

Lunar Surface EVA Capabilities

Extravehicular Activity and Human surface Mobility Program
2023

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Introduction



- The purpose of this presentation is to help provide NASA, international partners and other stakeholders an overview of the capabilities of an EVA suited crewmember on the Lunar Surface
- The presentation will cover:
 - Basics of EVA Operations
 - Lunar Surface Concept of Operations
 - Relevant Performance Requirements
 - EVA Compatibility and Interface Documents
 - xEMU Reference Design and capabilities overview

This presentation is intended for use as reference-only context data and not for use as a contract “Applicable Document” or the definitive source of formal “Shalls” on acquisitions, project requirements, etc. Throughout this presentation, citation to configuration managed documents appropriate for such use are provided. Please consult with EHP SE&I for implementation.

EHP and Performing Organizations



- **EVA and Human Surface Mobility Program:** EHP is comprised of several key elements, including Mission Implementation (currently focused on ISS EVA execution), EVA Development, the Lunar Terrain Vehicle (LTV), Pressurized Rover Systems and EHP technology development and partnerships. The main goal of the EHP is to provide safe, reliable, and effective EVA and HSM capabilities that allows astronauts to survive and work outside the confines of a base spacecraft in order to explore on and around the Moon.
- **Engineering Directorate**
 - Provides technical expertise to assess the xEVAS contractor design solution, technical processes, and analysis/test results.
 - Performs Government Furnished Equipment (GFE) projects as requested
 - Maintains historic records of previous government EVA systems
- **Flight Operations Directorate**
 - Provides the Plan / Train / Fly for NASA's EVAs. This spans across the different vehicles ISS, Gateway, HLS, and future surface vehicles and modules
 - Tasks include development of Operations concepts, training facilities, training hardware and software, and execution hardware and software
 - Final Operations products (procedures, training, flight rules, etc.) for mission execution
- **Human Health and Performance Directorate**
 - The Human Health and Performance Directorate enables optimization of human health and performance throughout all phases of spaceflight
 - HH&P supports EHP and its projects by providing expertise in many human health and performance-focused disciplines
 - HH&P supports EHP by implementing an integrated strategy that recognizes the human as an equal component of the EVA system and accounts for human system variability
- **Safety and Mission Assurance Directorate**
 - Provides expertise in Safety, Reliability, and Quality Assurance
 - Identify, characterize, mitigate, and communicate risk in support of both hardware development and spaceflight

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Basics of EVA Operations

Basics of Extravehicular Activities (EVAs)



- An EVA or Spacewalk is anytime when a crewmember is no longer protected from the external environment by their host spacecraft
- During EVAs, crew members rely on a spacesuit to provide a habitable environment, protecting the suited crewmember from the natural and induced environments and providing life support functions
- EVAs are typically performed in buddy pairs
 - Pairing crewmembers provides aid for contingency responses. This is modeled after scuba diving and other high-risk activities.
 - Crewmembers may work on nominal tasks either together or separately, but their separation distance from one another is typically planned and managed with consideration for contingency response
- **EVA operations are planned to be as efficient as possible and are typically limited in duration based on both crew endurance and suit system consumable resources**
 - For example, U.S. EVAs on ISS have and currently are planned to a 6.5 hrs. nominal timeline, not counting reserves
- **EVA task operations vary in both time and technique between crew members**
 - Individual crew members vary in size and strength
 - Crew members interact and manipulate a suit differently. Tasks cannot be as structured as a robotic operation.

EVA Space Suits



- A spacesuit is required to provide the same key systems as other spacecraft.
 - **Sustaining the life of the crewmember**
 - Protection from the environment (i.e. lack of physiologically acceptable atmospheric pressure, touch temperature extremes, MMOD, plasma charging voltages, etc)
 - Providing life support functions
 - Thermal Control
 - Maintain habitable pressure w/breathable atmosphere
 - Hydration and Nutrition
 - Waste management
 - **Enabling Mobility**
 - Translate to and from each worksite whether by walking, driving, etc
 - Perform necessary tasks with gloved hands and tools
 - **Enabling Voice and Data Communication**

EVAs are a Major Risk Driver



- Historically, an EVA is one of the top 3 highest risk events in Human Spaceflight
- Spacesuits are a great asset that enable us to perform construction, assembly and science tasks in environments we wouldn't otherwise be able to operate
- However, there are some limitations that need to be considered when planning EVA activities
 - Crewmembers are required to operate with the added mass of the suit and within the volume/flexibility of the suit
 - Physical injuries may be more likely: Mass, Fit, Center of Gravity can contribute to sprains, strains, abrasions, etc. even fractures
 - Small cuts/holes/leaks can be catastrophic
 - Some hazards are inherent to pure O₂, reduce pressure environment
 - Decompression Sickness
 - Fire

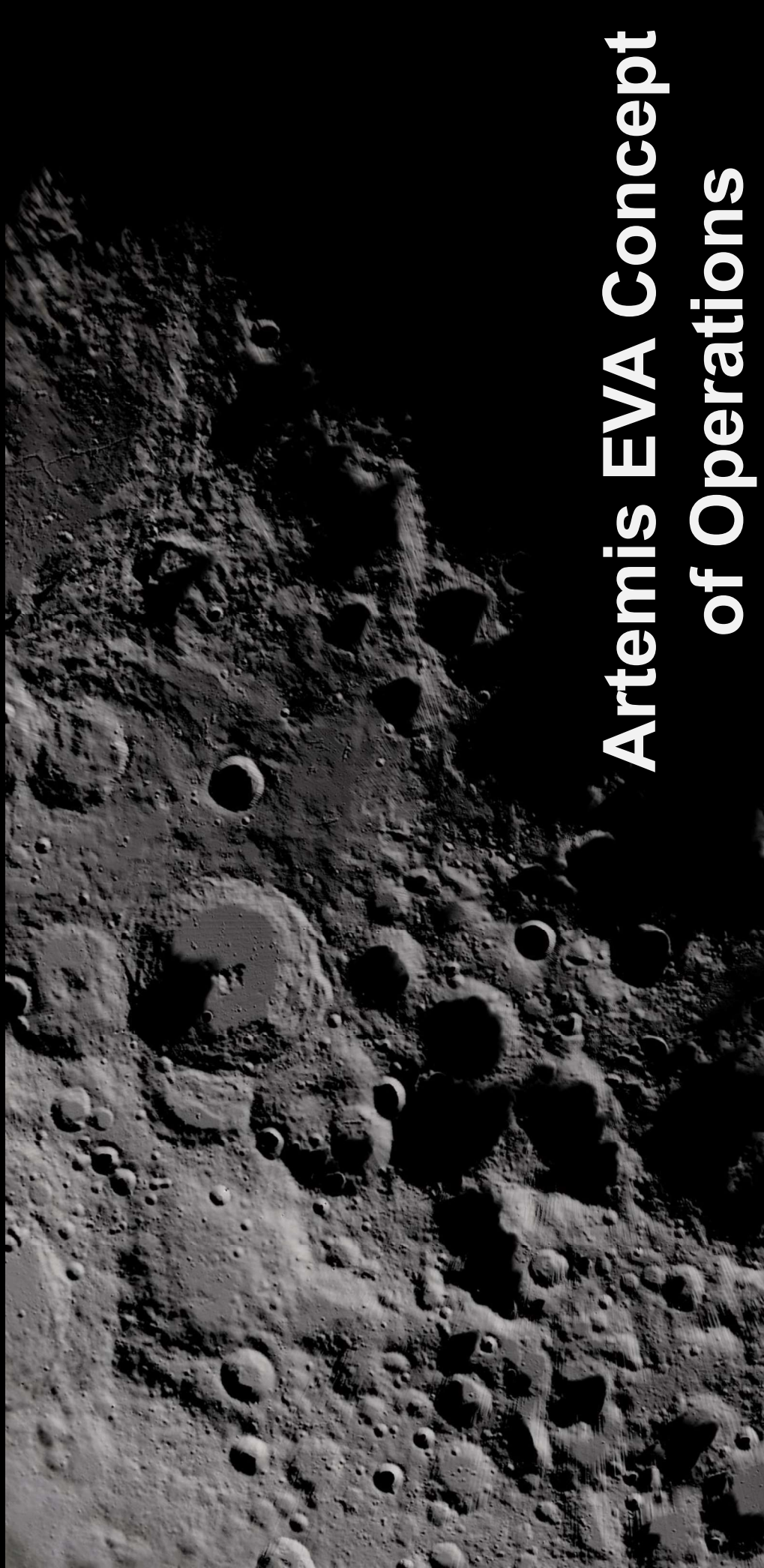
Note: The state of the art in spacesuits today use gas-pressurized garments. These garments are the best known compromise of all constraints, but nonetheless present residual forces similar to the loads required to bend/deform a balloon. Thus, suits are operated at the lowest pressure physiologically acceptable with margin, which in turn requires 100% O₂ to avoid decompression sickness when going EVA from a higher pressure spacecraft

The so-called “Time to effect” of catastrophic events can be short

The inherent risk of EVA drives operations planning, preparation, & execution, thus the design of each EVA is driven by not just the nominal tasks but also what response would be taken to a list of credible contingencies at each step of the EVA



Artemis EVA Concept of Operations



Lunar Surface EVA Con Ops



The xEVA System allows crewmembers to conduct excursions outside a habitable vehicle in order to perform exploration, research, construction, servicing, and repair operations. The system includes the xEVA suit and Flight Support Equipment (FSE), the EVA Task Tools and Equipment, and Accessories

The *Exploration EVA System Concept of Operations* (EVA-EXP-0042) captures NASA's current Exploration mission architecture, concepts of operations, stakeholder expectations, and high-level definition of the prospective capabilities and interfaces associated with performing an Extravehicular Activity (EVA) utilizing the Exploration EVA (xEVA) System and associated mission systems at all potential destinations.

EVA-EXP-0042 lays out the Artemis lunar surface con ops for EVA, including the science objectives driving the mission and the xEVA System capabilities needed to successfully complete the operations.

For additional details, reference:

[Exploration EVA System Concept of Operations](#)
(EVA-EXP-0042)

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EVA-EXP-0042
REVISION B
EFFECTIVE DATE: OCTOBER 7, 2020

National Aeronautics and
Space Administration

EXPLORATION EVA SYSTEM CONCEPT OF OPERATIONS

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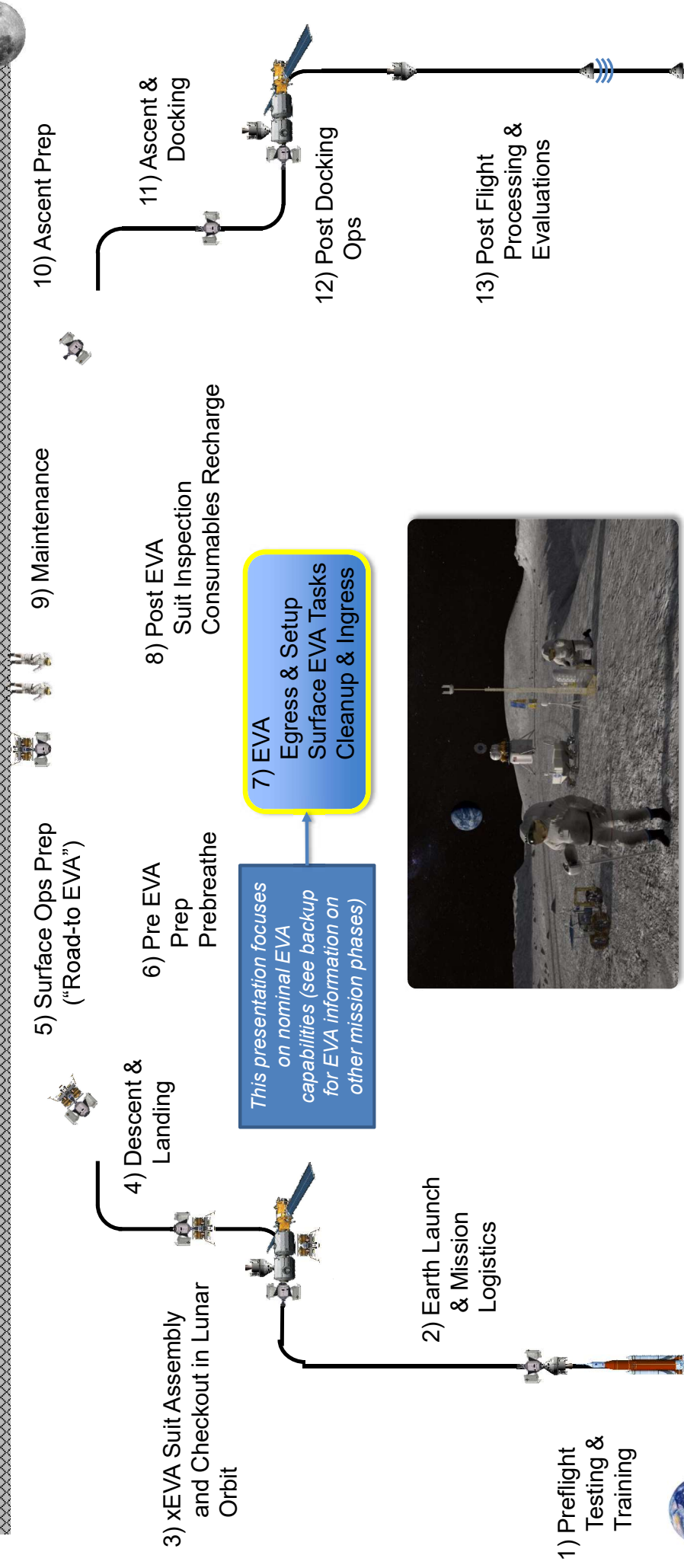
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EVA-OM-001

01/28/2020

Phases of Ops

(NASA reference mission)

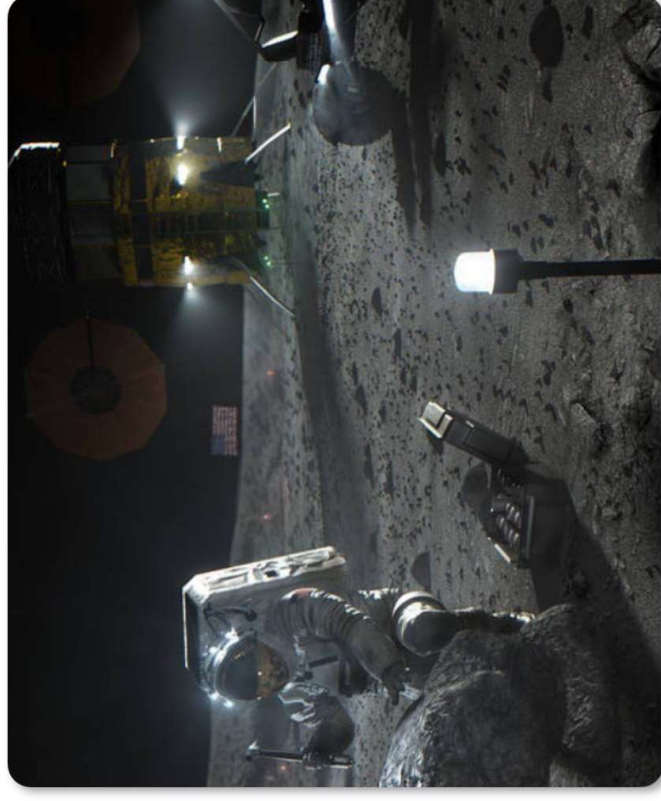


This presentation focuses on nominal EVA capabilities (see backup for EVA information on other mission phases)

Overview of Initial Artemis Missions



- The initial Artemis missions will focus on demonstrating human operations on the lunar surface, in addition to providing science sample return and deployment of long-lived experiment packages.
- Initial missions include the following aspects and parameters:
 - Mission takes place in lunar daylight, landing site currently undefined
 - Four crew fly to cislunar orbit, with two crewmembers staying in cislunar orbit and two crewmembers landing on the surface
 - Surface stay duration: 6.5 days
 - Crew on surface live in and conduct EVAs out of lander
 - Total number of surface EVAs: 2 – 5
 - Crew on EVA: 2
 - EVA duration: 4-8 hour excursions (6 ± 2 hours)
 - Excursion distances: up to a 2 km radius away from the lander walking
 - Based on walking at 2 km/hr (average) over fairly level, clear terrain
 - EVA suits will have 1 hour of contingency consumables
 - Slopes, natural features, lander ingress/repress operations may all affect range (total contingency consumable calculations)



Surface EVA Engineering Tasks



Prepare Equipment for Exploration

- Offload equipment from landers
- Load equipment onto transport system
- Maintain equipment and transport system

Construct Surface Infrastructure

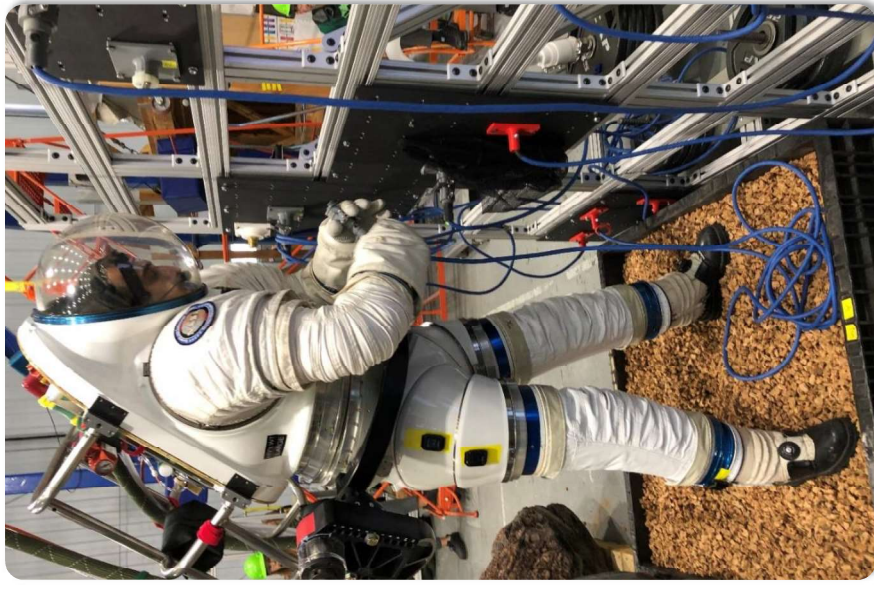
- Transport tools and equipment
- Deploy and align antennas and comm repeaters, route and connect power and communication lines
- Connect modular elements; install/remove fasteners, electrical connectors, and fluid connectors
- Prepare surfaces and grade regolith

Assemble and Maintain Equipment

- Install/remove fasteners, electrical connectors, and fluid connectors
- Remove dust and clean equipment
- Repair equipment

Prepare Ascent Vehicle

- Offload equipment
- Transfer equipment and samples from transport system to ascent vehicle
- Clean equipment and vehicle



Surface EVA Science Tasks



Observations

- Macro-scale (regional) context (mid to far field)
- Micro-scale (local) context (near field)
- Verbal descriptions
- Imagery

Rock Sample Acquisition

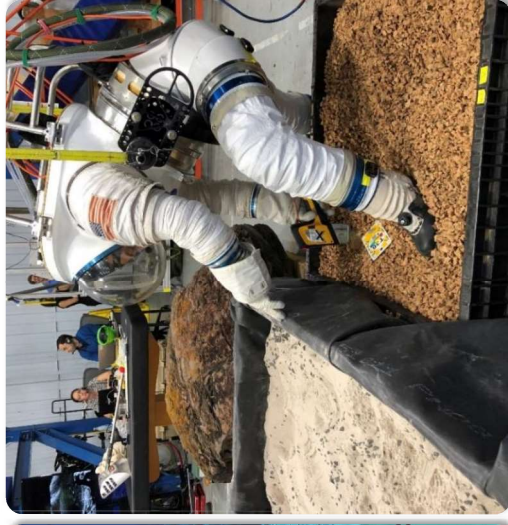
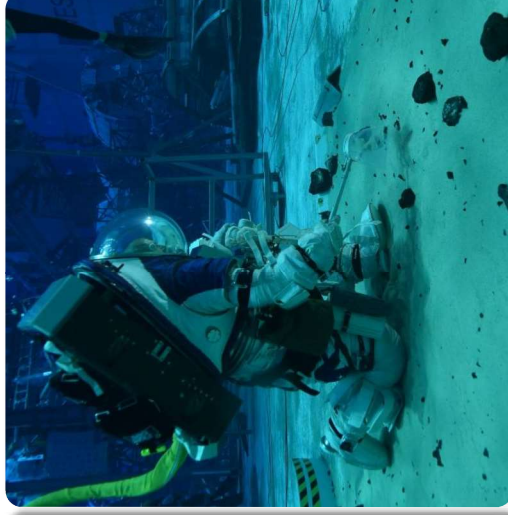
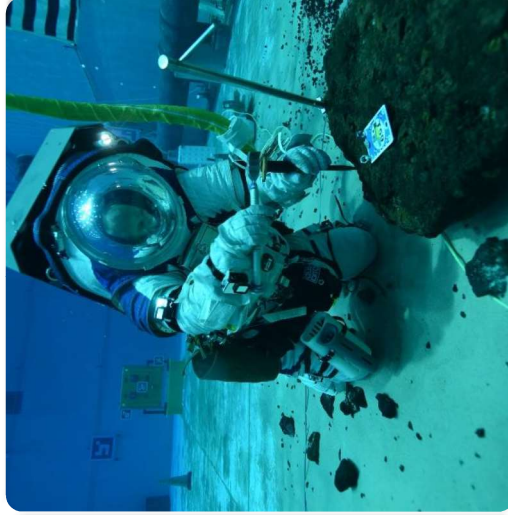
- **Float:** rocks that are loosely adhered to the surface [Tongs / Rake]
- **Chip:** piece of rock forcibly removed from a larger rock [Hammer / Chisel]
- **Core:** cylindrical samples of a rock [Core Drill and Bit]

Regolith Sample Acquisition

- **Bulk:** representative loose surface material [Scoop]
- **Core:** cylindrical sample of regolith at depth [Drive Tube / Drill]
- **Surface:** undisturbed material from the top ~1mm surface [Surface Sampler]

Data Collection

- Handheld (*in-situ*) instrument measurements
- Geotechnical measurements
- Science payload deployment



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Design Reference EVA Series



Surface Day 1

- Landing on lunar surface
- Road-to EVA: xEVA System, lander, and EVA prep

Surface Day 2

- **EVA 1**
- 6 hours (egress to ingress)
- EVA tasks (notional):
 - Contingency sample
 - Public affairs
 - Experiment package deploy
 - Sample acquisition
- Traverses stay relatively close to the lander

Surface Day 3

- **EVA 2**
- 6 hours (egress to ingress)
- EVA tasks (notional):
 - Characterize PSRs
 - Acquire samples from PSRs
- Traverses extend further from lander, walking up to 2 km away up/down slopes of up to 20°

