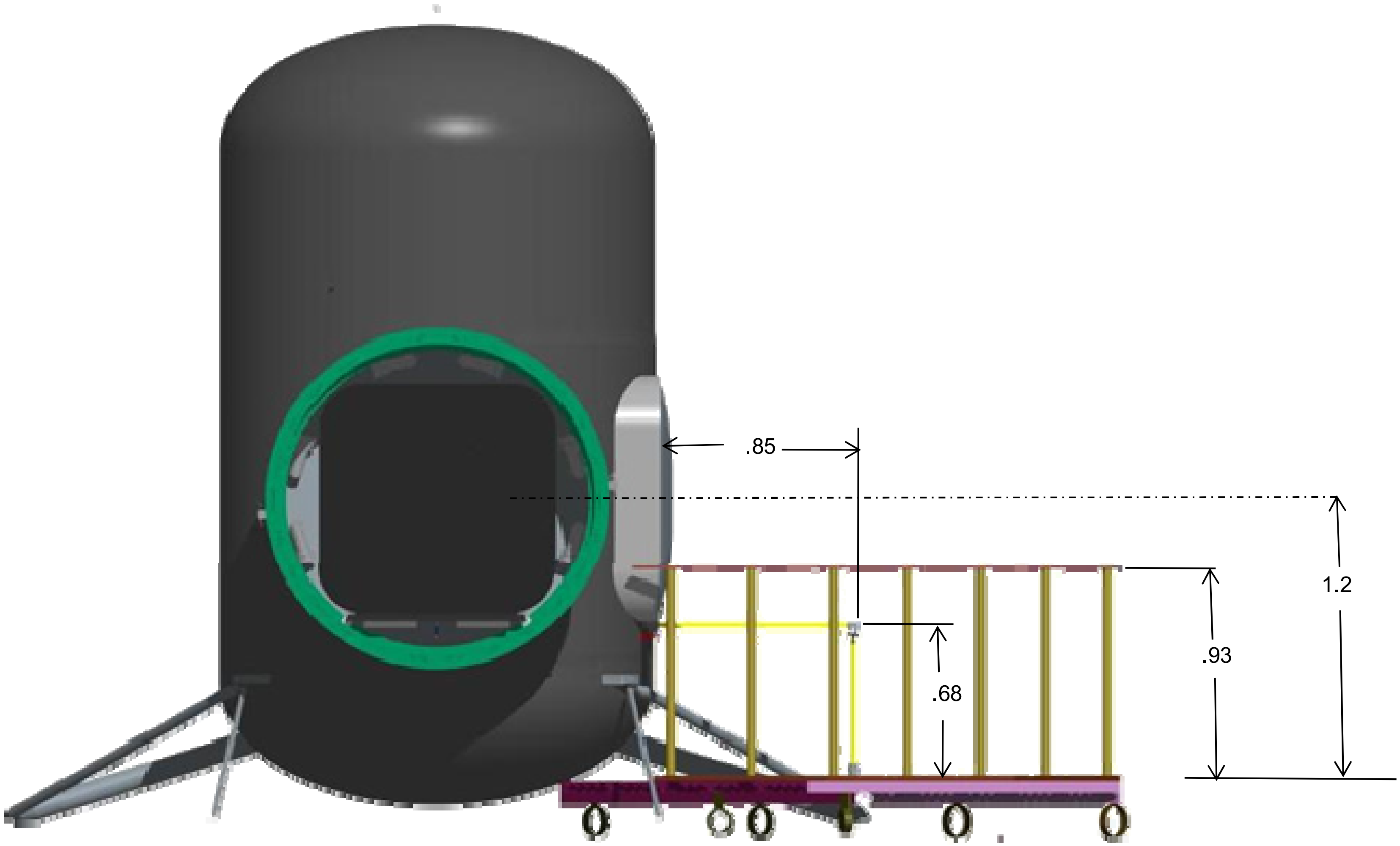


Figure 78. Side view showing porch dimensions used for mock-up fabrication (dimensions in meters).

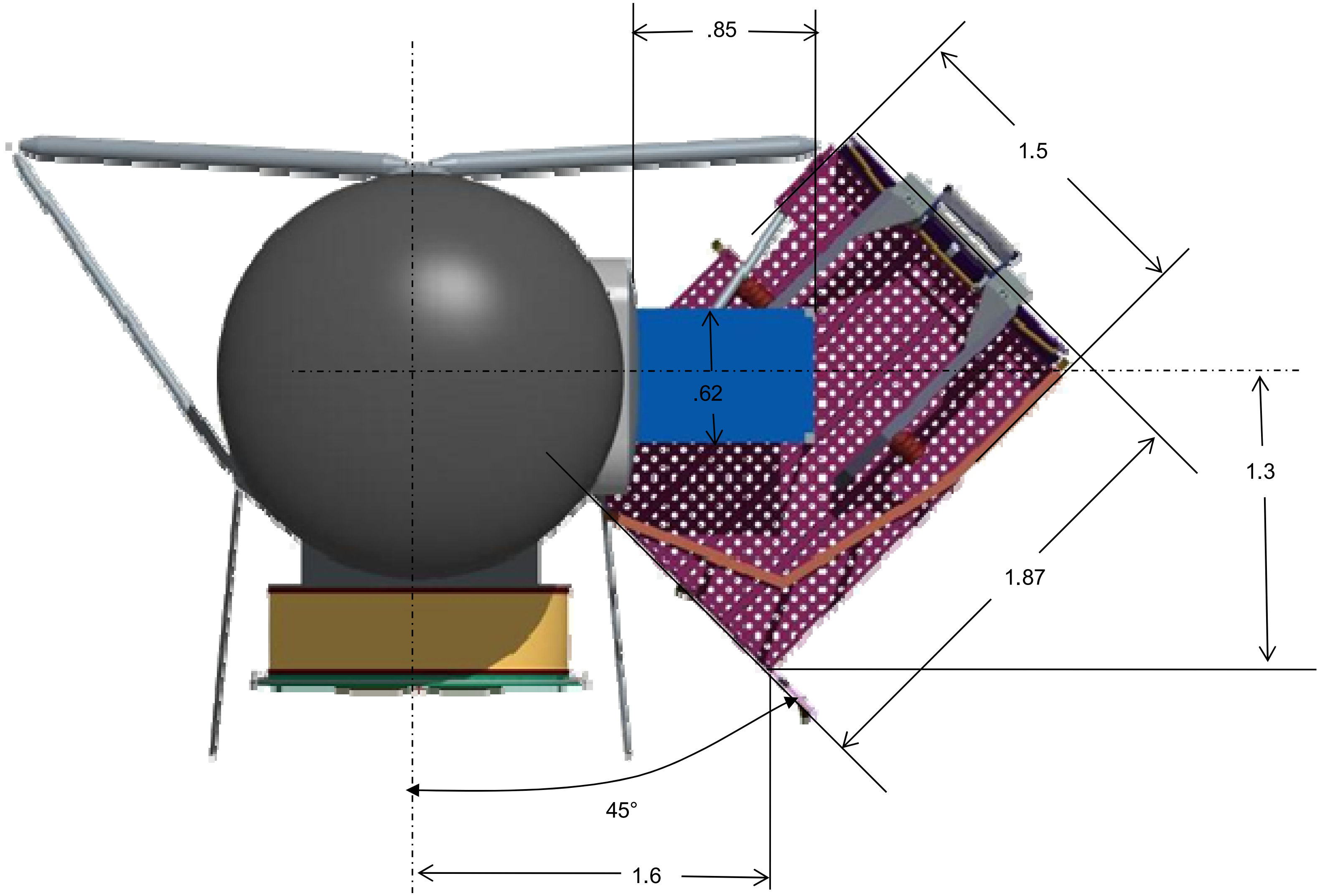


Figure 79. Top view showing porch dimensions used for mock-up fabrication (dimensions in meters).

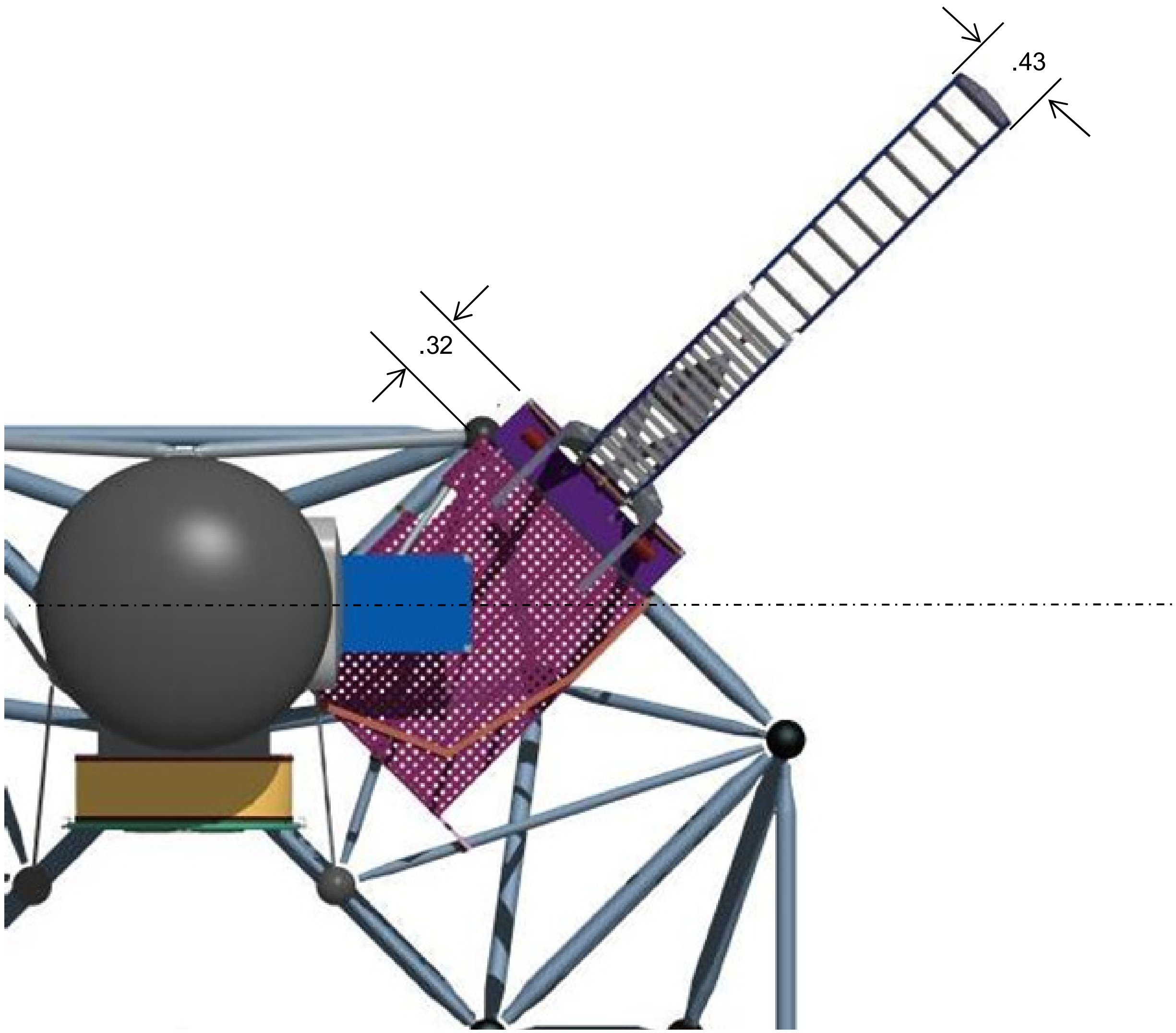


Figure 80. Top view of ladder dimensions used for mock-up fabrication (dimensions in meters).

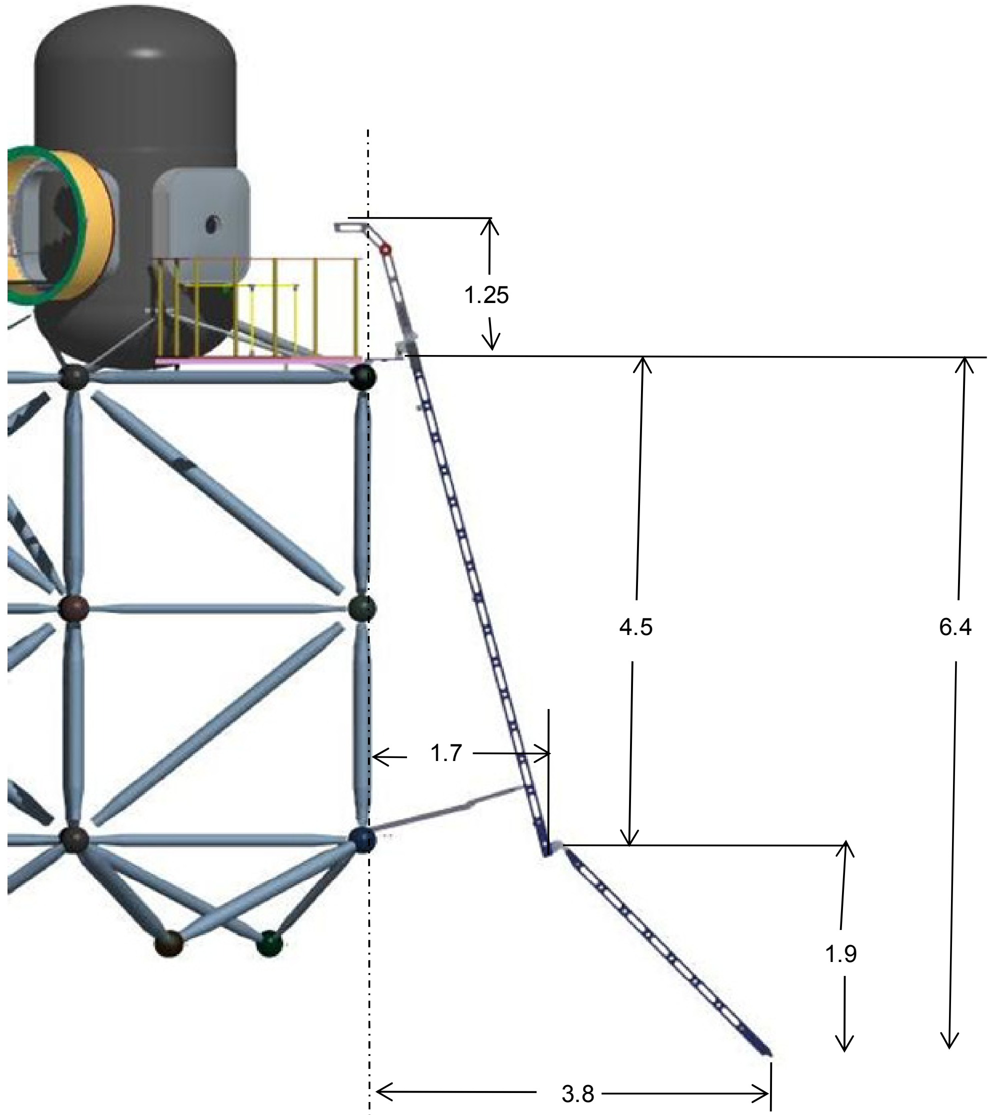


Figure 81. Side view of ladder dimensions used for mock-up fabrication (dimensions in meters); note that the ladder used during mission did not have two segments and different angles.

8.3 Timelines

8.3.1 Overview Timelines

N14	MD 1	MD2	MD3	MD4	MD5	MD6	MD7
7:30		DPC	DPC	DPC	DPC	DPC	DPC
8:00							
8:30		EVA prep	EVA prep	EVA prep	EVA prep	EVA prep	
9:00	Transport	CG Run 1a	CG Run 1b	ASC MOD/AIRLK	CG Run 2a	CG Run 2b	
9:30		*EPSP Circuit*	*(remainder of*	*SEV/hatch xlation*	*EPSP Circuit*	*(remainder of*	BLOOD DRAW
10:00	photo op	*Cargo Lander*	*tasks from 1a)*	*Asc /airlock tasks*	*Cargo Lander*	tasks from 2a)	
10:30	stow gear	*SEV Offload*			*SEV Offload*		
11:00	hab brief	*SEV Incap. Crew*		stow	*SEV Incap. Crew*		
11:30		stow	stow	SS/PVT	stow	stow	OFF
12:00	meal	SS/PVT	SS/PVT		SS/PVT	SS/PVT	
12:30	Unpsck						FROM
13:00		miday meal	miday meal	miday meal	miday meal	miday meal	
13:30	EVA prep	EVA Prep	EVA Prep		EVA Prep	EVA Prep	DIVING
14:00	S/L orient Tm a	CG Run 1a	CG Run 1b	ASC MOD/AIRLK	CG Run 2a	CG Run 2b	
14:30				*SEV/hatch xlation*			
15:00	SS/PVT			*Asc /airlock tasks*			
15:30	stow						
16:00	EVA prep			stow			
16:30	S/L orient Tm b	STOW	STOW	SS/PVT	STOW	STOW	
17:00		SS/PVT	SS/PVT		SS/PVT	SS/PVT	
17:30	STOW						
18:00	SS/PVT						
18:30							
19:00	MEAL	DPC	DPC	DPC	DPC	DPC	
19:30	meal	meal	meal	meal	meal	meal	
20:00							
20:30							

Figure 82. Timeline overview for mission days (MDs) 1-7.

			DEGRADED COMMUNICATION OPERATIONS				
	MD 8	MD9	MD10	MD11	MD12	MD13	MD14
7:30							
8:00							
8:30	EVA prep	EVA prep	EVA prep	EVA Prep	EVA Prep		BLOWDOWN
9:00	CG Run 3a	CG Run 3b	ASC MOD/AIRLK	EXPL.TRAVERSE	EXPL.TRAVERSE	BLOOD DRAW	
9:30	*Circuit*		*LER/hatch xlation*	PART A	PART B		RETURN TO SURFACE
10:00	*Lander*		*Asc /Airlock(PLSS)*				
10:30	*LER D/L*		*Sled*				
11:00	*LER INCAP*		stow				
11:30	stow	stow	SS/PVT	stow	stow		
12:00	SS/PVT	SS/PVT		SS/PVT	SS/PVT	DECO	
12:30							
13:00	miday meal	miday meal	miday meal	miday meal	miday meal		
13:30	EVA Prep	EVA Prep		EVA Prep	EVA Prep		
14:00	CG Run 3a	CG Run 3b	ASC MOD/AIRLK	EXPL.TRAVERSE	EXPL.TRAVERSE	NO	
14:30			*LER/hatch xlation*	PART A	PART B	DIVING	
15:00			*Asc /Airlock(PLSS)*				
15:30			*Sled*				
16:00			stow				
16:30	STOW	STOW	SS/PVT	STOW	STOW		
17:00	SS/PVT	SS/PVT		SS/PVT	SS/PVT		
17:30							
18:00							
18:30							
19:00							
19:30	MEAL	MEAL	MEAL	MEAL	MEAL		

Figure 83. Timeline overview for MDs 8-14.

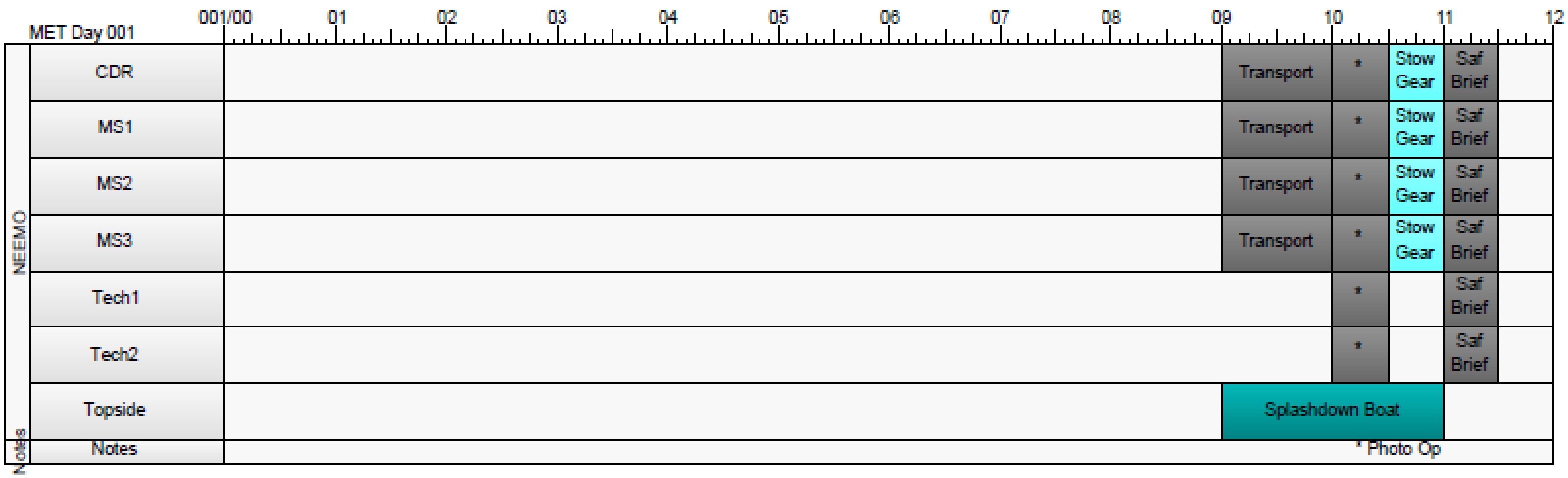
			DEGRADED COMMUNICATION OPERATIONS				
	MD 8	MD9	MD10	MD11	MD12	MD13	MD14
7:30							
8:00							
8:30	EVA prep	EVA prep	EVA prep	EVA Prep	EVA Prep		BLOWDOWN
9:00	CG Run 3a	CG Run 3b	ASC MOD/AIRLK	EXPL.TRAVERSE	EXPL.TRAVERSE	BLOOD DRAW	
9:30	*EPSP Circuit*	*(remainder of*	*SEV/hatch xlation*	PART A	PART B		RETURN TO SURFACE
10:00	*Cargo Lander*	*tasks from 3a)*	*Asc /airlock tasks*				
10:30	*SEV Offload*						
11:00	*SEV Incap. Crew*		stow				
11:30	stow	stow	SS/PVT	stow	stow		
12:00	SS/PVT	SS/PVT		SS/PVT	SS/PVT	DECO	
12:30							
13:00	midday meal	midday meal	midday meal	midday meal	midday meal		
13:30	EVA Prep	EVA Prep		EVA Prep	EVA Prep		
14:00	CG Run 3a	CG Run 3b	ASC MOD/AIRLK	EXPL.TRAVERSE	EXPL.TRAVERSE	NO	
14:30			*SEV/hatch xlation*	PART A	PART B	DIVING	
15:00			*Asc /airlock tasks*				
15:30							
16:00			stow				
16:30	STOW	STOW	SS/PVT	STOW	STOW		
17:00	SS/PVT	SS/PVT		SS/PVT	SS/PVT		
17:30							
18:00							
18:30							
19:00							
19:30	MEAL	MEAL	MEAL	MEAL	MEAL		
20:00							
20:30							

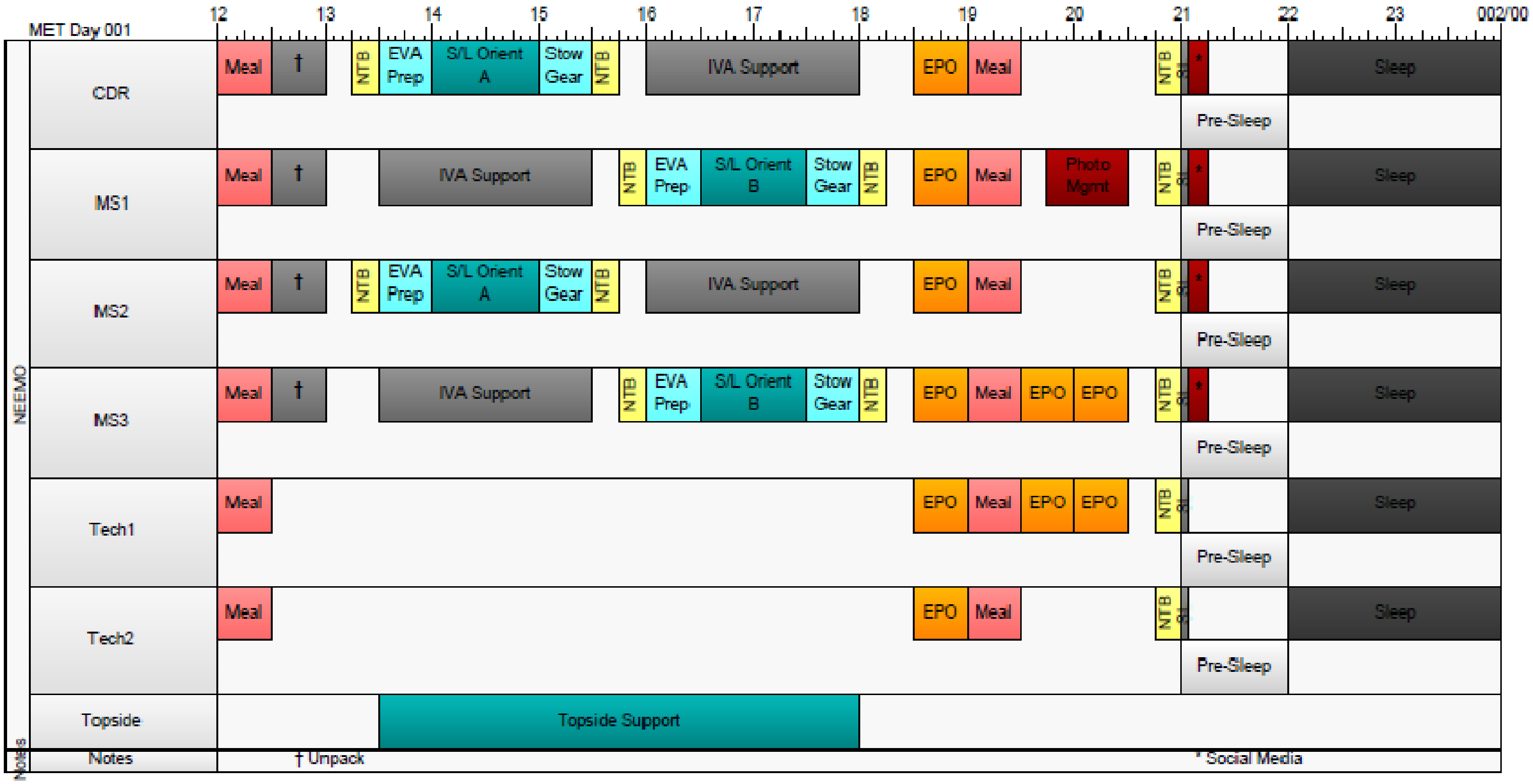
Figure 84. Example of detailed task timeline showing task elapsed time.

