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*

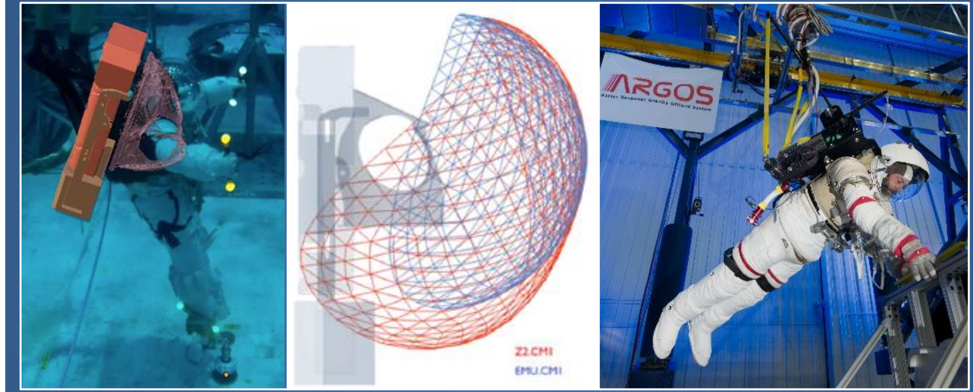
The human is already compensating for a lot during spaceflight…

Vision
Sensorimotor
Bone
Muscle
Aerobic
Immune

Cognition
Behavioral Health
Sleep
Radiation
Medication
… and others

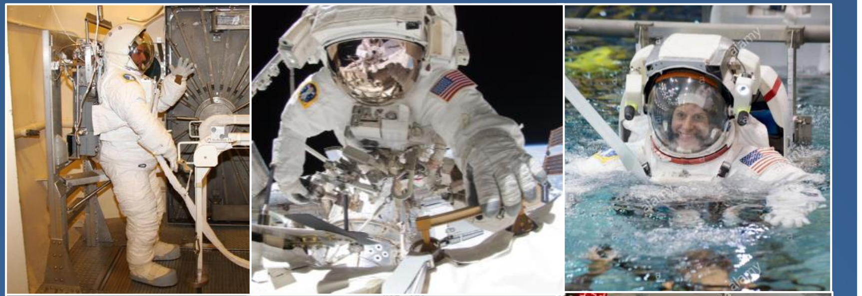
… lets not make them have to compensate for an inadequate EVA system, too