Surface Day 4

- Day off from EVA
- Required habitat and IV tasks

Surface Day 5

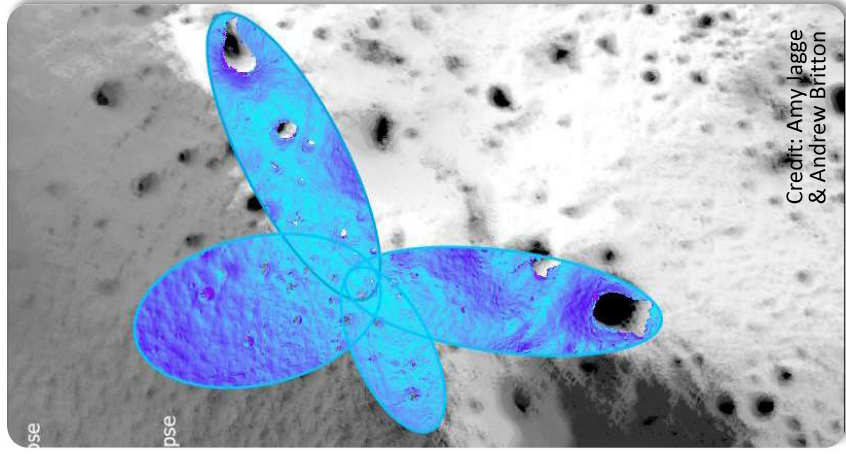
- **EVA 3**
- 6 hours (egress to ingress)
- EVA tasks (notional):
 - Acquire samples from Ejecta Blanket
- Traverses extend further from lander, walking up to 2 km away up/down slopes of up to 20°

Surface Day 6

- **EVA 4**
- 6 hours (egress to ingress)
- EVA tasks (notional):
 - Deploy geotechnical instrument
 - Deploy environmental monitoring station for ISRU
- Traverses extend further from lander, walking up to 2 km away up/down slopes of up to 20°

Surface Day 7

- **EVA 5**
- 1 hour (egress to ingress)
- Prep for ascent
- EVA tasks (notional):
 - Jettison hardware, if needed
- Ascent from surface to Gateway/Orion



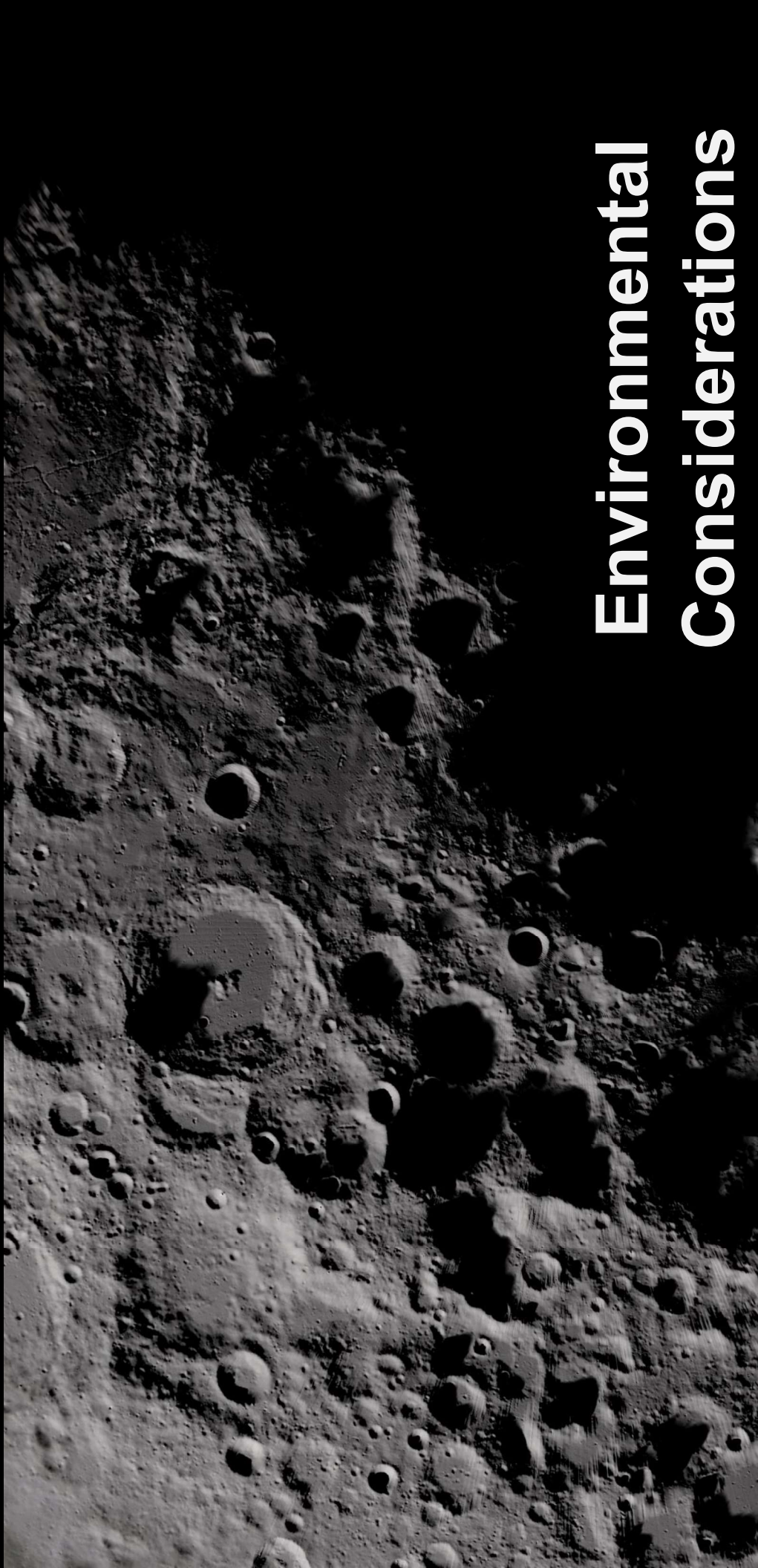
Credit: Amy Jagge
& Andrew Britton

NOTE: All EVAs are conceptual/notional only and are strictly for development of the xEVA system con ops, and not indicative of any actual flight plan or official mission profile

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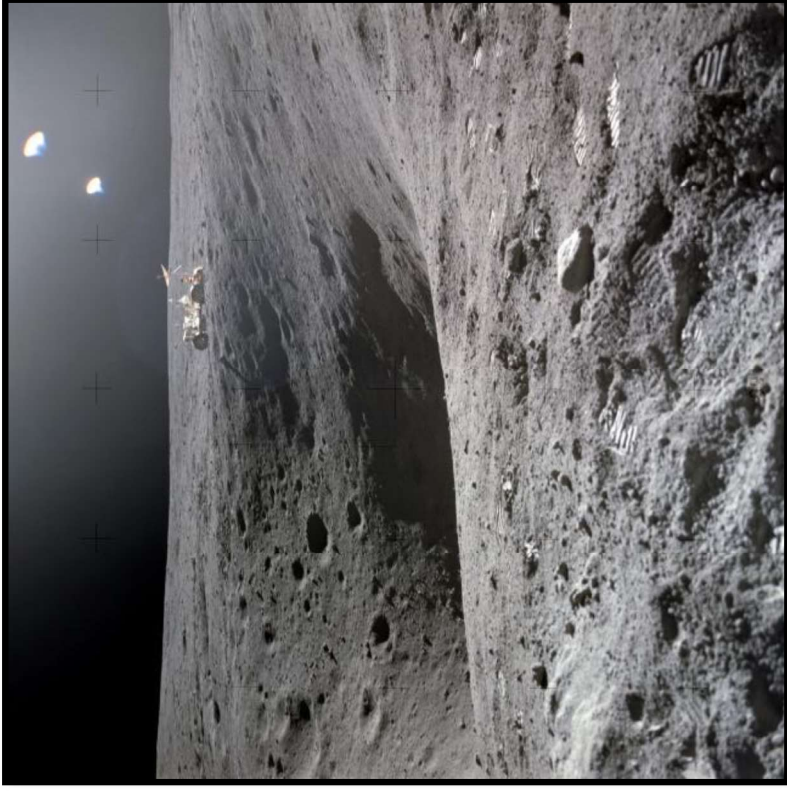
Environmental Considerations



EVA Environments



- Sample of environmental considerations:
 - Thermal
 - Pressure
 - Lighting
 - Radiation
 - Terrain
 - Dust
- Areas Covered:
 - Ground Handling and Processing
 - Launch and Landing
 - ISS Internal/External
 - Exploration Mission/Vehicle Internal
 - Gateway Internal/External
 - Cis-Lunar Space Environment
 - Lunar Surface
 - Human Landing Systems Internal
 - Mars Transit/Surface



For additional details, reference:
xEVA System Destination Environments Specifications
(EVA-EXP-0039)



EVA Crew Capabilities

NASA: Walking Suit Prototypes



Mark III
1989



WEI-Suit
1997



REI-Suit
2005



Z-1
2011



Z-2
2015

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xEMU Reference Design Overview



From 2017 to 2022, the xEMU Reference Design was created to provide a suit that met NASA's exploration requirements including lunar surface spacewalks.

- **Portable Life Support Subsystem**

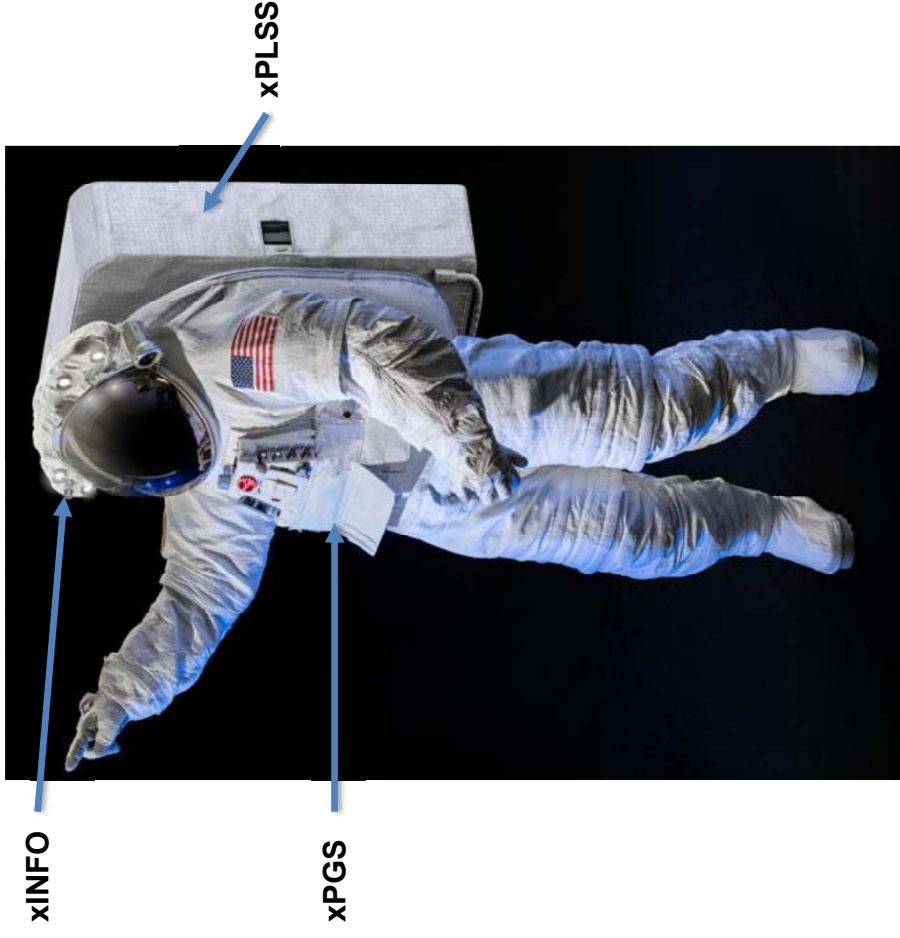
- Provides life support functions such as oxygen storage, thermal control, carbon dioxide removal and power for the overall system

- **Pressure Garment Subsystem**

- Provided anthropomorphic, pressurized, and protective structure worn by the crewmember

- **Informatics Subsystem**

- Provides data processor, cameras and lighting that promotes crew autonomy and efficiency during EVAs.



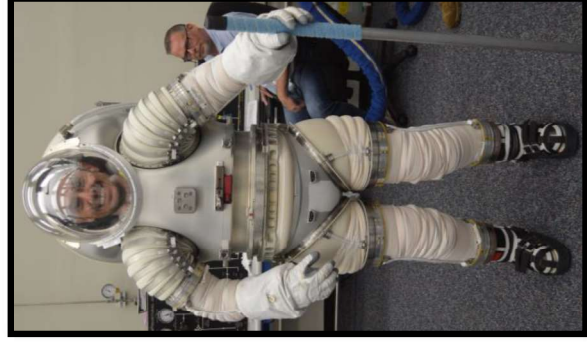
Pressure Garment Influence on Crew Capabilities



- Suit is composed of multiple layers that each meet multiple functions
 - **Inner layers** provide comfort and thermal control immediately adjacent to the human skin
 - **Middle layers** provide impact tolerance, size adjustment and mobility features along with pressure control against the vacuum of space
 - **Outer layers** protect against the environment extremes such as thermal contact with hot and cold objects and long exposure in permanently shadowed regions of the lunar south pole, MMOD strikes, dust, abrasion / cuts, and plasma
- The combination of these layers into a wearable suit assembly gives the appearance of bulkiness but is optimized for mobility and size adjustability for different crew member sizes



Inner Layers



Middle Layers



Outer Layers

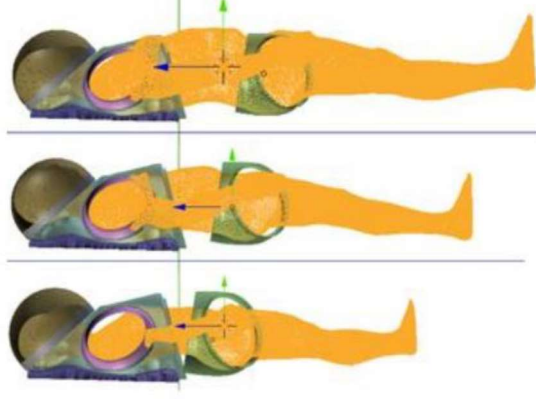
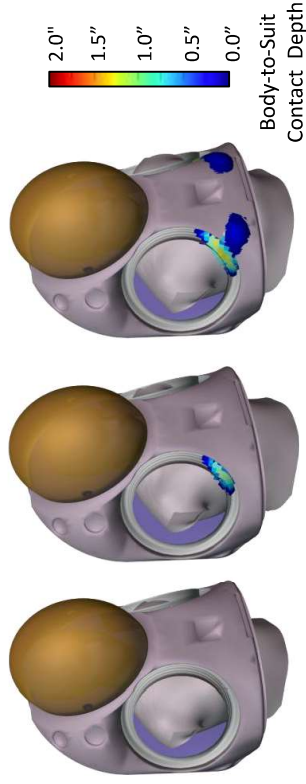
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Suit Size and Fit



- Significant investment has been made to better understand/characterize suit fit across a large anthropometric range

- Targeting 1st percentile female to 99th percentile male (consistent with expected Astronaut population)
- Suit fit and suit CG is affected by human variability
- EVA suits must adapt around the human



Suit Mass and CG xEMU reference



- Mass and CG of the xEMU/crew system varies by crew size
- xEMU system interface locations vary by crew size or are built around a crew reference point
 - Items that vary with crew size and system configuration
 - Overall system height
 - Overall system mass
 - System CG location
 - System width
 - Items that are designed to be crew centric
 - Crew eye point within helmet
 - Crew shoulder center of rotation
 - Crew hip center of rotation

EVA Suit Mobility



- Human-Suit Interactions are complex and multifactorial

- **Unsuited mobility exceeds suited mobility in all regards**

- Task analysis, hardware design, interface design yields the greatest increase on mobility and task capability
- Task success relies on task and interface design equally or greater than suit performance alone

- **Suited motion strategies and ranges of motion will differ from unsuited equivalents**

- Suited reach envelope will be smaller compared to an unsuited reach envelope.
- Interface design must place critical items within narrower area or allow suit movement to account for decreased reach envelope

- **Many things can be done suited but rely on intelligent interface design to increase crewmember capabilities**



EVA Suit Shoulder Mobility



- Shoulder mobility is a critical to ensure crew members have the proper range of motion and reduce the risk to injury
- Over the years there have been different concepts for how to improve the flexibility while providing the adequate amount of support and stability.
 - EMU Upper Arm Assembly - Two bearing gored soft shoulder with pivoted axial brackets
 - xEMU Shoulder Assembly - Two bearing rolling convolute shoulder with titanium primary linkages
 - Rolling convolute rings maintain nearly constant volume throughout full range of motion (ROM), which minimizes joint torque



EMU Shoulder



xEMU Shoulder

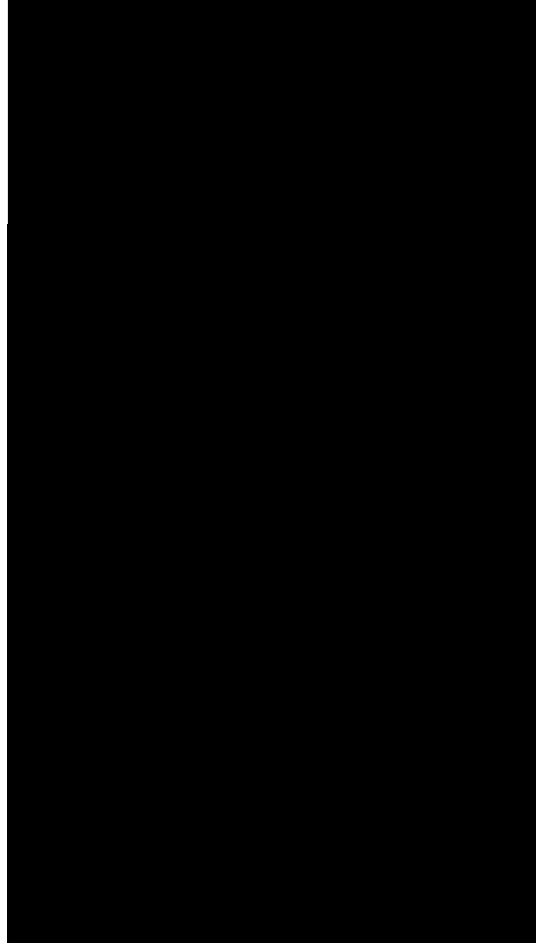


xEMU Mass Characteristics and Impacts



- Physical workload and fatigue is a concern (or area of focus) in general for lunar EVAs, but not specifically because of expected suit mass and CG
- Total lunar weight of crewmember+suit+PLSS will be less than unsuited earth weight
 - 120lb person in 380lb xEMU weighs approx. 83lb total on the moon i.e., less than unsuited earth weight
- Due to the differences of EVA environment, there is a minimum amount of stiffness and mobility elements needed to retain natural human biomechanics.

Selective mass increases such as bearings, Hard Upper Torso, etc increase mobility capabilities



Heavier suit

Lighter suit

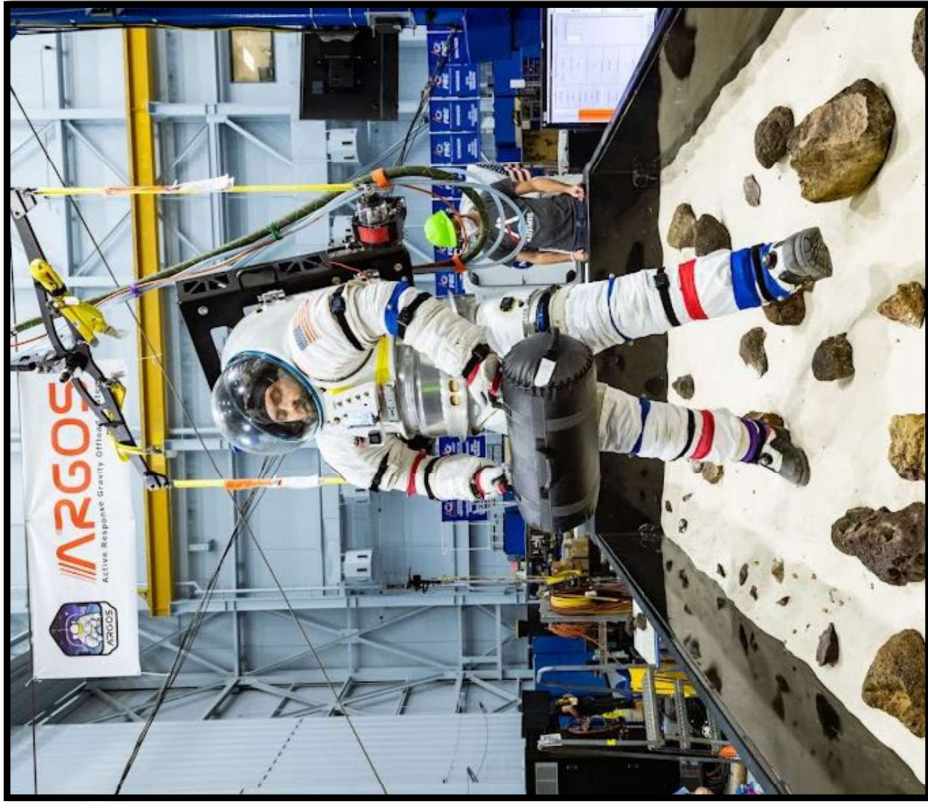


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xEMU Carrying Capabilities



- Multiple factors impact endurance tasks such as carrying/dragging capabilities, including:
 - Crewmember physical capabilities
 - EVA Suit weight **AND** weight distribution
 - Mass offloading/shifting (toolbox vs overhead)
 - Grip strength loss (xEMU loses about 50% of grip strength) and hand placements
 - Mass bulk and sizing
 - Terrain to be traversed
- **Endurance tasks that rely on human strength and capabilities will need intelligent interface designs (handles, etc) to maximize performance**
 - Initial offload testing has shown potential mass carrying capacity of ~30 lbs (which would weigh ~180 lbs in 1g), will vary per crewmember.
 - Extended duration carrying data is not yet available, and a clear way of communicating generic carrying capabilities in situations such as awkwardly sized objects or “teamed” lifts has not been documented for suited crew to date – typically tested case-by-case



xEMU Metabolic Rate Capabilities



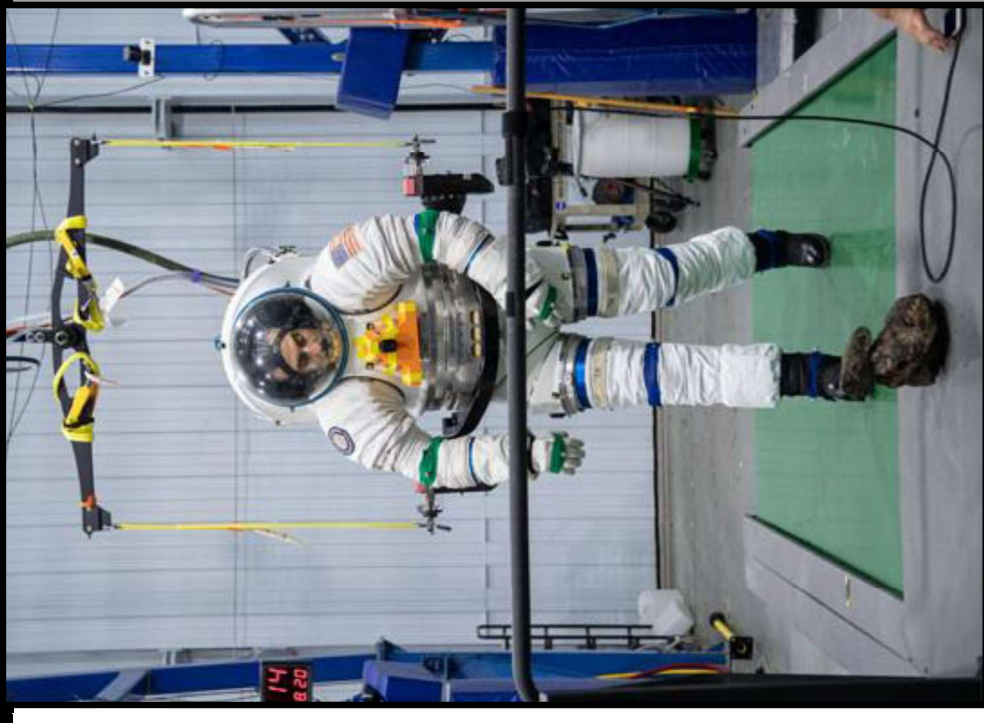
- Crew simulated runs met Consumable sizing & EVA duration
- Heat and CO2 removal nominal & upper end capability
- Contributes to several hazard reports including: – Thermal, CO2, dehydration, etc
- Crew fitness for duty & planned vehicle exercise countermeasures – EVA contributes to exercise quantity, but not as much to quality
- Nominal crew health & performance during EVA – Fatigue and workload management