Task	General Assumptions	Lander Assumptions	LSS Assumptions	EVA Time	IVA Time	Cumulative Time
				7:22	4:25	11:47
Pre-EVA	**2HRS IVA Time.** Operators are already familiar with tasks; no real time training needed. Assumes WEI of 3.0 based on 8hr EVA. Assumes prep is 3 times post. Includes suit don.		**LER / PUP includes hardware for water scavenging**		2:00	***2:00***
Depress, Egress	10 min depress, 20 mins egress (5 mins per person)			0:30		***2:30***
Crew Lander configuration	platform folded out, ladder deployed			0:15		***2:45***
Descend ladder	~2:30 per person x 2 people; EV3 and EV4 do contingency geological sampling EVA	Assume 'gated' rail that tether attaches to. ~5 gates (spaced every ~4 ft)	Tether arrestors attached to each suit	0:05		***2:50***
Translate from crew lander to cargo lander	Assume 4kph, 2km distance (LAT2)			0:30		***3:20***
Ascend ladder	~2:30 per person x 2 people. Tether to lander deck guide-wire once on lander deck	Ladder on cargo lander; Assume 'gated' rail that tether attaches to. ~5 gates (spaced every ~4 ft)	Tether arrestors attached to each suit	0:05		***3:25***
Worksite setup	Tools need tethers. tools required for connector clamps and attachment mechanism; assume standard bolt on all launch locks; how many power tools?	Toolbox is on cargo lander deck; grating for crew translation on deck; slide-wire around perimeter of deck for tethers - assume pre-installed.		0:20		***3:45***
Optional: install lander deck safety rail slide-wire		If not pre-installed, setup only where needed. Assume ~ 6 mins per 2 posts. Use power tool to tension wire between posts (3 mins)		0:40		***4:25***
Remove secondary support structure from LER1 + PUP1	4 per vehicle, 10 mins per structure Structure rotates and moves out of the way			0:40		***5:05***
Release launch locks on LER1+PUP1	10 mins per launch lock shaft, 2 per LER, 2 per PUP.		Launch locks actuated using power tools. Can be accessed from front or aft of each vehicle. Ganged rotating launch lock, drivable from a single point	0:30		***5:35***
Detach water line from lander fuel cell to LER1	Assumes line is launched in place, attached to aft of vehicle; secure line			0:10		***5:45***
Detach electrical connector between LER1 and lander bus				0:10		***5:55***
Crane Launch Restraint release	assumes crane is strategically located and only requires unbolting and rotated into place; assumes 5 launch restraints for every 8 foot of crane; this assessment assumes 24 ft crane		4 launch locks x 5 mins each.	0:20		***6:15***
Crane unfurl and ROM checkout	Swing outboard to unfurl. Using power tools (15 mins). ROM test (10 mins).			0:25		***6:40***
Attach tag-line to LER	Remove from toolbox, attach to LER			0:10		***6:50***
Descend ladder with tag line	~2:30 per person x 2 people	Assume 'gated' rail that tether attaches to. ~5 gates (spaced every ~4 ft)	Tether arrestors attached to each suit	0:05		***6:55***
Crane load test	Attach to lander deck (for example) and perform static load test. 5 mins attach. Series of tests for ~10 mins			0:15		***7:10***
Crane operator ascends ladder	EV1 ascends ladder, EV2 operates tag line			0:02		***7:12***
Raise LER1+PUP1 off lander and lower to surface	10 minutes to raise off deck, 15 mins to swing out, 10 to lower, 5 to release hook, 15 to raise hook and return to nominal position; assume array can remain deployed on PUP if needed.			0:55		***8:07***
Crane operator (EV1) descends ladder; while EV2 releases tag line from LER				0:05		***8:12***
Release aft cabana launch locks	2 launch locks x 5 mins			0:10		***8:22***
LER1+PUP1 checkout and ingress	Raise cabana, cx cabin atmosphere, ingress via suit ports.		One LER hatch must be able to be opened at launch.	0:30		***8:52***
Post-EVA	IVA Time				0:20	***9:12***
Configure & checkout LER1	checking tanks pressures, inventory, drive checks, etc				1:00	***10:12***
LER1 drive checkout	~2km test drive to Altair				0:15	***10:27***
Suit Port Egress Check	2 person EVA to verify suit port egress			0:10		***10:37***
Visual inspection of LER1+PUP1 and contingency sample				0:20		***10:57***
Ingress LER1					0:10	***11:07***
Post-EVA processing					0:40	***11:47***

Figure 85. Example EAMD reference task timeline for SEV off-load.

8.3.2 Detailed Pre-mission Timeline

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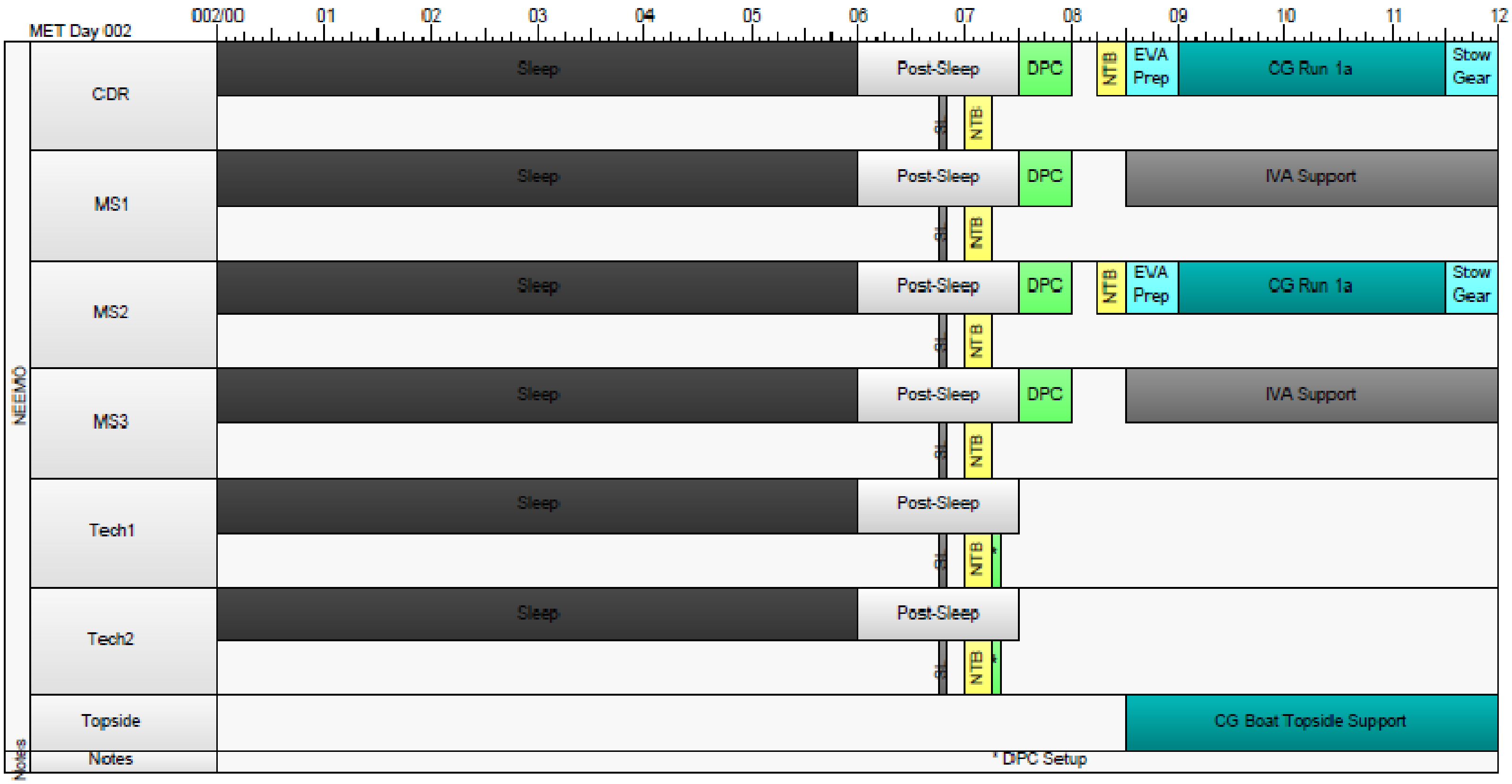
CDR
MS1
MS2
MS3
Tech1
Tech2
Topside
Notes
Meal
†
NTB
EVA Prep
S/L Orient A
S/L Orient B
Stow Gear
IVA Support
EPO
Photo Mgmt
Pre-Sleep
Sleep
Topside Support
† Unpack
* Social Media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CDR
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MS2
MS3
Tech1
Tech2
Topside
Notes
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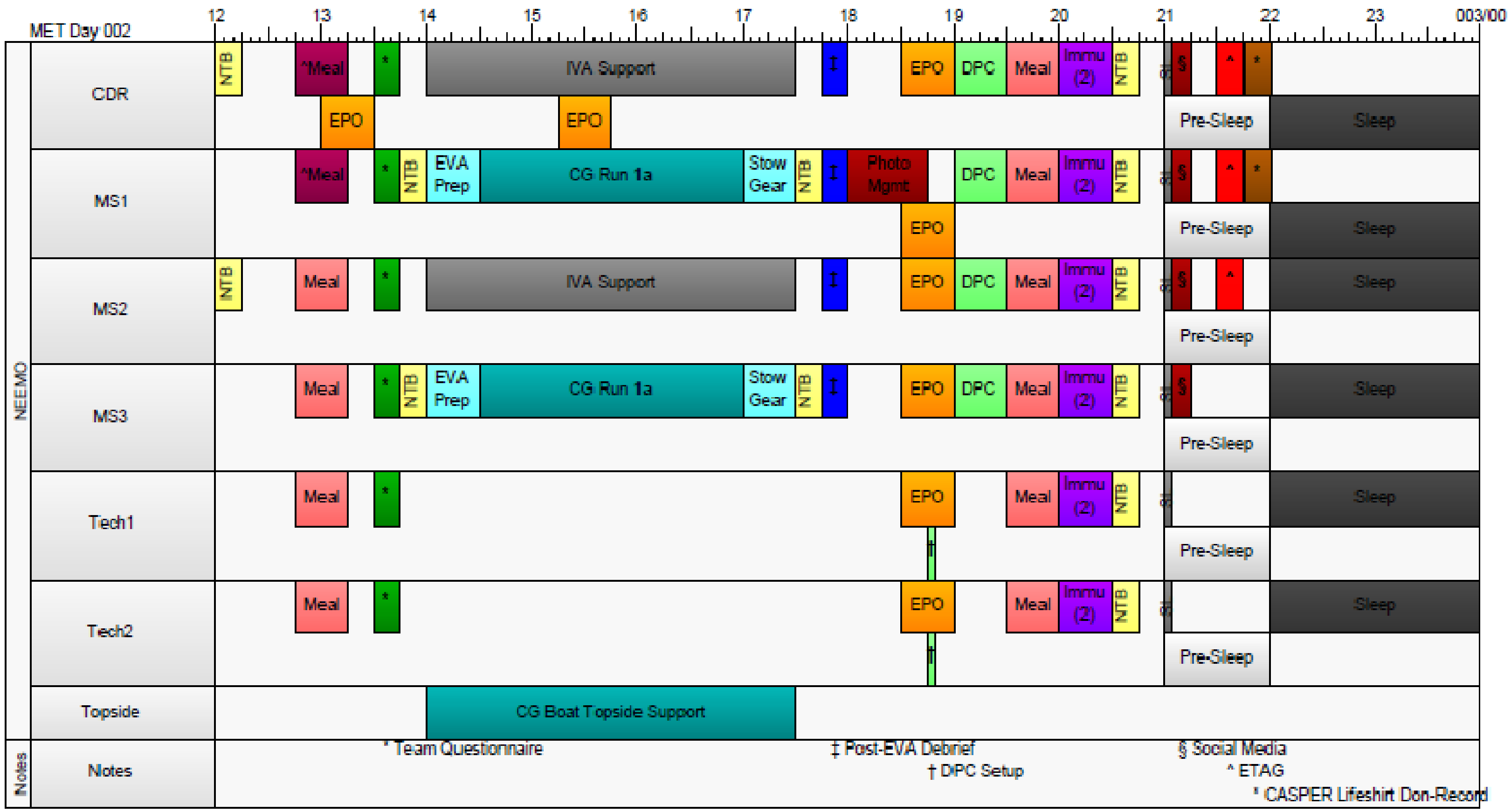
Post-Sleep
DPC
NTB
EVA Prep
CG Run 1a
Stow Gear
IVA Support
CG Boat Topside Support
* DPC Setup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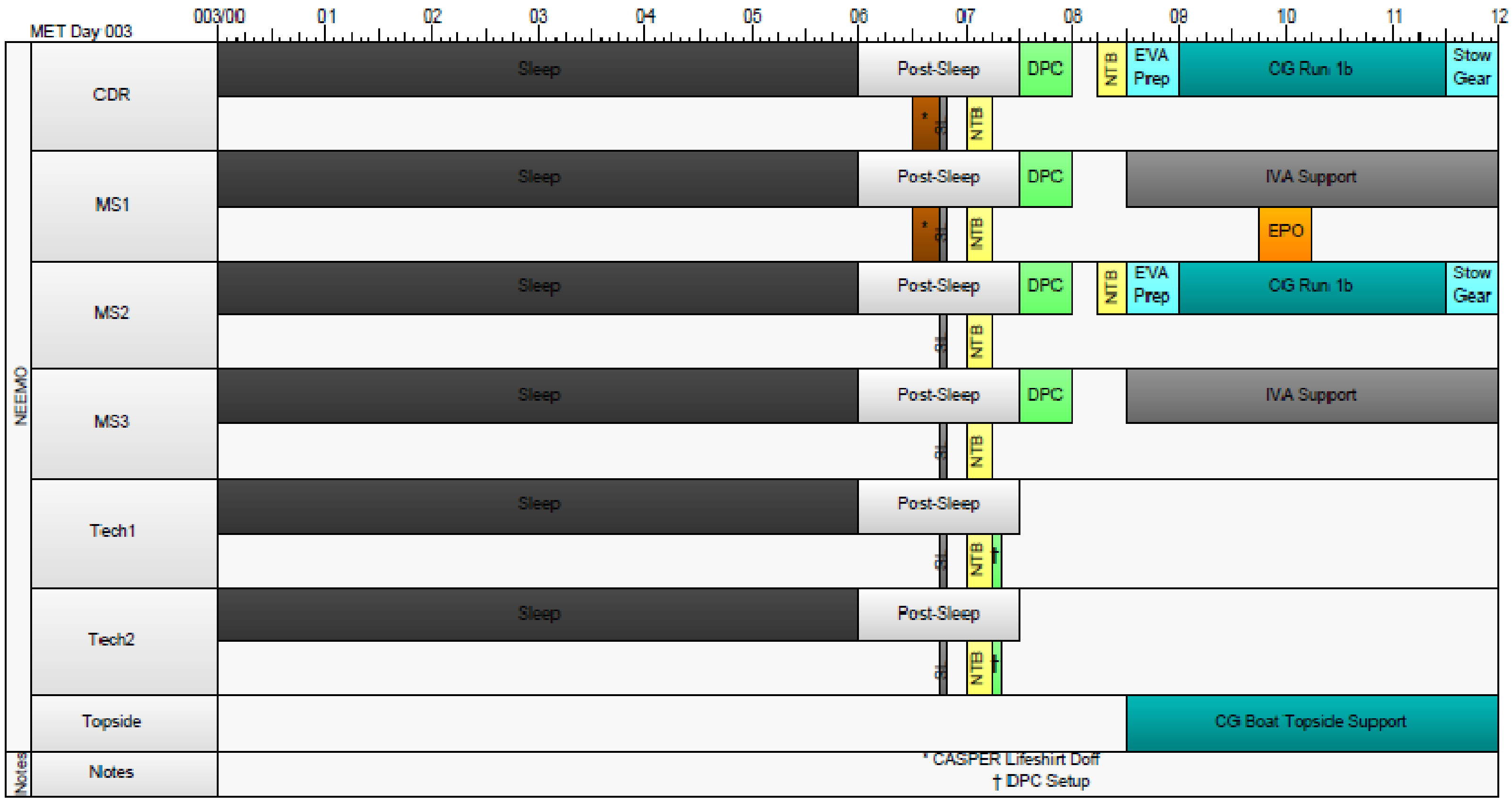
MS3
Tech1
Tech2
Topside
Notes
NTB
^Meal
Meal
*
EPO
IVA Support
EVA Prep
CG Run 1a
Stow Gear
‡
Photo Mgmt
DPC
Immu (2)
§
^
Pre-Sleep
Sleep
†
CG Boat Topside Support
* Team Questionnaire
‡ Post-EVA Debrief
† DPC Setup
§ Social Media
^ ETAG
CASPER Lifeshirt Don-Record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MS3
Tech1
Tech2
Topside
Notes
Sleep
Post-Sleep
DPC
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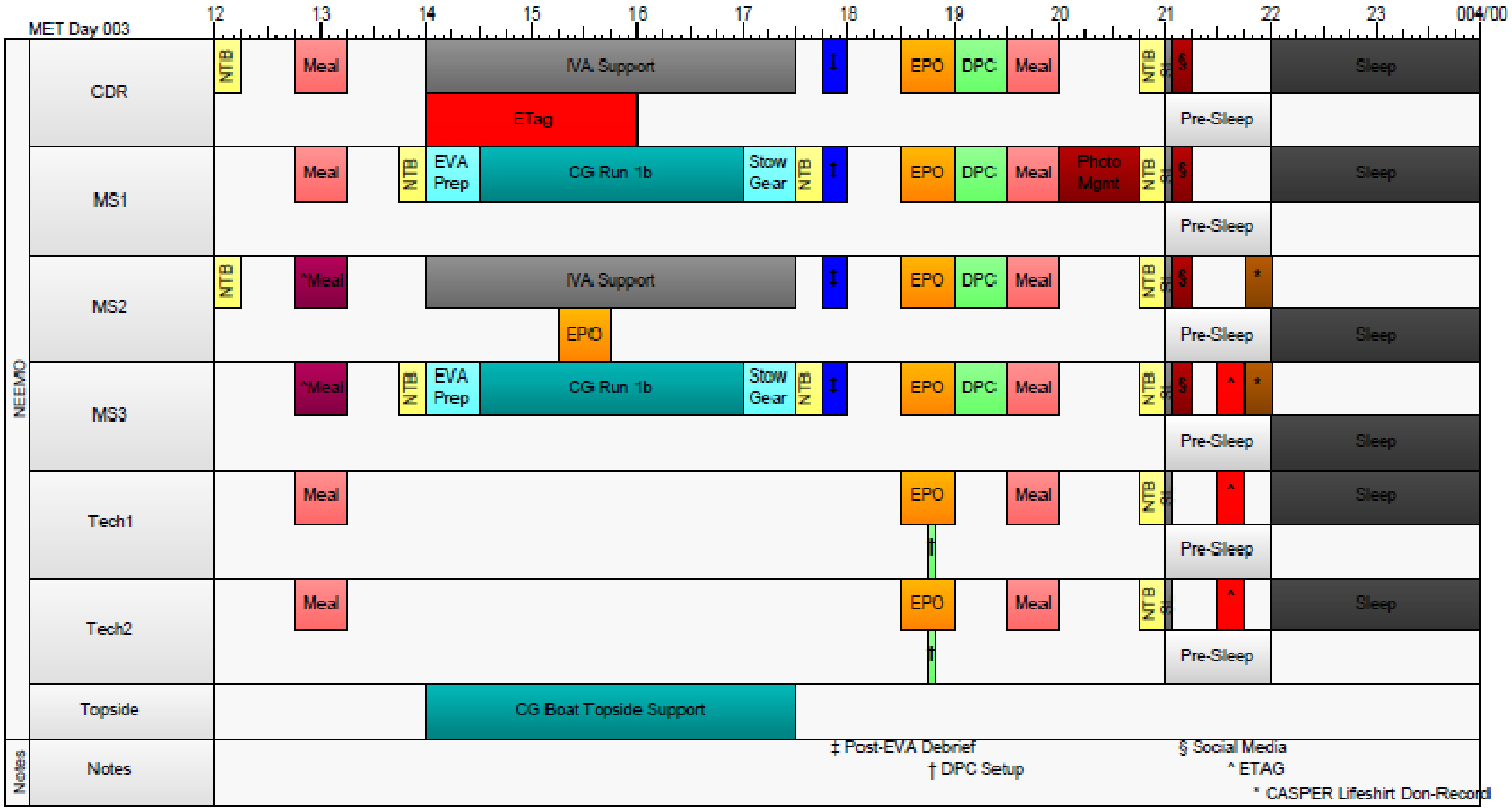
EVA Prep
CG Run 1b
Stow Gear
IVA Support
EPO
CG Boat Topside Support
* CASPER Lifeshirt Doff
† DPC Setup



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CDR
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MS2
MS3
Tech1
Tech2
Topside
Notes
NTB
Meal
^Meal
IVA Support
ETag
EVA Prep
CG Run 1b
Stow Gear
EPO
DPC
Photo Mgmt
Sleep
Pre-Sleep
CG Boat Topside Support
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† DPC Setup
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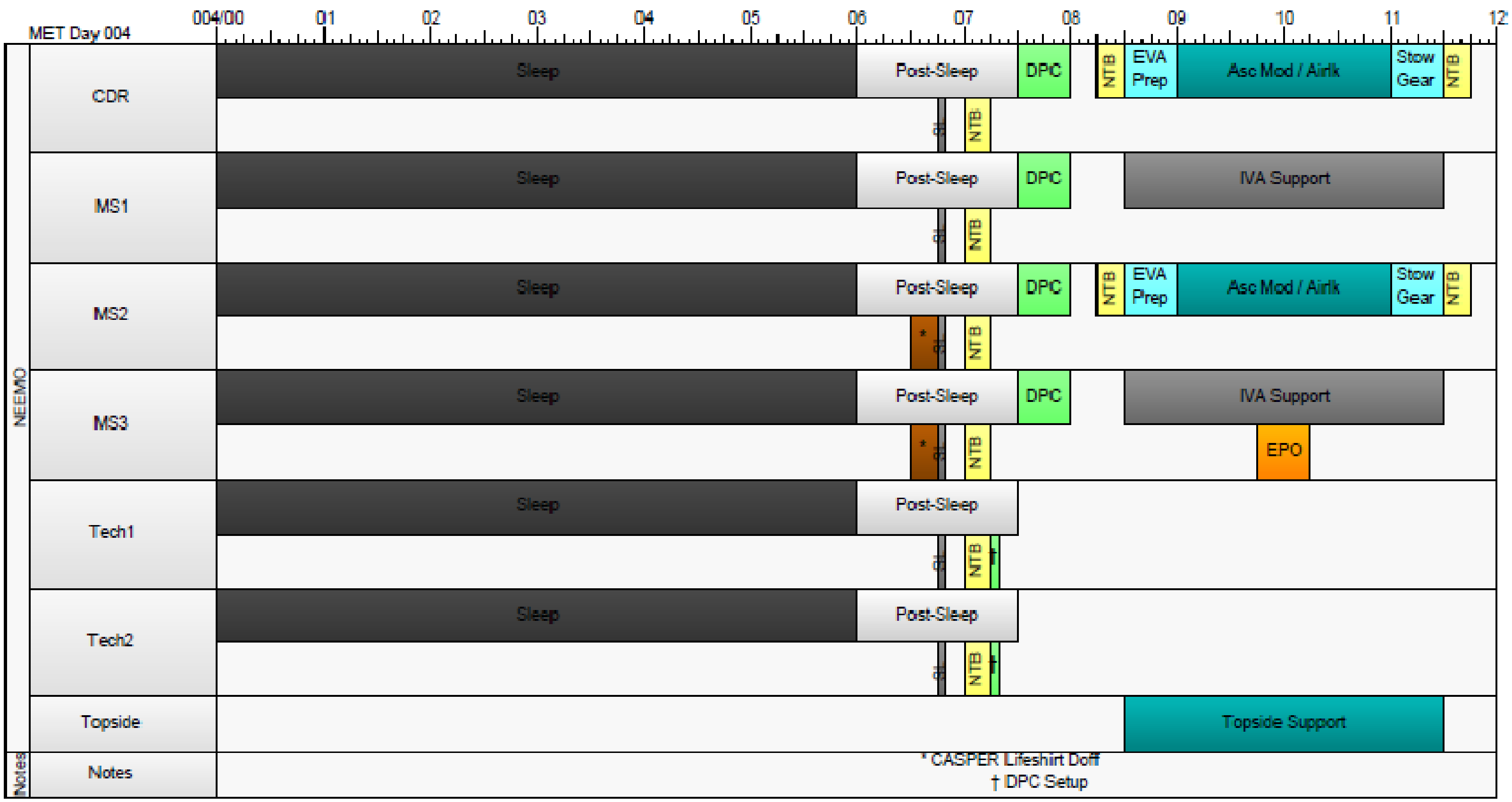
^ ETAG
* CASPER Lifeshirt Don-Record