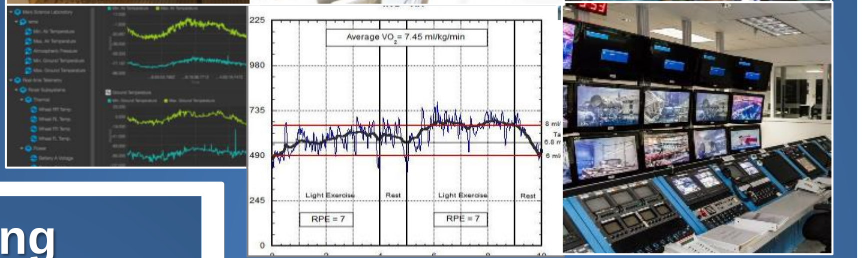
HH&P EVA on ISS & Beyond



Standard Performance Measures & Met Rate Characterization

EVA Medical Operations



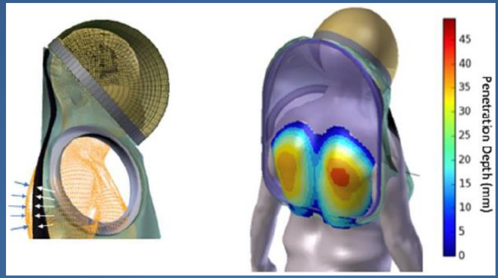


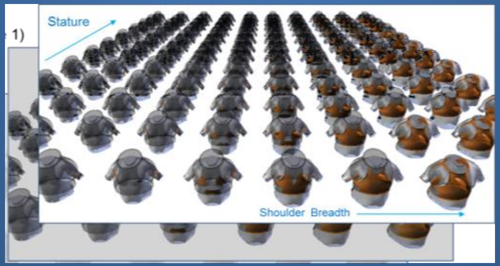
Informatics, ConOps & Decision Support

Prebreathe

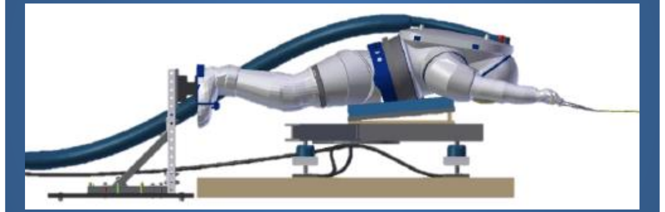
CO_2 Washout

Fleet Sizing





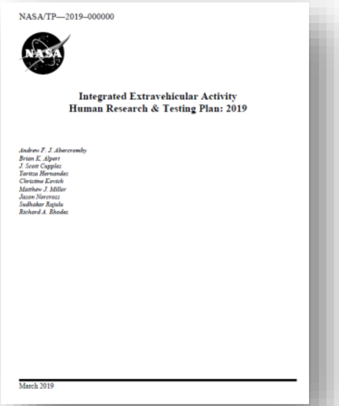
Human-Loads



Integrated EVA Human Research Plan

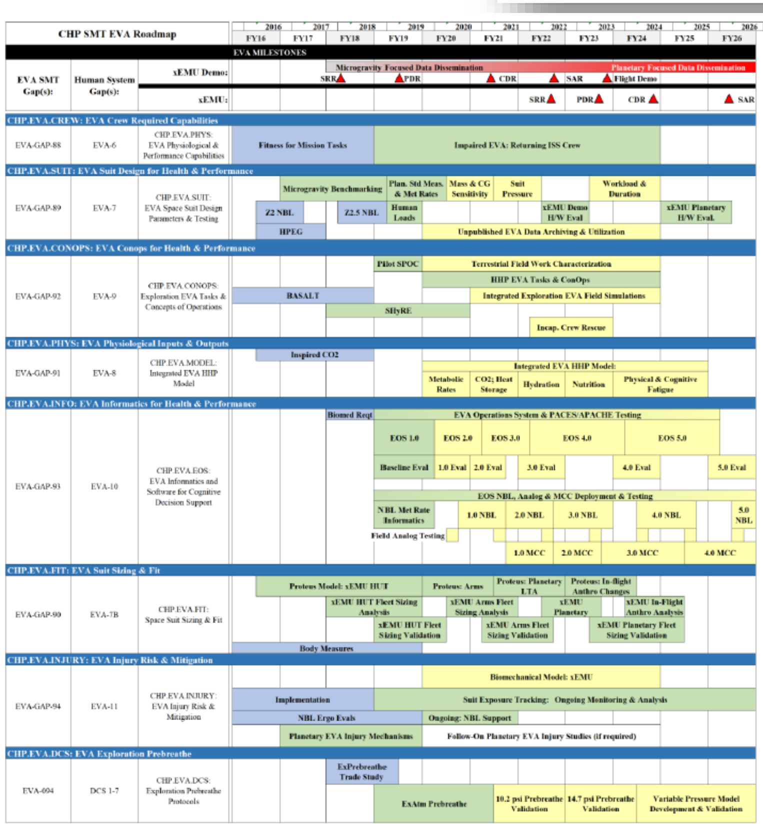
- **Updated annually**
  - Created 2016 (ICES Paper)
  - Updated 2017 (posted to nasa.gov/suitup)
  - Minor updates in 2018 (unpublished)
  - Updated in 2019 (NASA Tech Report)
- **Discuss and share testing plans & priorities**
- **Program agnostic**