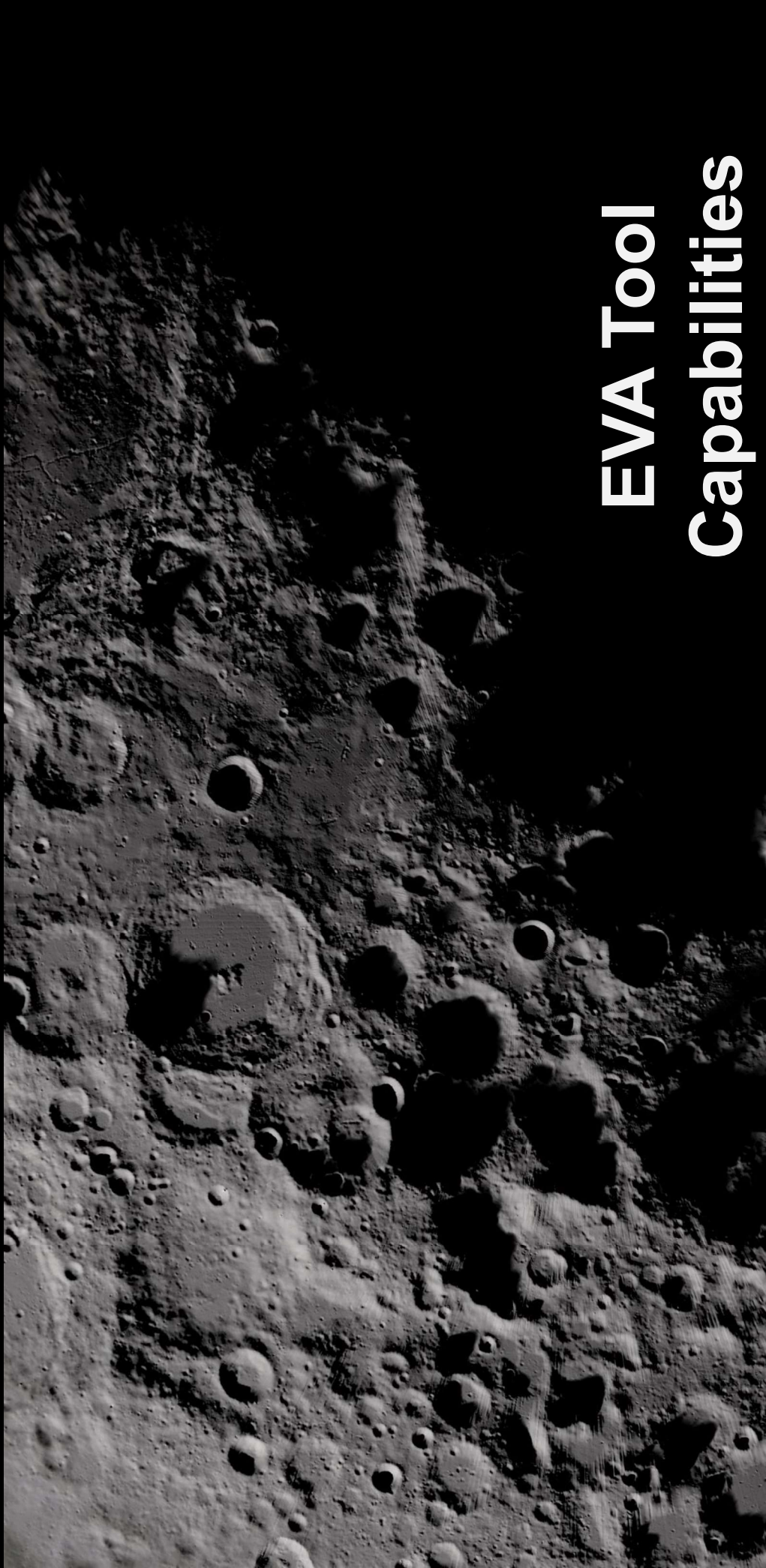
NASA's xEMU Reference Design can support a 1200 BTU/hr average over the EVA duration

For reference, 1200 BTU/hr is roughly equivalent to walking 5km/hr in 1g

Doing this for 8 hours is equivalent to about 40 km (25 miles)

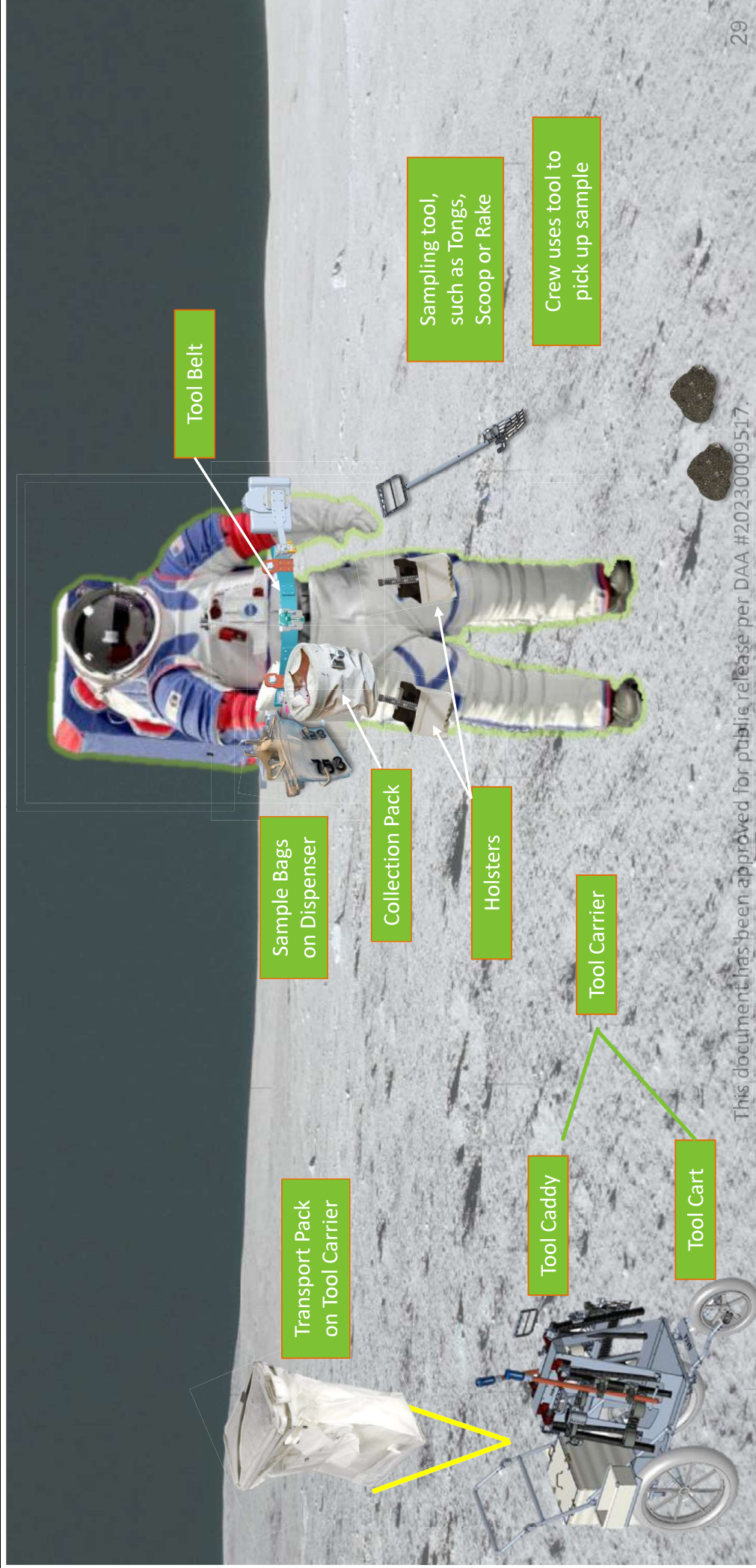
In other words, such a suit has the capacity to facilitate the metabolic equivalent of an unsuited person walking 25 miles, which can be “spent” in different ways such as short surges averaged out with rest periods





EVA Tool Capabilities

Ambient Sampling Con Ops



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Sampling Equipment



SAMPLE COLLECTION HARDWARE

Extension Handle	Rake	Scoop	Tongs	Contingency Sampler	Hammer	Chisel
Slide Hammer	Contact Sampler	Drive Tube	Cap Dispenser	Cap	Ramrod	

SAMPLE CONTAINERS

Sample Bag Dispenser w/ Small Sample Bags	Large Sample Bag	Collection Pack	Transport Pack/Liners
Primary Sealed Container – Bulk, Drive Tube, Drill Stem	Sample Return Pack	Secondary Sealed Container	

SAMPLE CONTEXT HARDWARE

Camera	Sample Markers
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OTHER HARDWARE

Portable Light	Dust Mitigation Kit	Scale
Tool Carrier	Flag	Cuff Checklist
Powered Drilling Kit		

SCIENCE INSTRUMENTS

TBD. Will include things like:

XRF	XRD	LiDAR	GPR
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SCIENCE PAYLOADS

TBD. Will include things like:

Geophones	ALSEP-like
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Suit to Tool Interfaces

Tool Belt	Holster
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EVA MAINTENANCE

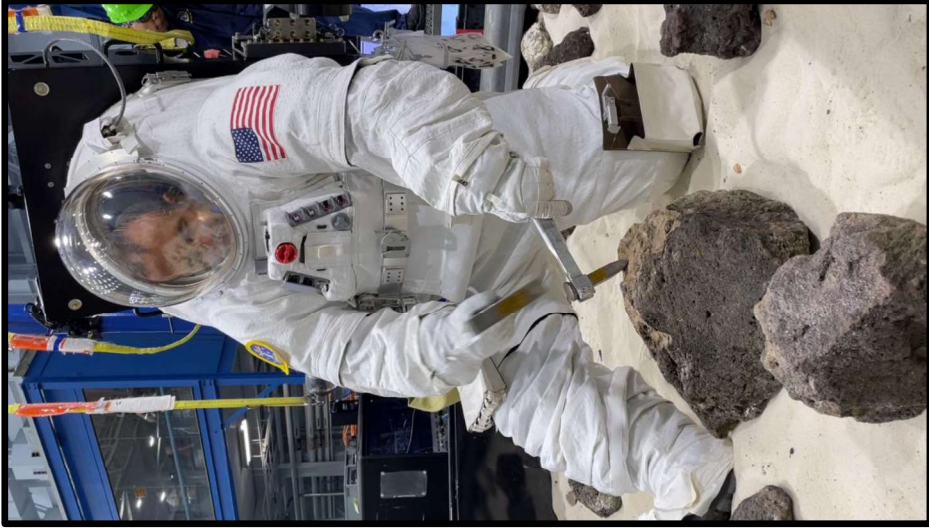
Socket Kit	Torque Wrench
Compound Cutter	Needle Nose Pliers

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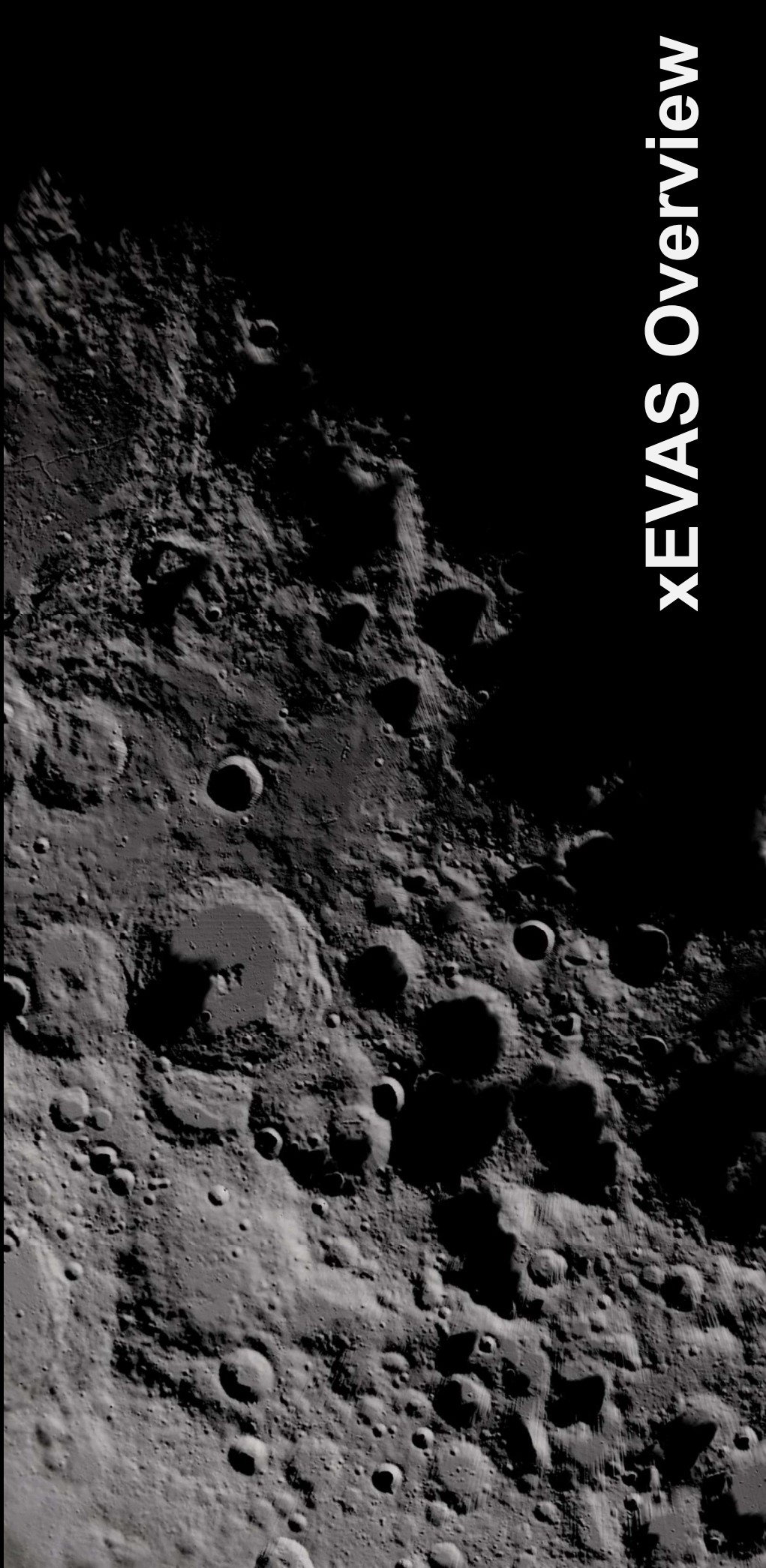
Videos of Tool use



Test subject in ARGOS in xEMU retrieving float sample using Tongs.



Test subject in ARGOS in xEMU creating a chip sample.



xEVAS Overview

Transition to xEVAS



- Starting in 2021, the NASA began the shift from a GFE Hardware Development model, where NASA develops and owns EVA hardware, to the Exploration EVA Services (xEVAS) contract, a commercial services-based acquisition approach where NASA will be a customer of EVA services and capabilities rather than owning hardware.
- The xEVAS capability requirements were developed utilizing the Exploration EVA Suit System Requirements Document (SSP51073) as the initial basis. Tailoring of the requirements was performed to help better align the requirements to the service-based approach.
 - SSP51073 has served as the guiding system performance requirements for the xEMU Reference Design
 - NASA has completed the build and assembly of the xEMU Design Verification Test (DVT) unit, hence NASA's confidence that there is at least one way to meet xEVAS requirements
- xEVAS RFP was released on 9/30/2021 and selection was announced on 6/1/2022
 - Axiom Space and Collins Aerospace were selected to design, develop, build, assemble, test, and maintain a fleet of flight and training xEVA equipment, in collaboration with NASA.

xEVAS Requirements



Applicability	Requirement #	Requirement
Artemis	RQMT-003*	Lunar EVA Capability. The xEVA System shall provide the capability for a mixed EVA crew complement to perform at least six (6) two-person EVAs on the lunar surface per Artemis mission.
ISS/Artemis	RQMT-004*	EVA Rate. The xEVA System shall provide the capability to perform EVAs at rate of at least one EVA every day.
ISS	RQMT-025	ISS Suit Mobility. The xEVA System spacesuit shall provide the overall mobility, dexterity, and tactility equal to or greater than current ISS EMU capabilities and existing EMU Phase VI glove performance.
ISS/Artemis	RQMT-026	Anthropometry. The xEVA System shall accommodate all NASA crew anthropometric dimensions provided in the Occupant Measurements Table 3.3.17-1.
Artemis	RQMT-058	xEVA System Mass. The xEVA System shall not exceed the control mass as defined in the xEVA System Control Masses Table 3.6.1-1 for items launched to support microgravity and lunar EVA operations. Artemis Launch - 15 kg per crewmember, Lunar Descent - 232.4 kg per crewmember/2.3 kg per EVA per crewmember, Lunar Ascent - 0 kg, Earth Landing - 0 kg
Artemis	RQMT-084	Quiescent Stowage. The xEVA System shall meet all requirements after being stowed in the internal vehicle environments defined in EVA-EXP-0039, Exploration EVA System Destinations Environment Specifications, in quiescent mode for a Threshold of 210 days with a Goal duration of three years without any services or human interaction.

* Denotes new key requirements not previously part of SSP 51073

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xEVAS Requirements: Environments / Interfaces



Applicability	Requirement #	Requirement
ISS/Artemis	RQMT-013	<u>Destination Environments</u> , The xEVA System shall meet all requirements during and after exposure to the following environments and mission phases as defined in EVA-EXP-0039, Exploration EVA System Destination Environments Specifications: Ground Handling and Processing, Launch and Landing, ISS Internal & External, Exploration Mission/Vehicle, Gateway Internal/Induced External, Cis-Lunar/Lunar and HLS Internal
Artemis	RQMT-033*	<u>Interface Reconfigurability</u> , The xEVA System shall interface with HLS and other Artemis and Exploration host vehicles in such a way that the host vehicle can be reconfigured to support alternate provider EVA within 48 total hours utilizing no more than 16 crew hours to de-configure the xEVA System.
ISS/Artemis	RQMT-035	<u>ISS EVA Generic Tools and Crew Aids Interfaces</u> , The xEVA System shall be compatible with all NASA provided EVA Tools and Crew Aids as described in SSP 30256, ISS EVA Standard Interface Control Document (ICD), EVA-EXP-0035, Exploration EVA System Compatibility Requirements, EVA Tool Catalog, and SSP 51080, EVA/ISS Interface Description Document.
Artemis	RQMT-036*	<u>Artemis EVA Generic Tools and Crew Aids Interfaces</u> , The four types of lunar exploration tools referenced in EVA-EXP-0042, are Mobility/transportation, Construction, Geology, and Contingency. The xEVA System shall provide lunar exploration tools including but not limited to...
Artemis	RQMT-083*	<u>Lunar Surface Permanently Shadowed Region (PSR) Exposure Time</u> , The xEVA System shall function nominally during and after exposure to at least 2 hours of the thermal environment of PSR of the lunar surface as specified in EVA-EXP-0039, Exploration EVA System Destinations Environment Specifications.
ISS/Artemis	RQMT-098*	<u>Compatibility with ECLS Systems</u> , The xEVA System shall limit the introduction of chemicals/substances (liquids and/or gases) listed below that may adversely affect performance of the ISS ECLS System Hardware or Artemis equivalent.