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MS2
MS3
Tech1
Tech2
Topside
Notes
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Post-Sleep
DPC
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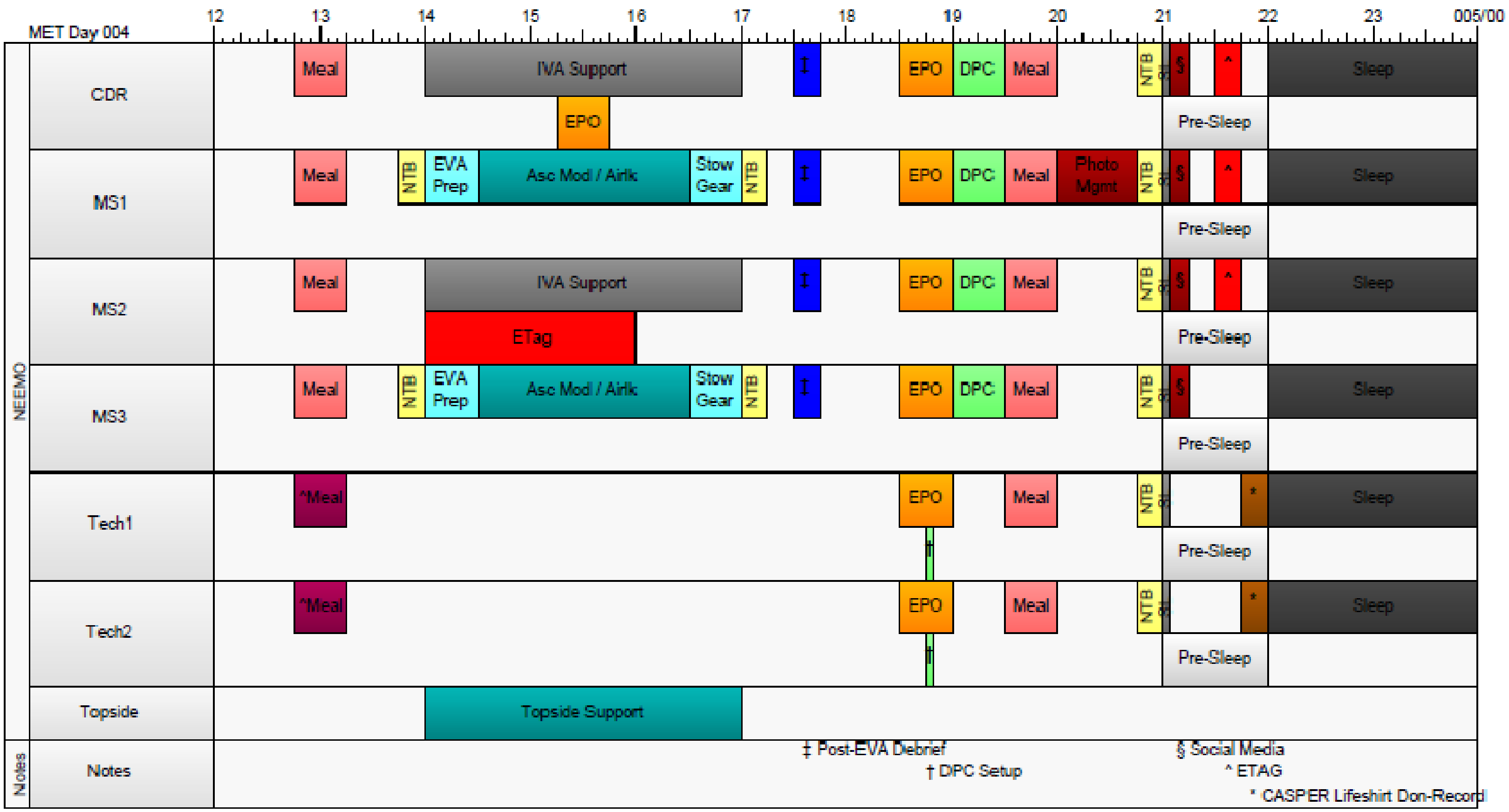
EVA Prep
Asc Mod / Airlk
Stow Gear
IVA Support
EPO
Topside Support
* CASPER Lifeshirt Doff
† DPC Setup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MS3
Tech1
Tech2
Topside
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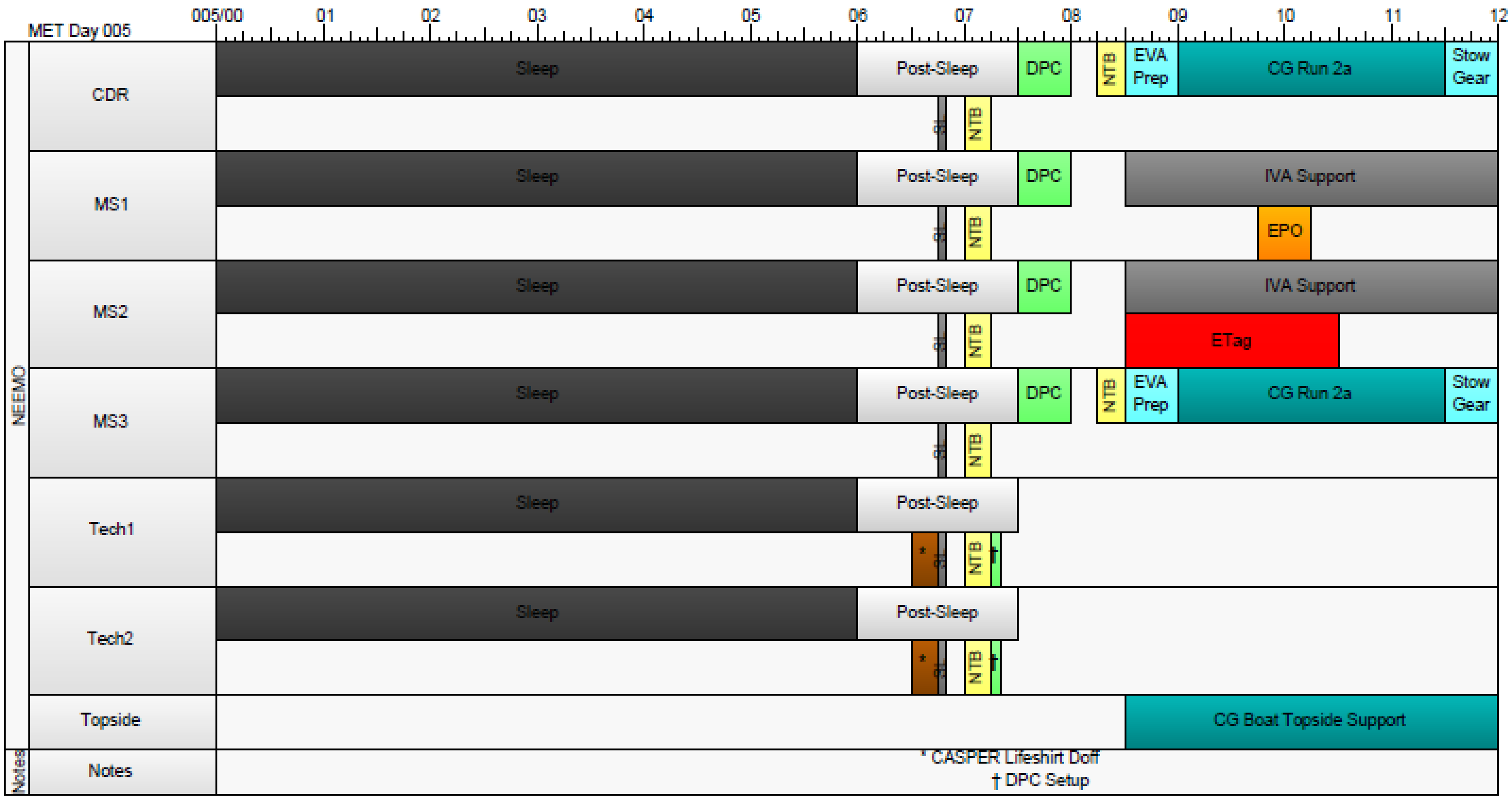
Meal
IVA Support
EPO
DPC
NTB
Sleep
Pre-Sleep
EVA Prep
Asc Mod / Airlk
Stow Gear
Photo Mgmt
ETag
^Meal
Topside Support
‡ Post-EVA Debrief
† DPC Setup
§ Social Media
^ ETAG
* CASPER Lifeshirt Don-Record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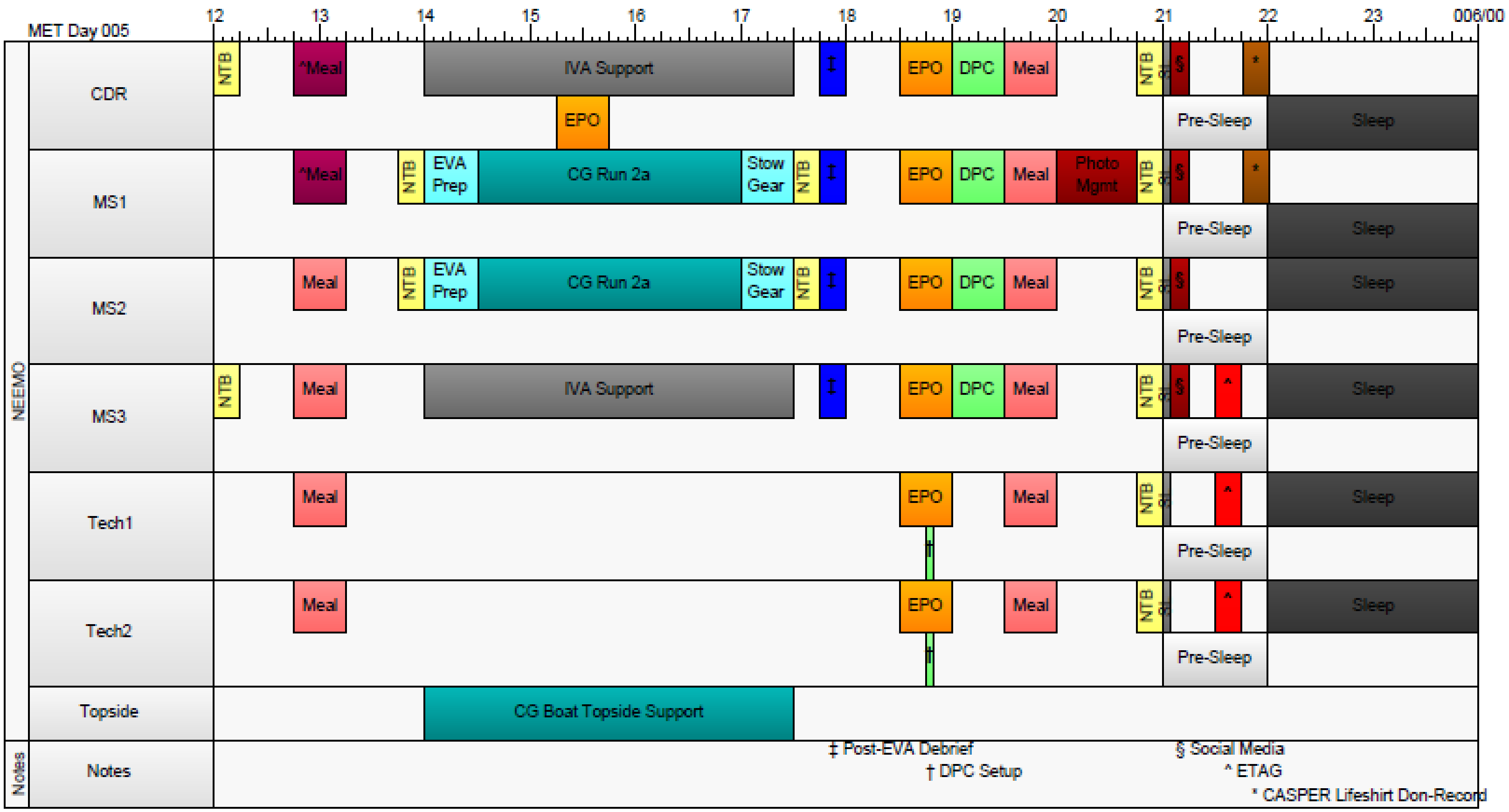
MS3
Tech1
Tech2
Topside
Notes
Sleep
Post-Sleep
DPC
NTB
EVA Prep
CG Run 2a
Stow Gear
IVA Support
EPO
ETag
CG Boat Topside Support
* CASPER Lifeshirt Doff
† DPC Setup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MS2
MS3
Tech1
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Topside
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NTB
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IVA Support
EPO
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Meal
Pre-Sleep
Sleep
EVA Prep
CG Run 2a
Stow Gear
Photo Mgmt
CG Boat Topside Support
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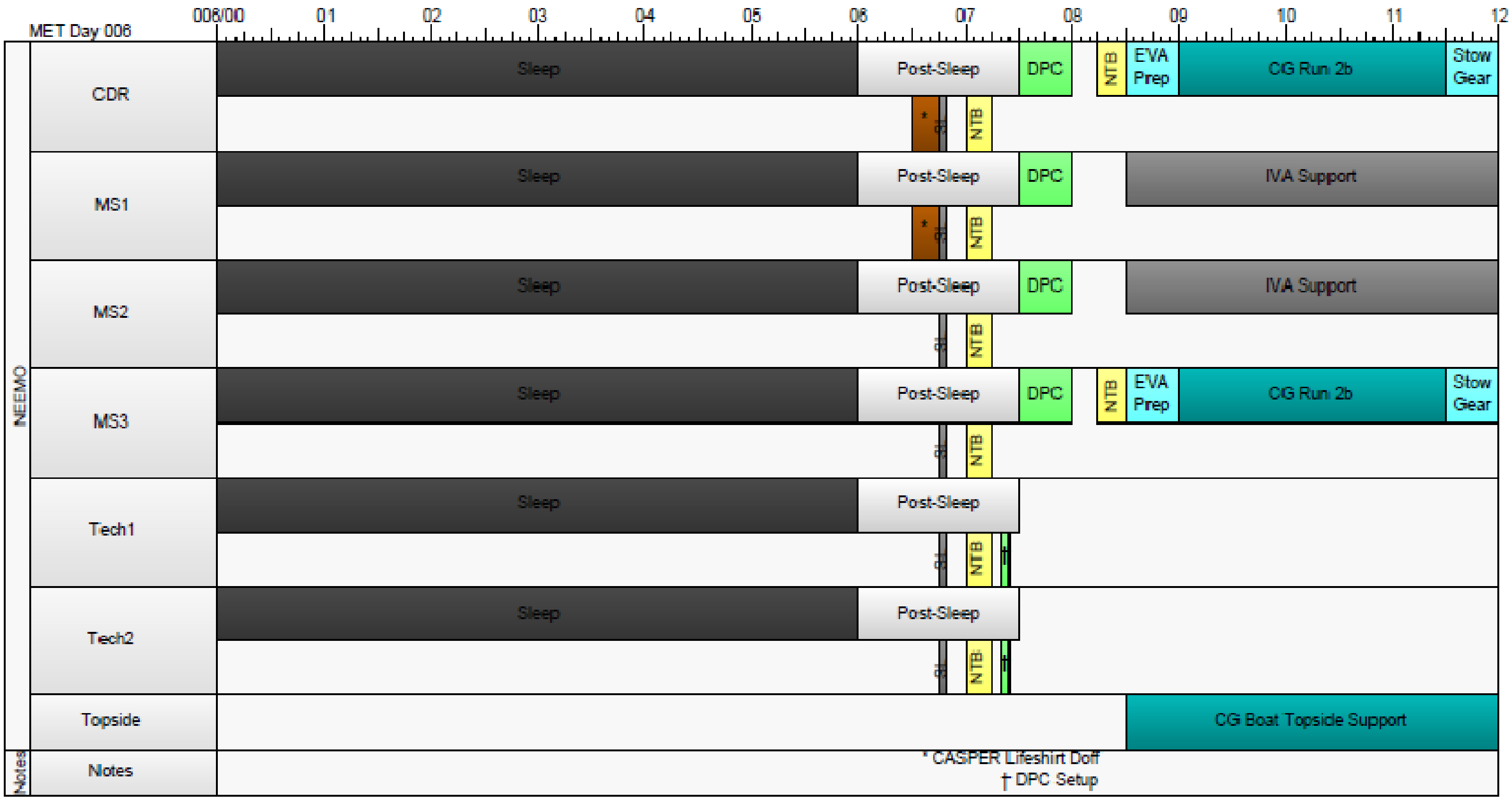
† DPC Setup
§ Social Media
^ ETAG
* CASPER Lifeshirt Don-Record



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MS2
MS3
Tech1
Tech2
Topside
Notes
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Post-Sleep
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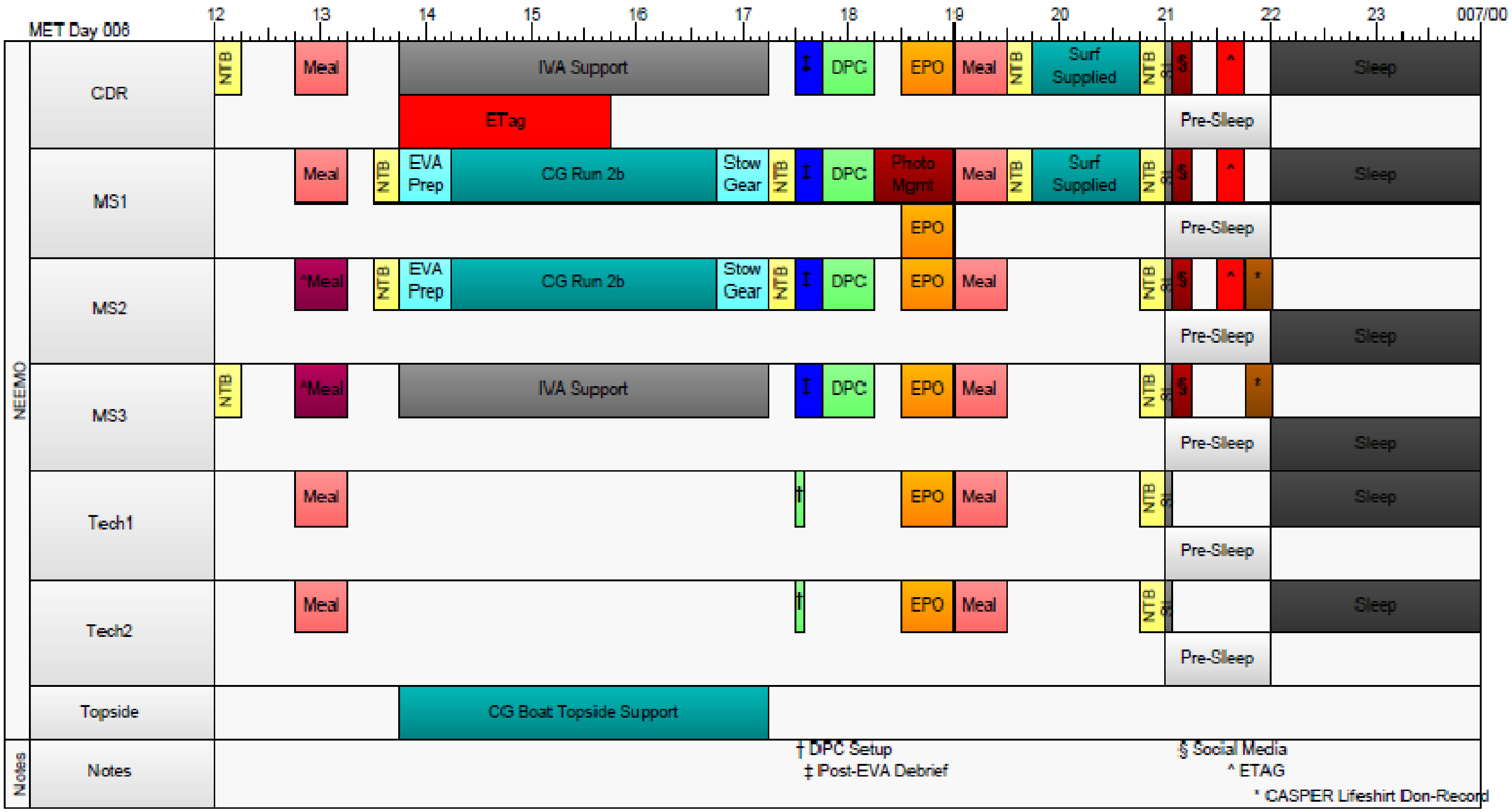
NTB
EVA Prep
CG Run 2b
Stow Gear
IVA Support
CG Boat Topside Support
* CASPER Lifeshirt Doff
† DPC Setup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Tech1
Tech2
Topside
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NTB
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IVA Support
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Sleep
ETag
Pre-Sleep
EVA Prep
CG Run 2b
Stow Gear
Photo Mgmt
^Meal
CG Boat Topside Support
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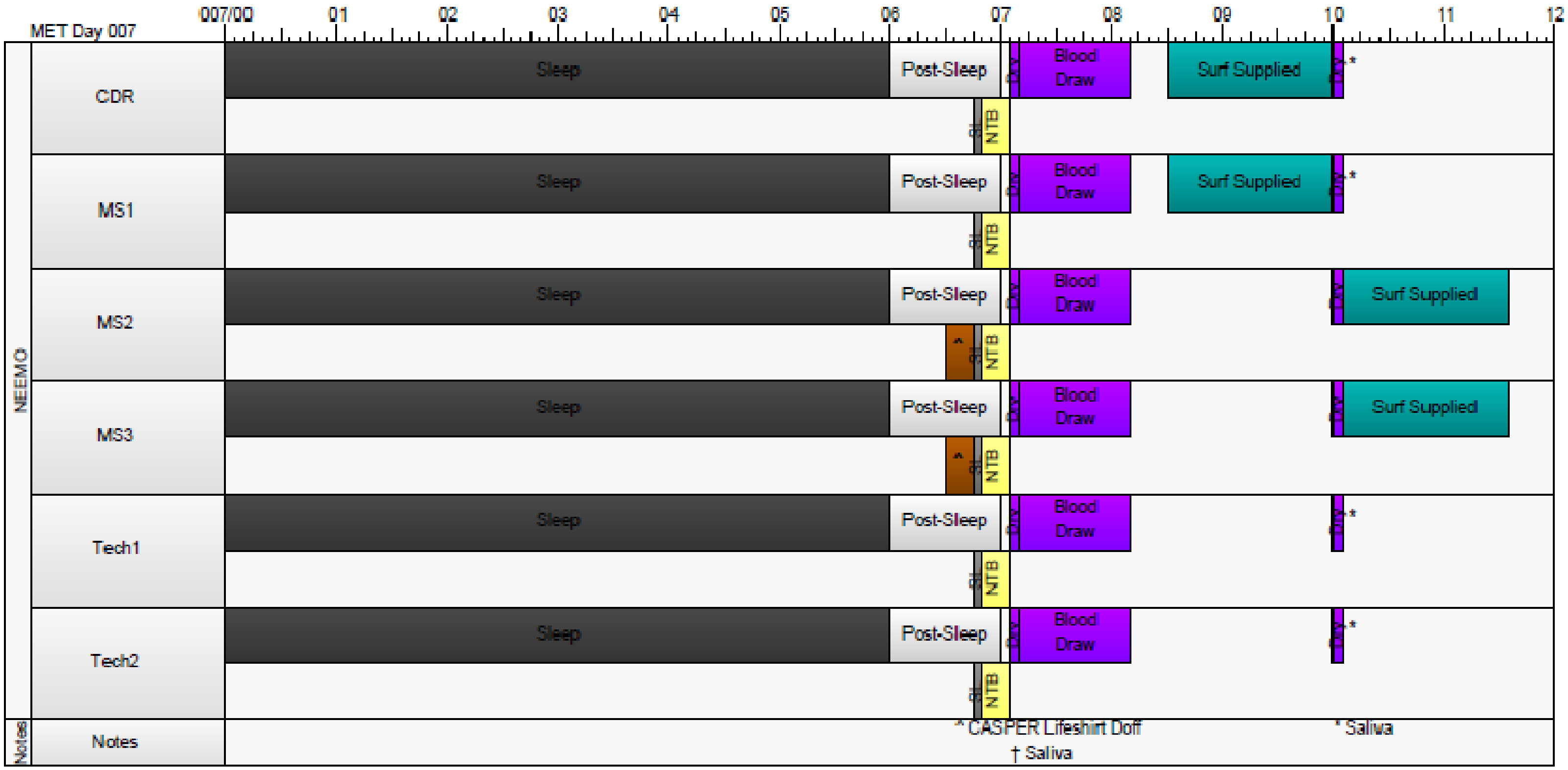
‡ Post-EVA Debrief
§ Social Media
^ ETAG
* CASPER Lifeshirt Don-Record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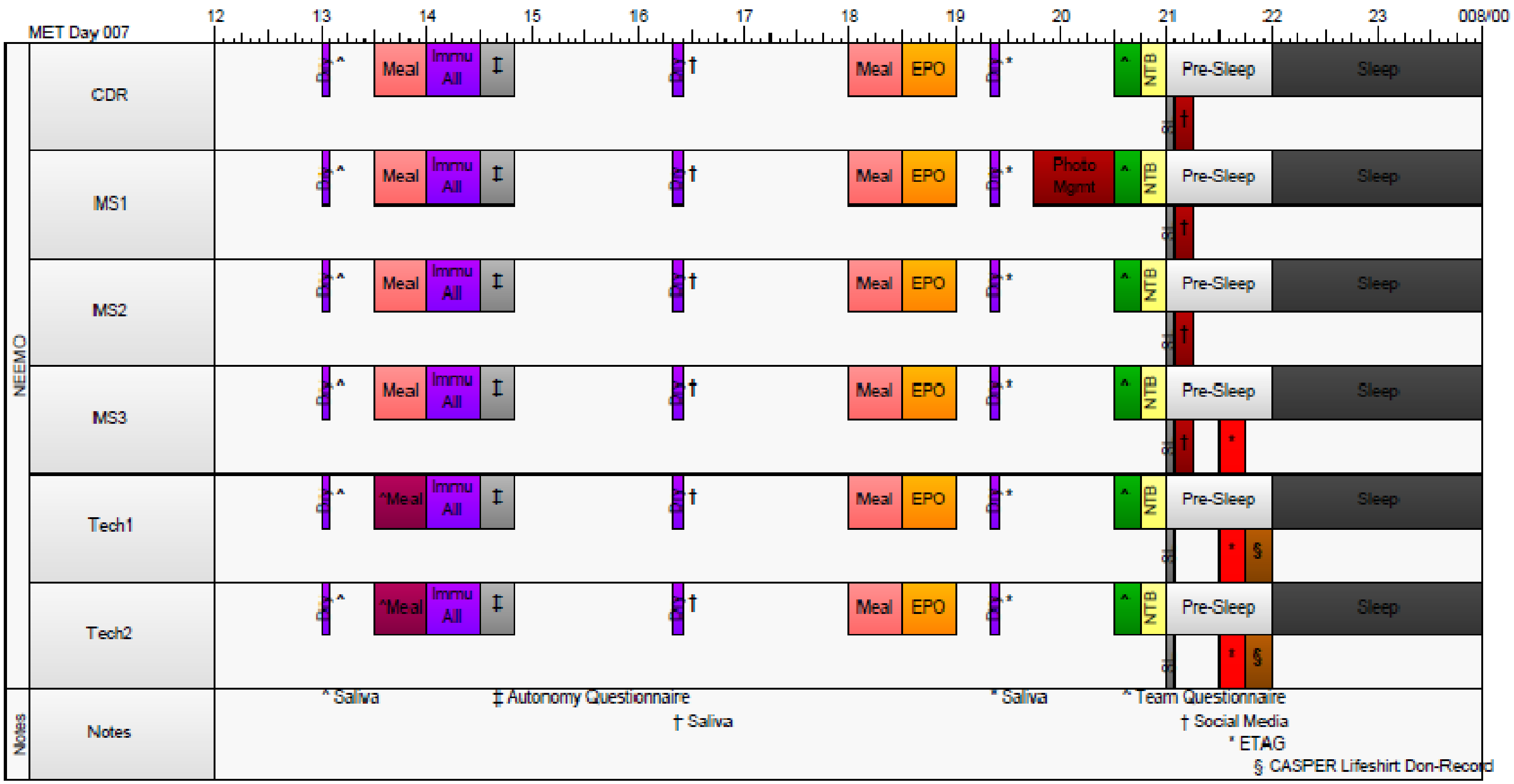
* Saliva



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* Saliva
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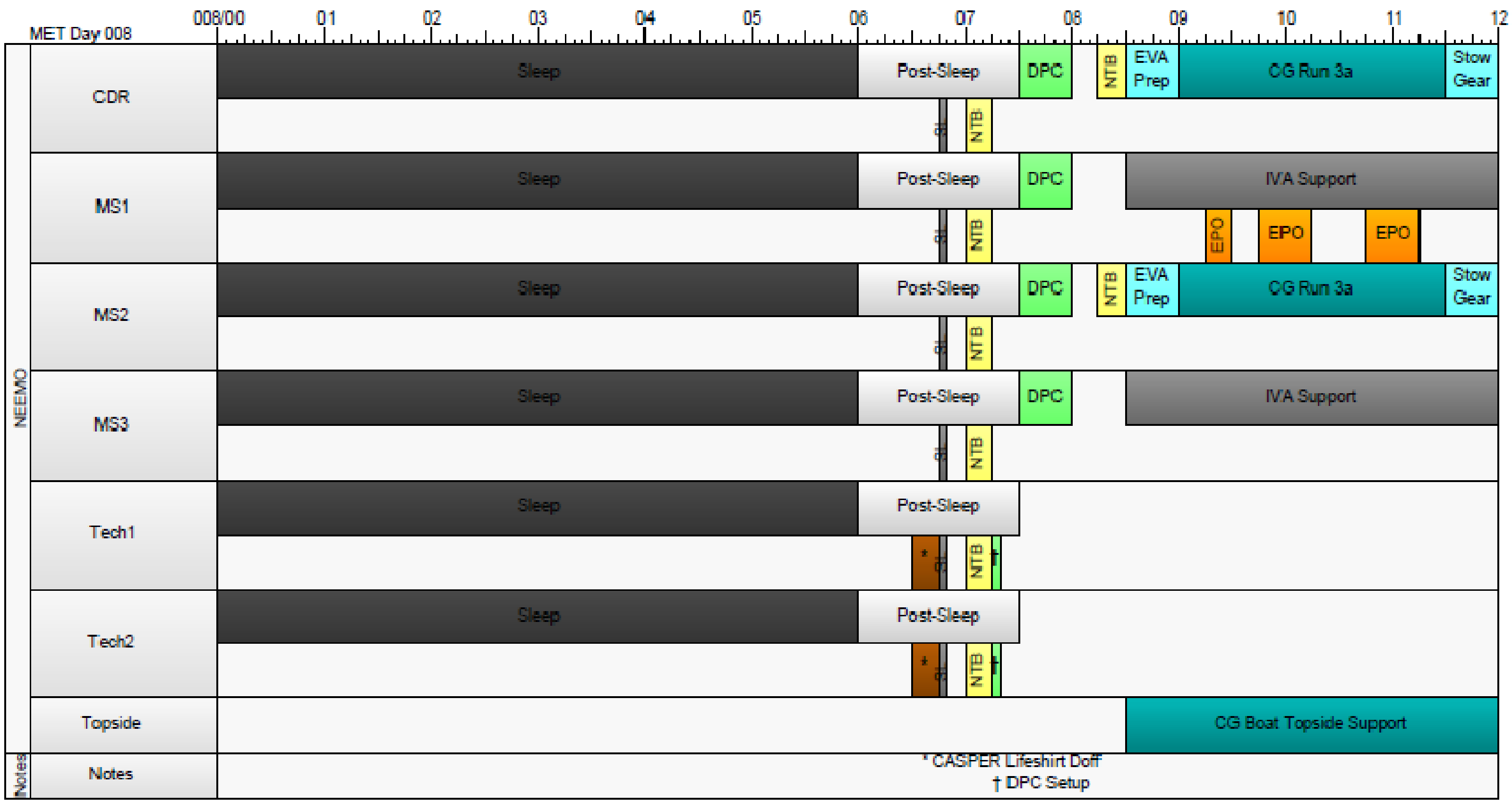
† Social Media
* ETAG
§ CASPER Lifeshirt Don-Record



