Exploration EVA Challenges: Human Health & Performance
EVA Technology Workshop, July 2019
Overview

• EVA Human Health & Performance
• Updates to Integrated EVA Human Research Plan
• Moon 2024
• HH&P Technical Summary
EVA Human Health & Performance

**EVA Mission:** Achieve safe, effective & affordable EVA capabilities that enhance the human experience wherever we explore beyond Earth

**HH&P Mission:** Optimize human health and performance throughout all phases of spaceflight

The human is already compensating for a lot during spaceflight…

Vision  Cognition
Sensorimotor  Behavioral Health
Bone  Sleep
Muscle  Radiation
Aerobic  Medication
Immune  … and others

… lets not make them have to compensate for an inadequate EVA system, too
HH&P EVA on ISS & Beyond

Standard Performance Measures & Met Rate Characterization

Prebreathe

CO₂ Washout

Fleet Sizing

Human-Loads

EVA Medical Operations

Informatics, ConOps & Decision Support
Integrated EVA Human Research Plan

- Updated annually
  - Created 2016 (ICES Paper)
  - Updated 2017 (posted to nasa.gov/suitup)
  - Minor updates in 2018 (unpublished)
  - Updated in 2019 (NASA Tech Report)

- Discuss and share testing plans & priorities

- Program agnostic

Note: 2019 version finalized prior to 2024 Boots-on-the-moon direction
## Human-centered EVA Gaps

<table>
<thead>
<tr>
<th>CH&amp;P Gap Title</th>
<th>CHP SMT Gap ID</th>
<th>EVA SMT Gap No</th>
<th>CH&amp;P Gap Wording</th>
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<tbody>
<tr>
<td>EVA Crew Required Capabilities</td>
<td>CHP.EVA.CREW</td>
<td>EVA-Gap-88</td>
<td>The physiological and cognitive performance capabilities that will be required of crewmembers during exploration EVA are not adequately understood.</td>
</tr>
<tr>
<td>EVA Suit Design for Health &amp; Performance</td>
<td>CHP.EVA.SUIT</td>
<td>EVA-Gap-89</td>
<td>The effects of suit design parameters on crew health and performance (physical and cognitive) during exploration EVA are not adequately understood.</td>
</tr>
<tr>
<td>EVA Suit Sizing &amp; Fit</td>
<td>CHP.EVA.FIT</td>
<td>EVA-Gap-90</td>
<td>The effects of EVA suit sizing and fit on crew health, performance, and injury risk are not adequately understood.</td>
</tr>
<tr>
<td>EVA Physiological Inputs and Outputs</td>
<td>CHP.EVA.PHYS</td>
<td>EVA-Gap-91</td>
<td>The physiological inputs and outputs associated with EVA operations in exploration environments are not adequately understood.</td>
</tr>
<tr>
<td>EVA ConOps for Health &amp; Performance</td>
<td>CHP.EVA.CONOPS</td>
<td>EVA-Gap-92</td>
<td>The effects on crew health &amp; performance (physical &amp; cognitive) of variations in EVA task design and operations concepts for exploration environments are not adequately understood.</td>
</tr>
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# Human-centered EVA Gaps

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<tr>
<td>EVA Informatics for Health &amp; Performance</td>
<td>CHP.EVA.INFO</td>
<td>EVA-Gap-93</td>
<td>The knowledge and use of real-time physiological, system, and operational parameters during EVA operations to improve crew health and performance (physical &amp; cognitive) is not adequately understood.</td>
</tr>
<tr>
<td>EVA Injury Risk &amp; Mitigation</td>
<td>CHP.EVA.INJURY</td>
<td>EVA-Gap-94</td>
<td>The risk of crew injury due to exploration EVA operations and methods for mitigating that risk are not adequately understood.</td>
</tr>
<tr>
<td>EVA Exploration Prebreathe</td>
<td>CHP.EVA.DCS</td>
<td>EVA-Gap-95</td>
<td>The DCS mitigation strategies and associated impacts on mission timelines, consumables, and the design of EVA and habitat systems for exploration missions are not adequately understood.</td>
</tr>
</tbody>
</table>
Brief Status on Recently Completed Tasks