* Denotes new key requirements not previously part of SSP 51073

xEVAS Requirements: Comm / Nav / Lighting



Applicability	Requirement #	Requirement
ISS/Artemis	RQMT-065	Information System. The xEVA System shall provide an EVA information system and graphical display with the following key information to the suited crew member: Key information which enable efficient mission execution include: Consumable monitoring and display (Both), Procedure viewer (Both), Display of photo imagery and graphics (Artemis required, ISS goal), Timeline viewer (Artemis), Data storage (Artemis), Display for send/receive of text messaging (Artemis), Camera viewfinder (Artemis required, ISS goal), Recording of crew audio/video/still image field notes (Artemis), Map display, which includes EVA crewmember position and supports real-time navigation (Artemis Only), Communication of relevant biomedical information. (Artemis required, ISS goal)
ISS/Artemis	RQMT-068	Simultaneous Two-Way Communications. The xEVA System spacesuit shall operate with communications systems and provide simultaneous data and two-way communication with 90% English word recognition, using ANSI/ASA S3.2-2009, Method for Measuring the Intelligibility of Speech over Communication Systems for minimum four EVA crew and all other assets simultaneously.
Artemis	RQMT-070	Vehicle-Based Wireless Data Communication for Exploration Destinations Beyond Low Earth Orbit. The xEVA System shall provide high-rate supplemental wireless data and video in accordance with EVA-EXP-0067, HLS xEVAS IRCD, between spacesuits and host vehicle with a minimum range of 300m (984 ft) with a goal of 2km (1.24 mi) in all terrain types.
Artemis	RQMT-071	Dedicated EVA Radio Frequency Communication for Exploration Destinations Beyond Low Earth Orbit. The xEVA System shall transmit data and voice and video in accordance with EVA-EXP-0067, HLS xEVAS IRCD, between spacesuits and host vehicle over safety critical RF communications with a minimum range of 500 m (1,640 ft) with a goal of 2km (1.24 mi) in all terrain types.
Artemis	RQMT-074	xEVA System Partial Gravity Integrated Lighting Capability. The xEVA System shall provide lighting for crewmembers to perform lunar surface EVAs and associated science objectives in accordance with the environments defined in EVA-EXP-0039, Exploration EVA System Destination Environments Specifications

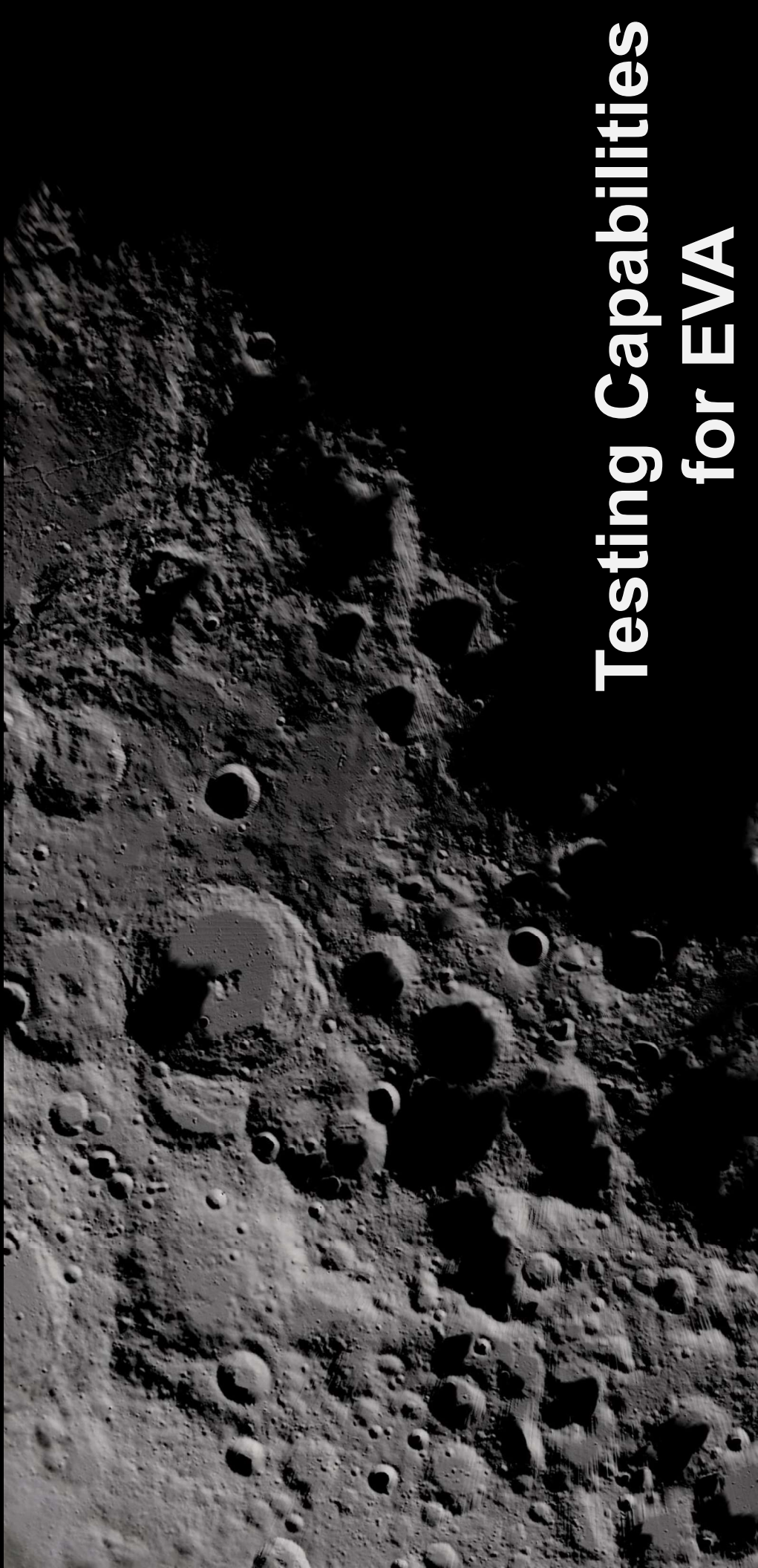
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xEVAS Requirements: Safety and Health



Applicability	Requirement #	Requirement
ISS/Artemis	RQMT-040	<u>Emergency Life Support.</u> The xEVA System shall provide emergency life support for the suited crew member to safely return to and ingress/repress the host vehicle in response to any human or hardware emergencies (reference HLS Design Reference Mission (DRM) or EVA-EXP-0042, xEVA System Concept of Operations). For ISS, the Threshold duration is 30 minutes, with a goal duration of 60 minutes. For Artemis the threshold duration is 60 minutes.
ISS/Artemis	RQMT-041*	<u>Pressure Garment Breach.</u> The xEVA System spacesuit shall provide the capability for the suited pressurized crew member to safely ingress and repress the airlock of the host vehicle following a breach of the pressure garment of at least 4.191mm (0.165 inches) Equivalent Sharp Edge Orifice Diameter (ESEOD). For ISS, the threshold duration is 30 minutes with a goal duration of 60 minutes. For Artemis, the threshold duration is 60 minutes.
ISS/Artemis	RQMT-043	<u>Incapacitated EVA Crewmember Rescue.</u> The xEVA System shall provide the capability for a single EVA crewmember to facilitate the translation, ingress, and repress of a single completely incapacitated fellow EVA crewmember. Both crewmembers shall be able to repress simultaneously following the rescue.
ISS/Artemis	RQMT-055	<u>In-Suit Nutrition.</u> The xEVA System spacesuit shall provide at least 1673.6 kJ (400 kcal) of crew nutrition while in a suited, pressurized configuration for EVAs of more than 4 hours duration, to be consumable at any point prior to suit doffing.

* Denotes new key requirements not previously part of SSP 51073



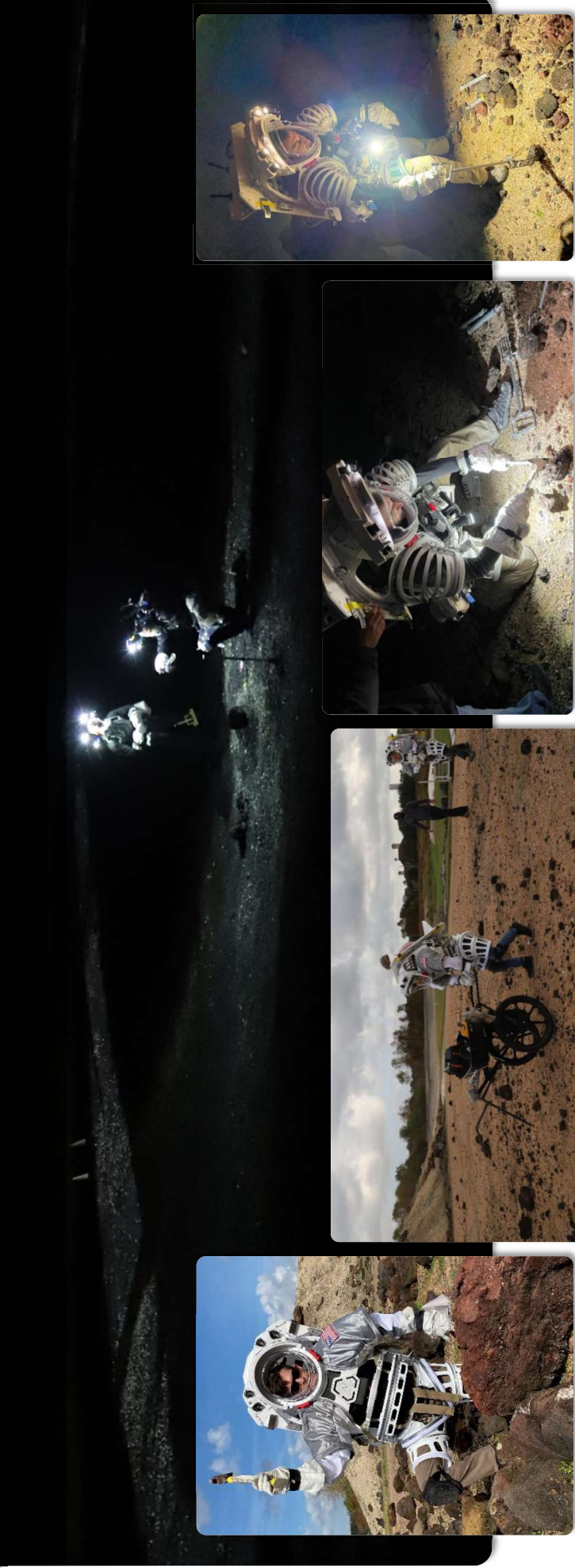
Testing Capabilities for EVA

JSC Rock Yard Testing



The JSC Rock Yard allows for smaller, leaner evaluations of science sampling tools, tool and sample management, and operations for conducting science during EVA excursions on lunar surface missions.

- High fidelity tool and hardware prototypes can be tested quickly
- Operational timelines and procedures can be exercised and evaluated
- Utilized for daytime and night/low light conditions
- Allows for the inclusion of informatics capabilities and technology development



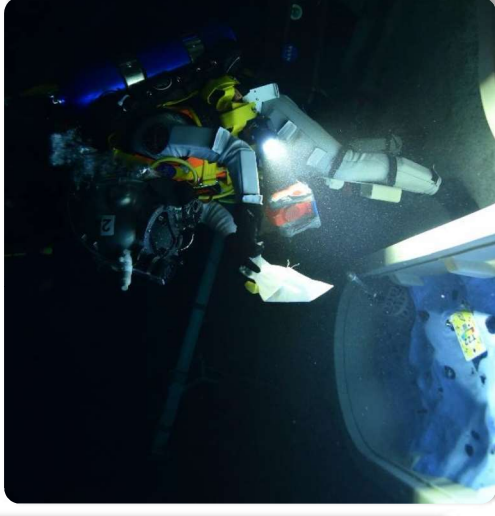
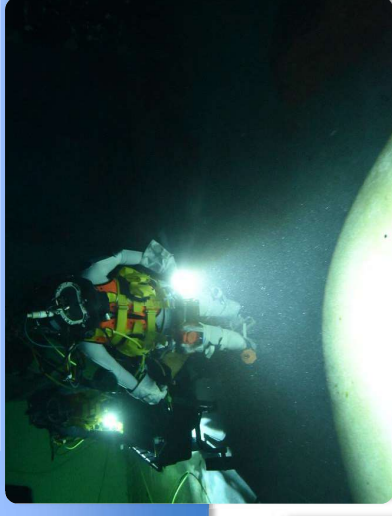
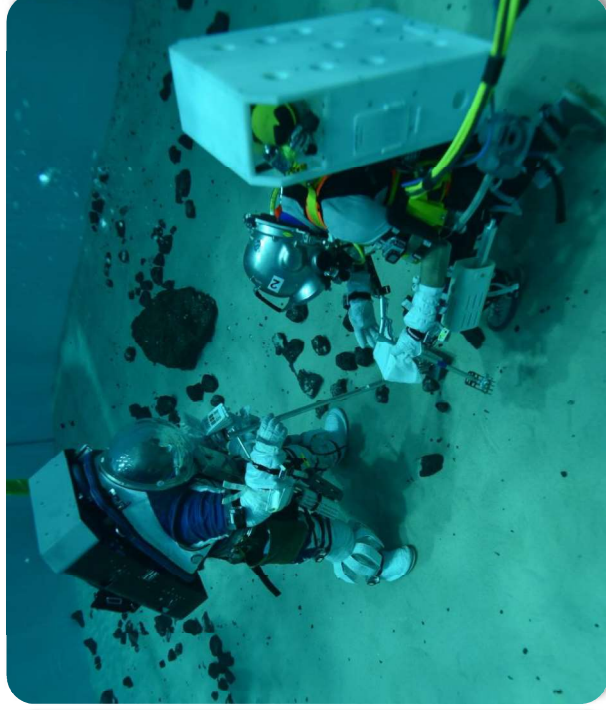
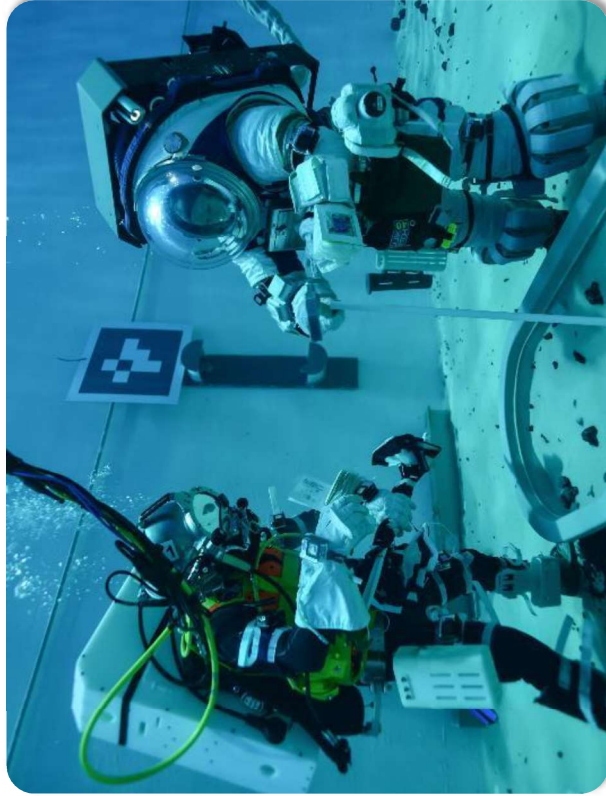
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Neutral Buoyancy Laboratory (NBL)



The NBL accomplishes simulation of a reduced gravity environment using underwater neutral buoyancy techniques.

- Allows for both micro-gravity and partial-gravity EVA testing and training
- Incorporates analog areas for geology tasks and capabilities for technology development (e.g., informatics)
- Includes low-light conditions
- Evaluations are conducted with surface supplied diving helmets and high-fidelity pressurized spacesuits
- Incorporates xEVA equipment and con ops



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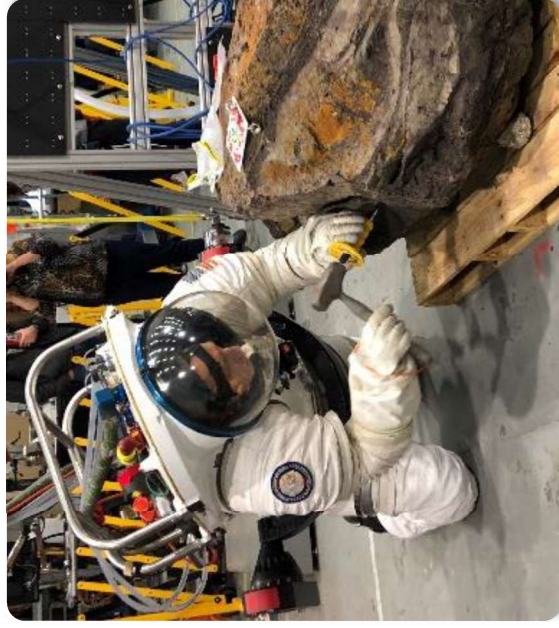
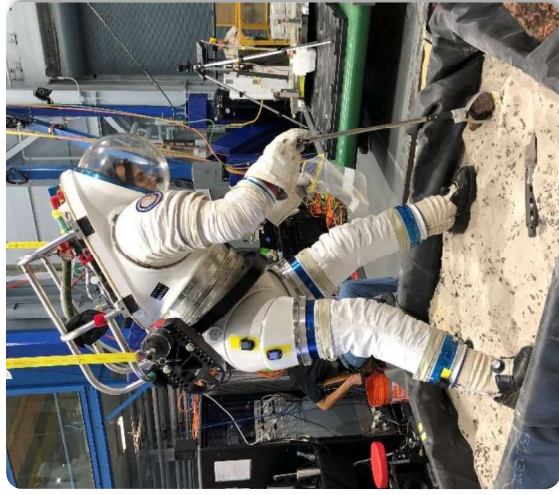
Active Response Gravity Offload System (ARGOS)



ARGOS is designed to simulate reduced gravity environments, such as Lunar, Martian, or microgravity, using a system similar to an overhead bridge crane with an inline load cell to continuously offload a portion of a human or robotic payload's weight during all dynamic motions.

- Provides test subject with simulated planetary gravity
- High fidelity tool and hardware prototypes can be tested efficiently
- Supports high-fidelity pressurized spacesuits

ROCK SAMPLING TOOLS & TASKS

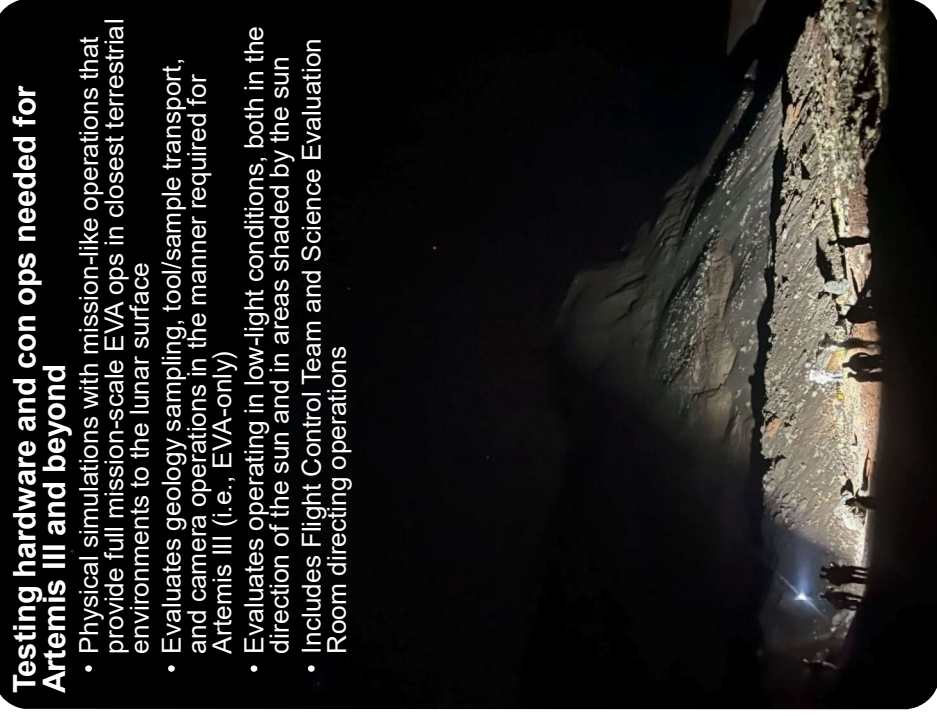


REGOLITH SAMPLING

ENGINEERING TASKS

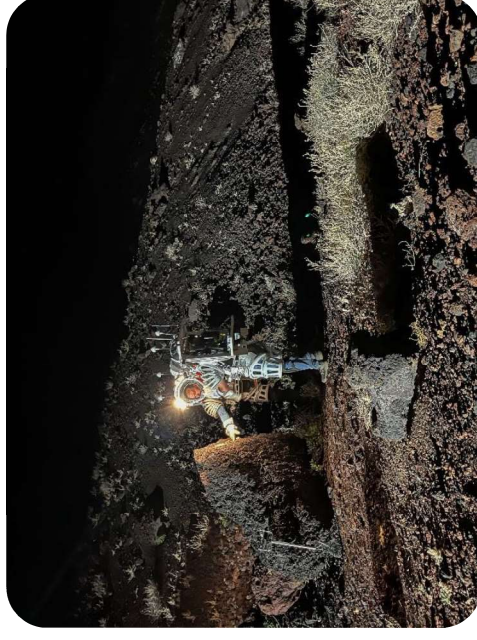
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Integrated Field Testing



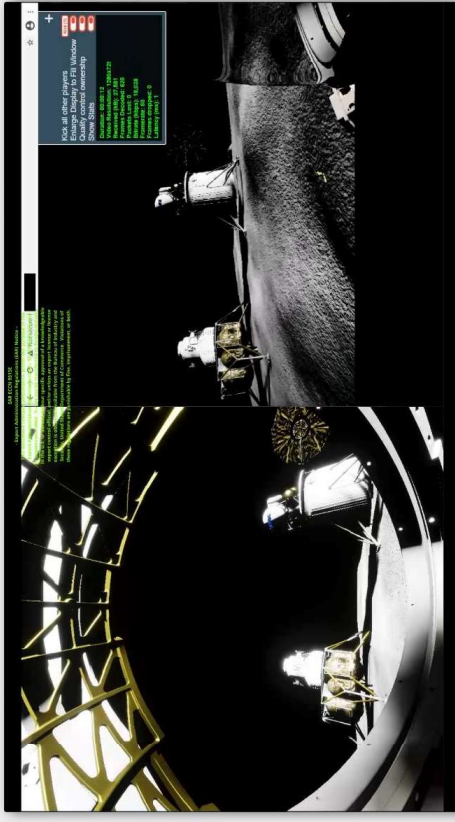
Testing hardware and con ops needed for Artemis III and beyond

- Physical simulations with mission-like operations that provide full mission-scale EVA ops in closest terrestrial environments to the lunar surface
- Evaluates geology sampling, tool/sample transport, and camera operations in the manner required for Artemis III (i.e., EVA-only)
- Evaluates operating in low-light conditions, both in the direction of the sun and in areas shaded by the sun
- Includes Flight Control Team and Science Evaluation Room directing operations



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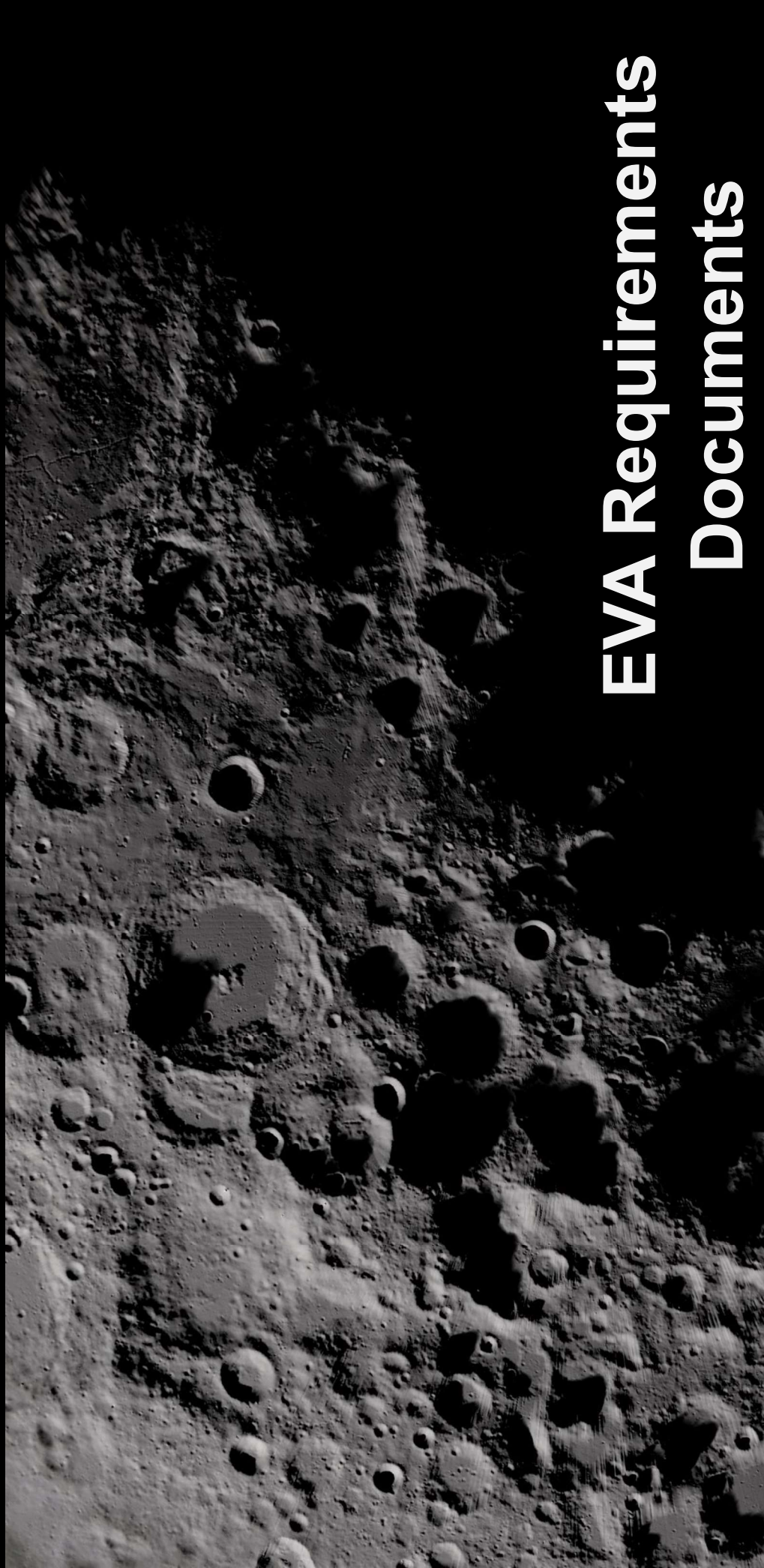
Virtual Reality Testing