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EPO
CG Boat Topside Support
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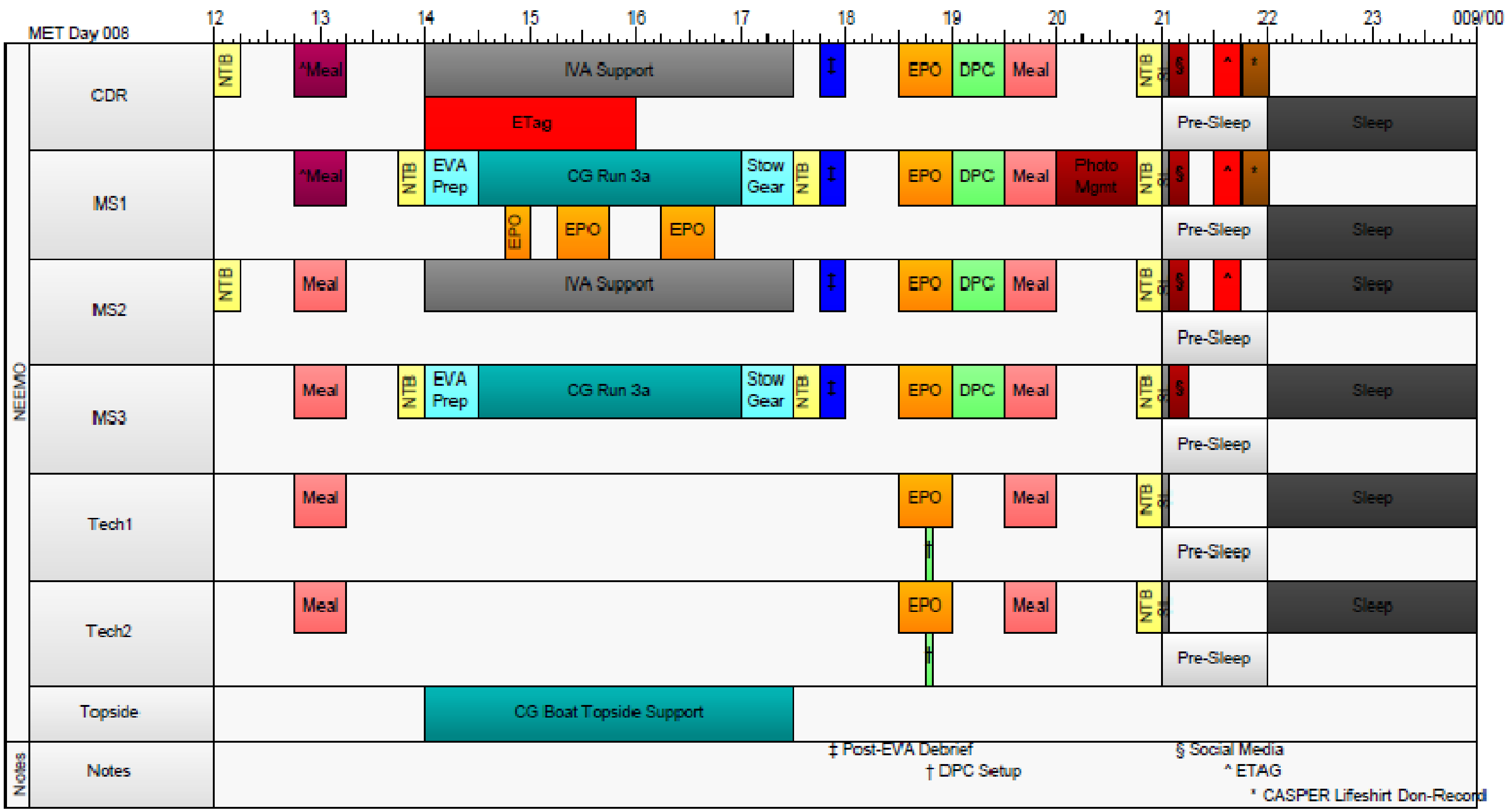
† DPC Setup



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IVA Support
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CG Run 3a
Stow Gear
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DPC
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§ Social Media
^ ETAG
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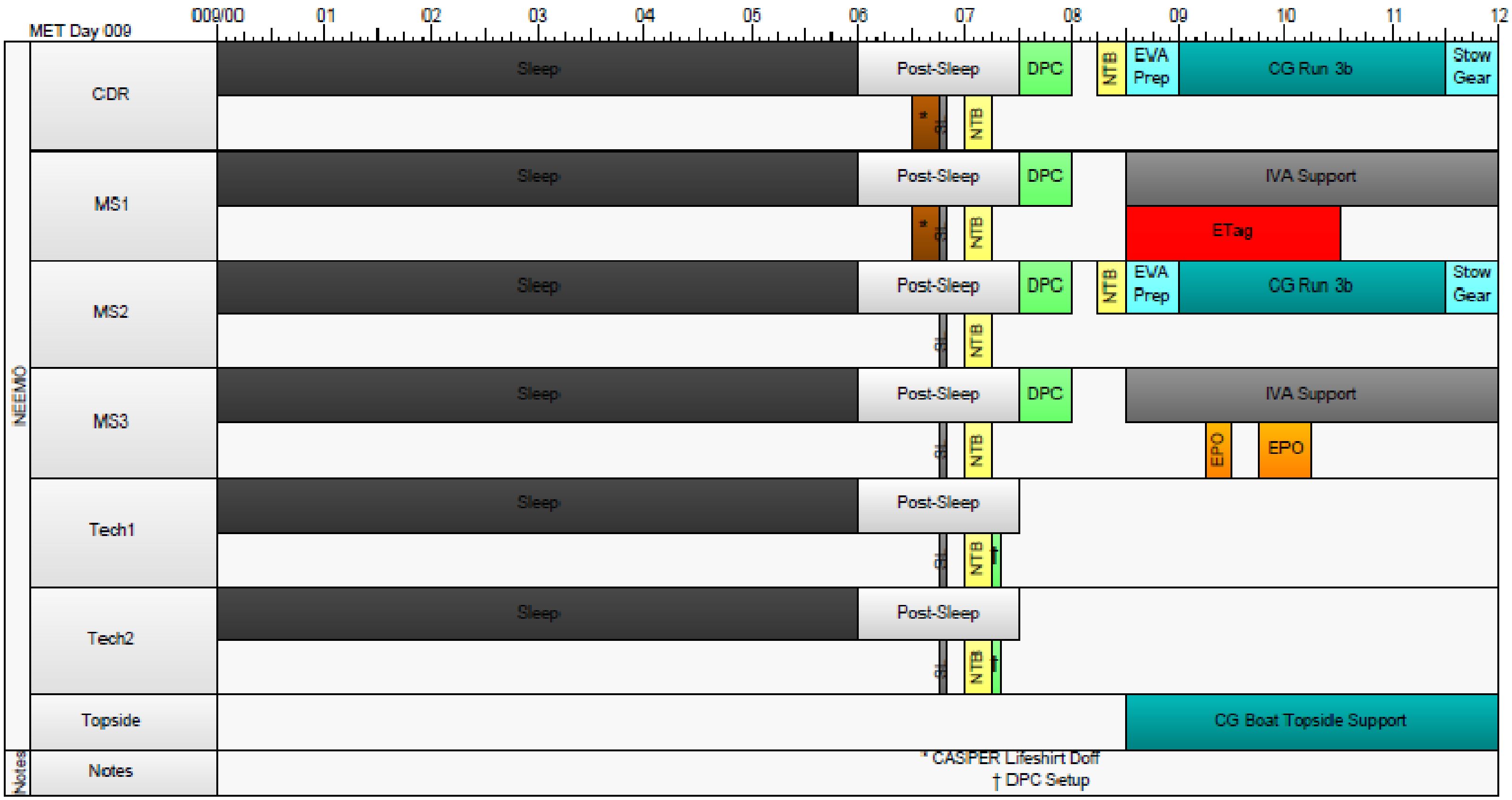
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Tech2
Topside
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Post-Sleep
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EVA Prep
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Stow Gear
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ETag
EPO
CG Boat Topside Support
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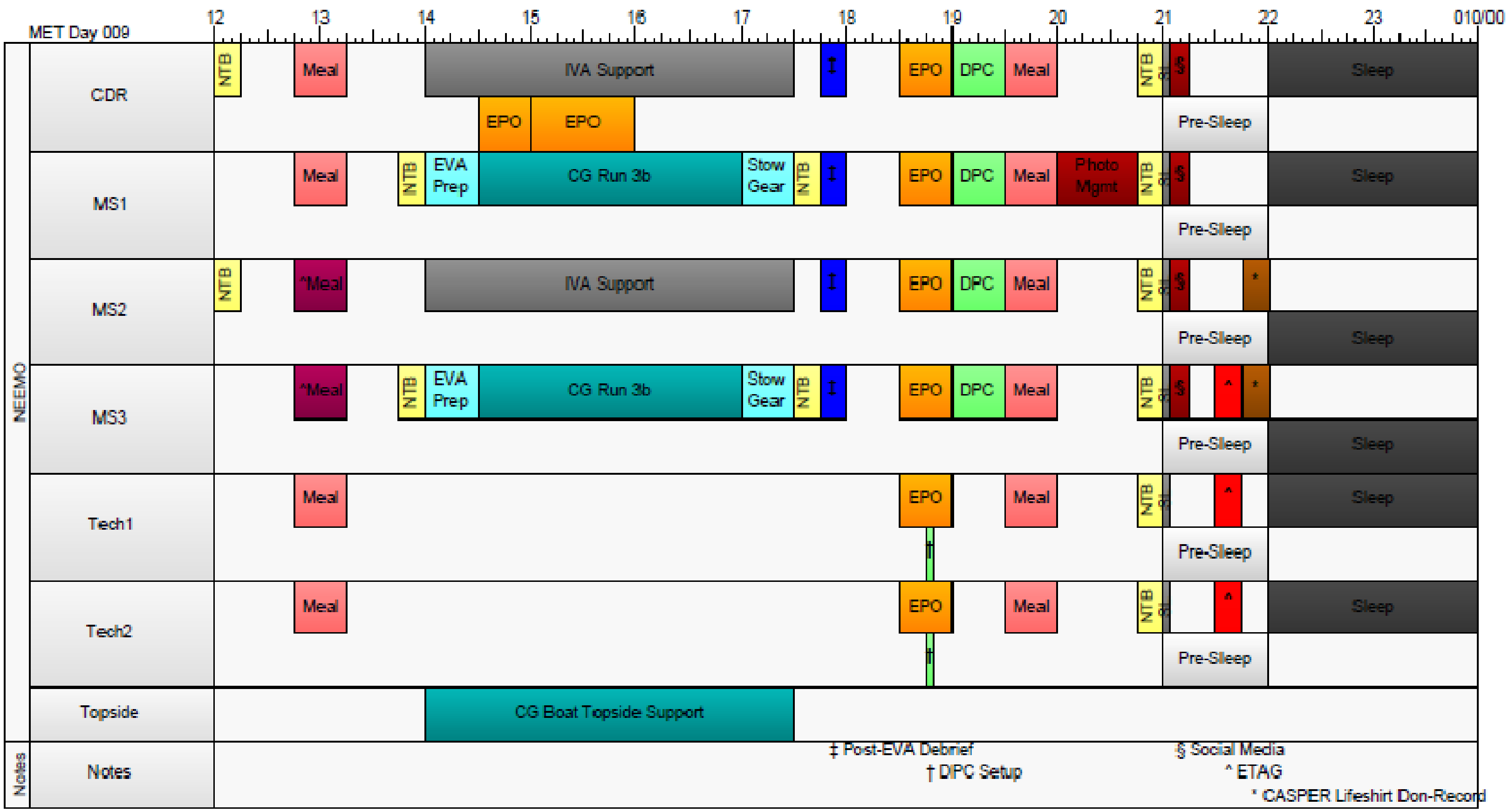
† DPC Setup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MS3
Tech1
Tech2
Topside
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NTB
Meal
^Meal
IVA Support
EPO
DPC
Sleep
Pre-Sleep
EVA Prep
CG Run 3b
Stow Gear
Photo Mgmt
CG Boat Topside Support
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^ ETAG
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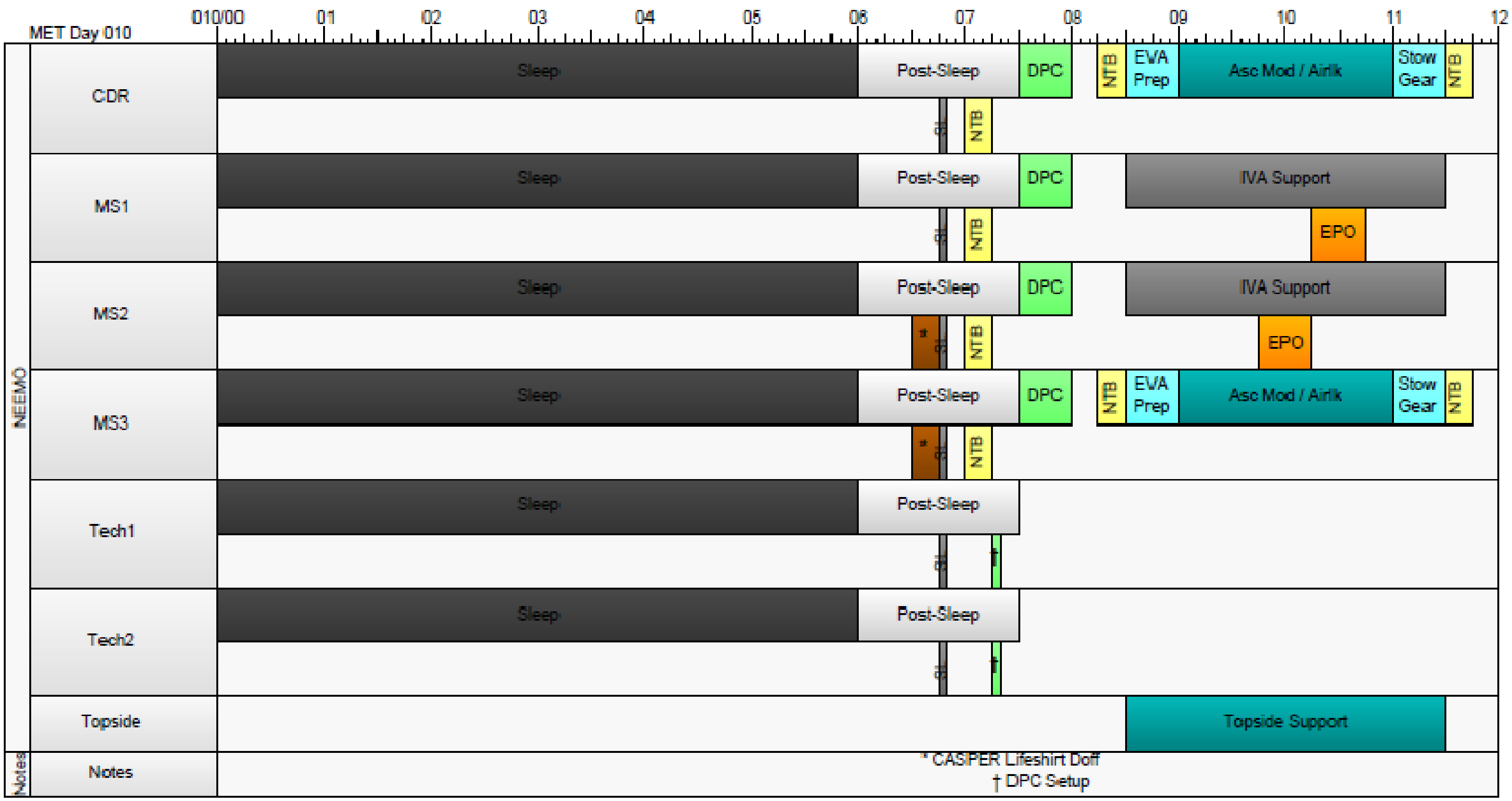
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MS3
Tech1
Tech2
Topside
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Post-Sleep
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IVA Support
EPO
Topside Support
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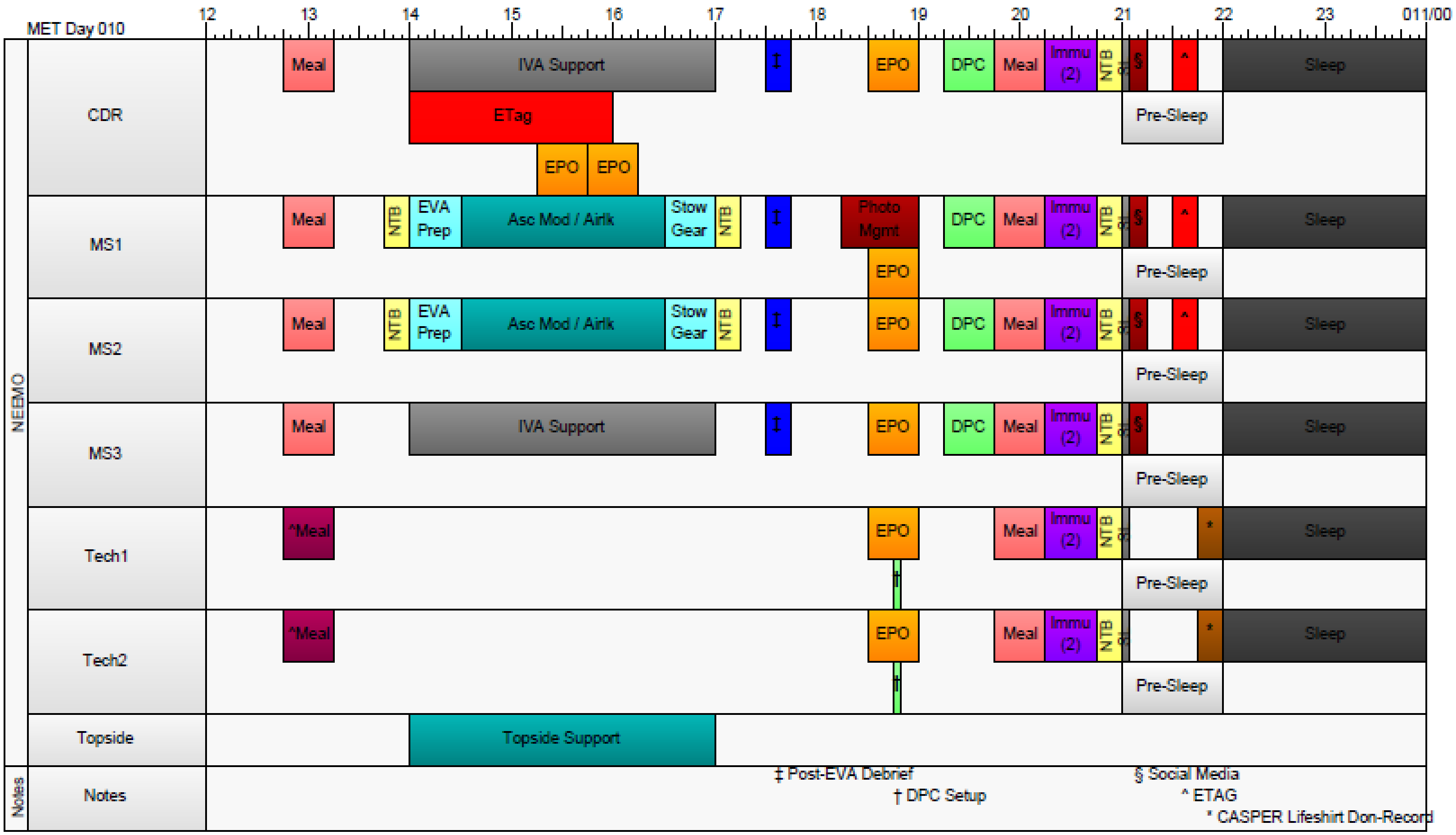
† DPC Setup



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Sleep
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MS1
Meal
NTB
EVA Prep
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Stow Gear
NTB
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Photo Mgmt
EPO
DPC
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Sleep
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Meal
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EVA Prep
Asc Mod / Airlk
Stow Gear
NTB
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Immu (2)
NTB
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Meal
IVA Support
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EPO
DPC
Meal
Immu (2)
NTB
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Pre-Sleep
Tech1
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EPO
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Immu (2)
NTB
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Sleep
Pre-Sleep
Tech2
^Meal
EPO
†
Meal
Immu (2)
NTB
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Sleep
Pre-Sleep
Topside
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Notes
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^ ETAG
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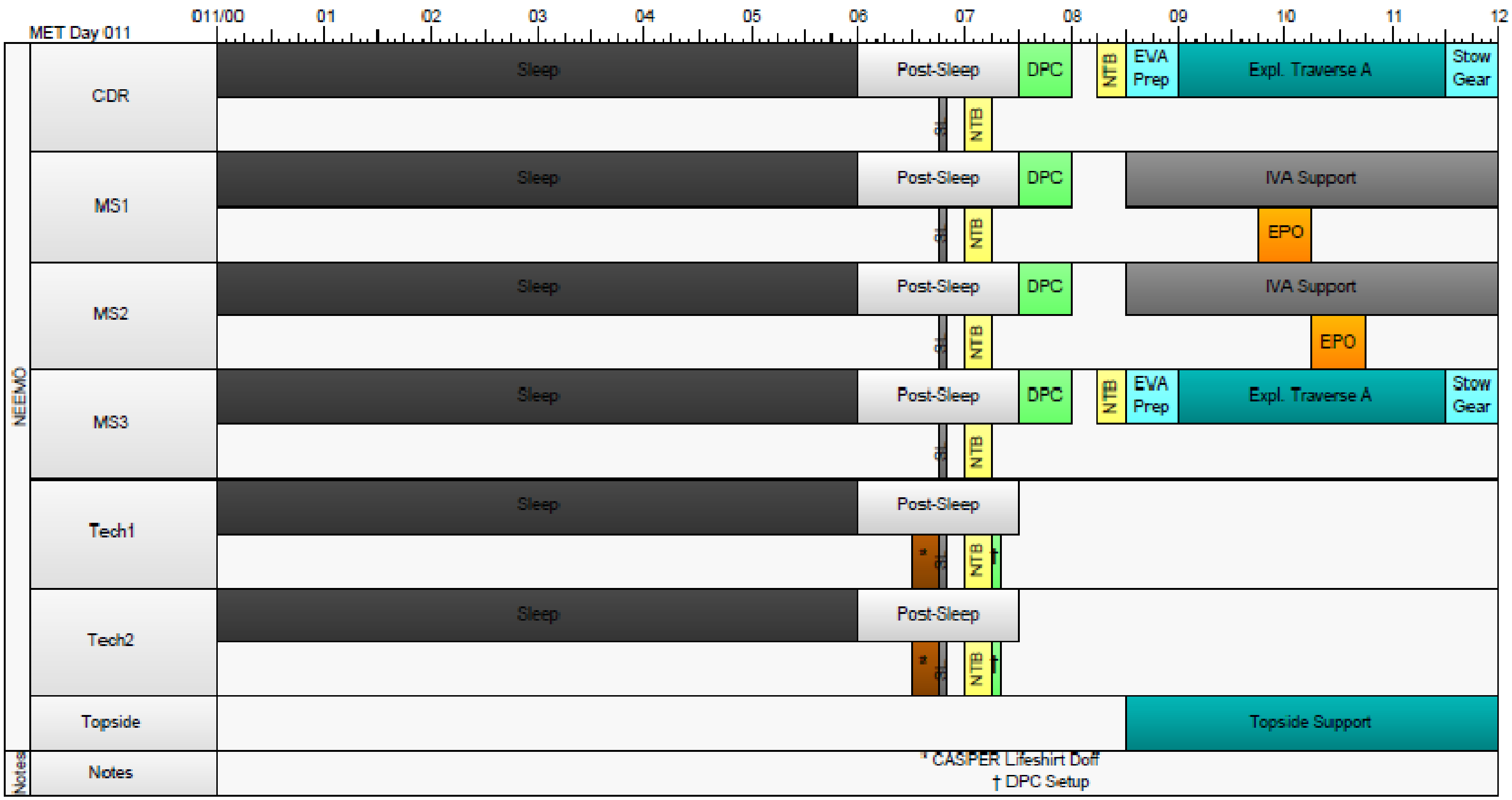
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Tech2
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IVA Support
EPO
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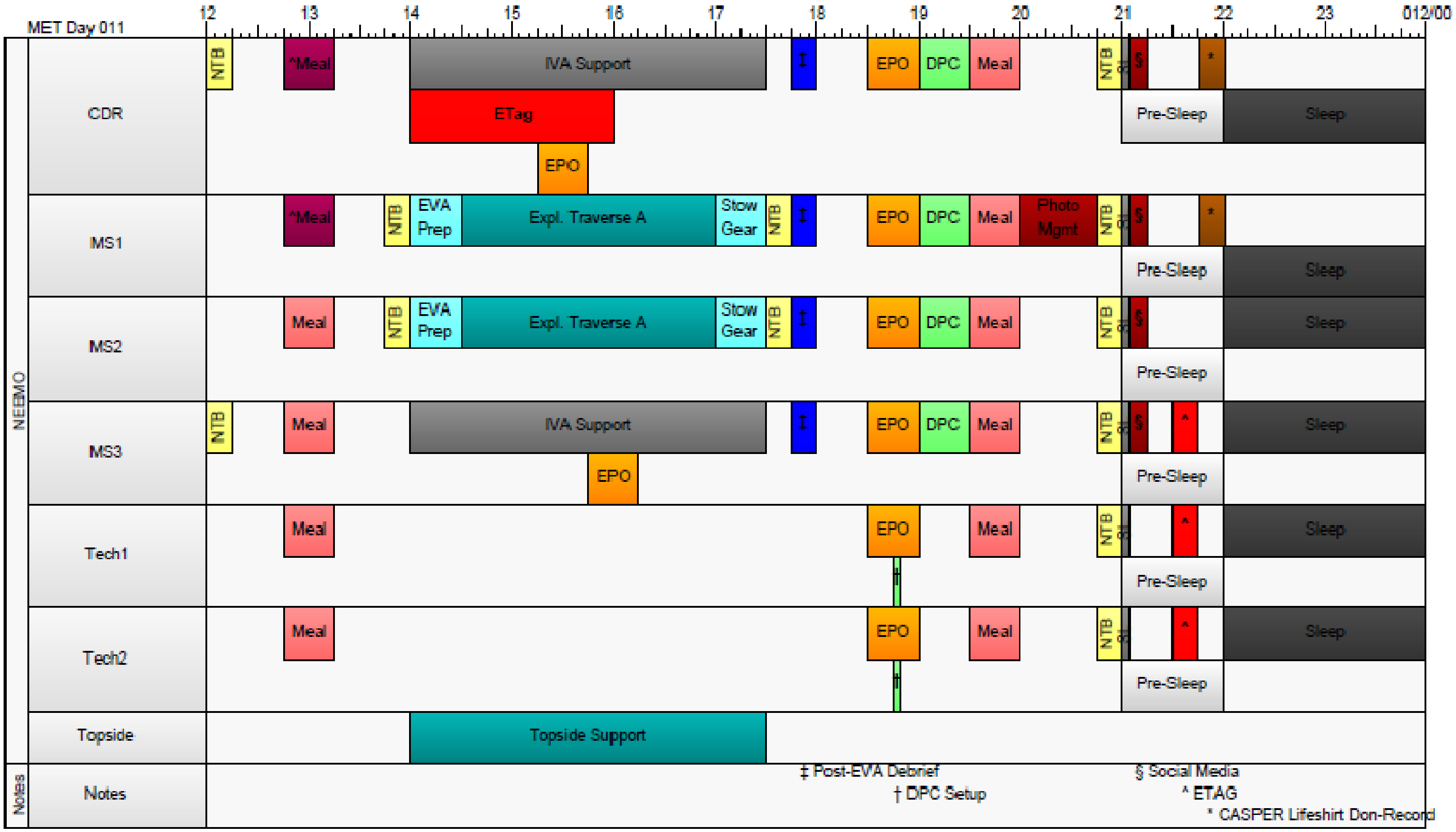