Updated Tasks
- Suit Sizing & Fit Study: Updated & Implemented (Z-2.5)
- Impaired EVA Study 2 Initiated (Study 1 bypassed)
- Increased scope and definition of EVA Bioinformatics & Decision Support tasks

Added Tasks
- Added xEMU HH&P V&V tests
- Added Terrestrial Field Work Characterization
- Added Integrated Exploration EVA Field Simulations
- Added Exploration Prebreathe tasks incl. 14.7, 10.2 and 8.2 psia prebreathes
How does Moon 2024 Change Things?

• Boots-on-the-Moon for < 7 day missions will require:
  – Prebreathe protocol validation
  – Implementation & verification of HH&P xEMU Requirements (NASA-STD-3001 Rev B)

• Likely that a 2024 EVA suit will not include full xEMU capabilities
  – Some HHP requirements may be waived for a short-duration 2024 mission

• EVA capabilities in 2024 are expected to be improved upon in subsequent missions
Anthropometry and Biomechanics Facility

- The Anthropometry and Biomechanics Facility (ABF) is the primary source for assessments of human-suit interaction
  - Suit fit and accommodation modeling, including suit and human 3D scans
  - Suited performance assessments using motion capture and kinematic analyses
  - Ergonomic analyses of humans working in the spacesuit

Suited scanning

Full body reach assessment
Suit Fit and Accommodation: Modeling & Validation

- A computational model is being developed to predict the probability of suit fit with any person’s 3D scan or anthropometry measurements
  - The model defines the characteristics of the current and future crewmember population accommodated by the suit
  - The model can help identify the key suit design and geometric parameters to maximize population accommodation
Suit-to-Body Compression Tolerance Mapping

- The fit/non-fit decision of the suit accommodation model is based on the interference between the suit and human body surface
  - Tolerance to skin compression varies across different body segments, anthropometry and subjective thresholds
  - The compression mapping study aims to create a comprehensive model of the acceptable levels of skin compression across the torso

Compression Tolerance Measurement

Color-coded mapping of acceptable depth of compression, example subject
Suited Performance Testing

- Crewmembers across a wide range of size and shape must not only be able to fit in the suit, but also function optimally
  - In suited performance testing, subjects complete maximal reach envelope testing, on-suit reaches and simulated functional tasks
  - Performance is assessed and compared across a range of subject sizes
Suit Kinematics Modeling

- Virtual models of reposable spacesuits and human bodies have been developed to simulate and visualize fit and mobility performance
  - Comparative illustrations of mobility performance across different suit designs or configurations
  - 3D visualization of mobility characteristics in suited versus unsuited kinematics
• An inexpensive and efficient test bed is being developed for pilot testing of suited activities
  – Subjects wearing a mockup MK-III suit will be evaluated with simulated perturbation to the visuo-vestibular system
  – Subjects will perform ambulation and simple functional tasks while wearing a VR headset with eye tracking
Suit Posture Estimation from Photos

• The ABF is developing software to rapidly assess EVA suit poses using conventional videos or photographs
  – 3D motion capture can be cost prohibitive and is limited for outdoor testing capability
  – The new tool can enable fast human-in-the-loop evaluation for ergonomic and biomechanical assessments
  – Retrospective analysis can also be performed on past EVA video archives
Wearable Sensor Garment to Measure Body Inside a Suit

- Measuring the posture of a subject inside the suit can provide critical information for assessing suited injury risks
  - A garment embedded with fabric stretch sensors was developed to predict torso shape and posture
  - The garment can be worn inside the spacesuit to better understand the human motions inside the suit
The exploration atmosphere (8.2 psia, 34% O₂) will enable high efficiency planetary EVAs by reducing prebreathe resources:

- A prebreathe protocol for this atmosphere must be developed and validated against NASA standards before operational implementation.
- Physiologic and cognitive adaptations to living in the exploration atmosphere, which includes mild hypobaric hypoxia, must also be characterized.
- Material compatibility with the low pressure, high F₁O₂ environment will be evaluated.