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EVA Requirements Documents



EVA Interface Requirements



xEVA Compatibility Interface Requirements

- Design requirements that allow EVA crew to safely interact with your hardware.
- Includes both planned interactions (e.g. riding on a rover,) or secondary interactions (e.g. kickloads if EVA crew may be translating near by).
- Examples: clearance needed for translating in an EVA suit and requirements for handling hardware with EVA tools while in an EVA suit.
- Documentation:
 - EVA-EXP-0035: xEVA System Compatibility IRD, on the xEVAS Providers
 - EVA-EXP-0070: HLS Program EVA Compatibility IRD
 - GP 10001: Gateway Program EVA Compatibility IRD
 - TBD: LTV EVA Compatibility IRD

xEVA to Host Vehicle Interface Requirements

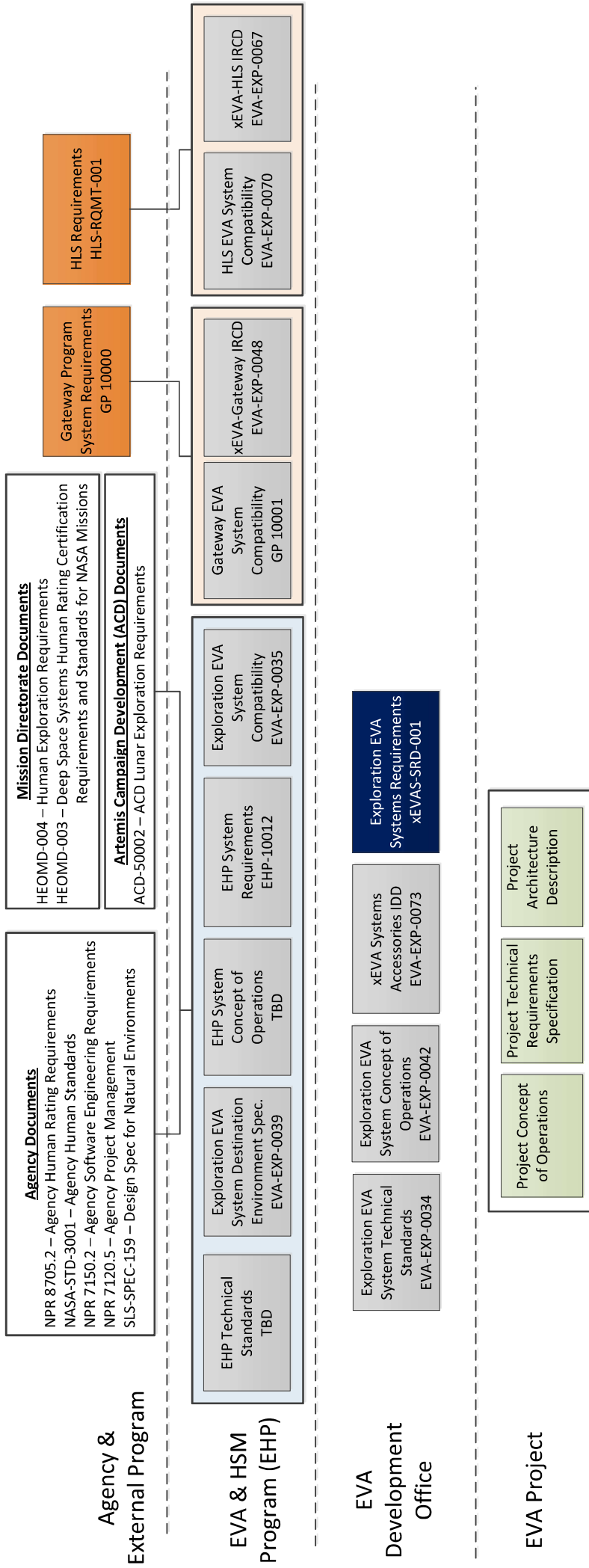
- Defines host vehicle and xEVA system requirements and the to enable EVA
- Examples: consumable recharge, power, communications, stowage volumes
- Documentation:
 - ISS-EVA: EVA-EXP-0032 and SSP 51080/EVA-EXP-0037
 - HLS-EVA: EVA-EXP-0067
 - Gateway-EVA: GP 10148
 - LTV-EVA: EVA-EXP-0080

xEVA Accessories Interface Requirements

- EVA-EXP-0073: Defines internal and external power and data interfaces with the EVA suit for small sensors/devices.

Requirements Flow Down

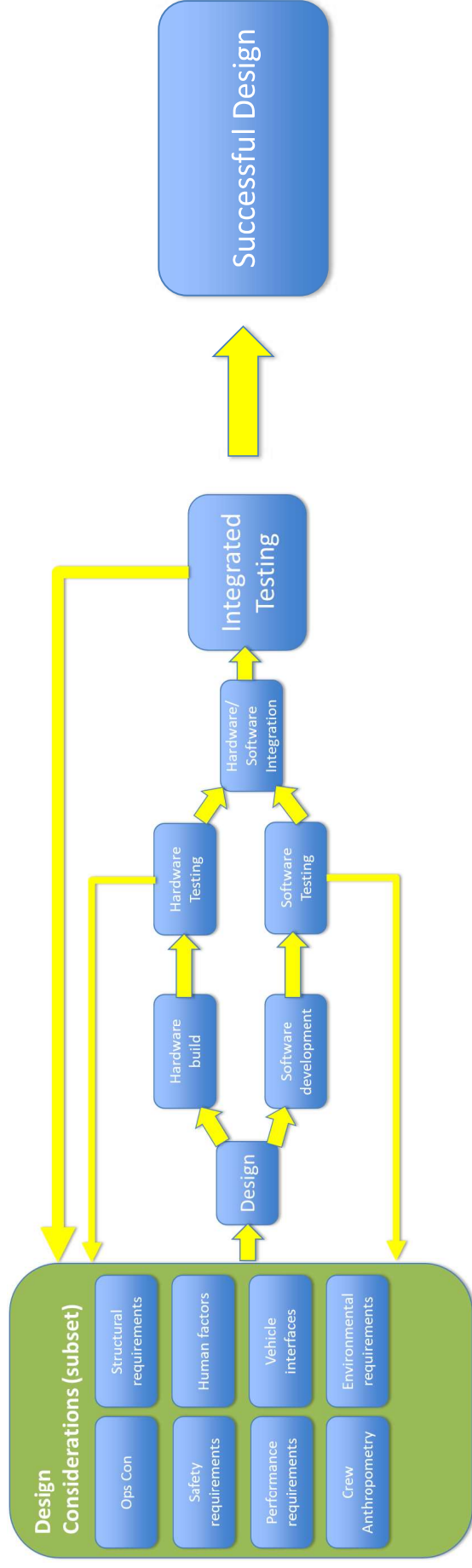
****Note: EHP requirements flow in-work**



Integrated design considerations



- Successful EVA hardware design results from an iterative design/build/test approach
- Must consider a variety of factors
- Lots of coordination with stakeholders



Items for future inclusion

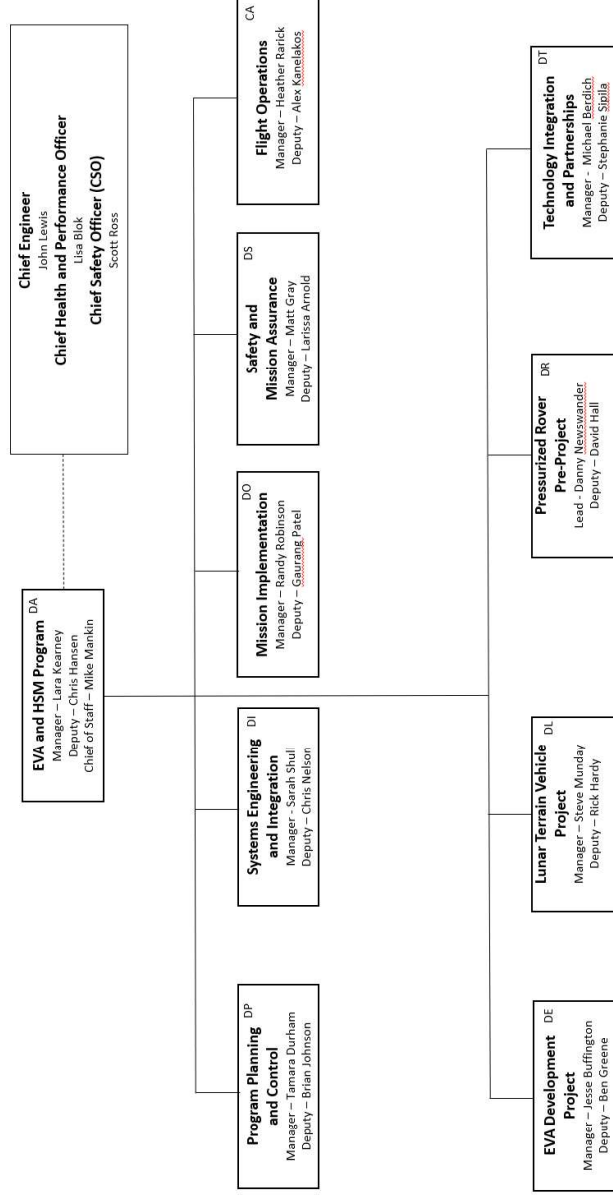


- The first 50 years of EVA experience have primarily been in microgravity
- Thus, there is a wealth of well-communicated products explaining EVA Crew capability for microgravity scenarios
- However, numerous opportunities exist to better document even basic information for EVA Crew capability in partial gravity:
 - Clearance diagrams that show how the physical dimensions of a “walking corridor” a suited crewmember might need in between ridged objects such as a habitat and a large boulder
 - Partial gravity loads scenarios – what loads does a suited crewmember impart on an object if they were to fall onto it in lunar gravity? What is the loads signature of a person “bouncing” inside the suit” and recontacting/settling on the object?
 - Quantifying so-called “performance outcomes” – How level can a suited crew member set up something such as a tripod? How accurately can the spatial positioning of objects such as site markers be deployed to?
 - How accurate can a crew member navigate an actual path vs. a planned path?

Points of Contact



- As with any frontier still under development, application of the available knowledge is a quickly evolving practice
- Potential users such as payload developers, spacecraft builders, commercial entities, etc are encouraged to contact NASA's EVA and Human Surface Mobility Program (EHP) for further collaboration
- The Systems Engineering and Integration team (EHP-DI) is the first line of contact for most entities



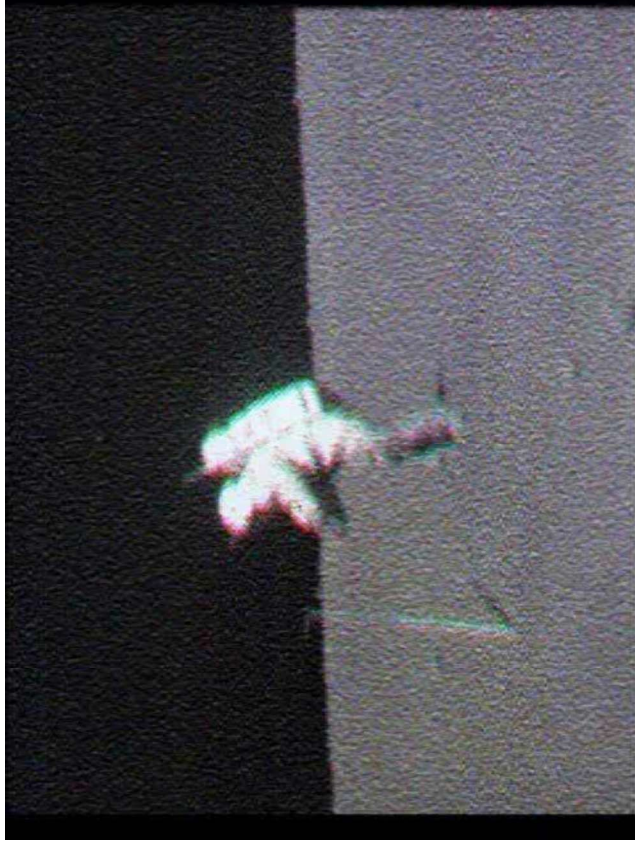
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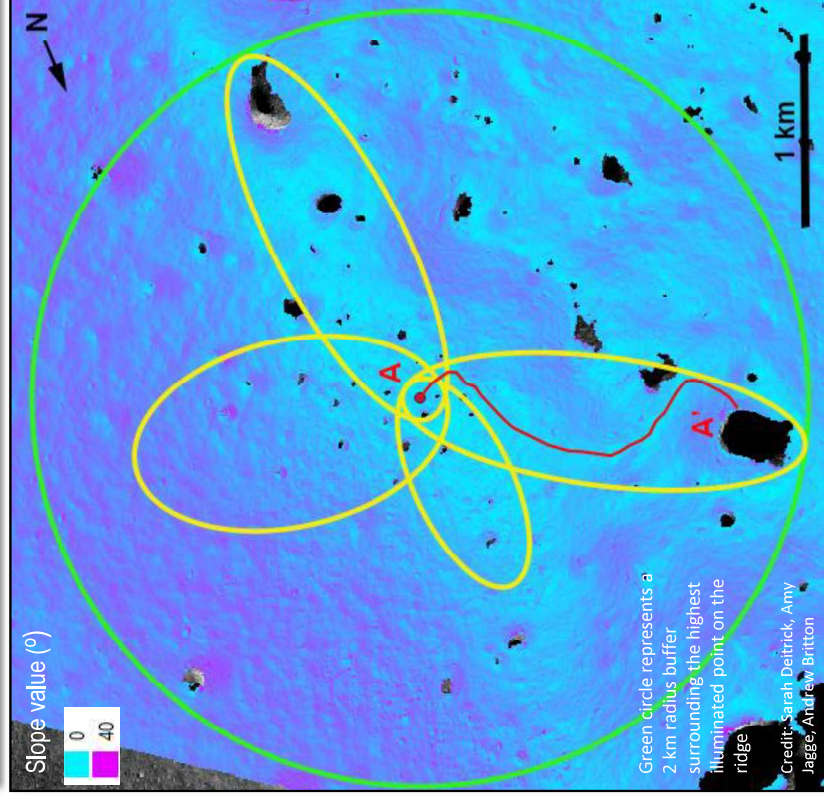
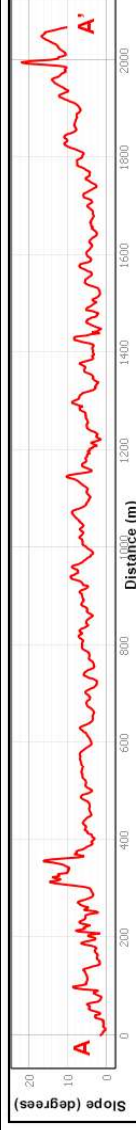
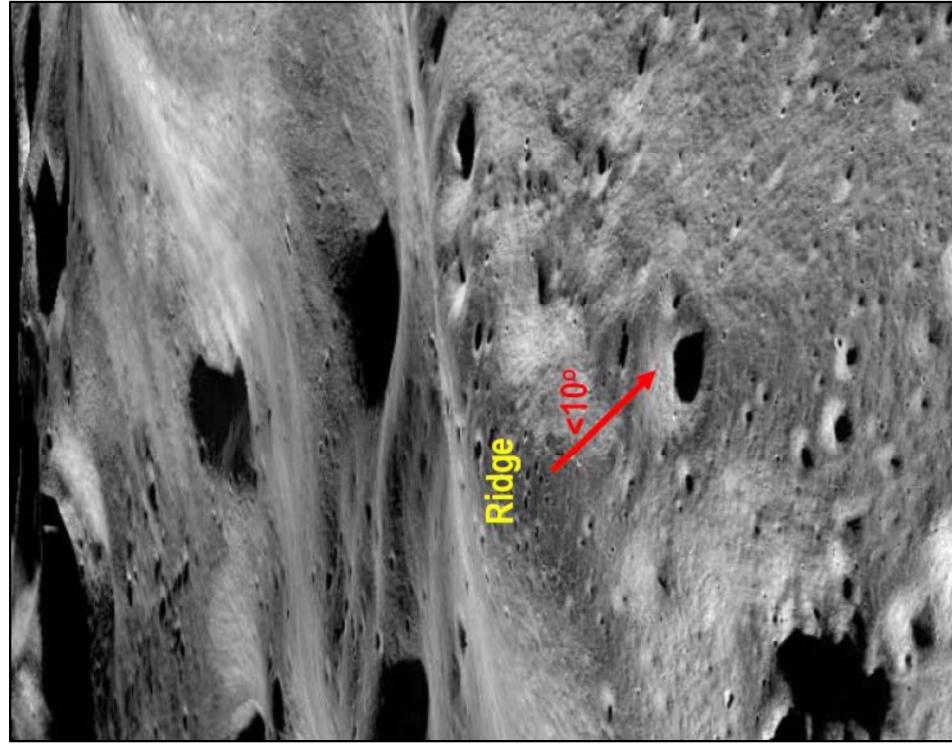
Backup



Apollo Videos



Terrain Environment



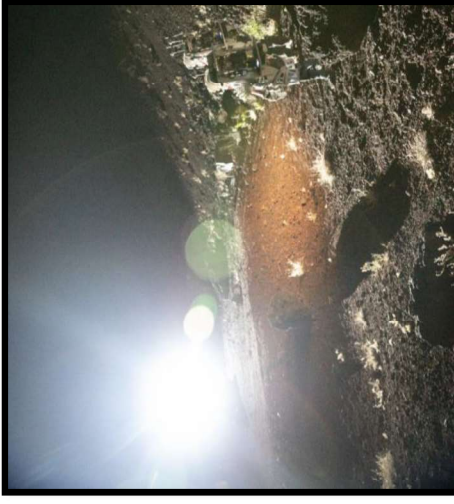
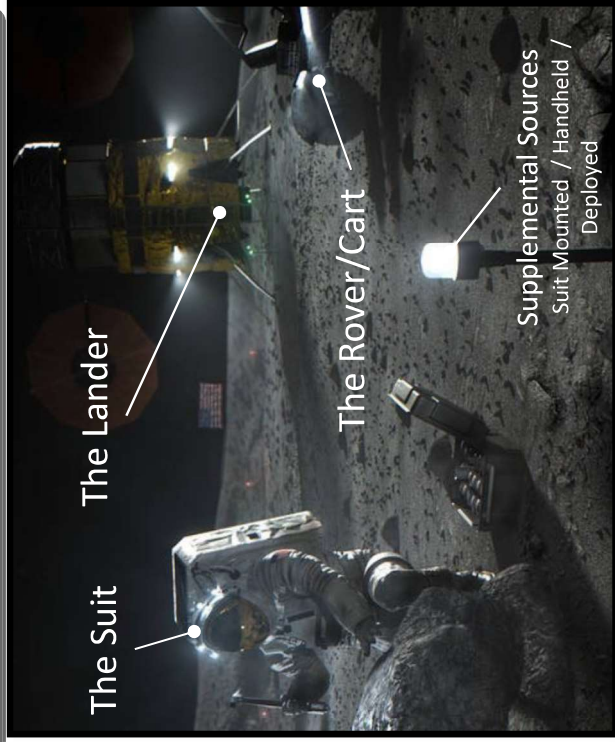
ENVIRONMENT

- Volcanic terrain
- Fine regolith and boulder field
- Impact and pit craters
- Slopes of up to 20°
- Shadowed areas and direct sunlight
- Permanently shadowed regions
- Ice water and volatiles

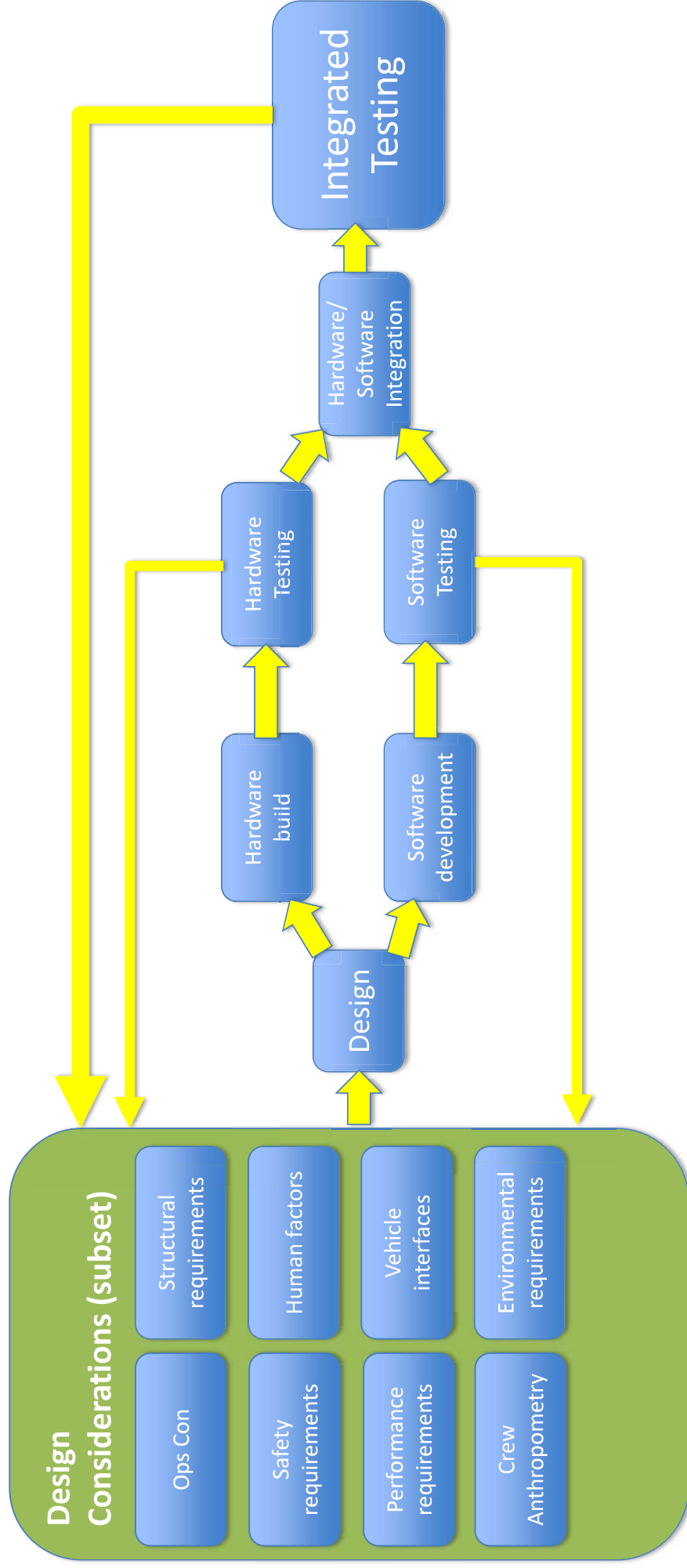
For additional details, reference:
**xEVA System Destination
 Environments Specifications**
 (EVA-EXP-0039)