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Tech2
Topside
Notes
NTB
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Meal
IVA Support
ETag
EPO
DPC
Photo Mgmt
EVA Prep
Expl. Traverse A
Stow Gear
Pre-Sleep
Sleep
Topside Support
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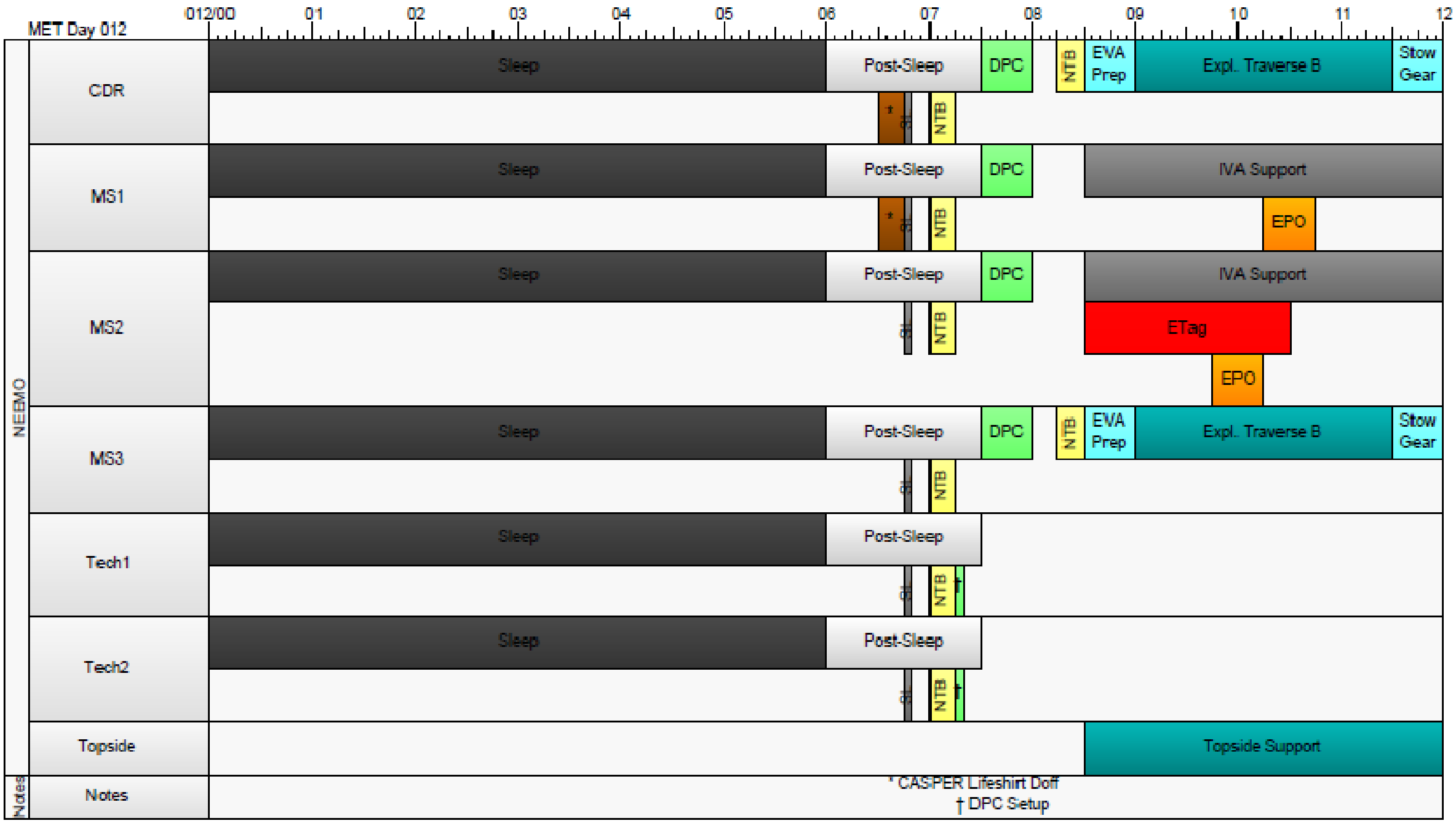
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MS3
Tech1
Tech2
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Sleep
Post-Sleep
DPC
NTB
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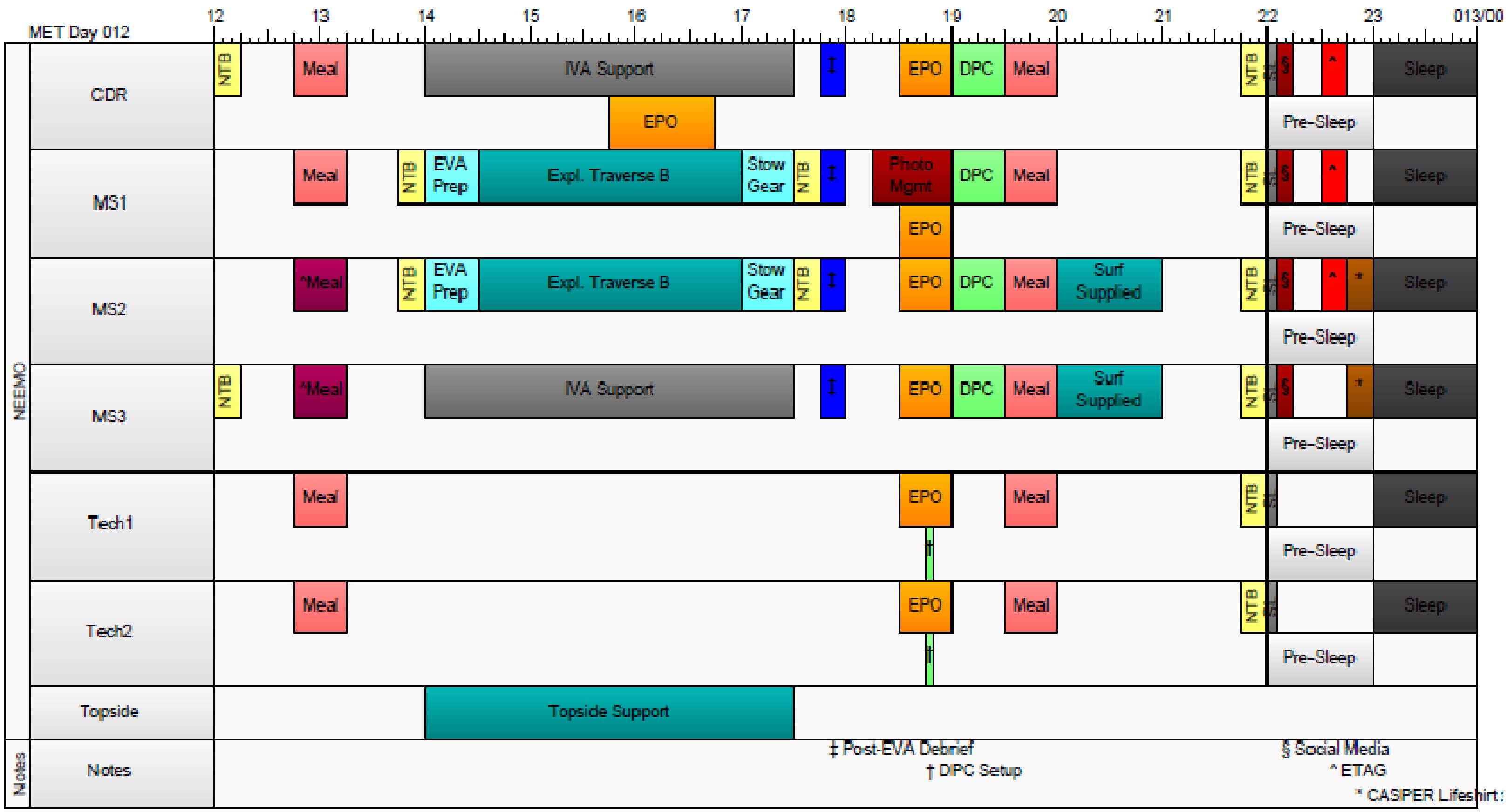
Expl. Traverse B
Stow Gear
IVA Support
EPO
ETag
Topside Support
* CASPER Lifeshirt Doff
† DPC Setup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MS2
MS3
Tech1
Tech2
Topside
Notes
NTB
Meal
^Meal
IVA Support
EPO
DPC
EVA Prep
Expl. Traverse B
Stow Gear
Photo Mgmt
Surf Supplied
Pre-Sleep
Sleep
Topside Support
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† DIPC Setup
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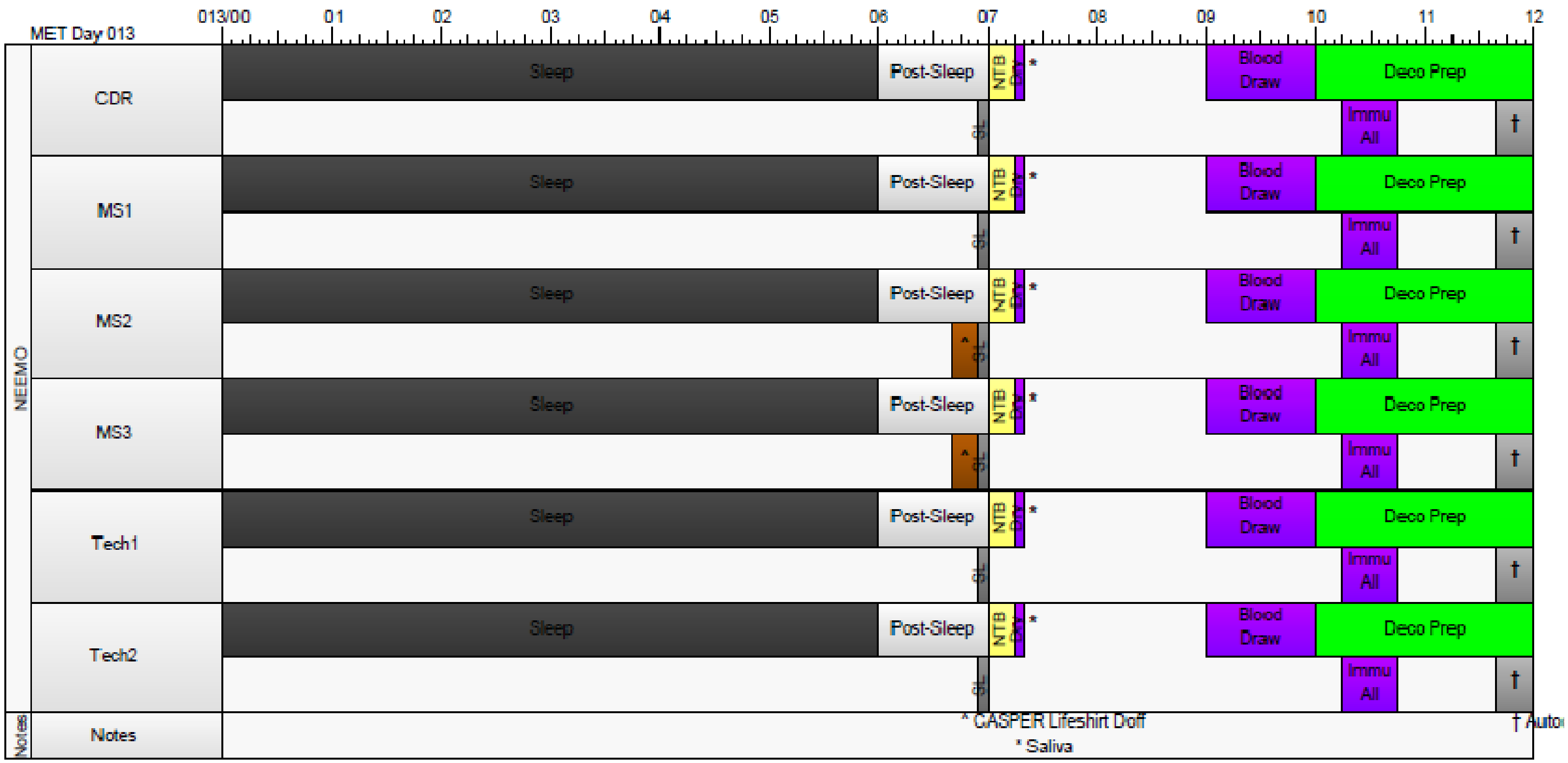
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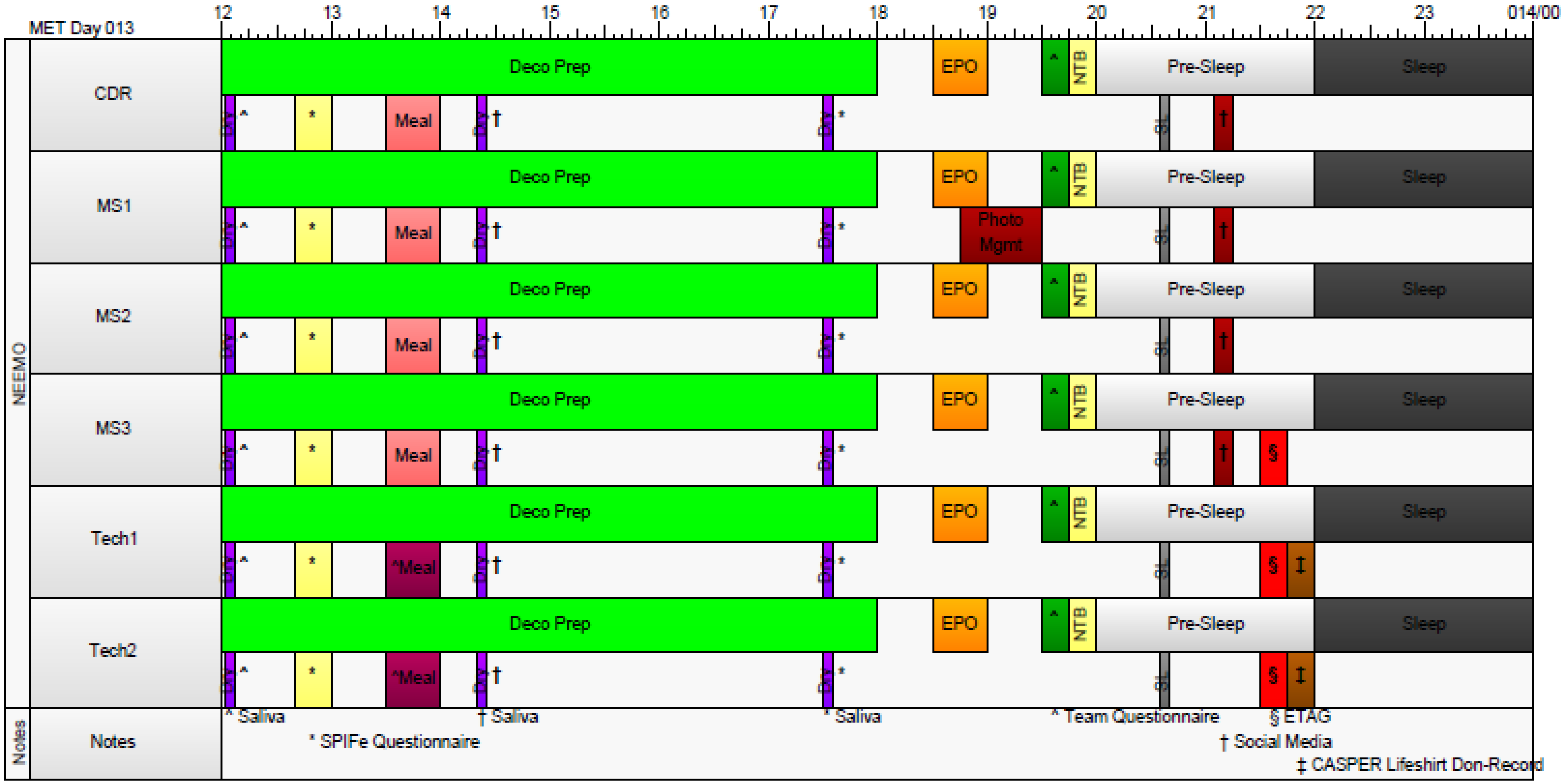
CDR
MS1
MS2
MS3
Tech1
Tech2
Sleep
Post-Sleep
NTB
Blood Draw
Deco Prep
Immu All
Notes
^ CASPER Lifeshirt Doff
* Saliva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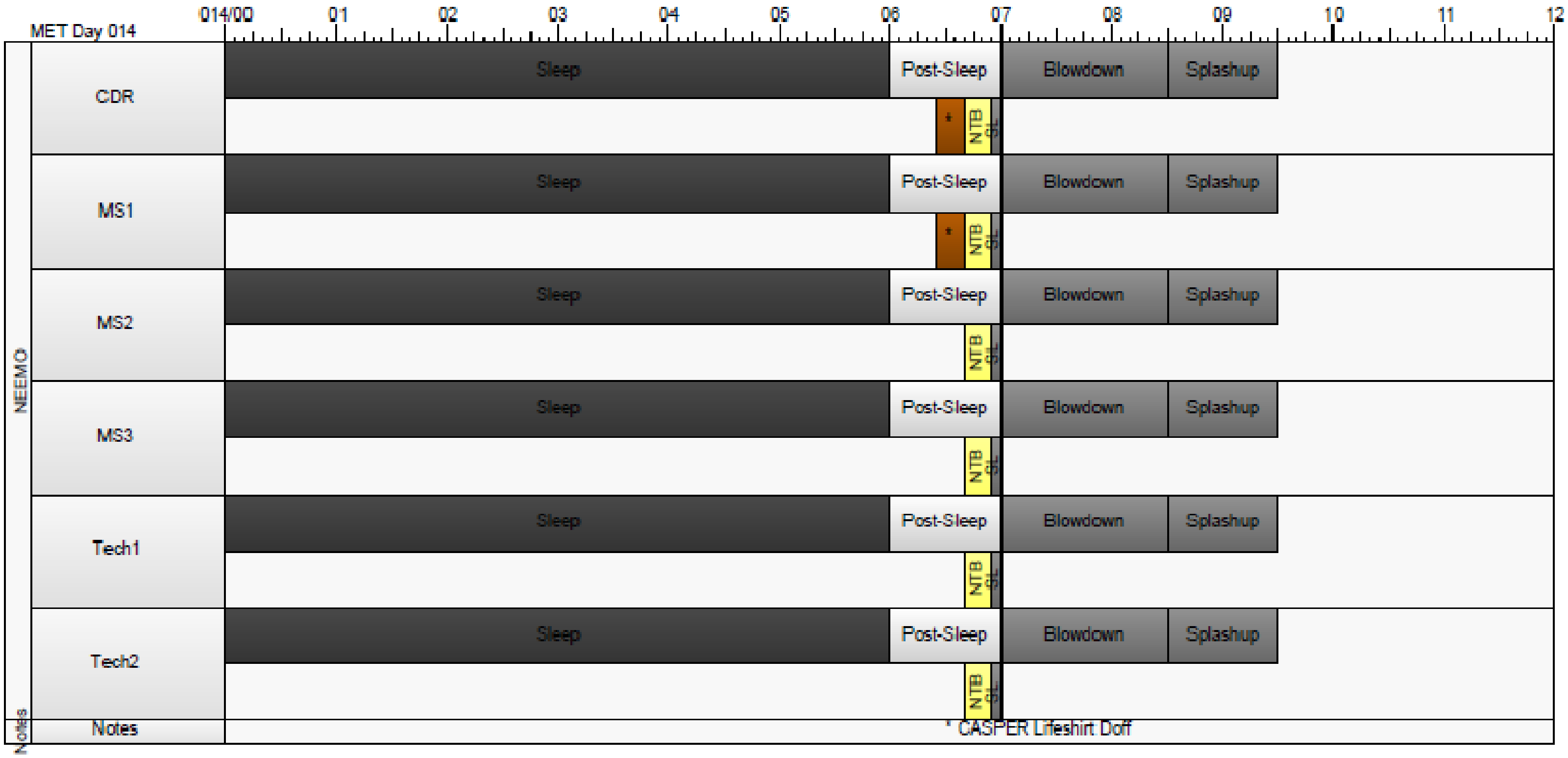
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8.4 Procedures

8.4.1 Center-of-Gravity Cargo-lander Task Extravehicular Activity Timelines and Procedures

Objectives/Description: To perform tests that elicit understanding of the effects of CG and optimal EVA suit weight on human performance while performing exploration tasks.

Crew members will wear the MK-12 suit (weighted in one of three possible Earth suit weights) and the PLSS-rig apparatus in three different CG configurations as they perform a series of tasks that mirror expected exploration mission activities (timed walking, jogging, and running, as well as picking up rocks, kneel and recovery, fall and recovery, shoveling activities, ladder climb, ramp climb, small payload off-/on-load, simulated incapacitated crew member upload, SEV off-load).

Location: Activities will be performed on a sandy seafloor location near the habitat and/on or near lander and SEV mock-ups. A 6.1-m (20-ft) path will be marked with a clear stop/start point for the ambulation task, and other task areas will designated.

> **CAUTION!**
>
> - **The top of ladders must be secured to support climbing activities**
> - **Fall protection systems must be used whenever climbing or working on lander mock-up**

Tools required

Support diver pre-positioned items

- Habitat ladder (secured at top) – height 3 m, 7.7 cm (10 ft, 3 in.); base width of 1.8 m, 10.2 cm (6 ft, 4 in.); rung spacing 30.5 cm (12 in.); bottom rung 0.6 m, 12.7 cm (2 ft, 5 in.)
- Shovel (with bucket)
- Three empty milk crates, stacked with opening at top
- Weights/rocks for "rock collection" activity in the following denominations (kg [lbs]): 5.4 (12), 4.5 (10), 4.1 (9), 3.6 (8), 3.2 (7), 2.7 (6), 2.3 (5), 1.8 (4), 1.4 (3), and 0.9 (2)
- Ramp: 122 cm (48 in.) wide, with 20-deg angle (≥ 4.6 m [15 ft] in length)
- Start/finish lines (quantity 2) with anchor weights
- 2 ea. PLSS rigs set to first configuration (pre-positioning optional)
- 4 ea. PLSS rig lunar weights (pre-positioning optional)
- Lander mock-up
- SEV mock-up
- Lander davit
- Lander ladder pre-positioned to first ladder angle
- Self-retracting lanyard for lander ladder fall protection
- "Small payload" crate with weights
- Rescue manikin with dive harness and PLSS plate
- Two 45.7-m (150-ft) ropes in rope bags
- Two double-sheave pulleys
- Two ratcheting single-sheave pulleys
- Two safety tethers with dual French-hook connectors and self-belay devices

- TBD locking carabiners

Aquarius items (pre-positioned)

- MK-12 suit
- Integrated Diver Vests (IDVs) and 3.6- to 2.3-kg (8- to 5-lb) weights (only back-pocket weights installed prior to leaving wet porch)
- Two full-body dive harnesses
- Two stopwatches or timing devices (to be used by IVA)
- Wetsuit/booties (no boots)
- Superlite™-17B helmet (Kirby Morgan Dive Systems, Inc., Santa Maria, Calif)
- *GCPS cue card.pdf*
- *CG_Cue Card*
- *OptWt_Cue_Card* (use correct version for EVA divers)
- *CG and Lander Tasks Datasheets* record – waterproof printed copies (one per crew member – front and back)

Support diver hand-carried/real-time items

- 2 ea. PLSS rigs (if not pre-positioned)
- 4 ea. PLSS rig lunar weights (if not pre-positioned)
- *CG Cue Card(s)*
- *OptWt_Cue_Card* (two versions cover all four crew members) – waterproof
- 4 ea., 1.1-cm (7/16-in.) nut drivers for PLSS rig reconfigurations
- Contingency tools for PLSS rig (1.1-cm [7/16-in.] wrench, no. 2 Phillips, nuts and bolts, wire ties)
- IDV weights
- MK-14 suit weights
- Tape measure
- **Video cam**era **and camera equipment (to provide side** and **front views)**

<table>
<tr><th>Proc. No.</th><th>HR : MIN</th><th>Topside/IV/MCC</th><th>EV1</th><th>EV2</th></tr>
<tr><td>1</td><td>N/A --</td><td><u>EVA PREPARATION/EGRESS</u> (00:30)

1. Topside divers (T1 & T2) in water
2. Topside ensures initial configuration of all equipment and mock-ups is correct
3. Intravehicular (IV) configures red/blue diver communications system
4. IV configures video and computers to be able to see seafloor view, lander deck view, tank farm view, and the task procedures (If visibility is poor, IV and extravehicular [EV] to decide whether it is safe and feasible to proceed)
5. IV ensures hard copy data sheets are ready to record data
6. Mission Control Center (MCC) ensures communications with divers on exit of wet porch
7. MCC ensures soft copy data sheets are ready to record data</td><td colspan="2"><u>EVA PREPARATION/EGRESS</u> (00:30)

1. Work with IV to perform SL-17 checklist and communications checklist.
2. Don wet suit/booties/gloves, IDV with weights per <u>OptWt_Cue_Card</u>, bailout bottle, SL-17, and full-body dive harness. NOTE- Do NOT wear Boots.
a. MK-12 and IDV Weights configured by Support Divers; down mode is EVA crew configures weights or uses HABTECH divers.
3. Egress wet porch and proceed to start/finish line to complete weigh out and configure CG rig.</td></tr>
<tr><td>2</td><td>00:00 --</td><td><u>INITIAL CG RIG/WEIGHT CONFIGURATION</u> (00:10)

<u>INITIAL CONFIGURATION:</u>
– EV1 on surface
– EV2 on surface
– T1 on surface
– T2 on surface
– CG rigs and weights ready for configuration

1. T1 and T2 configure CG rigs and assist crew in weigh out
2. MCC confirms and communicates with EV weigh out and CG being tested by each EV crew member</td><td colspan="2"><u>INITIAL CG RIG/WEIGHT CONFIGURATION</u> (00:10)

1. Work with topside divers to deploy umbilical.
2. Work with topside divers to add more weights as needed to achieve proper weight out.
3. Work with topside divers to don CG rig and verify correct CG.</td></tr>
<tr><td>3</td><td>00:10 ---</td><td><u>EPSP CG AND LANDER LADDER ACTIVITY</u> (00:10)</td><td><u>EPSP CG ACTIVITY</u> (00:10)</td><td><u>LANDER LADDER ACTIVITY</u> (00:10)</td></tr>
</table>

		INITIAL CONFIGURATION: – EV1 on surface – EV2 on surface – T1 on surface – T2 on surface – Traverse path marked – Shovel and bucket in place – Weights/rocks and crates in place – Lander ladder configuration set **NOTE:** For each task, IV guides crew through GCPS questions for each task and populates waterproof data sheet. **GRAVITY COMPENSATION AND PERFORMANCE SCALE:** For GCPS data collection, IV poses the following questions and records the corresponding score on the EPSP & Lander CG_OptWt_data sheets. – Can the task be reliably performed? If no, enter score of 10. If yes, ask following question. – Is adequate task performance attainable with tolerable workload? If no, prompt crew for appropriate score 7-9 per GCPS cue card definitions. If yes, ask the following question. Is task performance adequate without improvements? If no, prompt crew for appropriate score in 4-6 range per GCPS cue card definitions. If yes, prompt crew for appropriate score in 1-3 range per GCPS cue card definitions. 1. MCC confirms and communicates with EV lander ladder angle being tested 2. IV records start/stop times for each task on hardcopy data sheets; MCC records the same in soft copy data sheets	1. Call “start” to IV for this set of activities. 2. Call “start” for ambulation; traverse path four times in ambulation method of preference and provide description of preference to IVA, verbally calling out as start and stop markers are crossed. a. Call “stop” and provide IV with GCPS data and other required metrics. 3. Call “start” for ramp incline; traverse ramp incline one time in ambulation method of preference verbally calling out at start, and call “stop” when top of ramp is reached. a. Call “stop” and provide IV with GCPS data and other metrics. 4. Call “start” for ramp decline; traverse ramp decline one time in ambulation method of preference verbally calling out at start when leaving top of ramp, and call “stop” when both feet are again on seafloor. a. Call “stop” and provide IV with GCPS data and other required metrics. 5. Call “start” for kneel/recover; perform kneel and recovery activity one time. a. Call “stop” and provide IV with GCPS data and other metrics. 6. Call “start” for fall/recover; perform forward fall down and recovery to standing position activity one time. a. Call “stop” and provide IV with GCPS data and other required metrics. 7. Call “start” for shoveling; perform shoveling activity by moving 15 shovel loads of sand into bucket. a. Call “stop” and provide IV with GCPS data and other metrics. b. Empty sand contents from bucket back to seafloor. 8. Call “start” for weight/rock collection; perform weight/rock collection of all rocks in collection area. a. Retrieve weights/rocks provided and place each weight into crate stack. b. Call “stop” and provide IV with GCPS data and other metrics. c. Return weights/rocks to original seafloor location (1.8 m [6 ft] from crate stack). 9. Call “start” for EPSP ladder climb; perform EPSP ladder climb activity by ascending and descending	1. Proceed to the lander ladder. 2. Call “start” to IV for this task and inform of ladder angle being used. 3. Connect to fall protection. 4. Call “start” to IVA (for this ladder configuration). 5. Ascend ladder to the deck and step off to lander deck. 6. Step off deck to ladder and descend ladder. 7. Call “stop” to IV and provide GCPS rating, other metrics, and comments. 8. Divers reconfigure and repeat steps 3 through 6 for next ladder angle for a total of three ladder angles.