### EVA SMT Gap No EVA Exploration Prebreathe

**Day 1** 3hr @ 100% O₂, 14.7 psia; Ascend to 8.2 psia / 34% O₂; Equilibrate
**Day 2** Prebreathe; 6hr EVA @ 4.3 psia, 85% O₂
**Day 3** Rest & Hypoxia Characterization
**Day 4** Prebreathe; 6hr EVA @ 4.3 psia, 85% O₂
**Day 5** Rest & Hypoxia Characterization
**Day 6** Prebreathe; 6hr EVA @ 4.3 psia, 85% O₂
**Day 7** Rest & Hypoxia Characterization
**Day 8** Prebreathe; 6hr EVA @ 4.3 psia, 85% O₂
**Day 9** Rest & Hypoxia Characterization
**Day 10** Prebreathe; 6hr EVA @ 4.3 psia, 85% O₂
**Day 11** Prebreathe; 6hr EVA @ 4.3 psia, 85% O₂
NBL Informatics

- Collecting metabolic rate data for all suited NBL runs this fiscal year (3-4 NBL runs per week)
- Standardizing timeline tracking / task categorization for NBL EVAs to add value to this data archive
- Developed a new metabolic rate data collection system for installation at the NBL to automate this process

**Task Timeline Tracking:**

Physical Workload --> Metabolic Rate

**Training Feedback and EVA Planning:**

**Task Analysis:**

<table>
<thead>
<tr>
<th>Task</th>
<th>Category</th>
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<tbody>
<tr>
<td>EVA Setup/Cleanup</td>
<td>EVA Setup (Free-Floor)</td>
</tr>
<tr>
<td>Worksite Setup (Free-Floor)</td>
<td>EVA Cleanup (Free-Floor)</td>
</tr>
<tr>
<td>Worksite Cleanup (Free-Floor)</td>
<td>EVA Cleanup (Free-Floor)</td>
</tr>
<tr>
<td>Other work</td>
<td>Miscellaneous Work (Free-Floot)</td>
</tr>
<tr>
<td>Bolts</td>
<td>(Bolts, (Free-Floot))</td>
</tr>
<tr>
<td>Fluid Connectors</td>
<td>Fluid Connectors (Free-Floot)</td>
</tr>
<tr>
<td>Electrical Connectors</td>
<td>Electrical Connectors (Free-Floot)</td>
</tr>
<tr>
<td>Paid or Unpaid work</td>
<td>Paid work (Free-Floot)</td>
</tr>
</tbody>
</table>

**CH&P Gap Title**

EVA Informatics for Health & Performance

**EVA SMT Gap No**

EVA-Gap-93
Benefits of the new metabolic rate data collection system:

- Miniaturized and automated system integrated with NBL Environmental Control System (ECS) panels
- Eliminated labor hours for moving the carts, calibrating, and setting up data acquisition (~20 hours per month)
- Provide real-time information for training, for troubleshooting, and for reporting (~10 hours per month)
Exploration EVA Decision Support

- Develop models leveraging EVA data archive to estimate metabolic rate profiles for a given crew & task list
- Data-driven decision support tools for training, planning, and operations
- NBL Informatics is an example of the EVA Operations System (EOS) decision support tools
Return to planetary EVA testing on ARGOS!

- Develop a planetary EVA task simulation environment using the ARGOS which can be used to characterize metabolic workload and human performance while performing EVA in Lunar gravity
  - Developed multiple, detailed procedures for various task categories including: geology, maintenance, ambulation circuits, and science instrument deploy.
    - Integration with multiple stakeholders in the EVA, space suit development, engineering, planetary science to ensure operational relevance.
  - Also in development is a PLSS CG simulator to evaluate effect of PLSS mass on subject performance and workload.
Impaired EVA – Part I Capsule Egress