Lighting Environment

- With sun low on the horizon ($\sim 1^\circ - 9^\circ$), crew will be in long, deep shadows, in addition to contending with having to look nearly directly towards the sun at times
- Lights will support visual sight of suited astronaut boots, ground ahead, EV partner, lander, and the worksite
- Primary lights are helmet-mounted, but will likely need to be supplemented by supplementary lights (e.g., waist-mounted light) and/or lights on surface assets



EVA design process



Lunar Excursion Ranges and Navigation



Notes:

- Does not stack failures - if the vehicle fails, the suit is presumed to function nominally (and vice-versa)

EVA Suits Only

- Walkback Range is ~2 km
- Assumes ~2 km/hr walking pace on relatively level regolith
- Does not account for slope or obstacles (boulders)
- Distance may decrease due to terrain or operational considerations
- Apollo 14 walked 1.45 km from lander

Suits + LTV + PR

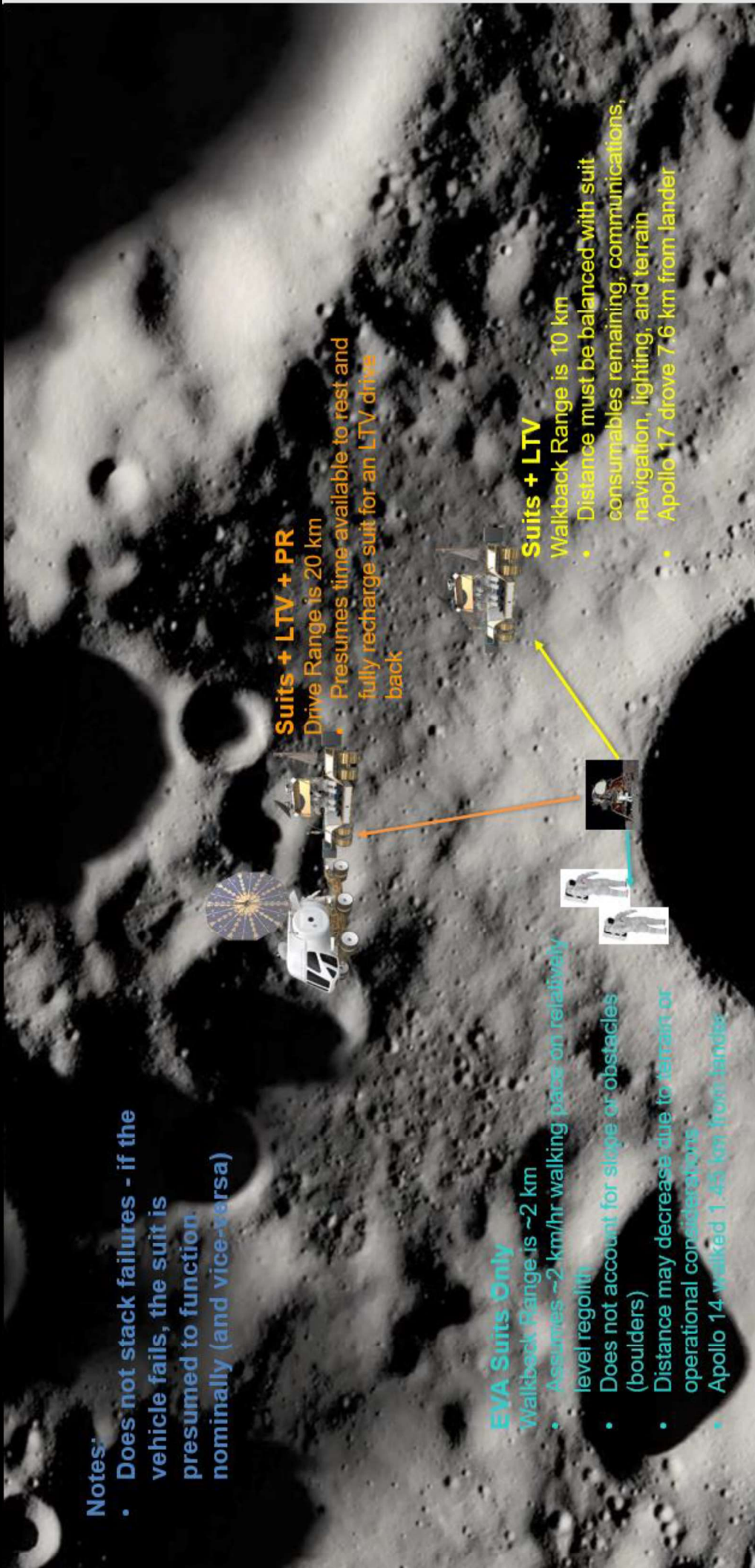
Drive Range is 20 km

- Presumes time available to rest and fully recharge suit for an LTV drive back

Suits + LTV

Walkback Range is 10 km

- Distance must be balanced with suit consumables remaining, communications, navigation, lighting, and terrain
- Apollo 17 drove 7.6 km from lander



Notable Human-Centric Developments



EVA Suit Design + “Human System”

The Human System is one of many systems found within an EVA Suit System

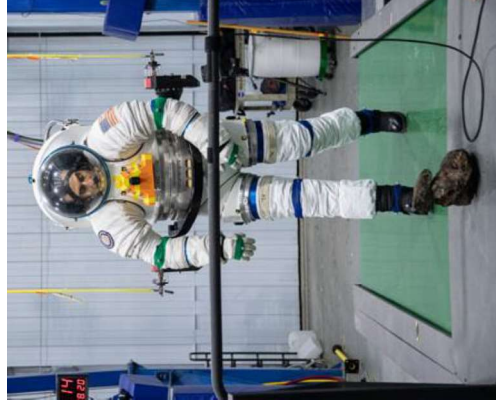
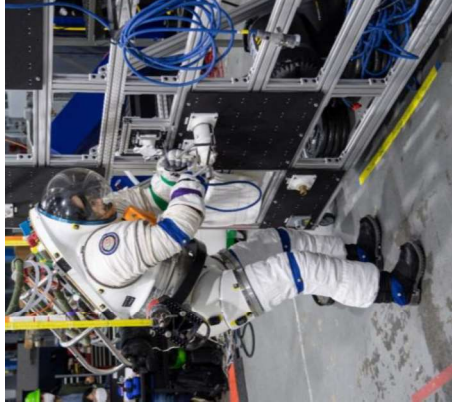
- xEMU featured Human-Centered Requirements that aimed to develop/implement a standardized approach for Human Health and Performance evaluation in spacesuits

NASA EVA Suits have had various reconfigurable suit pressure setpoints

- Ability to repress while on EVA increases likelihood of positive outcomes
- Increases complexity but increases operational flexibility

Mobility of crewmember prioritized across many different task objectives.

- Ladders, task boards (switches, cranking, kneel, mate/demate, stowing, etc), walking (+/- slopes), carry, etc
- Tasks analyzed with metabolic load



NASA xEVA Design Reference Suit



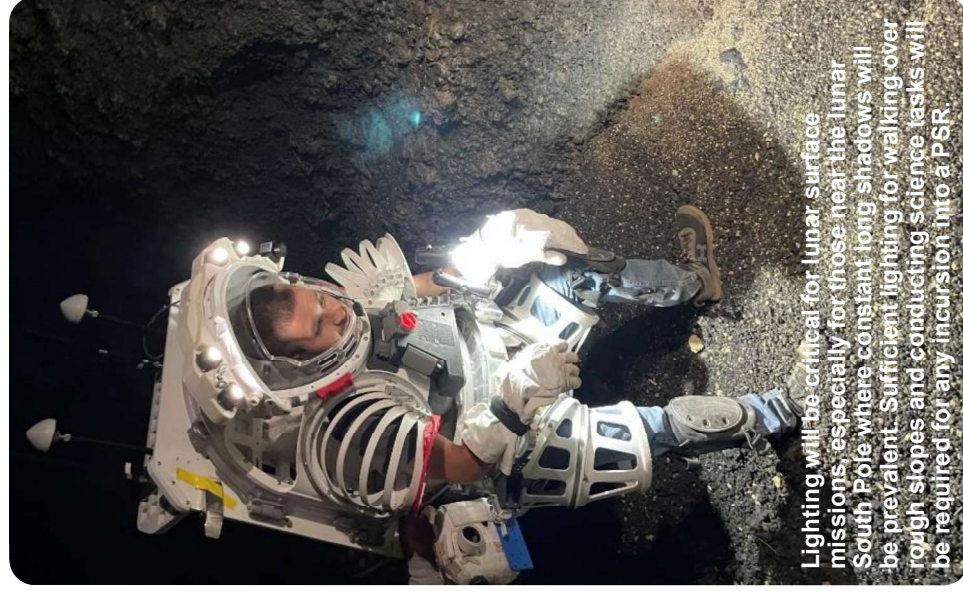
The Exploration Extravehicular Mobility Unit (xEMU) is the design reference EVA suit system previously being developed by NASA for use during lunar flight dynamic phases (if needed), microgravity EVAs, and lunar surface excursions.

All of the data and lessons learned from the xEMU Reference Design will be made available to vendors under the [Exploration Extravehicular Activity Services \(xEVAS\)](#) contract.

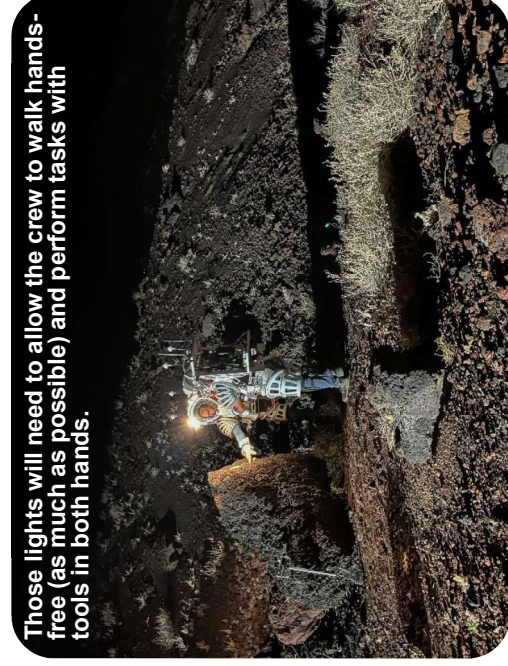


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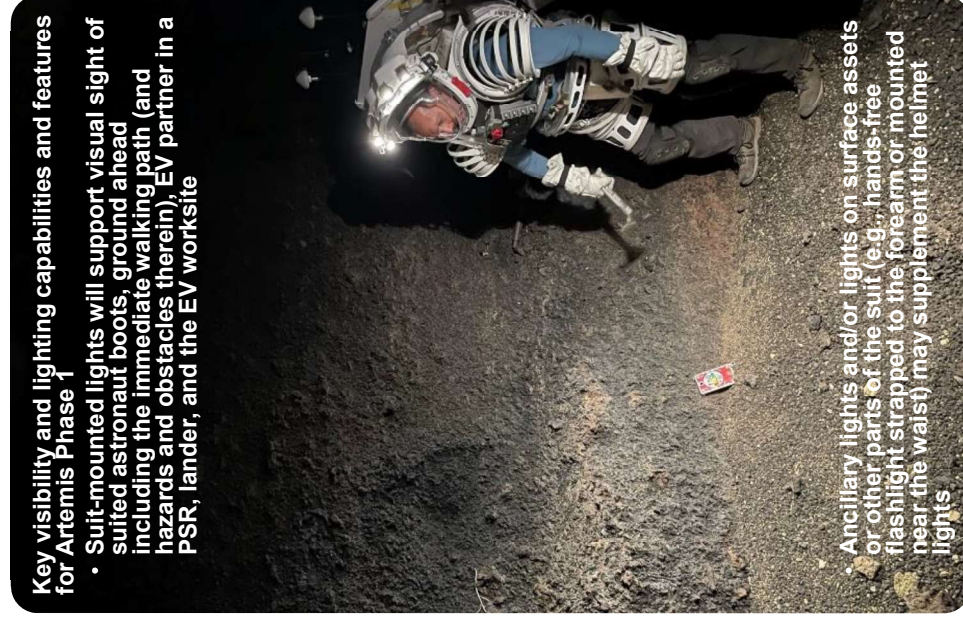
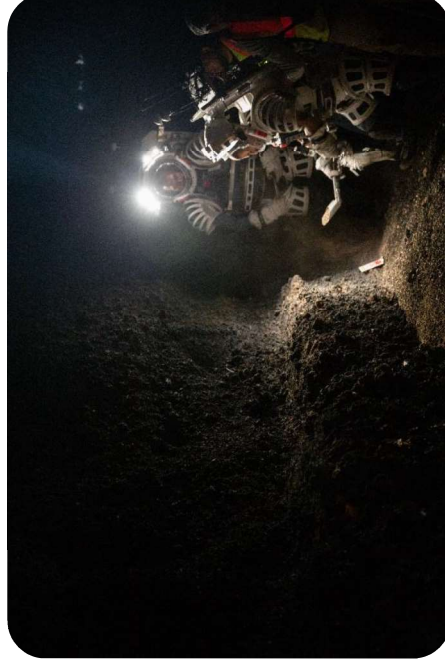
Surface EVA Tasks in Shadows



Lighting will be critical for lunar surface missions, especially for those near the lunar South Pole where constant long shadows will be prevalent. Sufficient lighting for walking over rough slopes and conducting science tasks will be required for any incursion into a PSR.



Those lights will need to allow the crew to walk hands-free (as much as possible) and perform tasks with tools in both hands.



Key visibility and lighting capabilities and features for Artemis Phase 1

- Suit-mounted lights will support visual sight of suited astronaut boots, ground ahead including the immediate walking path (and hazards and obstacles therein), EV partner in a PSR, lander, and the EV worksite

- Ancillary lights and/or lights on surface assets or other parts of the suit (e.g., hands-free flashlight strapped to the forearm or mounted near the waist) may supplement the helmet lights

Notable Human-Centric Developments

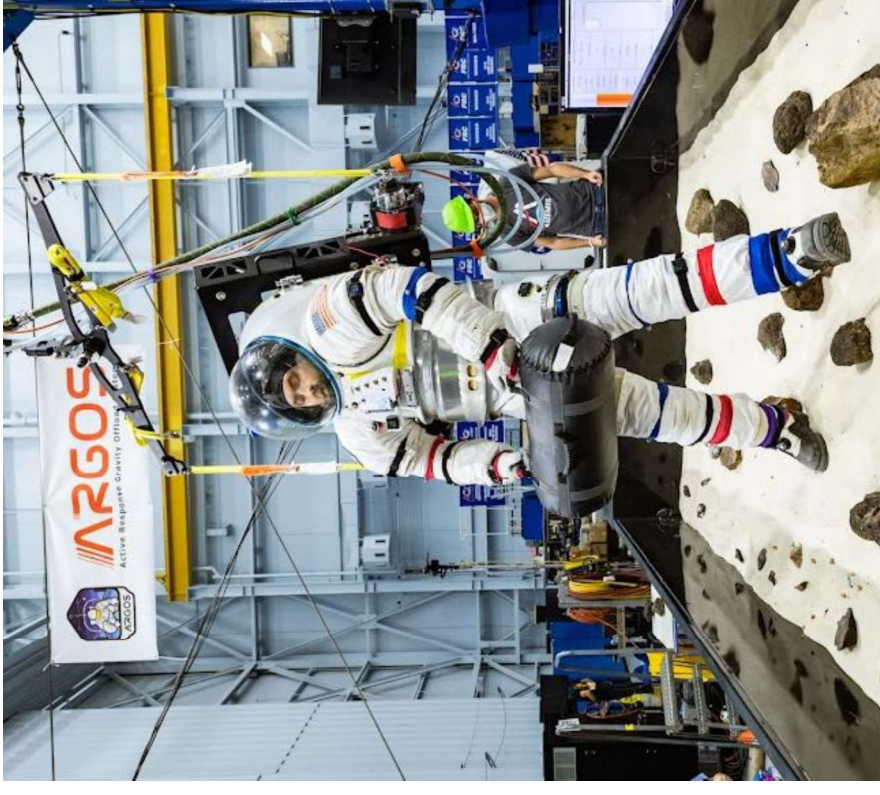


Suited Injury – Integrated Approach

- Significant work has been completed for task analysis: modeling that characterizes potential injury mechanism and helps determine mitigations
- Pro-active approach to reducing suit-driven injury to crewmembers
- Historical data reviewed from: Apollo, Space Shuttle, ISS, EVA Training, Ground Studies, Neutral Buoyancy Lab (NBL)

Incapacitated Crew Rescue Study

- Integrated approach including: Crew interaction, usage of tools and assets for prevention and rescue, suit/human interfaces, suit to suit interfaces, and suit to vehicle interfaces
- Rescuer performance impacts included in assessment
- Significant cross-organizational input from: XX, SA, SD, SK, SF, FOD, NA



Pre-EVA Ops (Day of EVA)



EVA Prep

- Suit initialization and power up on vehicle power
- Suit Donning
- Suit Checkout
 - Primary and backup systems checkout
 - Final suit fitcheck

EVA Prebreathe

- Purge
 - Suit is pressurized and purge valve is open
 - Removes N₂ from suit
- Prebreathe
 - Surface EVA protocols are in development
 - May make use of vehicle saturation atmosphere, prebreathe time and/or exercise, and the ability of the suit to operate for periods at higher delta pressures



Crew in ISS EMUs in the ISS Joint Airlock

Egress & Setup

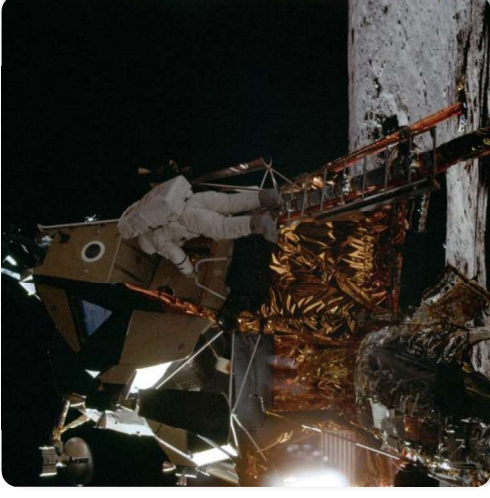


Depress

- Initiate cabin/airlock depress

Egress

- Descend ladder, stairs, ramp, or elevator to get to the surface
- Crew may bring some equipment, such as geology tools, with them from inside the cabin as necessary



Post Egress Setup

- Destow/offload anything brought on the exterior of the vehicle
 - Tools and equipment (sample collection tools and instruments)
 - Equipment transport system
- Set up dust mitigation kit



- 

Post EVA and Maintenance



Post EVA

- Repress lander/airlock
- Utilize HLS ECLSS to remove any particulates in atmosphere
- Doff xEVA suit
- Clean suits
- Perform inspection of suit
- Remove additional dust and bag xEMU as required to prevent migration
- Recharge consumables (O₂, H₂O, power)
- Download required xEVA suit data

Maintenance

- No preventative maintenance required on initial lunar surface mission
- Swap spares as needed



Outline (DRAFT)



- Basics of EVA Operations
 - Limitations
 - Risk Aspect
- Artemis EVA Con Ops
 - Environments
- NASA Reference Designs (xEMU is one of several reference designs)
 - Basic characteristics of a suited crew member
 - Weight, CG, field of view, overall size, anthropometric specs
 - Capabilities associated with Lunar Surface traverse
 - movement constraints, manipulation constraints, leverage, metabolism, walking clearance, etc.
 - what weight can be carried and for what distance, tasks that can and can't be done, etc.
 - Capabilities associated with performing engineering/science tasks
 - Mobility
 - Tools
- Integrated Testing
- EVA Compatibility Requirements
- xEVAS Overview
- Key xEVAS Requirements

Limitations of EVA Operations



Make 2 slides

- Although EVA space suits provide a crewmember with protection from the space environment, they also limit their abilities beyond a shirt sleeve environment.
 - Limited mobility / flexibility
 - Pressurized gloves make it difficult to do hand intensive or intricate tasks. Specialized hardware is needed due to space suit dexterity.
 - Joint motion is restricted, bending down is more difficult and raising hands overhead may be virtually impossible.
 - Repeated motion can lead to injuries — many rotator shoulder cuff injuries attributed to EMU
 - Add quote
 - Greater mass
 - A space suit adds mass to the crewmember's nominal mass which the crewmember needs to account for during operations.
 - It is equivalent to about a 70lb backpack on Earth hikes
 - Greater volume
 - The volume that the spacesuit takes utilizes more space than a shirt sleeve environment. Tight spaces that restrict movement and body positioning can adversely affect crew health and mission priorities.
 - A suit is about twice as big as a shirt sleeve crewmember
 - Center of gravity differences
 - The additional mass and its location on the spacesuit changes the crewmembers typical center of gravity such that many tasks like walking, kneeling, turning, climbing can throw off their balance. Although NASA uses a variety ways to train these differences, they can only simulate part of the equation such that lunar EVAs may still have some learning and real-time adjustments.
- Suit Limitations
 - EVA suits have restrictions with what it can interact with (sharp edges, materials, etc)
 - EVA suits 'off-gas and/or transfer contaminants' to the space around them such that the environment is no longer pure
 - Internal environment of the suit is pure O2 which has flammability and contamination constraints
- Additional Lunar Considerations
 - Extreme Lighting conditions
 - Lunar South Pole will have oblique lighting angles casting extreme shadows, Lunar regolith can be highly reflective, Permanently Shaded Regions (PSRs) are extremely dark and very cold
 - Navigation
 - Difficult to perceive distances because extreme lighting, shadows and atmosphere have perception issues
 - No google maps/GPS on the moon — planned system unknown at this time

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xEMU Reference Design Capabilities