		3. MCC reminds crew that this is not a race and that chosen task speed should not compromise performance 4. MCC prompts EV crew members for GCPS and other required metrics after each task 5. IV records overall time for EV crew member to complete entire course in current CG-weight configuration; MCC records the same in soft copy	ladder one time. a. Call “stop” and provide IV with GCPS data and other metrics. 10. Call “stop” to IV for this set of activities.	
4	00:20 --	**INITIAL CONFIGURATION:** – EV1 on surface – EV2 on surface – T1 on surface – T2 on surface – Traverse patch marked – Shovel and bucket in place – Weights/rocks and crates in place – Lander ladder configured to proper angle 1. MCC confirms and communicates with EV lander ladder angle being tested 2. IV records start/stop times for each task on hard copy; MCC does the same in soft copy 3. MCC prompts EV crew members for GCPS data and other metrics after each task and records in soft copy; IV records hard copy 4. MCC records overall time for EV crew member to complete entire course in current CG-weight configuration; IV records hard copy	**LANDER LADDER ACTIVITY (00:10)** 1. Proceed to the lander ladder. 2. Call “start” to IV for this task and inform of ladder angle being used. 3. Connect to fall protection. 4. Call “start” to IVA (for this ladder configuration). 5. Ascend ladder and step off to lander deck. 6. Step off deck onto ladder and descend ladder. 7. Call “stop” to IV and provide GCPS rating and comments. 8. Divers reconfigure and repeat steps 3 through 6 for next ladder angle for a total of three ladder angles.	**EPSP CG ACTIVITY (00:10)** 1. Call “start” to IV for this set of activities. 2. Call “start” for ambulation; traverse path four times in ambulation method of preference and provide description of preference to IVA, verbally calling out as start and stop markers are crossed. a. Call “stop” and provide IV with GCPS data and other required metrics. 3. Call “start” for ramp incline; traverse ramp incline one time in ambulation method of preference, verbally calling out at start, and call “stop” when top of ramp is reached. a. Call “stop” and provide IV with GCPS data and other metrics. 4. Call “start” for ramp decline; traverse ramp decline one time in ambulation method of preference, verbally calling out at start when leaving top of ramp, and call “stop” when both feet are again on seafloor. a. Call “stop” and provide IV with GCPS data and other required metrics. 5. Call “start” for kneel/recover; perform kneel and recovery activity one time. a. Call “stop” and provide IV with GCPS data and other metrics. 6. Call “start” for fall/recover; perform forward fall down and recovery to standing position activity one time. a. Call “stop” and provide IV with GCPS data and other required metrics. 7. Call “start” for shoveling; perform shoveling activity by moving 15 shovel loads of sand into bucket. a. Call “stop” and provide IV with GCPS data and other metrics.

				b. Empty sand contents from bucket back to seafloor. 8. Call “start” for weight/rock collection; perform weight/rock collection of all rocks in collection area. a. Retrieve weights/rocks provided and place each weight into crate stack. b. Call “stop” and provide IV with GCPS data and other metrics. c. Return weights/rocks to original seafloor location (1.8 m [6 ft] from crate stack). 9. Call “start” for EPSP ladder climb; perform EPSP ladder climb activity by ascending and descending ladder one time. a. Call “stop” and provide IV with GCPS data and other metrics. 10. Call “stop” to IV for this set of activities.
5	**00:30 ---**	**<u>LANDER SMALL PAYLOAD OFFLOAD ACTIVITY</u> (00:05)** **<u>INITIAL CONFIGURATION:</u>** – EV1 on surface – EV2 on surface – T1 on surface – T2 on deck – Small payload on deck If small payload is not initially on deck: 1. T2 attaches rope to payload 2. T1 hoists payload to deck 3. Reset payload launch locks. 4. IV records start/stop times for each task on hard copy; MCC does the same in soft copy 5. MCC prompts EV for comments and GCPS ratings, other metrics, and records and records softcopy; IV records hard copy	**<u>LANDER SMALL PAYLOAD OFF-LOAD ACTIVITY</u> (00:05)** 1. Proceed to the surface near payload landing area. 2. Monitor EV2 preparation of small payload for lowering. 3. During payload lowering, ensure that payload is clear of lander structure and landing area is free of obstacles; communicate winch commands as needed (eg, slower, faster, stop). 4. Once payload is on the surface, detach davit from payload. 5. Call “stop” to IV and provide GCPS rating, other metrics, and comments.	**<u>LANDER SMALL PAYLOAD OFF-LOAD ACTIVITY</u> (00:05)** 1. Proceed to base of <u>lander</u> ladder. 2. Set up fall protection. 3. Ascend ladder. 4. Transition to deck fall protection. 5. Call “start” to IV for this task. 6. Release launch locks on small payload. 7. Attach davit to payload. 8. Use davit winch to lift payload and maneuver payload so payload can be lowered to surface. 9. Use davit winch to lower payload to surface. 10. Call “stop” to IV and provide GCPS ratings, other metrics, and comments.
6	**00:35 --**	**<u>LANDER SMALL PAYLOAD ON-LOAD ACTIVITY</u> (00:05)**	**<u>LANDER SMALL PAYLOAD ON-LOAD ACTIVITY</u> (00:05)**	**<u>LANDER SMALL PAYLOAD ON-LOAD ACTIVITY</u> (00:05)**

		INITIAL CONFIGURATION: – EV1 on surface – EV2 on deck – T1 on surface – T2 on deck – Small payload on surface If small payload is not initially on surface: 1. T2 releases payload launch locks 2. T2 connects davit to payload and lower to surface 3. T1 disconnects payload from davit once on surface 4. IV records start/stop times for each task on hard copy; MCC does the same in soft copy 5. MCC prompts EV for comments and GCPS ratings, other metrics, and record; IV records hard copy	1. Attach davit to payload connector. 2. During payload raising, ensure that payload is clear of lander structure; communicate winch commands as needed (eg, slower, faster, stop). 3. Call "stop" to IV and provide GCPS rating, other metrics, and comments.	1. Call "start" to IV for this task. 2. Maneuver davit and use winch to lower connector to payload on surface. 3. Once the payload is attached to the winch, use winch to lift payload and maneuver payload so payload can be lowered to deck. 4. Use davit winch to lower payload to deck. 5. Unhook davit from payload. 6. Call "stop" to IV and provide GCPS rating, metrics, and comments.
7	00:40 ---	**LANDER INCAPACITATED CREW MEMBER UPLOAD (00:05)** **INITIAL CONFIGURATION:** – EV1 on surface – EV2 on deck – T1 on surface – T2 on deck – Rescue manikin face down on surface under davit – Tagline loose on back deck of SEV – Large davit ready for use 1. T1 ensures tagline loose on back deck of SEV 2. IV records start/stop times for each task on hard copy; MCC does the same in soft copy 3. MCC prompts EV for comments and GCPS ratings, other metrics, and record; IV records hard copy	**LANDER INCAPACITATED CREW MEMBER UPLOAD (00:05)** 1. Call "start" to IV for this task. 2. Proceed to back deck of SEV and retrieve tagline. 3. Communicate with EV2 to lower davit line. 4. Attach large davit line to incapacitated crew member at both shoulder D-rings. 5. Attach tagline to incapacitated crew member at one of the waist D-rings. 6. Communicate with EV2 that the incapacitated crew member is ready for raising. 7. Communicate with EV2 and provide the necessary tagline control of incapacitated crew member during raising; communicate winch commands as needed (eg, slower, faster, stop). 8. Release tagline after communication from EV2 that the raising is complete. 9. Call "stop" to IV and provide GCPS rating, other metrics, and comments.	**LANDER INCAPACITATED CREW MEMBER UPLOAD (00:05)** 1. Proceed to davit winch. 2. Communicate with EV1 and lower large davit line prior to surface. 3. Acknowledge and confirm with EV1 communication that system is ready for raising. 4. Use davit winch to raise incapacitated crew member to height necessary to clear lander railing; communicate the necessary tagline control to EV1 during the raising (eg, slack, tension). 5. Maneuver davit so that the incapacitated crew member can be lowered to deck; communicate the necessary tagline control to EV1 during the maneuver (eg, slack, tension). 6. Use davit winch to lower incapacitated crew member (face up) to deck; communicate the necessary tagline control to EV1 during the lowering (eg, slack, tension). 7. Communicate to EV1 that the raising is complete and tagline can be released. 8. Call "stop" to IV and provide GCPS ratings, other metrics, and comments.

8	00:45 ---	**LANDER SEV OFF-LOAD ACTIVITY (00:15)** **INITIAL CONFIGURATION:** – SEV aft deck detached and on surface – SEV cabin on deck with launch locks reset and secondary structure in place – SEV attached to davit – EVA1 on surface – EVA2 on deck – T1 on surface – T2 on deck – Tagline loose on deck 1. T2 attaches SEV to davit 2. T2 ensures tagline is loose on deck 3. IV records start/stop times for each task on hard copy; MCC does the same in soft copy 4. MCC prompts EV for comments and GCPS ratings, other metrics, and records; IV records hard copy	**LANDER SEV OFF-LOAD ACTIVITY (00:15)** 1. Proceed to surface near SEV landing area. 2. Monitor EV2 preparation of SEV for lowering. 3. Receive tagline attached to SEV from EV2. 4. Step clear of the landing area and tension the tagline. 5. Control rotation of SEV during lowering to ensure that SEV is clear of structure; communicate winch commands as needed (eg, slower, faster, stop). 6. Call "stop" to IV and provide GCPS ratings, other metrics, and comments.	**LANDER SEV OFF-LOAD ACTIVITY (00:15)** 1. Call "start" to IV for this task. 2. Release each of four SEV launch locks, using fall protection as necessary during access. 3. Detach SEV electrical connectors. 4. Detach and clear each of four parts of SEV secondary support structure, using fall protection as necessary during access. 5. Attach tagline to eyebolt on SEV, lower end to EV1, and confirm tagline is taut prior to lift. 6. Use davit winch to lift SEV and maneuver SEV so SEV can be lowered to surface; respond to communication on winch commands as needed (eg, slower, faster, stop); communicate tagline commands as needed during maneuver (eg, slack, tension). 7. Use davit winch to lower SEV to surface. 8. Call "stop" to IV and provide GCPS ratings, other metrics, and comments.
9	01:00--	**RESET LANDER SEV, SMALL PAYLOAD, AND INCAPACITATED CREW MEMBER (00:10)** **INITIAL CONFIGURATION:** – EV1 on surface – EV2 on deck – T1 on surface – T2 on deck – SEV on surface – Rescue manikin on deck 1. T2 uses davit winch to lower davit line to SEV on surface 2. T1 attaches SEV to davit 3. T1 attaches tagline to SEV and controls	**RESET LANDER SEV, SMALL PAYLOAD, AND INCAPACITATED CREW MEMBER (00:10)** 1. Clear area around lander where incapacitated crew member will be jettisoned to surface. 2. After EV2 descends ladder and SEV has been placed back on the deck, proceed to bottom of ladder. 3. Attach to ladder fall protection system. 4. Ascend ladder and step onto deck. 5. Transition to deck fall protection system.	**RESET LANDER SEV, SMALL PAYLOAD, AND INCAPACITATED CREW MEMBER (00:10)** 1. Detach davit from incapacitated crew member. 2. Ensure landing area is clear, communicate that jettison is about ready to occur, and jettison incapacitated crew member to surface. 3. Proceed to top of ladder. 4. Transition to ladder fall protection system. 5. Descend ladder. 6. Disconnect from ladder fall protection system and clip to bottom of ladder.

		rotation during lift 4. T2 raises SEV with davit winch 5. T1 lowers SEV into position on lander deck 6. T2 releases tagline once SEV is on deck and proceeds to deck to assist T1 7. T1 and T2 reset launch locks and secondary structure		
10	**01:10 ---**	**LANDER SMALL PAYLOAD OFF-LOAD ACTIVITY (00:05)** **INITIAL CONFIGURATION:** – EV2 on surface – EV1 on surface – T1 on surface – T2 on deck – Small payload on deck If small payload is not initially on deck: 1. T2 attaches rope to payload 2. T1 hoists payload to deck 3. Reset payload launch locks 4. IV records start/stop times for each task; MCC does the same in soft copy 5. MCC prompts EV for comments and GCPS ratings, other metrics, and records; IV records hard copy	**LANDER SMALL PAYLOAD OFF-LOAD ACTIVITY (00:05)** 1. Proceed to base of lander ladder. 2. Call "start" to IV for this task. 3. Set up fall protection. 4. Ascend ladder. 5. Transition to deck fall protection. 6. Release launch locks on small payload. 7. Attach davit to payload. 8. Use davit winch to lift payload and maneuver payload so payload can be lowered to surface. 9. Use davit winch to lower payload to surface. 10. Call "stop" to IV and provide GCPS rating, other metrics, and comments.	**LANDER SMALL PAYLOAD OFF-LOAD ACTIVITY (00:05)** 1. Proceed to the surface near payload landing area. 2. Monitor EV1 preparation of small payload for lowering. 3. During payload lowering, ensure that payload is clear of lander structure and that landing area is free of obstacles; communicate winch commands as needed (eg, slower, faster, stop). 4. Once payload is on the surface, detach davit from payload. 5. Call "stop" to IV and provide GCPS ratings, other metrics, and comments.
11	**01:15 ---**	**LANDER SMALL PAYLOAD ON-LOAD ACTIVITY (00:05)** **INITIAL CONFIGURATION:** – EV2 on surface – EV1 on deck – T1 on surface – T2 on deck – Small payload on surface	**LANDER SMALL PAYLOAD ON-LOAD ACTIVITY (00:05)** 1. Call "start" to IV for this task. 2. Maneuver davit and use winch to lower connector to payload on surface. 3. Once the payload is attached to the winch, use winch to lift payload and maneuver payload so payload can be lowered to deck. 4. Use davit winch to lower payload to deck. 5. Unhook davit from payload. 6. Call "stop" to IV and provide GCPS ratings, other	**LANDER SMALL PAYLOAD ON-LOAD ACTIVITY (00:05)** 1. Attach davit to payload connector. 2. During payload raising, ensure that payload is clear of lander structure; communicate winch commands as needed (eg, slower, faster, stop). 3. Call "stop" to IV and provide GCPS ratings, other metrics, and comments.

		If small payload is not initially on surface: 1. T2 releases payload launch locks 2. T2 connects davit to payload and lowers to surface 3. T1 disconnects payload from davit once on surface 4. IV records start/stop times for each task on hard copy; MCC does the same in soft copy 5. MCC prompts EV for comments and GCPS ratings, other metrics, and records; IV records hard copy	metrics, and comments.	
12	01:20 -	**<u>LANDER INCAPACITATED CREW MEMBER UPLOAD</u> (00:05)** **<u>INITIAL CONFIGURATION:</u>** – EV2 on surface – EV1 on deck – T1 on surface – T2 on deck – Rescue manikin on surface beneath <u>large</u> davit – Tagline loose on back deck of SEV 1. T1 attaches rescue manikin to suitport 2. T1 ensures tagline loose on back deck of SEV 3. T1 attaches davit to PLSS plate of rescue manikin 4. IV records start/stop times for each task; MCC does the same in soft copy 5. MCC prompts EV for comments GCPS ratings, other metrics, and records; IV records hard copy	**<u>LANDER INCAPACITATED CREW MEMBER UPLOAD</u> (00:05)** 1. Proceed to davit winch. 2. Communicate with EV1 and lower <u>large</u> davit line prior to surface. 3. Acknowledge and confirm with EV1 communication that system is ready for raising. 4. Use davit winch to raise incapacitated crew member to height necessary to clear lander railing; communicate the necessary tagline control to EV1 during the raising (eg, slack, tension). 5. Maneuver davit so that the incapacitated crew member can be lowered to deck; communicate the necessary tagline control to EV1 during the maneuver (eg, slack, tension). 6. Use davit winch to lower incapacitated crew member (face up) to deck; communicate the necessary tagline control to EV1 during the lowering (eg, slack, tension). 7. Communicate to EV1 that the raising is complete and that tagline can be released. 8. Call "stop" to IV and provide GCPS ratings, other metrics, and comments.	**<u>LANDER INCAPACITATED CREW MEMBER UPLOAD</u> (00:05)** 1. Call "start" to IV for this task. 2. Proceed to back deck of SEV and retrieve tagline. 3. Communicate with EV1 to lower <u>large</u> davit line. 4. Attach davit line to incapacitated crew member at both shoulder D-rings. 5. Attach tagline to incapacitated crew member at one of the waist D-rings. 6. Communicate with EV1 that the incapacitated crew member is ready for raising. 7. Communicate with EV1 and provide the necessary tagline control of incapacitated crew member during raising; communicate winch commands as needed (eg, slower, faster, stop). 8. Release tagline after communication from EV1 that the raising is complete. 9. Call "stop" to IV and provide GCPS ratings, other metrics, and comments.
13	01:25 --	**<u>LANDER SEV OFF-LOAD ACTIVITY</u> (00:15)**	**<u>LANDER SEV OFF-LOAD ACTIVITY</u> (00:15)**	**<u>LANDER SEV OFF-LOAD ACTIVITY</u> (00:15)**

		INITIAL CONFIGURATION: – SEV aft deck detached and on surface – SEV cabin on deck with launch locks reset and secondary structure in place – SEV attached to large davit – EV2 on surface – EV1 on deck – T1 on surface – T2 on deck – Tagline loose on deck 1. T2 attaches SEV to large davit 2. T2 ensures tagline is loose on deck 3. IV records start/stop times for each task; MCC does the same in soft copy 4. MCC prompts EV for comments and GCPS ratings, other metrics, and records; IV records hard copy	1. Call “start” to IV for this task. 2. Release each of four SEV launch locks, using fall protection as necessary during access. 3. Detach SEV electrical connectors. 4. Detach and clear each of four parts of SEV secondary support structure, using fall protection as necessary during access. 5. Attach tagline to eyebolt on SEV, lower end to EV2, and confirm tagline is taut prior to lift. 6. Use davit winch to lift SEV and maneuver SEV so it can be lowered to surface; respond to communication on winch commands as needed (eg, slower, faster, stop); communicate tagline commands as needed during maneuver (eg, slack, tension). 7. Use davit winch to lower SEV to surface. 8. Call “stop” to IV and provide GCPS ratings, other metrics, and comments.	1. Proceed to surface near SEV landing area. 2. Monitor EV1 preparation of SEV for lowering. 3. Receive tagline attached to SEV from EV1. 4. Step clear of the landing area and tension the tagline. 5. Control rotation of SEV during lowering to ensure that SEV is clear of structure; communicate winch commands as needed (eg, slower, faster, stop). 6. Call “stop” to IV and provide GCPS ratings, other metrics, and comments.
14	**01:40 -**	**RESET LANDER SEV, SMALL PAYLOAD, AND INCAPACITATED CREW MEMBER (00:10)** **INITIAL CONFIGURATION:** – EV2 on surface – EV1 on deck – T1 on surface – T2 on deck – SEV on surface – Rescue manikin on deck – Davit attached to rescue manikin – Tagline attached to rescue manikin 1. T2 uses davit winch to lower large davit line to SEV on surface 2. T1 attaches SEV to davit 3. T1 attaches tagline to SEV and controls rotation during lift	**RESET LANDER SEV, SMALL PAYLOAD, AND INCAPACITATED CREW MEMBER (00:10)** 1. Detach davit from incapacitated crew member. 2. Ensure landing area is clear, communicate that jettison is about ready to occur, and jettison incapacitated crew member to surface. 3. Proceed to top of ladder. 4. Transition to ladder fall protection system. 5. Descend ladder. 6. Disconnect from ladder fall protection system and clip to bottom of ladder.	**RESET LANDER, SEV, SMALL PAYLOAD, AND INCAPACITATED CREW MEMBER (00:10)** 1. Assist topside as needed with reset activities on surface.

		4. T2 raises SEV with davit winch 5. T1 lowers SEV into position on lander deck 6. T2 releases tagline once SEV is on deck and proceeds to deck to assist T1 7. T1 and T2 reset launch locks and secondary structure		
15	**01:50 ---**	**<u>RECONFIGURATION OF PLSS RIG TO CG NO. 2</u> (00:10)** 1. MCC calls out configuration CG-weight – Note: Crew member Opt Wt Cue Cards may differ for each person 2. Support divers complete reconfiguration and signal "OK" to crew member 3. MCC confirms "OK to start" to EV crew	**<u>RECONFIGURATION OF PLSS RIG TO CG NO. 2</u> (00:10)** 1. Proceed to habitat ladder. 2. Doff PLSS rig apparatus by facing ladder and holding railing while support divers assisting crew member. 3. EV crew member hand signals to diver the configuration number-letter. 4. Divers reconfigure PLSS rig. 5. Don PLSS rig. 6. EV verbally signals IV with "OK to start."	
16	**02:00 ---**	**<u>REPEAT PROCEDURES 3-14 AT CG NO. 2 (01:40)</u>** 1. MCC communicates with crew which procedures will be repeated with new configuration	**<u>REPEAT PROCEDURES 3-14 AT CG NO. 2 (01:40)</u>** 1. Crew repeats procedures 3 through 14 above with new configuration.	
17	**03:40 ---**	**<u>RECONFIGURATION OF PLSS RIG TO CG NO. 3</u> (00:10)** 1. MCC calls out configuration CG-weight – Note: Crew member Opt Wt Cue Cards may be different for each person 2. Support divers complete reconfiguration and signal "OK" to crew member 3. MCC confirms "OK to start" to EV crew	**<u>RECONFIGURATION OF PLSS RIG TO CG NO. 3</u> (00:10)** 1. Proceed to habitat ladder. 2. Doff PLSS rig apparatus by facing ladder and holding railing while support divers assisting crew member. 3. EV crew member hand signals to diver the configuration number-letter. 4. Divers reconfigure PLSS rig. 5. Don PLSS rig/ 6. EV verbally signals IV with "OK to start."	
18	**03:50 ---**	**<u>REPEAT PROCEDURES 3-14 AT CG NO. 3 (01:40)</u>** 1. MCC communicates with crew which procedures will be repeated with new configuration	**<u>REPEAT PROCEDURES 3-14 AT CG NO. 3 (01:40)</u>** 1. Crew repeats procedures 3 through 14 above with new configuration.	

19	**05:30 ---**	**<u>DOFF/INGRESS/POST-EVA</u> (00:30)** 1. Clean up and transfer equipment to surface as necessary	**<u>DOFF/INGRESS/POST-EVA</u> (00:30)** 1. Doff PLSS-rig apparatus. 2. Doff Miller™ weight belt (Morgan Diving Corp.) 3. Doff full-body dive harness. 4. Doff MK-12 suit. 5. Reenter wet porch. 6. Doff SL-17. 7. Detailed test objective (DTO) complete. 8. Transfer data from waterproof sheet to electronic data sheet file entitled, CG_OptWt_Datasheets.xls and uplink file to NEEMO SharePoint for transfer to principal investigator (PI).

8.4.2 Space Exploration Vehicle and Crew-lander-based Extravehicular Activity Timeline and Procedures

Objectives/Description:

To perform tests that assess the operations concepts and human performance associated with working in and around an ascent module, an airlock, small cranes, and hatches of different dimensions. Different methods of ingressing incapacitated crew member(s) will also be assessed both via suitport and side-hatch.

Crew members will wear the MK-12 suit (weighted to one possible Earth suit weight) and a volumetric PLSS mock-up.

Location: Activities will be performed on a sandy seafloor location near the SEV or on the lander deck near the ascent module and airlock mock-up.

Tools required

Support diver pre-positioned items

- SEV mock-up
- Ascent module mock-up
- Airlock mock-up
- Two PLSS mock-ups for use by subjects performing tasks
- Rescue manikin with dive harness and PLSS
- Two ropes in rope bags
- Two double-sheave pulleys
- Two ratcheting single-sheave pulleys
- TBD locking carabiners

Aquarius items (pre-positioned)

- MK-12 suit
- IDVs and 3.6- to 2.3-kg (8- to 5-lb) weights (only back-pocket weights installed prior to leaving wet porch)
- Two stopwatches or timing devices (to be used by IVA)
- Wetsuit/booties (no boots)
- Superlite™-17B
- *GCPS cue card.pdf*
- *OptWt_Cue_Card* (use correct version for EVA divers)
- *SEV-based Tasks Datasheet* record – waterproof printed copies (one per crew member – front and back)

Support diver hand-carried/real-time items

- *OptWt_Cue_Card* (two versions cover all four crew members) – waterproof
- IDV weights
- MK-14 suit weights
- Tape measure
- **Video camera and camera equipment (to provide side and front views)**

Proc. No.	HR : MIN	Topside/IV/MCC	EV1	EV2
1	N/A --	**EVA PREP/EGRESS (00:30)** 1. Topside divers (T1 and T2) in water 2. Topside ensures initial configuration of all equipment and mock-ups is correct 3. IV configures red/blue diver communications system 4. IV configures video and computers to be able to see seafloor view, lander deck view, tank farm view, and the task procedures (if visibility is poor, IV and EV to decide whether it is safe and feasible to proceed) 5. IV ensures hard copy or computer data sheets are ready to record data 6. MCC ensures communications with divers on exit of wet porch 7. MCC ensures soft copy data sheets are ready to record data	**EVA PREP/EGRESS (00:30)** 1. Work with IV to perform SL-17 checklist and communications checklist. 2. Don wetsuit/booties/gloves, IDV with weights per OptWt_Cue_Card, bailout bottle, and SL-17. NOTE - Do NOT wear Boots. a. MK-12 and IDV weights configured by support divers; down mode is EVA crew configures weights or uses HABTECH divers. 3. Egress wet porch and proceed to the SEV mock-up to begin SEV-based tasks, with IV concurrence.	
2	00:00 --	**COMPLETE WEIGH-OUT (00:05)** **INITIAL CONFIGURATION:** – EV1 on surface – EV2 on surface – T1 on surface – T2 on surface – Weights ready to complete weigh out – PLSS mock-ups ready for donning 1. T1 and T2 configure and assist crew in completing weigh out and donning PLSS mock-ups 2. MCC confirms and communicates with EV weigh out correct and complete	**COMPLETE WEIGH OUT (00:05)** 1. Work with topside divers to deploy umbilical. 2. Work with topside divers to add more weights as needed to achieve proper weigh out.. 3. Work with topside divers to don PLSS mock-ups.	

Proc. No.	HR : MIN	Topside/IV/MCC	EV1	EV2
3	00:05 --	**<u>SMALL PAYLOAD AND AIRLOCK/ASCENT MODULE INGRESS</u> (00:10)** **<u>INITIAL CONFIGURATION:</u>** – EV1 on deck – EV2 on surface – T1 on deck – T2 on deck – Small payload on deck – Airlock/ascent module on deck – Small crane on deck 1. If small payload is not initially on deck , topside attach rope to payload; hoist payload to deck; reset payload launch locks 2. Topside works with EV to perform airlock/ascent module ingress by managing umbilical 3. IV records start/stop times for each task on hard copy; MCC does the same in soft copy 4. MCC prompts EV for comments and GCPS ratings, other metrics, and records; and records soft copy; IV records hard copy	**<u>LANDER SMALL PAYLOAD ACTIVITY</u> (00:10)** 1. Proceed to top of <u>lander</u> ladder in porch area. 2. Connect to deck fall protection. 3. Call "start" to IV for this task. 4. Release launch locks on small payload. 5. Attach small crane to payload. 6. Use small crane to lift payload and maneuver payload so it can be lowered to surface. 7. Use small crane to lower payload to surface. 8. Call "stop" to IV and provide GCPS ratings, other metrics, and comments. 9. Call "start" to IV for this task. 10. Use small crane to lift payload and maneuver payload so it can be lowered to porch. 11. Use small crane to lower payload to porch. 12. Detach payload from small crane. 13. Call "stop" to IV and provide GCPS ratings, other metrics, and comments. 14. Repeat or try different methods of small payload transfer if EV2 task is not complete.	**<u>AIRLOCK/ASCENT MODULE INGRESS (00:10)</u>** 1. Proceed to base of <u>lander</u> ladder. 2. Set up fall protection. 3. Ascend ladder. 4. Transition to deck fall protection. 5. Call "start" to IV for this task before beginning ingress. 6. Perform four in- and out-hatch translations through the airlock hatchway. 7. Call "stop" to IV and provide GCPS ratings, other metrics, and comments. 8. Work with topside assistance as needed to enter ascent module from the top. 9. Call "start" to IV for this task before beginning ingress. 10. Perform four in- and out-hatch translations through the ascent module hatchway and tunnel. 11. Call "stop" to IV and provide GCPS ratings, other metrics, and comments. 12. Work with topside assistance as needed to exit ascent module and return to porch area at top of lander ladder, using deck fall protection as required.