Purpose:
• Determine if deconditioned crew can safely egress a capsule unassisted after up to a year on the ISS
  – Crew will self-egress their capsule, walk a short distance, and doff their LEA suits unassisted.
• Demonstrate the ability to perform a minimal EVA unassisted within 24 hours of landing
  – Current con-ops for Mars landers include enough power for the first 24 hours.
  – Within that time, crew may have to perform an EVA to secure power.
Impaired EVA – Part II Early EVA

• **Tested EVA Capabilities**
  – First 24 Hours
    • Ingress EVA suit
    • Translate through hatch
    • Ladder descent
    • Walk & connect supply umbilicals
    • Object translation
    • Align with rear entry donning stand
    • Egress EVA suit
  – Additional Tasks Done Pre and Later Post-landing
    • Agility obstacle course
    • Jump down and stabilize
    • Incline/decline ambulation and instrument deploy
APACHE: Assessments of Physiology And Cognition in Hybrid-reality Environments

- APACHE is a new lab environment in the Building 21 high bay that uses a variety of techniques (Virtual/Hybrid reality, weighted suits, treadmills, audio/video communication loops) to model the physical and cognitive stress of the EVA environment.
- The lab employs a suite of data interfaces to capture a wide range of metrics related to both physical and cognitive performance.
- By serving as an easy-entry, low overhead analog, APACHE allows different surface EVA conops to be tested and compared in a controlled environment with objective, reproducible metrics.

<table>
<thead>
<tr>
<th>High Physical</th>
<th>High Physical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Cognitive</td>
<td>High Cognitive</td>
</tr>
<tr>
<td>Low Physical</td>
<td>Low Physical</td>
</tr>
<tr>
<td>Low Cognitive</td>
<td>High Cognitive</td>
</tr>
</tbody>
</table>
Suited Exposure and Injury Surveillance

- Implement a centralized input software tool (Exposure Incidence System) to facilitate systematic collection of data associated with suited exposures to characterize type, frequency & severity of complaints and injuries
  - Use data to mitigate injuries, improve human performance and comfort
  - Educate broader EVA community on risks of EVA and inform mitigations

Subject Characteristics
- Age, Sex
- Anthropometry
- Strength
- Fitness

Spacesuit
- Type
- Sizing
- Prime vs Secondary
- Pressure

Task Characteristics
- Training
- Flight
- Research
- Facility

Suit Related Injury
- Yes
- Type
- Location
- Severity
- No

Suited Injury
Likelihood & Consequence

CH&P Gap Title
EVA SMT Gap No
EVA Injury Risk & Mitigation
EVA-Gap-94
Inspired CO₂ Standard and xEMU Requirement

• Characterized historical EMU CO₂ washout performance using improved methodology
• Terrestrial literature to define starting point discussion for exposure limits
• Modeled crew exposures from historical flight EVA and NBL training metabolic rates
• Consensus CO₂ exposure limits for acute exposures during EVA

Table 1. xEMU P₁CO₂ Limits.

<table>
<thead>
<tr>
<th>P₁CO₂ (mmHg)</th>
<th>Allowable Cumulative Duration †† (hours per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 15.0</td>
<td>Do Not Exceed</td>
</tr>
<tr>
<td>&gt; 12.5</td>
<td>≤ 0.5</td>
</tr>
<tr>
<td>&gt; 10.0</td>
<td>≤ 1.0</td>
</tr>
<tr>
<td>&gt; 7.0</td>
<td>≤ 2.5</td>
</tr>
<tr>
<td>&gt; 4.0</td>
<td>≤ 7.0</td>
</tr>
<tr>
<td>≤ 4.0</td>
<td>≤ 14.0</td>
</tr>
</tbody>
</table>
Summary

• EVA Frequency, Intensity, Flexibility & Autonomy pose new challenges
• Gaps in Knowledge & Technology
  – e.g., metabolic rates; thermal control; nutrition; hydration; fatigue (physical & cognitive); injury mechanisms; fit; DCS; decision support
• Limited human risk data vs. known and immediate engineering and/or ops impacts

More Data & Better Data → Less Conservatism and/or More Informed Risk

EVA community is working together to optimize EVA Health & Performance