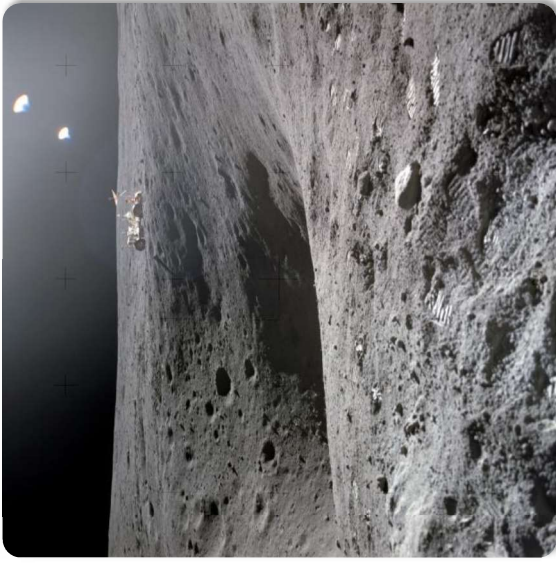
- Development of the xEMU Reference Design was intended to provide a suit that would allow crewmembers to conduct excursions outside a vehicle to perform exploration, research, construction, servicing, and repair operations
- A few key suit capabilities for lunar surface goals include:
 - Supports EVAs of up to 8 hours in duration
 - Mobility & surface ambulation during partial-gravity surface operations
 - Ability to perform engineering and science tasks while standing and non-neutral postures (e.g., kneeling), including conducting geological sampling tasks with tools (tongs, scoop, rake, hammer, chisel, etc.)
 - Capability to operate for up to 2 hours of contiguous exposure in a shadowed area, including Permanently Shadowed Regions (PSRs)
 - Translation via walking, crawling on hands and knees (short distances with slow controlled motions), scrambling (traversing sloped terrain while using one's hands), and climbing steps and ladders
 - Walking up/down/across a slope of up to 20° (*Apollo 15 traversed on slopes of ~17°*)
 - Ambulating on traverses of up to 2 km away from the lander (*Apollo 14 walked ~1.45 km from the lander*), and a total of 16 km in any given EVA
 - Improved lighting and cameras to support visual sight of ground ahead, EV partner in a PSR, lander, and the EV worksite

EVA Mobility on Lunar Surface



Mobility

- Translation via walking, crawling on hands and knees (short distances with slow controlled motions, scrambling (traversing sloped terrain while using one's hands), and climbing steps and ladders
- Walking up/down/across a slope of up to 20°
[Note: Apollo 15 traversed on slopes of ~18° - 20° and Apollo 17 on slopes of ~16°]
- Ambulating on traverses of up to 2 km away from the lander and a total of 16 km in any given EVA (depending on terrain)
[Note: Apollo 14 walked ~1.45 km from the lander]
- Traversing across regolith and scree, down into and out of craters, volcanic terrains (including lava tubes), and shadowed regions (with the appropriate equipment and assets)
- Performing tasks while standing and non-neutral postures (e.g., kneeling), including conducting geological sampling tasks with tools (tongs, scoop, rake, hammer, chisel, etc.)
- Ability to safely carry equipment, including pushing/pulling a carrier



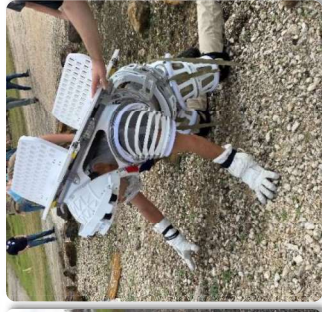
Kneeling



Ambulating



Scrambling



Pushing/Pulling



Scooping



Raking



Hammering



Coring



Trenching

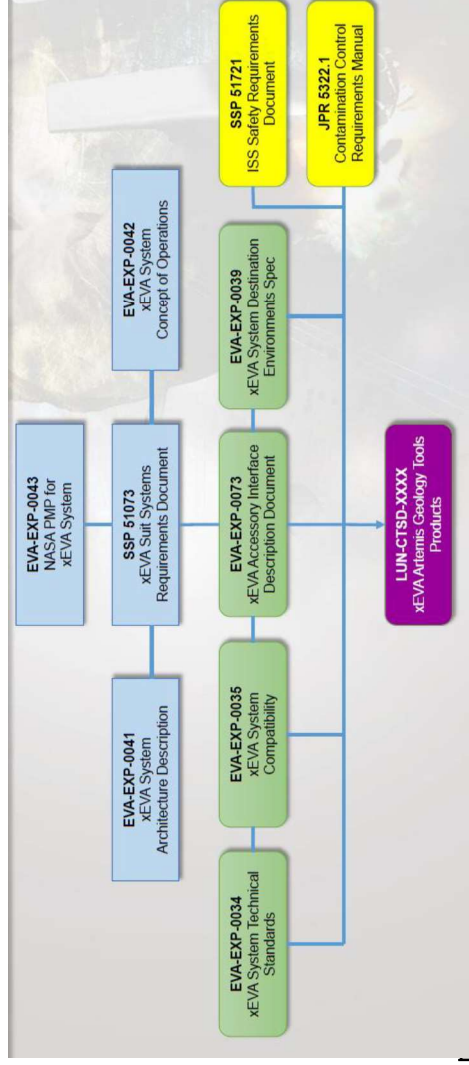


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Requirements Considered for Tool Design



- All Artemis xEVA Geology Tools have specific functional, physical, environmental, safety, human interface and expected life requirements defined by the tasks each tool is expected to perform and vetted through the team of stakeholders from ARES, FOD, Safety and Program offices.
 - EVA specific requirements (i.e EVA glove compatibility, suited crewmember actuation loads, etc) that are based on ISS EVA requirements or carried in EVA-EXP documents have been levied on all the tools.



- Prototype hardware evaluations..

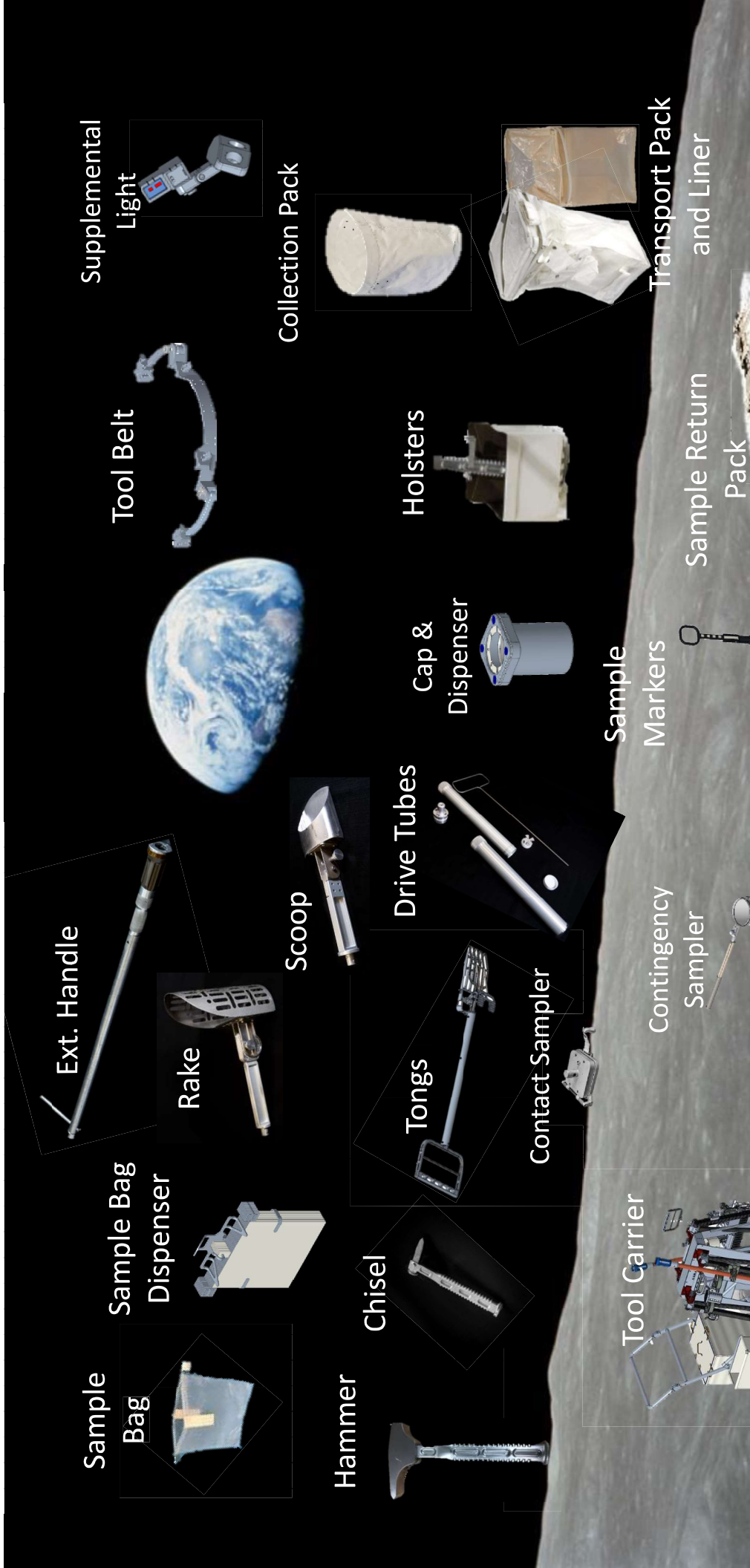
as well as quick-look glovebox

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Mobility



Suite of Artemis Lunar Geology Tools Being Incrementally Developed



Sample Bags and Sample Bag Dispensers



Sample Bags

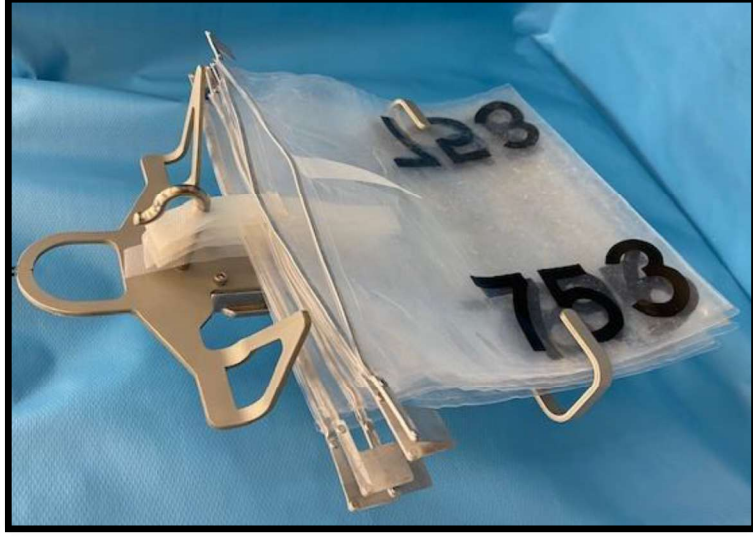
Metal
Hanger

Pull Tab

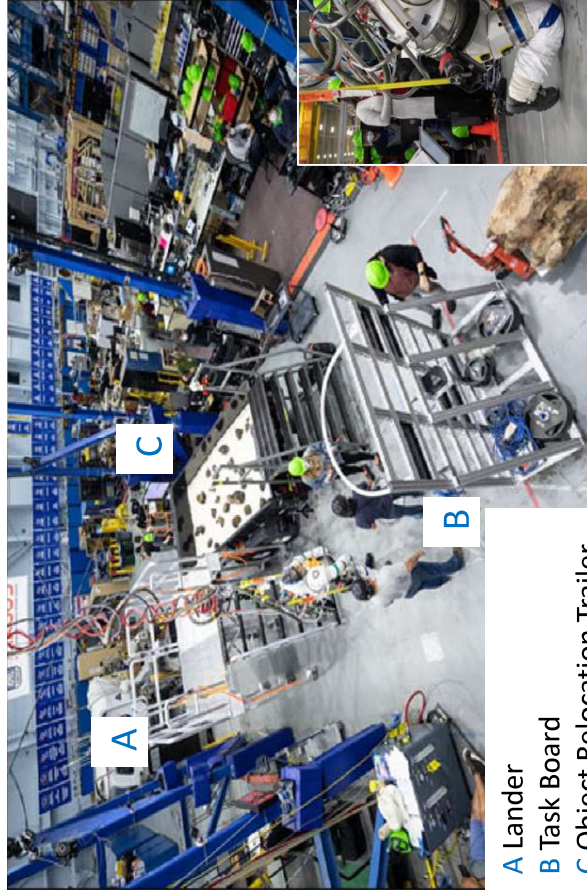
Bag
Label



Sample Bags and Sample Bag Dispenser



Images



A Lander

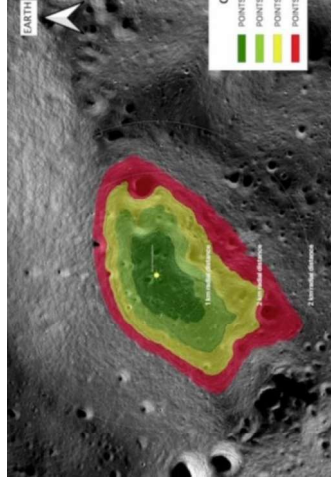
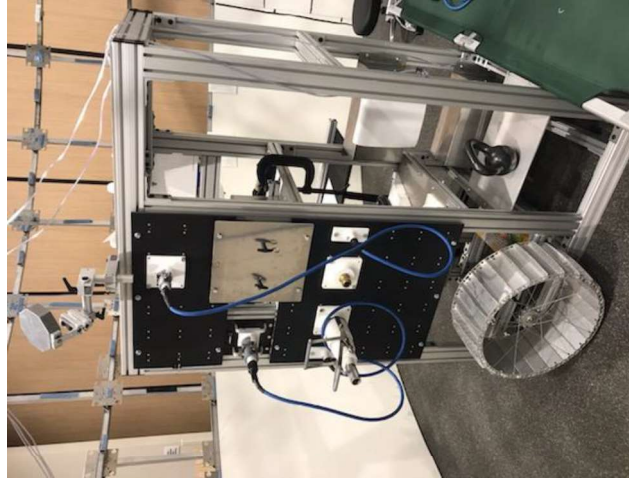
B Task Board

C Object Relocation Trailer



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Notable Human-Centric Developments



Advanced Technology and Simulation Training

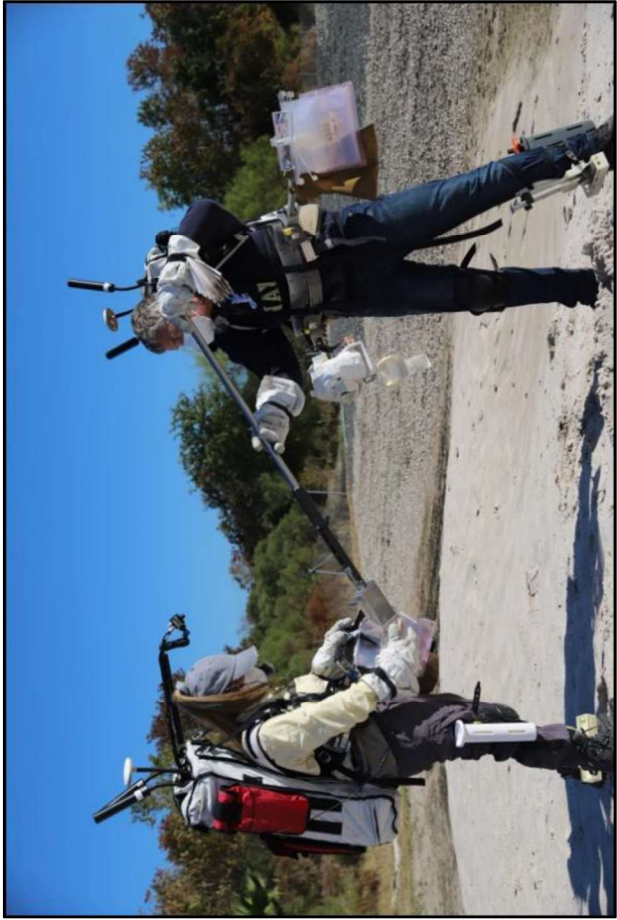
- Development of content to conduct EVA simulations in shirtsleeve virtual reality or pressurized suit testbeds.
- Development of physiologic and functional models that provide individualized and task-specific monitoring and/or prediction of crew state parameters.
- Integration of crew state and life support system models; various software tools for planning, executing, and replanning of EVAs; visualizations and interfaces to support exploration operations; and autonomous decision support systems.

EVA Operations and Hardware Testing

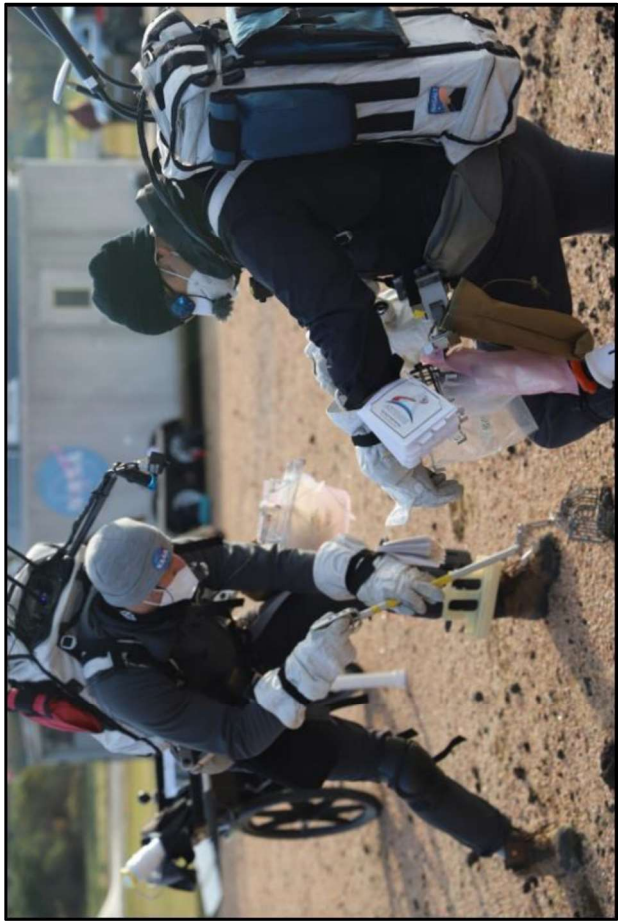


- During the design phase, FOD EVA is involved in early design reviews to evaluate the crew – hardware interactions.
 - FOD EVA will provide the hardware team with assessments of the compatibility of the design to EVA operations. There may be required changes (safety) and desired changes (EVA efficiency and ops ease).
- After a tool, payload, or hardware has a preliminary design, FOD EVA and the crew office will test the EVA Operations with it.
 - Hardware will be rated: acceptable, unacceptable (design changes required), and inconclusive
- EVA is a unique skill and does not always align to defined actions
 - The crew office and FOD (Flight Operations Directorate) EVA assess hardware and develop procedures that incorporates workarounds if required.
- Evaluations could be in a glove box, vacuum chamber, off-load system, or underwater
- Hardware modifications may be need to be compatible with EVA
 - Large handholds
 - Show PGT vs drill, ratchet differences? Show how EVA is different

Testing



Two test subjects put a regolith Scoop sample into a Sample Bag during a test at the JSC Rock Yard



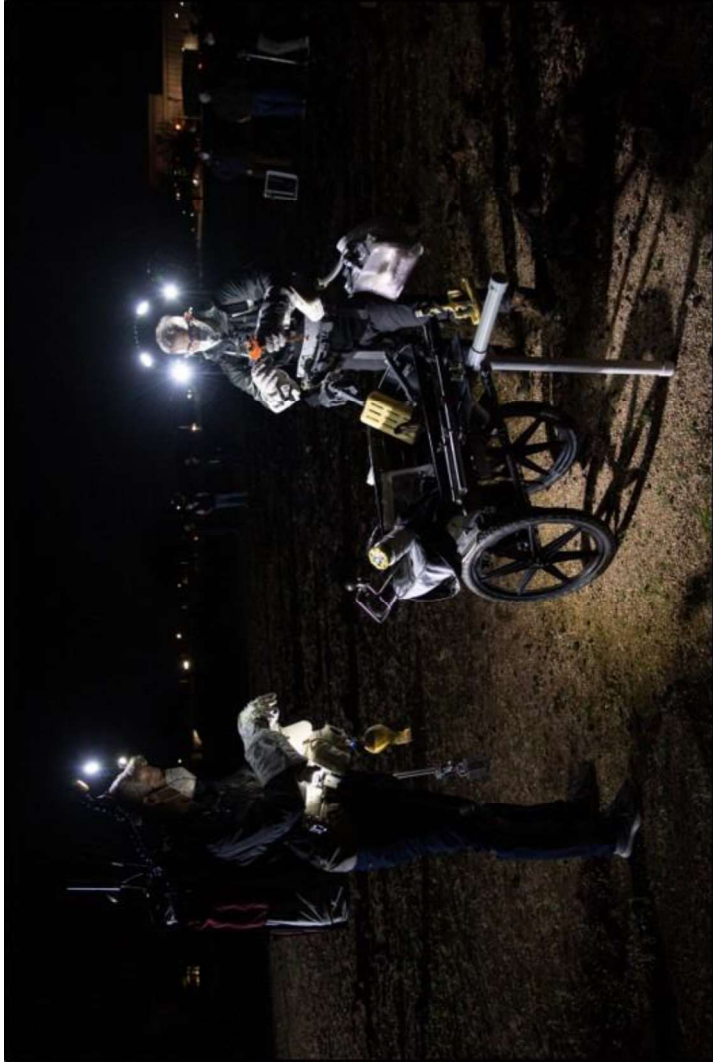
Two test subjects work together to retrieve a float sample during a test at the JSC Rock Yard

Testing



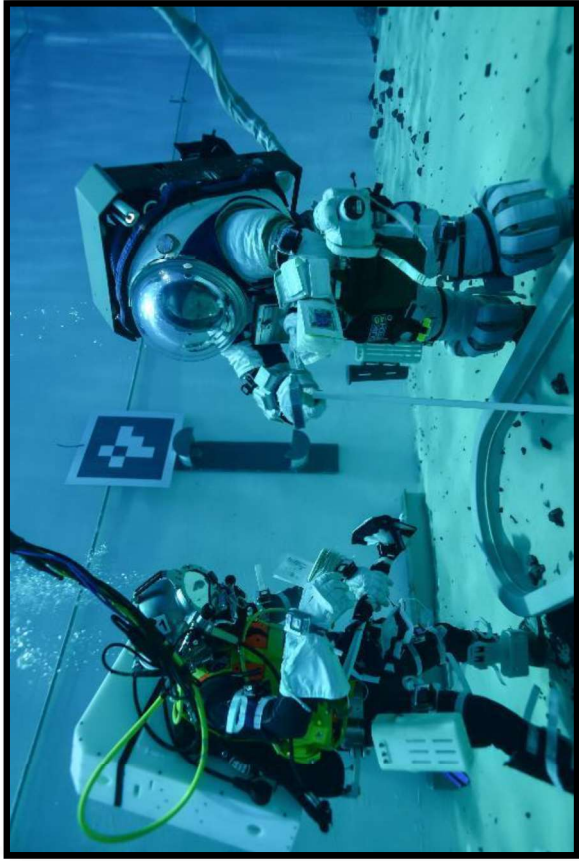
Test subject inspects a sample

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Test subjects prepare to translate a Tool Carrier to the next station at the JSC Rock Yard