Proc. No.	HR : MIN	Topside/IV	EV1	EV2
4	00:15 --	**SMALL PAYLOAD AND AIRLOCK/ASCENT MODULE INGRESS (00:10)** **INITIAL CONFIGURATION:** – EV1 on surface – EV2 on deck – T1 on deck – T2 on deck – Small payload on deck – Airlock/ascent module on deck – Small crane on deck 1. If small payload is not initially on deck , topside attaches rope to payload; hoists payload to deck; resets payload launch locks 2. Topside works with EV to perform airlock/ascent module ingress by managing umbilical 3. IV records start/stop times for each task on hard copy; MCC does the same in soft copy 4. MCC prompts EV for comments and GCPS ratings, other metrics, and records; and records soft copy; IV records hard copy	**AIRLOCK/ASCENT MODULE INGRESS (00:10)** 1. Proceed to base of lander ladder. 2. Set up fall protection. 3. Ascend ladder. 4. Transition to deck fall protection. 5. Call “start” to IV for this task before beginning ingress. 6. Perform four in- and out-hatch translations through the airlock hatchway. 7. Call “stop” to IV and provide GCPS ratings, other metrics, and comments. 8. Work with topside assistance as needed to enter ascent module from the top. 9. Call “start” to IV for this task before beginning ingress. 10. Perform four in- and out-hatch translations through the ascent module hatchway and tunnel. 11. Call “stop” to IV and provide GCPS ratings, other metrics, and comments. 12. Work with topside assistance as needed to exit ascent module and return to porch area at top of lander ladder, using deck fall protection as required,	**LANDER SMALL PAYLOAD ACTIVITY (00:10)** 1. Proceed to top of lander ladder in porch area. 2. Connect to deck fall protection. 3. Call “start” to IV for this task. 4. Release launch locks on small payload. 5. Attach small crane to payload. 6. Use small crane to lift payload and maneuver payload so payload can be lowered to surface. 7. Use small crane to lower payload to surface. 8. Call “stop” to IV and provide GCPS ratings, other metrics, and comments. 9. Call “start” to IV for this task. 10. Use small crane to lift payload and maneuver payload so payload can be lowered to porch. 11. Use small crane to lower payload to porch. 12. Detach payload from small crane. 13. Call “stop” to IV and provide GCPS ratings, other metrics, and comments. 14. Repeat or try different methods of small payload transfer if EV2 task is not complete.

Proc. No.	HR : MIN	Topside/IV	EV1	EV2
5	00:25 --	**LANDER INCAPACITATED CREW MEMBER UPLOAD (00:05)** **INITIAL CONFIGURATION:** – EV1 on surface – EV2 on deck – T1 on surface – T2 on deck – Rescue manikin on surface – Airlock/ascent module on deck – Small crane on deck 1. Topside lowers or jettisons rescue manikin to base of lander ladder at end of task 2. IV records start/stop times for each task on hard copy; MCC does the same in soft copy 3. MCC prompts EV for comments and GCPS ratings, other metrics, and records; and records soft copy; IV records hard copy	**LANDER INCAPACITATED CREW MEMBER UPLOAD (00:05)** 1. Proceed to base of lander ladder. 2. Call "start" to IV for this task. 3. Attach small crane line to incapacitated crew member at central shoulder D-ring. 4. Attach to lander ladder fall protection system. 5. Communicate with EV2 that the incapacitated crew member is ready for raising. 6. Communicate with EV2 while climbing the lander ladder and provide the necessary control of incapacitated crew member during raising; communicate winch commands as needed (eg, slower, faster, stop). 7. Transition to deck fall protection system and assist EV2 in maneuvering incapacitated crew member onto porch. 8. Call "stop" to IV and provide GCPS ratings, other metrics, and comments.	**LANDER INCAPACITATED CREW MEMBER UPLOAD (00:05)** 1. Proceed to top of lander ladder in porch area. 2. Connect to deck fall protection. 3. Call "start" to IV for this task. 4. Communicate with EV1 and lower small crane line prior to surface. 5. Acknowledge and confirm with EV1 communication that system is ready for raising. 6. Use small crane to raise incapacitated crew member to height necessary to place him/her onto the porch; communicate with EV1 during the raising as necessary as EV1 climbs ladder next to incapacitated crew member. 7. Maneuver small crane so the incapacitated crew member can be lowered to the porch with the assistance of EV1. 8. Use small crane to lower incapacitated crew member (face up) to porch with the assistance of EV1. 9. Call "stop" to IV and provide GCPS ratings, other metrics, and comments.

Proc. No.	HR : MIN	Topside/IV	EV1	EV2
6	00:30 -	**LANDER INCAPACITATED CREW MEMBER UPLOAD (00:05)** **INITIAL CONFIGURATION:** – EV1 on deck – EV2 on surface – T1 on surface – T2 on deck – Rescue manikin on surface – Airlock/ascent module on deck – Small crane on deck 1. IV records start/stop times for each task on hard copy; MCC does the same in soft copy 2. MCC prompts EV for comments and GCPS ratings, other metrics and records; and records soft copy; IV records hard copy	**INCAPACITATED CREW MEMBER UPLOAD (00:05)** 1. Proceed to top of lander ladder in porch area. 2. Connect to deck fall protection. 3. Call "start" to IV for this task. 4. Communicate with EV2 and lower small crane line prior to surface. 5. Acknowledge and confirm with EV2 communication that system is ready for raising. 6. Use small crane to raise incapacitated crew member to height necessary to place him/her onto the porch; communicate with EV2 during the raising as necessary as EV2 climbs ladder next to incapacitated crew member. 7. Maneuver small crane so that the incapacitated crew member can be lowered to the porch with the assistance of EV2. 8. Use small crane to lower incapacitated crew member (face up) to porch with the assistance of EV2. 9. Call "stop" to IV and provide GCPS ratings, other metrics, and comments.	**INCAPACITATED CREW MEMBER UPLOAD (00:05)** 1. Proceed to base of lander ladder. 2. Call "start" to IV for this task. 3. Communicate with EV1 to lower small crane line. 4. Attach small crane line to incapacitated crew member at central shoulder D-ring. 5. Attach to lander ladder fall protection system. 6. Communicate with EV1 that the incapacitated crew member is ready for raising. 7. Communicate with EV1 while climbing the lander ladder and provide the necessary control of the incapacitated crew member during raising; communicate winch commands as needed (eg, slower, faster, stop). 8. Transition to deck fall protection system and assist EV1 in maneuvering incapacitated crew member onto porch. 9. Call "stop" to IV and provide GCPS ratings, other metrics, and comments.

Proc. No.	HR : MIN	Topside/IV	EV1	EV2
7	00:35 --	**INCAPACIATED CREW MEMBER AIRLOCK/ASCENT MODULE INGRESS (00:10)** **INITIAL CONFIGURATION:** – EV1 on deck – EV2 on deck – T1 on deck – T2 on deck – Rescue manikin on porch – Airlock/ascent module on deck – Small crane on deck 1. Topside work with EV to enter/exit ascent module from time as needed 2. IV records start/stop times for each task on hard copy; MCC does the same in soft copy 3. MCC prompts EV for comments and GCPS ratings, other metrics, and records; and records soft copy; IV records hard copy	**INCAPACIATED CREW MEMBER AIRLOCK/ASCENT MODULE INGRESS (00:10)** 1. Proceed to top of lander ladder in porch area. 2. Call "start" to IV for this task. 3. Position incapacitated crew member in front of airlock on porch. 4. Enter airlock and set up haul system. 5. Exit airlock and connect haul system from interior of airlock to incapacitated crew member. 6. Haul on haul system, moving and lifting incapacitated crew member into airlock. 7. Enter airlock and close airlock door. 8. Open ascent module door and pass incapacitated crew member to EV2 on inside of ascent module. 9. Call "stop" to IV and provide GCPS rating, other metrics, and comments.	**INCAPACIATED CREW MEMBER AIRLOCK/ASCENT MODULE INGRESS (00:10)** 1. Work with topside assistance as needed to enter ascent module from the top. 2. Work with EV1 to transfer incapacitated crew member through tunnel into ascent module. 3. Work with topside assistance as needed to exit ascent module and return to porch area at top of lander ladder, using deck fall protection as required.

Proc. No.	HR : MIN	Topside/IV	EV1	EV2
8	00:45 --	**INCAPACIATED CREW MEMBER AIRLOCK/ASCENT MODULE INGRESS (00:10)** **INITIAL CONFIGURATION:** – EV1 on deck – EV2 on deck – T1 on deck – T2 on deck – Rescue manikin on porch – Airlock/ascent module on deck – Small crane on deck 1. Topside work with EV to enter/exit ascent module from time as needed. 2. IV records start/stop times for each task on hard copy; MCC does the same in soft copy. 3. MCC prompts EV for comments and GCPS ratings, other metrics, and records; and records soft copy; IV records hard copy	**INCAPACIATED CREW MEMBER AIRLOCK/ASCENT MODULE INGRESS (00:10)** 1. Work with topside assistance as needed to enter ascent module from the top. 2. Work with EV2 to transfer incapacitated crew member through tunnel into ascent module. 3. Work with topside assistance as needed to exit ascent module and return to porch area at top of lander ladder, using deck fall protection as required.	**INCAPACIATED CREW MEMBER AIRLOCK/ASCENT MODULE INGRESS (00:10)** 1. Proceed to top of lander ladder in porch area. 2. Call "start" to IV for this task. 3. Position incapacitated crew member in front of airlock on porch. 4. Enter airlock and set up haul system. 5. Exit airlock and connect haul system from interior of airlock to incapacitated crew member. 6. Haul on haul system, moving and lifting incapacitated crew member into airlock. 7. Enter airlock and close airlock door. 8. Open ascent module door and pass incapacitated crew member to EV1 on inside of ascent module. 9. Call "stop" to IV and provide GCPS ratings, other metrics, and comments.

Proc. No.	HR : MIN	Topside/IV	EV1	EV2
9	00:55 --	**SUITPORT INCAPACITATED CREW MEMBER ACTIVITY (00:05)** **INITIAL CONFIGURATION:** – EV2 on surface – EV1 on surface – T1 on surface – T2 on surface – SEV mock-up on surface – Rescue manikin on surface – Haul system available on SEV mock-up 1. Topside ensures rescue manikin and hauls system in place prior to start of scenario 2. Assists in resetting of scenario between solo and dual rescuer scenarios 3. IV records start/stop times for each task on hard copy; MCC does the same in soft copy 4. MCC prompts EV for comments and GCPS ratings, other metrics, and records; and records soft copy; IV records hard copy	**SUITPORT INCAPACITATED CREW MEMBER ACTIVITY (00:05)** 1. Communicate to EV2 that EV3 appears to be incapacitated. 2. Observe EV2 performing tasks solo. 3. Reset and repeat tasks with EV2 still in primary role but assisting as needed with tasks (eg, setup of haul system, locking off of haul system, etc.) 4. EV to communicate task completion and provide GCPS and other required metrics and comments	**SUITPORT INCAPACITATED CREW MEMBER ACTIVITY (00:05)** 1. Proceed to SEV mock-up area. 2. Call "start" to IV for this task. 3. Locate downed crew member, turn the crew member to his/her back, and perform initial medical assessment. 4. Communicate status of incapacitated crew member to EV1 and plan for stabilization and transport. 5. Set up haul system between SEV suitport and incapacitated crew member. 6. Haul on haul system, moving and lifting incapacitated crew member onto aft deck of SEV. 7. Lift incapacitated crew member with haul system while ensuring orientation of the PLSS plate with the suitport; lock off the haul system as necessary to make adjustments. 8. Lift incapacitated crew member until the bottom of the PLSS plate is in place in the channel at the bottom of the suitport. 9. Lock off haul system and latch incapacitated crew member to suitport. 10. EV to communicate task completion and provide GCPS and other required metrics and comments. 11. Reset and repeat tasks with EV1 still in primary role but performing tasks with EV2 assisting as needed with tasks (eg, setup of haul system, locking off of haul system, etc.).

Proc. No.	HR : MIN	Topside/IV	EV1	EV2
10	01:00 --	<u>**SUITPORT INCAPACITATED CREW MEMBER ACTIVITY**</u> **(00:05)** **<u>INITIAL CONFIGURATION:</u>** – EV2 on surface – EV1 on surface – T1 on surface – T2 on surface – SEV mock-up on surface – Rescue manikin on surface – Haul system available on SEV mock-up 1. Topside ensures rescue manikin and haul system in place prior to start of scenario 2. Assists in resetting of scenario between solo and dual rescuer scenarios 3. IV records start/stop times for each task on hard copy; MCC does the same in soft copy 4. MCC prompts EV for comments and GCPS ratings, other metrics, and records; and records soft copy; IV records hard copy	<u>**SUITPORT INCAPACITATED CREW MEMBER ACTIVITY**</u> **(00:05)** 1. Proceed to SEV mock-up area. 2. Call "start" to IV for this task. 3. Locate downed EV3, turn the crew member to his/her back, and perform initial medical assessment. 4. Communicate status of incapacitated EV3 to EV2 and plan for stabilization and transport. 5. Set up haul system between SEV suitport and incapacitated EV3. 6. Haul on haul system, moving and lifting incapacitated EV3 onto aft deck of SEV. 7. Lift incapacitated EV3 with haul system while ensuring orientation of the PLSS plate with the suitport, locking off the haul system as necessary to make adjustments. 8. Lift incapacitated EV3 until the bottom of the PLSS plate is in place in the channel at the bottom of the suitport. 9. Lock off haul system and latch incapacitated EV3 to suitport. 10. EV to communicate task completion and provide GCPS and other required metrics and comments. 11. <u>Reset and repeat tasks with EV1 still in primary role but performing tasks with EV2 assisting as needed with tasks (eg, setup of haul system, locking off of haul system, etc.).</u>	<u>**SUITPORT INCAPACITATED CREW MEMBER ACTIVITY**</u> **(00:05)** 1. Communicate to EV1 that EV3 appears to be incapacitated. 2. Observe EV1 performing tasks solo. 3. Reset and repeat tasks with EV1 still in primary role but assisting as needed with tasks (eg, setup of haul system, locking off of haul system, etc.). 4. EV to communicate task completion and provide GCPS rating and comments.

Proc. No.	HR : MIN	Topside/IV	EV1	EV2
11	01:05 --	**101.6 CM × 152.4 CM (40 IN. × 60 IN.) PORT SIDE-HATCH (WITH TUNNEL) INCAPACITATED CREW MEMBER ACTIVITY (00:05)** **INITIAL CONFIGURATION:** – EV1 on surface – EV2 on surface – T1 on surface – T2 on surface – SEV mock-up on surface – Port side-hatch configured to 101.6 cm × 152.4 cm (40 in. × 60 in.) – Rescue manikin on surface – Haul system available on SEV mock-up 1. Topside ensures rescue manikin and hauls system in place prior to start of scenario 2. Assists in resetting of scenario between solo and dual rescuer scenarios 3. IV records start/stop times for each task on hard copy; MCC does the same in soft copy 4. MCC prompts EV for comments and GCPS ratings, other metrics, and records; and records soft copy; IV records hard copy	**101.6 CM × 152.4 CM (40 IN. × 60 IN.) PORT SIDE-HATCH (WITH TUNNEL) INCAPACITATED CREW MEMBER ACTIVITY (00:05)** 1. Proceed to SEV mock-up area. 2. Call "start" to IV for this task. 3. Locate downed crew member, turn the crew member to his/her back, and perform initial medical assessment. 4. Communicate status of incapacitated crew member to EV2 and plan for stabilization and transport. 5. Set up haul system between SEV side-hatch and incapacitated crew member. 6. Haul on haul system, moving and lifting incapacitated crew member into side-hatch doorway. 7. Lock-off haul system. 8. Push incapacitated crew member completely into SEV, sliding along cross wire between hatches. 9. EV to communicate task completion and provide GCPS and other required metrics and comments 10. Reset and repeat tasks with EV1 in primary role but EV2 assisting as needed with tasks (eg, setup of haul system, locking off of haul system, etc.).	**101.6 CM × 152.4 CM (40 IN. × 60 IN.) PORT SIDE-HATCH (W/ TUNNEL) INCAPACITATED CREW MEMBER ACTIVITY (00:05)** 1. Communicate to EV1 that EV3 appears to be incapacitated. 2. Observe EV1 performing tasks solo. 3. Reset and repeat tasks with EV1 still in primary role but EV2 assisting as needed with tasks (eg, setup of haul system, locking off of haul system, etc.). 4. EV to communicate task completion and provide GCPS and other required metrics and comments.

Proc. No.	HR : MIN	Topside/IV	EV1	EV2
12	01:10 --	**101.6 CM × 152.4 CM (40 IN. × 60 IN.) PORT SIDE-HATCH (W/ TUNNEL) INCAPACITATED CREW MEMBER ACTIVITY (00:05)** **INITIAL CONFIGURATION:** – EV1 on surface – EV2 on surface – T1 on surface – T2 on surface – SEV mock-up on surface – Port side-hatch configured to 101.6 cm × 152.4 cm (40 in. × 60 in.) – Rescue manikin on surface – Haul system available on SEV mock-up 1. Topside ensures rescue manikin and hauls system in place prior to start of scenario 2. Assists in resetting of scenario between solo and dual rescuer scenarios 3. IV records start/stop times for each task on hard copy; MCC does the same in soft copy 4. MCC prompts EV for comments and GCPS ratings, other metrics, and records; and records soft copy; IV records hard copy	**101.6 CM × 152.4 CM (40 IN. × 60 IN.) PORT SIDE-HATCH (WITH TUNNEL) INCAPACITATED CREW MEMBER ACTIVITY (00:05)** 1. Communicate to EV2 that EV3 appears to be incapacitated. 2. Reset and repeat tasks with EV2 still in primary role but EV2 assisting as needed with tasks (e.g. setup of haul system, locking off of haul system, etc.). 3. EV to communicate task completion and provide GCPS and other required metrics and comments.	**101.6 CM × 152.4 CM (40 IN. × 60 IN.) PORT SIDE-HATCH (WITH TUNNEL) INCAPACITATED CREW MEMBER ACTIVITY (00:05)** 1. Proceed to SEV mockup area. 2. Call 'start" to IV for this task. 3. Locate downed crew member, turn the crew member to his/her back, and perform initial medical assessment. 4. Communicate status of incapacitated crew member to EV1 and plan for stabilization and transport. 5. Setup haul system between SEV side-hatch and incapacitated crew member. 6. Haul on haul system, moving and lifting incapacitated crew member into side-hatch doorway. 7. Lock-off haul system. 8. Push incapacitated crew member completely in SEV, sliding along cross-wire between hatches. 9. EV to communicate task completion and provide GCPS and other required metrics and comments . 10. Reset and repeat tasks with EV2 still in primary role but with EV1 assisting as needed with tasks (e.g. setup of haul system, locking off of haul system, etc.).
13	01:15 --	**RESET SCENARIO AND RECONFIGURE PORT SIDE-HATCH (WITH TUNNEL) TO 101.6 CM × 101.6 CM (40 IN. × 40 IN.) (00:05)** 1. Topside resets scenario and reconfigures port side-hatch to 101.6 cm × 101.6 cm (40 in. x 40 in.) size	**RESET SCENARIO AND RECONFIGURE PORT SIDE-HATCH (W/ TUNNEL) TO 40"x40" (00:05)** 1. Crew assists topside in resetting and reconfiguring for next test condition.	

Proc. No.	HR : MIN	Topside/IV	EV1	EV2
14	01:20 --	**REPEAT PROCEDURES 5-6 WITH 101.6 CM × 101.6 CM (40 IN. × 40 IN.) PORT SIDE-HATCH (WITH TUNNEL) (00:10)** **INITIAL CONFIGURATION:** – EV1 on surface – EV2 on surface – T1 on surface – T2 on surface – SEV mock-up on surface – Port side-hatch configured to 101.6 cm × 101.6 cm (40 in. × 40 in.) – Rescue manikin on surface – Haul system available on SEV mock-up 1. MCC communicates with crew which procedures will be repeated with 101.6 cm × 101.6 cm (40 in. × 40 in.) hatch size 2. IV records start/stop times for each task on hard copy; MCC does the same in soft copy 3. MCC prompts EV for comments and GCPS ratings, other metrics, and records; and records soft copy; IV records hard copy	**REPEAT PROCEDURES 5-6 WITH 101.6 CM × 101.6 CM (40 IN. × 40 IN.) PORT SIDE-HATCH (WITH TUNNEL) (00:10)** 1. Crew repeats procedures 5 and 6 above with new configuration.	
15	01:30 --	**RECONFIGURE CREW MEMBER WEIGH OUT TO IVA WEIGHT (00:05)** 1. Topside configures and assists crew in completing weigh out for IVA weight 2. MCC confirms and communicates with EV weight out correct and complete	**RECONFIGURE CREW MEMBER WEIGH OUT TO IVA WEIGHT (00:05)** 1. Doff PLSS mock-ups. 2. Work with topside divers to adjust weights as needed to achieve proper IVA weight out to lunar gravity.	

<table>
<tr><th>Proc. No.</th><th>HR : MIN</th><th>Topside/IV</th><th>EV1</th><th>EV2</th></tr>
<tr>
<td>16</td>
<td>01:35 --</td>
<td><u>SEV HATCH TRANSLATIONS</u> (00:10)

<u>INITIAL CONFIGURATION:</u>
– EV2 on surface
– EV1 on surface
– T1 on surface
– T2 on surface
– SEV mock-up on surface
– Starboard side-hatch configured to 101.6 cm × 152.4 cm (40 in. ×60 in.)

1. Topside reconfigure side-hatch after completion of first configuration

2. IV records start/stop times for each task on hard copy; MCC does the same in soft copy

3. MCC prompts EV for comments and GCPS ratings, other metrics, and records; and records soft copy; IV records hard copy</td>
<td><u>SEV HATCH TRANSLATIONS</u> (00:10)

1. Call “start” to IV for this task before beginning translations.

2. Perform four in- and out-hatch translations through the hatchway at initial configuration.

3. Call “stop” to IV and provide GCPS rating, other metrics, and comments.

4. Work with topside as needed to communicate and assist with reconfiguration of side-hatch to 101.6 cm × 101.6 cm (40 in. × 40 in.).

5. Call “start” to IV for this task before beginning translations.

6. Perform four in- and out-hatch translations through the hatchway at second configuration.

7. Call “stop” to IV and provide GCPS rating, other metrics, and comments.</td>
<td><u>SEV HATCH TRANSLATIONS</u> (00:10)

1. Call “start” to IV for this task before beginning translations.

2. Perform four in- and out-hatch translations through the hatchway at initial configuration.

3. Call “stop” to IV and provide GCPS rating, other metrics, and comments.

4. Work with topside as needed to communicate and assist with reconfiguration of side-hatch to 101.6 cm × 101.6 cm (40 in. × 40 in.).

5. Call “start” to IV for this task before beginning translations.

6. Perform four in- and out-hatch translations through the hatchway at second configuration.

7. Call “stop” to IV and provide GCPS rating, other metrics, and comments.</td>
</tr>
<tr>
<td>17</td>
<td>01:45 --</td>
<td><u>CLEANUP/INGRESS</u> (00:30)

• Clean and transfer equipment to surface as necessary</td>
<td colspan="2"><u>CLEANUP/INGRESS</u> (00:30)
1. Doff Miller weight belt.
2. Doff MK-12 suit.
3. Reenter wet porch.
4. Doff SL-17.
5. DTO complete.
6. Transfer data from waterproof sheet to electronic data sheet file entitled CG_OptWt_Datasheets.xls and uplink file to NEEMO SharePoint for transfer to PI.</td>
</tr>
</table>

8.5 Topside cue cards

8.5.1 Center-of-gravity and Cargo-lander-based Cue Cards

Proc. #	EVA Elapsed Time (HR : MIN)	TASKS	INITIAL CONFIGURATION
1	n/a	**EVA PREP/EGRESS (00:30)**	
2	00:00	**INITIAL CG RIG/WEIGHT CONFIGURATION (00:10)** – Configure CGs based on crewmember by communicating with EV	– EV1 & EV2 on sand – CG rigs & weights ready for config
3	00:10	**EPSP CG & LANDER LADDER ACTIVITIES (00:10)** – EV1 will be doing CG course – EV 2 will be doing lander ladder – Configure lander ladder angle based on crewmember and communication with EV	– EV1 & EV2 on sand – Lander ladder configured to initial angle for crewmember – Circuit traverse path marked – Circuit shovel & bucket in place – Circuit weights/rocks and crates in place
4	00:20	**EPSP CG & LANDER LADDER ACTIVITIES (00:10)** – REPEATING PROCEDURE 3 WITH EV CREWMEMBERS SWAPPING ROLES – Configure lander ladder angle based on crewmember and communication with EV	– EV1 & EV2 on sand – Lander ladder configured to initial angle for crewmember – Circuit traverse path marked – Circuit shovel & bucket in place – Circuit weights/rocks and crates in place
5	00:30	**LANDER SMALL PAYLOAD OFFLOAD ACTIVITY (00:05)** – EV2 will use large davit to offload payload – EV1 will assist from sand with tag line	– EV1 & EV2 on sand – Small payload on deck
6	00:35	**LANDER SMALL PAYLOAD ONLOAD ACTIVITY (00:05)** – EV2 will use large davit to onload payload – EV1 will assist from sand with tag line	– EV1 on sand – EV2 on deck – Small payload on sand
7	00:40	**LANDER INCAPACITATED CREWMEMBER UPLOAD (00:05)** – EV2 will use large davit to onload rescue manikin – EV1 will assist from sand with tag line	– EV1 on sand – EV2 on deck – Rescue manikin face down on sand under large davit – Tagline loose on back deck of rover
8	00:45	**LANDER ROVER OFFLOAD ACTIVITY (00:15)** – EV2 will use large davit to offload rover – EV1 will assist from sand with tag line	– EV1 on sand – EV2 on deck – Rover cabin on deck with launch locks reset – Rover attached to large davit – Tagline loose on deck
9	01:00	**RESET LANDER ROVER, SMALL PAYLOAD, & INCAPACITATED CREWMEMBER (00:10)** – Reset rover back on deck – Reset small payload on deck – Reset rescue manikin on sand	– EV1 on sand – EV2 on deck – Rover on sand – Rescue manikin on deck – Large davit attached to rescue manikin – Tagline attached to rescue manikin
10	01:10	**LANDER SMALL PAYLOAD OFFLOAD ACTIVITY (00:05)** – REPEATING PROCEDURE 5 WITH CREWMEMBERS SWAPPING ROLES	– EV1 & EV2 on sand – Small payload on deck

Proc. #	EVA Elapsed Time (HR : MIN)	TASKS	INITIAL CONFIGURATION
11	**01:15**	**LANDER SMALL PAYLOAD ONLOAD ACTIVITY (00:05)** − REPEATING PROCEDURE 6 WITH CREWMEMBERS SWAPPING ROLES	− EV2 on sand − EV1 & T2 on deck − Small payload on surface
12	**01:20 -**	**LANDER INCAPACITATED CREWMEMBER UPLOAD (00:05)** − REPEATING PROCEDURE 7 WITH CREWMEMBERS SWAPPING ROLES	− EV2 on sand − EV1 on deck − Rescue manikin attached to suitport − Large davit attached to PLSS plate of rescue manikin − Tagline loose on back deck of rover
13	**01:25**	**LANDER ROVER OFFLOAD ACTIVITY (00:15)** − REPEATING PROCEDURE 8 WITH CREWMEMBERS SWAPPING ROLES	− EV2 on sand − EV1 on deck − Rover cabin on deck with launch locks reset − Rover attached to large davit − Tagline loose on deck
14	**01:40 -**	**RESET LANDER ROVER, SMALL PAYLOAD, & INCAPACITATED CREWMEMBER (00:10)** − Reset rover back on deck − Reset small payload on deck − Reset rescue manikin on sand	− EV2 on sand − EV1 on deck − Rover on surface − Rescue manikin on deck − Large davit attached to rescue manikin − Tagline attached to rescue manikin
15	**01:50**	**RECONFIGURATION OF PLSS RIG TO CG #2 (00:10)** − Configure next CG for each crewmember	
16	**02:00**	**REPEAT PROCEDURES 3-14 AT CG #2 (01:40)** − PROCEDURES 3 -14 REPEATED AT NEW CG	− EV1 & EV2 on sand − Lander ladder configured to initial angle for crewmember − Circuit traverse path marked − Circuit shovel & bucket in place − Circuit weights/rocks and crates in place
17	**03:40**	**RECONFIGURATION OF PLSS RIG TO CG #3 (00:10)** − Configure next CG for each crewmember	
18	**03:50 -**	**REPEAT PROCEDURES 3-14 AT CG #3 (01:40)** − PROCEDURES 3 -14 REPEATED AT NEW CG	− EV1 & EV2 on sand − Lander ladder configured to initial angle for crewmember − Circuit traverse path marked − Circuit shovel & bucket in place − Circuit weights/rocks and crates in place
19	**05:30 -**	**DOFF/INGRESS/POST-EVA (00:30)** − Assist crew in doff of CG rig and extra weights − Perform any cleanup needed of test area − If last CG/Lander task in the timeline for the day, bring topside-supplied equipment back to boat (i.e. fall protection, ropes, etc.)	