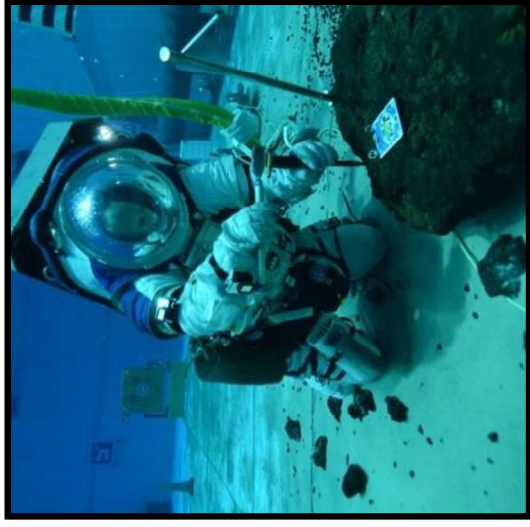
Testing



Test subject hammering in a flagpole

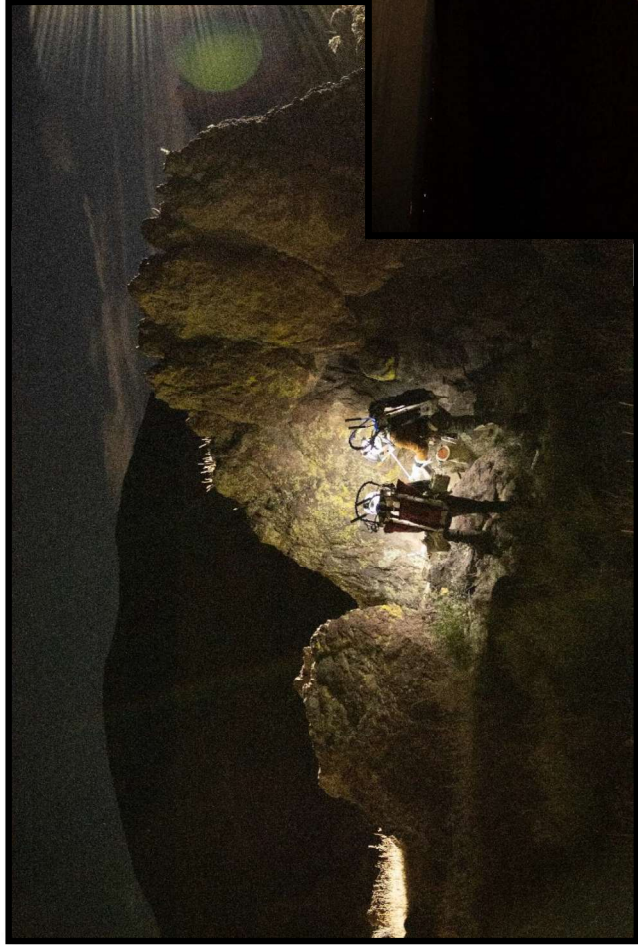


Test subject prepares for chiseling a rock

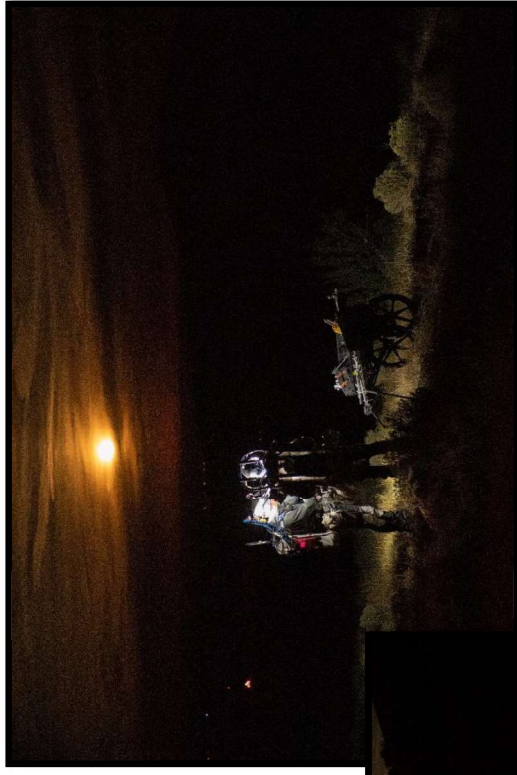


Test subject chisels a rock

Integrated Field Testing



Test subjects investigate a sample of interest in San Francisco Volcano Field



Test subjects plan next traverse in San Francisco Volcano Field

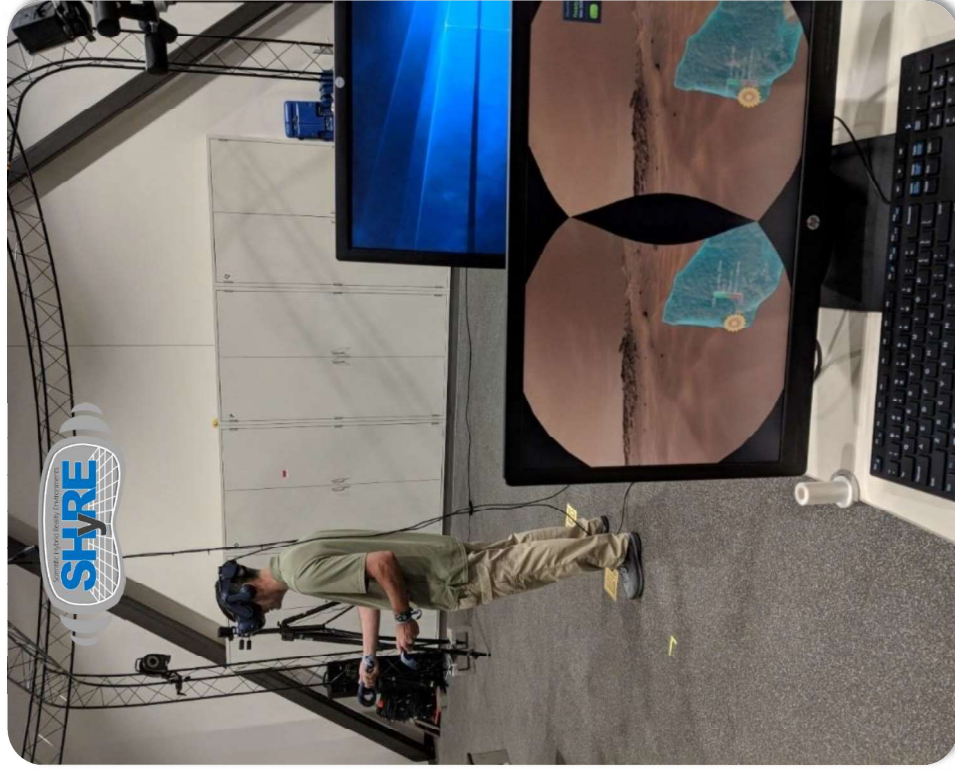
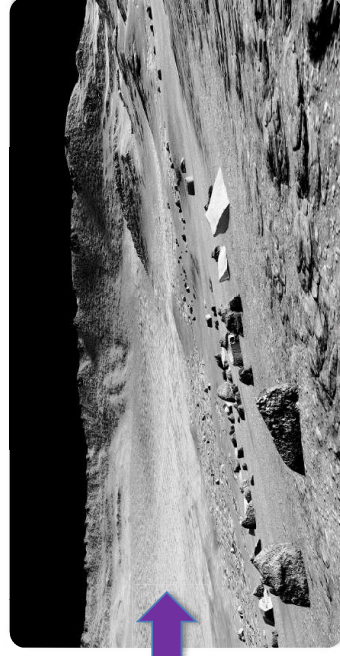


Test subjects investigate a sample of interest in San Francisco Volcano Field

Hybrid Reality Testing



- Developing a high scientific fidelity hybrid reality (HR) model of real-world geological sites of interest, including embedded data and applicable tool usage
- Builds off of several years of RIS⁴E *in situ* data collection in addition to data collected at the December 1974 flow, Kilauea Volcano, HI
- Testing environment that will be utilized for:
 - Ops con development for science-driven EVAs
 - Instrument deployment procedures
 - EVA Support System and IV Workstation capabilities for science
 - Crew training platform



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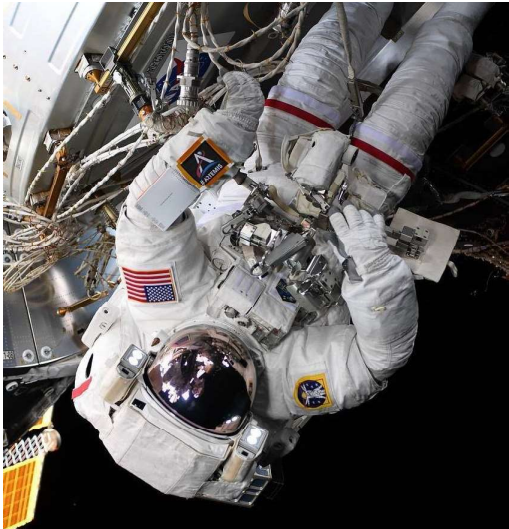
Notable Human-Centric Developments



Lunar Lighting

- Lunar South Pole will pose challenging lighting conditions:
 - Contrast of black sky against the bright sun
 - Oblique sunlight angles will cast extremely long shadows
 - Rocky Lunar terrain will create large areas of limited light
 - Lunar Regolith reflective properties
- Extensive lighting simulations have been performed to better characterize extreme lighting scenarios on Lunar Surface

EMU vs. xEMU Differences



EMU
(Shuttle / ISS)

Characteristic
Operating Pressure
Max EVA Time
PGS Mobility
Sizing Scheme
Suit Entry
Environmental Protection
CO2 Removal
Thermal Design
Oxygen (Ventilation)
Design Metabolic Range
Communication Systems
Informatics
Maintainability / Upgradeable
Mass



xEMU

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Guiding Principles & Processes for Testing



Principles

- Reduce and mitigate [gaps](#) and [risks](#)
- Conduct development testing of [hardware](#) and [con ops](#)
- Advance [technology development](#)

Processes

- [EHP SE&I ITF Panel](#) and Joint EVA Testing Forum ([JETF](#))
- Tracking Test Process
 - Objectives
 - Series
 - Events
- Utilizing testing capabilities and teams
 - Matrixed [Joint EVA Test Team](#)
- Informing the EVA & HSM Projects
 - xEVA System and xEVA Services ([xEVAS](#))
 - Lunar Terrain Vehicle
 - Pressurized Rover



Integrated Testing & Facilities



ITF facilitates integrated HITL testing associated with EVA and Surface Mobility to ensure development and operational milestones



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Joint EVA Test Team (JETT)



- The [JETT](#) is comprised of a collaboration of community testing SMEs and stakeholders managed by [EHP SE&ITF Group](#)
- Functions as the primary test team for tasking from the [EHP SE&ITF Panel](#) (or the the [JETF](#))
- Develops, coordinates, integrates, and executes integrated HITL testing for EVA (xEVA System and the xEVA Con Ops), Surface Mobility, and Technology Development
- Executes productive integrated developing testing on the road to enabling operationally effective Exploration systems and successful planetary surface operations
- JETT Goals:
 - Evaluate the NASA xEVA reference designs (spacesuit, tools, interfaces, etc.)
 - Address gaps and risks for Artemis and lunar surface operations
 - Flush out capabilities for science tasks
 - Push technology development, including NASA testing facility maturation
 - Enable quick turnaround research and development (R&D) for EVA
 - Support the xEVAS contract
 - Help enable training for Artemis surface EVA operations



WHO	WHAT	WHEN	WHERE	WHY	HOW
Multidisciplinary team across the EVA community (Program, xEVA System, Science, Operations, HH&P)	Integrated EVA-focused testing for Exploration/Artemis	As required and/or requested	NASA Facilities • JSC Rock Yard • NBL • ARGOS • etc. Field Environment	• xEVA System Dev • xEVAS Support • Risk/Gap Closure • EVA Con Ops • R&D / Technology Dev • Training Hardware	Evaluations tracked via Test Series

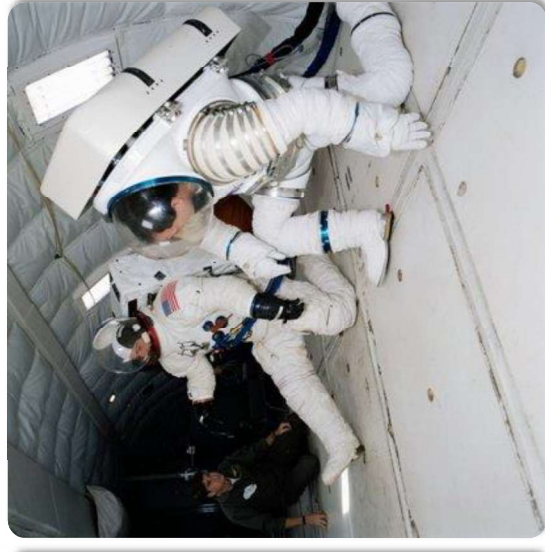
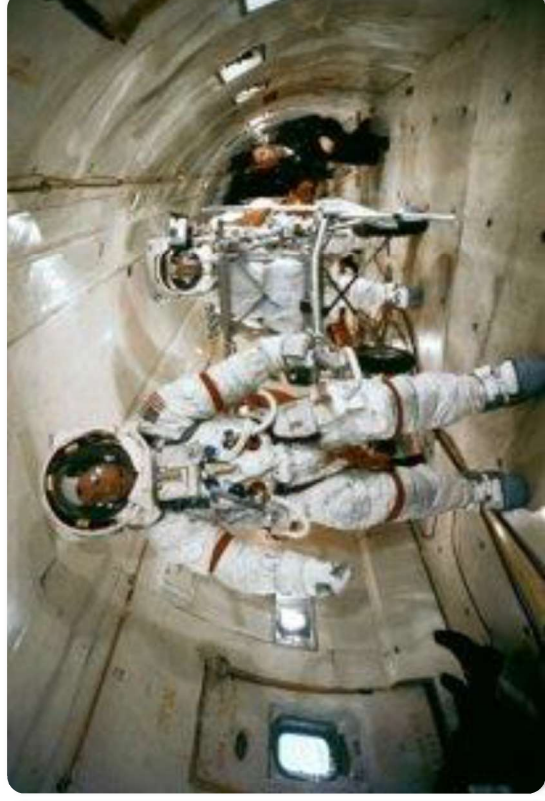
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Parabolic Flight (Reduced Gravity Aircraft)



Specialized aircraft allow for the parabolic flight profiles. These profiles enable brief moments of varying degrees of “reduced gravity” for ~25 seconds, from microgravity to lunar or Martian partial-gravity levels.

- Hardware design and development, utilizing high-fidelity pressurized spacesuits and tools
- Human factors testing
- Development of EVA techniques and training of crew



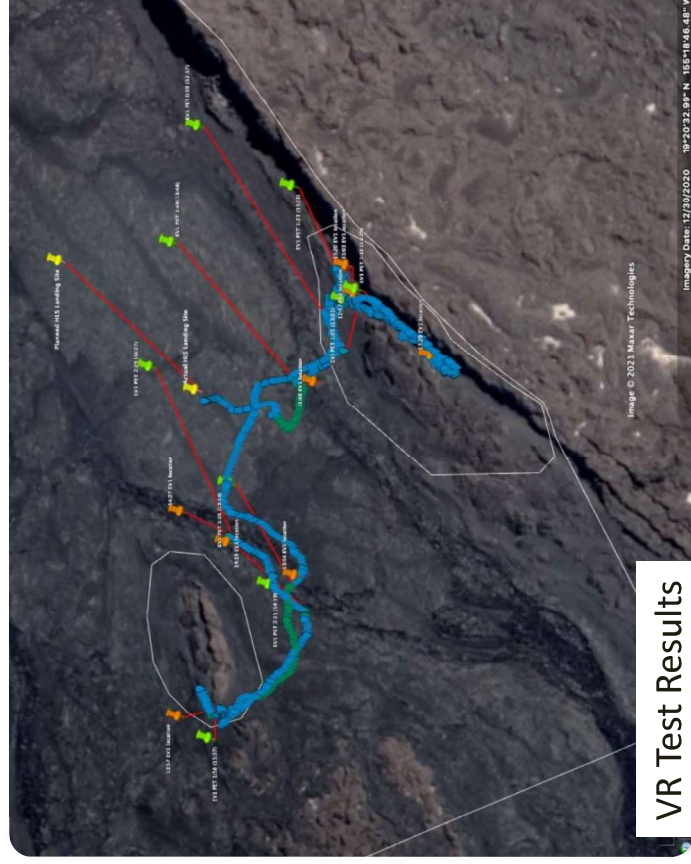
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Comparing Results Across Test Environments

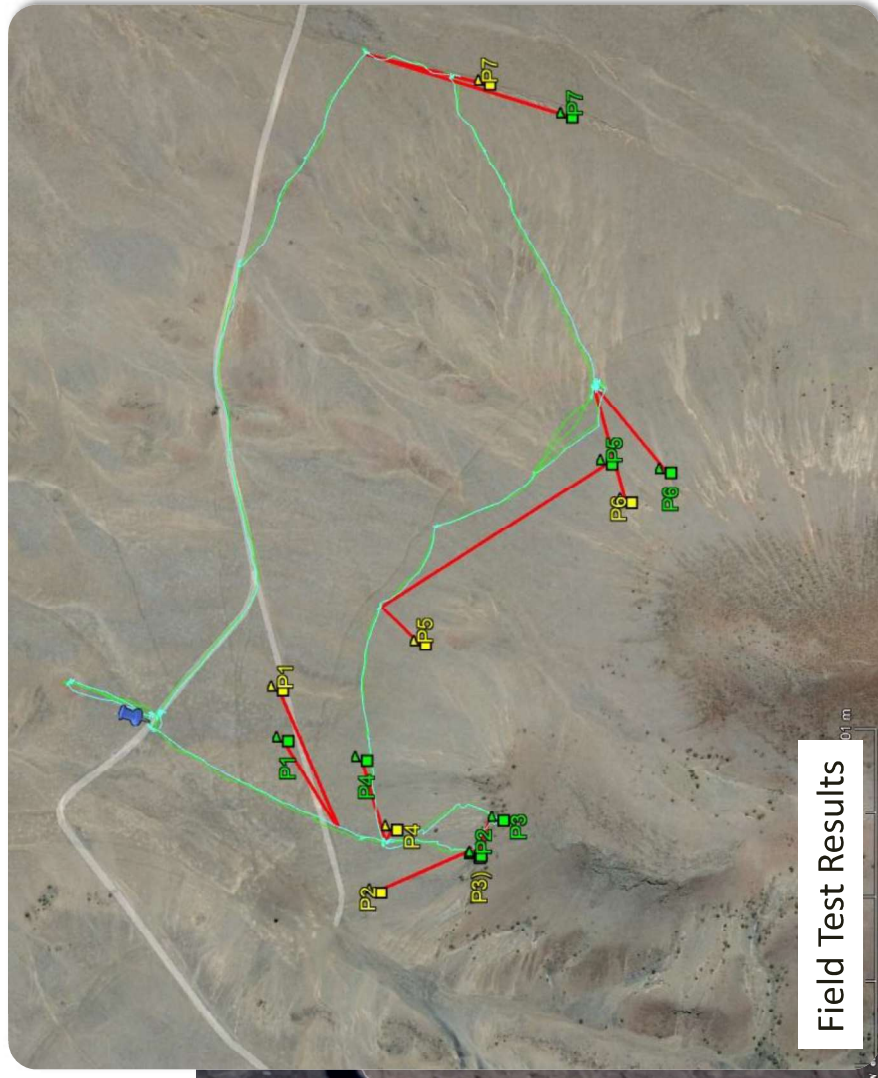


Artemis 3 EV crew position determination

- Green dots = where MCC thinks EV1 is located
- Orange/Yellow dots = where EV1 thinks they are located
- Red lines = error



VR Test Results



Field Test Results

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Feeding Results into Commercial Vendors



Test results and lessons learned feed into development of the Exploration systems and inform commercial vendors

EHP SE&I TF

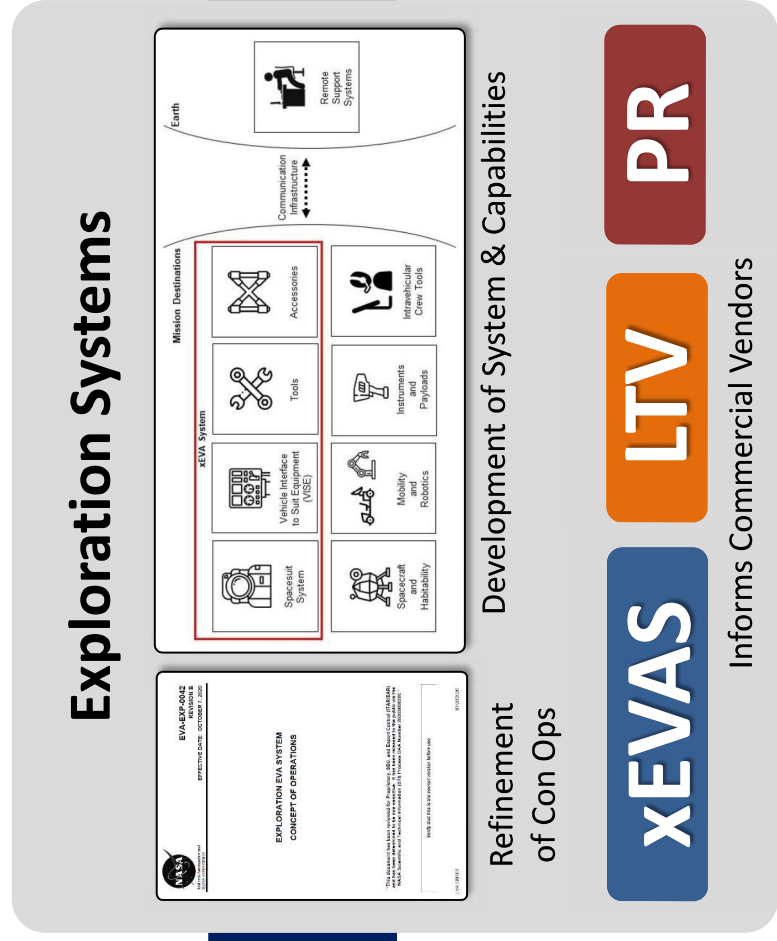


Test Results

Integrated Testing

Labs

Field

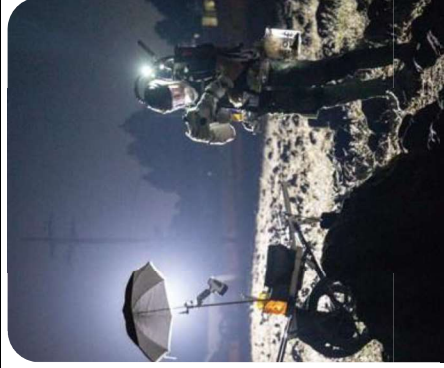


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Facilities and Testing



JSC Lighting Lab



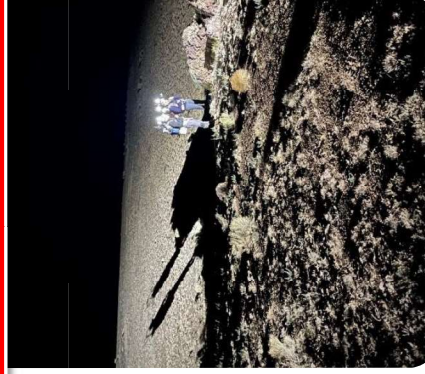
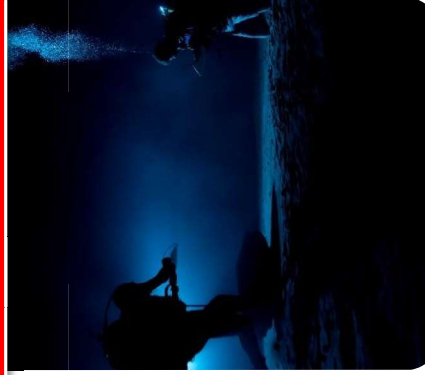
JSC Rock Yard



JSC NBL



Field Testing



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