8.5.2 Space Exploration vehicle and Crew-lander-based Cue Cards

<u>For all procedures on this cue card prior to start</u>:

- **Rover mockup is on sand**
- **EV crew and topside support are near rover mockup**

Proc. #	EVA Elapsed Time (HR : MIN)	TASKS	INITIAL CONFIGURATION
1	**n/a**	**EVA PREP/EGRESS (00:30)**	
2	**00:00**	**COMPLETE WEIGH-OUT (00:05)** - Configure weigh-out based on crewmember by communicating with EV	- PLSS mockups ready to don - Weights ready to complete weight-out
3	**00:05**	**SMALL PAYLOAD & AIRLOCK/ASCENT MODULE INGRESS (00:10)** - EV1 will upload small payload with small davit - EV2 will perform airlock/ascent module ingress	- EV1 & EV2 on sand - Small payload on deck - Airlock/ascent module on deck - Small davit on deck near lander ladder
4	**00:15**	**SMALL PAYLOAD & AIRLOCK/ASCENT MODULE INGRESS (00:10)** - <u>REPEATING PROCEDURE 3</u> WITH EV CREWMEMBERS SWAPPING ROLES	- EV1 & EV2 on deck - Small payload on deck - Airlock/ascent module on deck - Small davit on deck near lander ladder
5	**00:25**	**LANDER INCAPACITATED CREWMEMBER UPLOAD (00:05)** - EV1 will ascend ladder next to incapacitated crewmember - EV2 will operate small davit	- EV1 on sand - EV2 on deck - Rescue manikin on sand - Airlock/ascent module on deck - Small davit on deck near lander ladder
6	**00:30**	**LANDER INCAPACITATED CREWMEMBER UPLOAD (00:05)** - <u>REPEATING PROCEDURE 5</u> WITH EV CREWMEMBERS SWAPPING ROLES	- EV1 on deck - EV2 on sand - Rescue manikin on sand - Airlock/ascent module on deck - Small davit on deck near lander ladder
7	**00:35**	**INCAPACITATED CREWMEMBER AIRLOCK/ASCENT MODULE INGRESS (00:10)** - EV1 will use haul system to ingress rescue manikin to airlock - EV2 will enter ascent module from and receive rescue manikin from EV1 in airlock	- EV1 & EV2 on deck - Rescue manikin on porch - Airlock/ascent module on deck - Small davit on deck - Haul system in airlock
8	**00:45**	**INCAPACITATED CREWMEMBER AIRLOCK/ASCENT MODULE INGRESS (00:10)** - <u>REPEATING PROCEDURE 7</u> WITH EV CREWMEMBERS SWAPPING ROLES	- EV1 & EV2 on deck - Rescue manikin on porch - Airlock/ascent module on deck - Small davit on deck - Haul system in airlock
9	**00:55**	**SUITPORT INCAPACITATED CREWMEMBER ACTIVITY (00:05)** - EV1 (solo) uses haul system to raise rescue manikin to suitport - EV2 observes and plays assisting role only after EV1 has performed the task once solo	- EV1 & EV2 on sand - Rover on sand - Rescue manikin on sand - Haul system attached above suit port
10	**01:00**	**SUITPORT INCAPACITATED CREWMEMBER ACTIVITY (00:05)** - <u>REPEATING PROCEDURE 9</u> WITH EV CREWMEMBERS SWAPPING ROLES	- EV1 & EV2 on sand - Rover on sand - Rescue manikin on sand - Haul system attached above suit port

Proc. #	EVA Elapsed Time (HR : MIN)	TASKS	INITIAL CONFIGURATION
11	01:05	**40"x60" SIDE-HATCH INCAPACITATED CREWMEMBER ACTIVITY (00:05)** − EV1 (solo) uses haul system to raise rescue manikin to suitport − EV2 observes and plays assisting role only after EV1 has performed the task once solo	− EV1 & EV2 on sand − Rover on sand w/ side-hatch configured to 40"x60" − Rescue manikin on sand − Haul system attached inside rover
12	01:10	**40"x60" SIDE-HATCH INCAPACITATED CREWMEMBER ACTIVITY (00:05)** - REPEATING PROCEDURE 11 WITH EV CREWMEMBERS SWAPPING ROLES	− EV1 & EV2 on sand − Rover on sand w/ side-hatch configured to 40"x60" − Rescue manikin on sand − Haul system attached inside rover
13	01:15	**RESET SCENARIO & RECONFIGURE SIDE-HATCH TO 40"x40" (00:05)** − Remove rescue manikin from inside rover and place on sand outside side hatch	− Rover on sand w/ side-hatch configured to 40"x60" − Rescue manikin on sand − Haul system attached inside rover
14	01:20	**REPEAT PROCEDURES 11-12 W/ 40"x40" SIDE-HATCH (W/ TUNNEL) (00:10)** − REPEATING PROCEDURES 11 -12 AT NEW SIDE-HATCH CONFIGURATION	− Rover on sand w/ side-hatch configured to 40"x40" − Rescue manikin on sand − Haul system attached inside rover
15	01:30	**RECONFIGURE CREWMEMBER WEIGH-OUT TO IVA WEIGHT (00:05)** − Remove weights from EV crewmembers to reduce their weigh-out to their IVA weight − Remove PLSS mockups from EV crewmembers	− Weights available for reconfiguration to IVA weight
16	01:35	**ROVER HATCH TRANSLATIONS (00:15)** − Each EV crewmember performs 4 in/out hatch translations at 40"x40" side hatch size − Reconfigure side-hatch to 40"x60" − Each EV crewmember performs 4 in/out hatch translations at 40'x60" side hatch size	− EV1 & EV2 at IVA weights without PLSS mockups − Rover on sand w/ side-hatch configured to 40"x40"
17	01:50	**CLEANUP/INGRESS (00:30)** − Perform any cleanup needed of test area − If last rover-based task in the timeline for the day, bring topside-supplied equipment back to boat (i.e. haul system, ropes, etc.)	

8.6 Data sheets

8.6.1 Extravehicular Activity Physiology, Systems, and Performance Center-of-gravity Data Sheets

Instructions: **For protocol evaluation, all activities will be timed, but the goal is not to do the tasks as fast as possible. For all tasks, please take the time needed to evaluate the specified activity in order to provide accurate ratings.** **Yellow highlighted boxes indicate data entry fields to be completed.**

Gravity Compensation & Performance Scale (GCPS):

1	**Excellent –** easier than 1G
2	**Good –** equivalent to 1G
3	**Fair –** minimal compensation for desired performance
4	**Minor –** moderate compensation for desired performance
5	**Moderately objectionable –** considerable compensation for adequate performance
6	**Very objectionable –** extensive compensation for adequate performance
7	**Major deficiencies –** considerable compensation for control; performance compromised
8	**Major deficiencies –** intense compensation; performance compromised
9	**Major deficiencies –** adequate performance not attainable w/ maximum tolerable compensation
10	**Major deficiencies –** unable to perform task

EVA Task Acceptibility Rating Scale:

Totally Acceptable-no improvements necessary		Acceptable-minor improvements desired		Borderline-improvements warranted		Unacceptable-improvements required		Totally Unacceptable-major improvements required	
1	2	3	4	5	6	7	8	9	10

Rating of Perceived Exertion (RPE):

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

Complete Exploration task below- providing IV with start/stop times, GCPS, RPE, & EVA Task Acceptability ratings (described above)

CG & Lander Proc. # & Substep (Role)	Planned EVA Task Duration (Min: Sec)	Task	EVA Time (Min:Sec) Start Time	Stop Time	GCPS	RPE	EVA Task Acceptability	Comments (use back or additional sheet for additional comments as needed)
3.2 (EV1) or 4.2 (EV2)	10:00 to complete all tasks	**Ambulation (Walk 2x; Preferred 2x) (Record type in comments)**						
3.3 (EV1) or 4.3 (EV2)		**Ramp (Ascending) (1x)**						
3.4 (EV1) or 4.4 (EV2)		**Ramp (Descending) (1x)**						
3.5 (EV1) or 4.5 (EV2)		**Kneel & recovery (1x)**						
3.6 (EV1) or (4.6 (EV2)		**Fwd Fall & Recovery (1x)**						
3.7 (EV1) or 4.7 (EV2)		**Shoveling (15x into bucket)**						
3.8 (EV1) or 4.8 (EV2)		**Rock Pick-up (all)**						
3.9 (EV1) or 4.9 (EV2)		**EPSP Ladder Up/Dn (1x)**						

8.6.2 Cargo Lander-based Data Sheets

Instructions: **For protocol evaluation, all activities will be timed, but the goal is not to do the tasks as fast as possible. For all tasks, please take the time needed to evaluate the specified activity in order to provide accurate ratings.** Yellow highlighted boxes indicate data entry fields to be completed.

Gravity Compensation & Performance Scale (GCPS):

1	**Excellent –** easier than 1G
2	**Good –** equivalent to 1G
3	**Fair –** minimal compensation for desired performance
4	**Minor –** moderate compensation for desired performance
5	**Moderately objectionable –** considerable compensation for adequate performance
6	**Very objectionable –** extensive compensation for adequate performance
7	**Major deficiencies –** considerable compensation for control; performance compromised
8	**Major deficiencies –** intense compensation; performance compromised
9	**Major deficiencies –** adequate performance not attainable w/ maximum tolerable compensation
10	**Major deficiencies –** unable to perform task

EVA Task Acceptibility Rating Scale:

Totally Acceptable-no improvements necessary		Acceptable-minor improvements desired		Borderline-improvements warranted		Unacceptable-improvements required		Totally Unacceptable-major improvements required	
1	2	3	4	5	6	7	8	9	10

Rating of Perceived Exertion (RPE):

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

Complete Exploration task below- providing IV with start/stop times, GCPS, RPE, & EVA Task Acceptability ratings (described above)

CG & Cargo Lander Proc. # (Role)	Planned EVA Task Duration (Min: Sec)	Task	EVA Time (Min:Sec) Start Time	Stop Time	GCPS	RPE	EVA Task Acceptability	Comments (use back or additional sheet for additional comments as needed)
3 (EV1) or 4 (EV2)	10:00 to complete all ladder angles	Lander Ladder Up/Dn - 10 deg (1x)						
		Lander Ladder Up/Dn - 20 deg (1x)						
		Lander Ladder Up/Dn - 30 deg (1x)						
5 (EV2) or 10 (EV1)	05:00	Small Payload Offload (deck role)						
6 (EV2) or 11 (EV1)	05:00	Small Payload Onload (deck role)						
7 (EV2) or 12 (EV1)	05:00	Incap. Crew Onload (deck role)						
8 (EV2) or 13 (EV1)	15:00	LER Offload (deck role)						
5 (EV1) or 10 (EV2)	05:00	Small Payload Offload (sand role)						
6 (EV1) or 11 (EV2)	05:00	Small Payload Onload (sand role)						
7 (EV1) or 12 (EV2)	05:00	Incap. Crew Onload (sand role)						
8 (EV1) or 13 (EV2)	15:00	LER Offload (sand role)						

8.6.3 Space Exploration Vehicle- and Crew-lander-based Data Sheets

Instructions: **For protocol evaluation, all activities will be timed, but the goal is not to do the tasks as fast as possible. For all tasks, please take the time needed to evaluate the specified activity in order to provide accurate ratings.**

Yellow highlighted boxes indicate data entry fields to be completed.

Gravity Compensation & Performance Scale (GCPS) Rating	
1	**Excellent** – easier than 1G
2	**Good** – equivalent to 1G
3	**Fair** – minimal compensation for desired performance
4	**Minor** – moderate compensation for desired performance
5	**Moderately objectionable** – considerable compensation for adequate performance
6	**Very objectionable** – extensive compensation for adequate performance
7	**Major deficiencies** – considerable compensation for control; performance compromised
8	**Major deficiencies** – intense compensation; performance compromised
9	**Major deficiencies** – adequate performance not attainable w/ maximum tolerable compensation
10	**Major deficiencies** – unable to perform task

Rating of Perceived Exertion (RPE) Scale	
6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

EVA Task Acceptibility Rating Scale:

Totally Acceptable-no improvements necessary		Acceptable-minor improvements desired		Borderline-improvements warranted		Unacceptable-improvements required		Totally Unacceptable-major improvements required	
1	2	3	4	5	6	7	8	9	10

Complete Exploration task below- providing IV with start/stop times, GCPS, RPE, & EVA Task Acceptability ratings (described above)

CG & Cargo Lander Proc. # (Role)	Planned EVA Task Duration (Min: Sec)	Task	EVA Time (Min:Sec) Start Time	Stop Time	GCPS	RPE	EVA Task Acceptability	Comments (use back or additional sheet for additional comments as needed)
3 (EV1) or 4 (EV2)	10:00	Small Payload Offload w/ Small Davit (solo)						
3 (EV2) or 4 (EV1)	10:00	Airlock/Ascent Module Ingress						
5 (EV2) or 6 (EV1)	05:00	Incapacitated Crewmember Upload w/ Small Davit (deck role)						
5 (EV1) or 6 (EV2)	05:00	Incapacitated Crewmember Upload w/ Small Davit (ladder role)						
7 (EV1) or 8 (EV2)	10:00	Incapacitated Crewmember Airlock/Ascent Module Ingress (haul role)						
7 (EV2) or 8 (EV1)	10:00	Incapacitated Crewmember Airlock/Ascent Module Ingress (asc. Mod. role)						
9 (EV2) or 10 (EV1)	05:00	Suitpot Incap. Crew (solo)						
11 (EV1) or 12 (EV2)	05:00	40"x60" Incap. Crew (solo)						
14	05:00	40"x40" Incap. Crew (solo)						
16	15:00 for all hatch translations	40"x40" Hatch Translation (IVA weight) (4x)						
		40"x60" Hatch Translation (IVA weight) (4x)						

Questionnaires

Lander Ladder After-Task Questionnaire

Subject Number: | Date: | Ladder Angle:

The purpose of this questionnaire is to determine the lander ladder characteristics of a small payload and to obtain your recommendations for future assessments. Please complete the following questionnaire by ***putting an "x" under the rating number*** *for each characteristic with the appropriate answer and to add any* ***comments*** *for that characteristic. Your comments are important so please take the time to describe your feedback in detail. Please give this questionnaire your full attention and do not hesitate to ask if you are not certain what is being asked in any of the questions. Do not leave any blanks.* ***Thank you for your time and effort****. Remember to* ***SAVE*** *your work.*

Rate the following Altair Lunar Lander ladder functional **characteristics**:

For each characteristic, select and circle the number that most accurately describes your opinion for the following:	**Totally Acceptable-No improvements necessary**		**Acceptable-Minor improvements desired**		**Borderline-Improvements warranted**		**Unacceptable-Improvements required**		**Totally Unacceptable-Major improvements**		**Comments**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Upon completion of ascending ladder and standing/secured on Lander deck:											
a. Attaching fall restraint system to ladder											
b. Ease of ladder ascension											
c. Ease of translation from ladder system to deck fall restraint system											
d. Translation around Lander deck with fall restraint system											
e. Accessibility to ladder hand rail											
Upon completion of descending ladder, calling task complete and giving GCPS:											
f. Ease of translation from deck to ladder fall restraint system											
g. Ease of translation down ladder											
h. Detaching ladder fall restraint system once on surface											

Additional Notes:

Lander Emergency After-Task Questionnaire

Subject Number: | Date:

*The purpose of this questionnaire is to determine the lander davit functional characteristics during an emergency and to obtain your recommendations for future assessments. Please complete the following questionnaire by **putting an "x" under the rating number** for each characteristic with the appropriate answer and to add any **comments** for that characteristic. Your comments are important so please take the time to describe your feedback in detail. Please give this questionnaire your full attention and do not hesitate to ask if you are not certain what is being asked in any of the questions. Do not leave any blanks. **Thank you for your time and effort**. Remember to **SAVE** your work.*

Rate the following Altair Lunar Lander emergency functional **characteristics**:

For each characteristic, select and circle the number that most accurately describes your opinion for the following:	**Total Acceptable-No improvements necessary**		**Acceptable-Minor improvements desired**		**Borderline-Improvements warranted**		**Unacceptable-Improvements required**		**Totally Unacceptable-Major improvements**		**Comments**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Upon completion of setting up haul system between Lander deck and incapacitated crewmember:											
a. Accessibility to Lander davit winch											
b. Ease of controlling davit winch in lowing davit line to surface											
c. Attaching davit line to incapacitated crew member's shoulder D-rings											
d. Attaching davit tagline to incapacitated crew member's waist D-ring											
e. Location of attach point of incapacitated crew member's suit											
Upon completion of lifting and placing incapacitated crewmember completely onto Lander deck:											
f. Ease of controlling davit winch when raising incapacitated crew member from surface to Lander deck											
g. Ease of maneuvering davit with incapacitated crew member over the Lander rail for preparation to lower to deck											
h. Ease of controlling davit to lower incapacitated crew member to deck in a face up position											
i. Detaching davit tagline from incapacitated crew member											

Additional Notes:

Lander Rover Off-Load After-Task Questionnaire

Subject Number: | Date:

The purpose of this questionnaire is to determine the lander off-loading characteristics of the rover and to obtain your recommendations for future assessments. Please complete the following questionnaire by ***putting an "x" under the rating number*** *for each characteristic with the appropriate answer and to add any* ***comments*** *for that characteristic. Your comments are important so please take the time to describe your feedback in detail. Please give this questionnaire your full attention and do not hesitate to ask if you are not certain what is being asked in any of the questions. Do not leave any blanks.* ***Thank you for your time and effort****. Remember to* ***SAVE*** *your work.*

Rate the following Altair Lunar Lander off-loading functional **characteristics**:

For each characteristic, select and circle the number that most accurately describes your opinion for the following:	**Totally Acceptable-No improvements necessary**		**Acceptable-Minor improvements desired**		**Borderline-Improvements warranted**		**Unacceptable-Improvements required**		**Totally Unacceptable-Major improvements**		**Comments**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Upon completion of preparing and connecting rover:											
a. Releasing rover launch locks											
b. Detaching rover electrical connectors											
c. Attaching davit line to eyebolt on rover											
d. Controlling davit winch while lowering rover to surface											
Upon completion of lowering rover:											
e. Maneuvering davit with rover in preparation for lowering to surface											
f. Using tagline to control rover rotation during lowering from surface											
g. Detaching davit line from rover once on surface											

Additional Notes:

AL Hatch and AL/AM Tunnel Emergency After-Task Questionnaire

Subject Number: | Date: | Side Hatch Size:

The purpose of this questionnaire is to determine the AL hatch and AL/AM tunnel functional characteristics and to obtain your recommendations for future assessments. Please complete the following questionnaire by ***putting an "x" under the rating number*** *for each characteristic with the appropriate answer and to add any* ***comments*** *for that characteristic. Your comments are important so please take the time to describe your feedback in detail. Please give this questionnaire your full attention and do not hesitate to ask if you are not certain what is being asked in any of the questions. Do not leave any blanks.* ***Thank you for your time and effort****. Remember to* ***SAVE*** *your work.*

Rate the following Altair AL hatch and AL/AM tunnel functional **characteristics** for incapacitated crewmember:

For each characteristic, select and circle the number that most accurately describes your opinion for the following:	**Totally Acceptable-No improvements necessary**		**Acceptable-Minor improvements desired**		**Borderline-Improvements warranted**		**Unacceptable-Improvements required**		**Totally Unacceptable-Major improvements**		**Comments**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
a. Assembling the incapacitated crewmember haul system within the AL Module											
b. Attaching the haul system inside the AL											
c. Moving the incapacitated crewmember to the AL hatch for											
d. Attaching the haul system to the incapacitated crewmember and lifting crew into position of AL											
e. Translating incapacitated crewmember into AL hatch											
f. Disconnecting incapacitated crew from haul system and closing AL hatch											
g. Passing incapacitated crew through AL/AM tunnel to waiting crew in AM											

Additional Notes:

AL/AM Tunnel After-Task Questionnaire

Subject Number:	Date:	Side Hatch Size:

The purpose of this questionnaire is to determine the AL/AM tunnel functional characteristics and to obtain your recommendations for future assessments. Please complete the following questionnaire by ***putting an "x" under the rating number*** *for each characteristic with the appropriate answer and to add any* ***comments*** *for that characteristic. Your comments are important so please take the time to describe your feedback in detail. Please give this questionnaire your full attention and do not hesitate to ask if you are not certain what is being asked in any of the questions. Do not leave any blanks.* ***Thank you for your time and effort****. Remember to* ***SAVE*** *your work.*

Rate the following Altair AL/AM tunnel functional **characteristics**:

For each characteristic, select and circle the number that most accurately describes your opinion for the following:	Totally Acceptable-No improvements necessary		Acceptable-Minor improvements desired		Borderline-Improvements warranted		Unacceptable-Improvements required		Totally Unacceptable-Major improvements		Comments
	1	2	3	4	5	6	7	8	9	10	
a. Internal tunnel volume of the tunnel functional for translation operations											
b. Height of the tunnel functional for translation operations											
c. Width of the tunnel functional for translation operations											
d. Step up height of the tunnel from the Al to AM functional for translation operations											

Additional Notes:

Interior 40x40 Hatch After-Task Questionnaire

Subject Number: Date:

The purpose of this questionnaire is to determine if an interior 40"x40" hatch is functional for a 14-day mission and to obtain your recommendations for future assessments. Please complete the following questionnaire by ***putting an "x" under the rating number*** *for each characteristic with the appropriate answer and to add any* ***comments*** *for that characteristic. Your comments are important so please take the time to describe your feedback in detail. Please give this questionnaire your full attention and do not hesitate to ask if you are not certain what is being asked in any of the questions. Do not leave any blanks.* ***Thank you for your time and effort****. Remember to* ***SAVE*** *your work.*

Q1. Rate the following interior 40x40 hatch functional characteristics:

For each characteristic, indicate the number that most accurately describes your opinion for the following:	**Totally Acceptable-No improvements necessary**		**Acceptable-Minor improvements desired**		**Borderline-Improvements warranted**		**Unacceptable-Improvements required**		**Totally Unacceptable-Major improvements required**		**Comments**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
a. Overall hatch dimensions adequate for IVA translation											
b. Hatch step over height adequate for IVA translation											
c. Hatch height adequate for IVA translation											
d. Width of hatch (24") adequate for IVA translation. *Note: The*											

Additional Notes:

Q2. Approximately how many times did you translate through the 40"x40" hatch inside Aquarius today?

Q3. Based on your simulated 1/6g experience do you think the 1g IVA hatch translation inside Aquarius (40" x 24" hatch) is easier or harder than translation through a 40" x 40" hatch would be in 1/6g? Please explain your answer.					
	Much Easier in 1g	Easier in 1g	Same	Harder in 1g	Much Harder in 1g
Comments (if different from previous days):					

Q4. For how long a 1/6g mission do you estimate that a 40" x 40" IV hatch would be acceptable? *Note: The actual width of the interior hatch in Aquarius is 24".*						
	Not Acceptable for Any Mission	Up to 7 days	Up to 14 days	Up to 30 days	Up to 6 months	Would not affect maximum mission duration
Comments (if different from previous days):						

Interior 40x40 Hatch Evaluation Questionnaire

Subject Number:	Date:	Side Hatch Size:

The purpose of this questionnaire is to determine if an interior 40x40 hatch is functional for a 14-day mission and to obtain your recommendations for future assessments. Please complete the following questionnaire by ***putting an "x" under the rating number*** *for each characteristic with the appropriate answer and to add any* ***comments*** *for that characteristic. Your comments are important so please take the time to describe your feedback in detail. Please give this questionnaire your full attention and do not hesitate to ask if you are not certain what is being asked in any of the questions. Do not leave any blanks.* ***Thank you for your time and effort****. Remember to* ***SAVE*** *your work.*

Q1 Rate the level of **difficulty** related to translating through the 40x40 hatch:

1	2	3	4	5
Very Easy	Easy	Borderline	Difficult	Very Difficult

Additional Comments

Q2 Rate the level of **discomfort** related to translating through the 40x40 hatch:

1	2	3	4	5
No Discomfort	Minor Discomfort	Moderate Discomfort	Significant Discomfort	Extreme Discomfort

Additional Comments

Q3 Rate the level of **fatigue** related to translating through the 40x40 hatch:

1	2	3	4	5
No Fatigue	Minor Fatigue	Moderate Fatigue	Significant Fatigue	Extreme Fatigue

Additional Comments

Q4 Rate the level of **annoyance** related to translating through the 40x40 hatch:

1	2	3	4	5
Not Annoying at All	Minor Annoyance	Moderately Annoying	Significantly Annoying	Extremely Annoying

Additional Comments

8.7 Rating scales for subjective measures

The gravity compensation and performance scale is described in Table 25, and the Borg RPE scale is shown in Table 26. Finally, the Corlett and Bishop discomfort scale is depicted in figure 86.

Table 25. Gravity Compensation and Performance Scale

1	**Excellent** – easier than 1*g*
2	**Good** – equivalent to 1*g*
3	**Fair** – minimal compensation for desired performance
4	**Minor** – moderate compensation for desired performance
5	**Moderately objectionable** – considerable compensation for adequate performance
6	**Very objectionable** – extensive compensation for adequate performance
7	**Major deficiencies** – considerable compensation for control; performance compromised
8	**Major deficiencies** – intense compensation; performance compromised
9	**Major deficiencies** – adequate performance unattainable with maximum tolerable compensation
10	**Major deficiencies** – unable to perform task

Table 26. Borg Rating of Perceived Exertion Scale

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

1.1

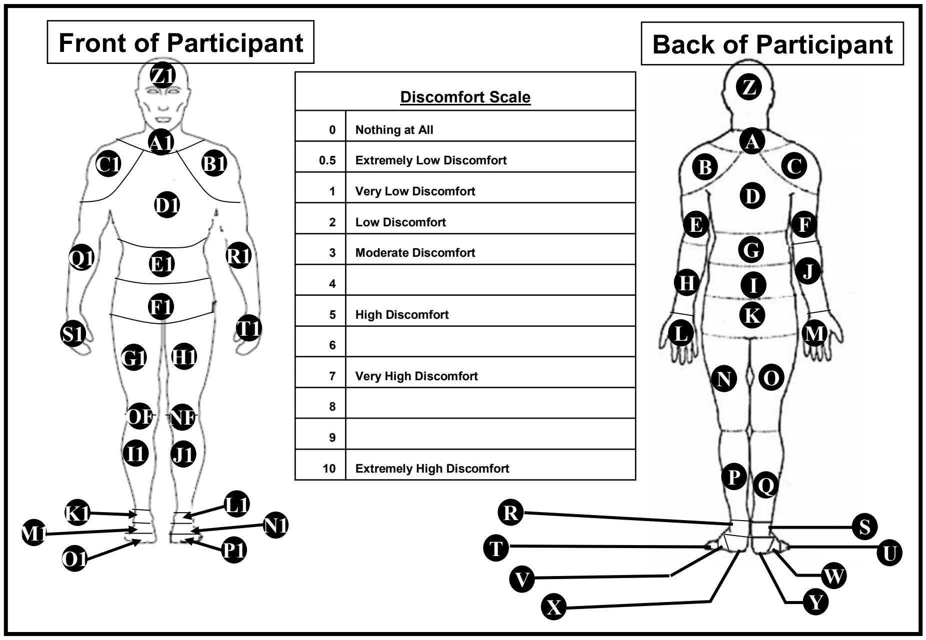

Figure 86. Corlett and Bishop discomfort scale.

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13. ABSTRACT *(Maximum 200 words)*

The Space Exploration Vehicle (SEV) offers numerous health and safety advantages that accrue from having a pressurized safe haven/radiation shelter in close proximity to the crew at all times during exploration operations. It also combines a comfortable shirtsleeve, sensor-augmented environment for gross translations and geological/mapping observations with the ability to rapidly place suited astronauts outside of the vehicle using suitports to take full advantage of the unique human talents of perception, judgment, and dexterity. The concept is being developed by designing, prototyping, and testing in close coordination with developing other exploration systems including the extravehicular activity (EVA) suit. Different test objectives necessitate different test sites, and objectives of the NASA Extreme Environment Mission Operations (NEEMO) 14 test required a simulated reduced-gravity environment. The ability to simulate microgravity and reduced gravity for extended durations during EVA tasks means that NEEMO missions represent a cost-effective opportunity to understand the operation and interaction of hardware and humans in these environments. The success of future exploration missions depends on the ability to perform EVA tasks efficiently and safely, whether those tasks represent a nominal mode of operation or a contingency capability; all systems must be designed with EVA accessibility and operability as important considerations.

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