Note: 2019 version finalized prior to 2024 Boots-on-the-moon direction


NASA/TP—2019-000000

Integrated Extravehicular Activity Human Research & Testing Plan: 2019

March 2019

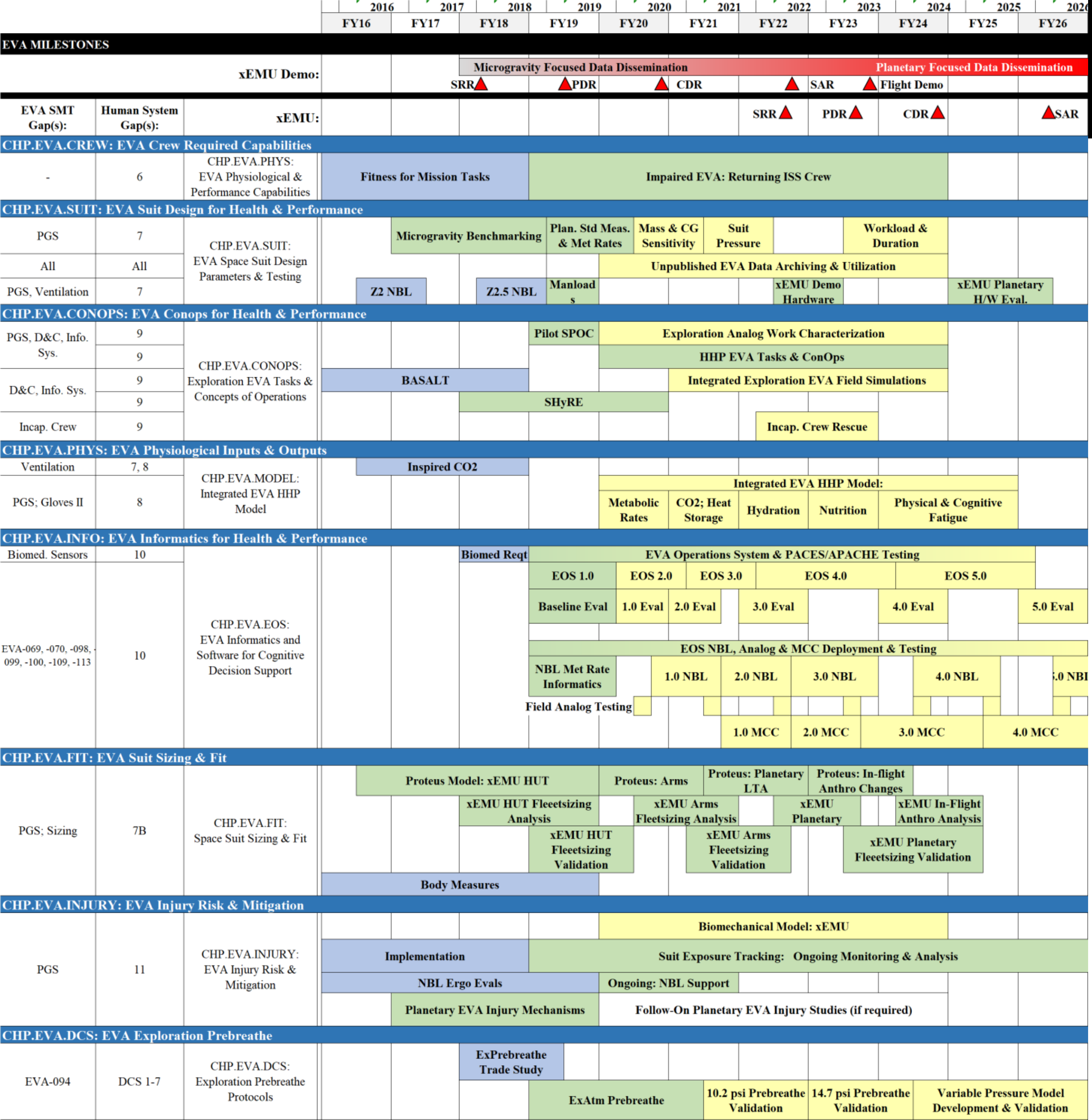


Human-centered EVA Gaps

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

Human-centered EVA Gaps

CH&P Gap Title	CHP SMT Gap ID	EVA SMT Gap No	CH&P Gap Wording
EVA Informatics for Health & Performance	CHP.EVA.INFO	EVA-Gap-93	The knowledge and use of real-time physiological, system, and operational parameters during EVA operations to improve crew health and performance (physical & cognitive) is not adequately understood.
EVA Injury Risk & Mitigation	CHP.EVA.INJURY	EVA-Gap-94	The risk of crew injury due to exploration EVA operations and methods for mitigating that risk are not adequately understood.
EVA Exploration Prebreathe	CHP.EVA.DCS	EVA-Gap-95	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.



Updates

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**

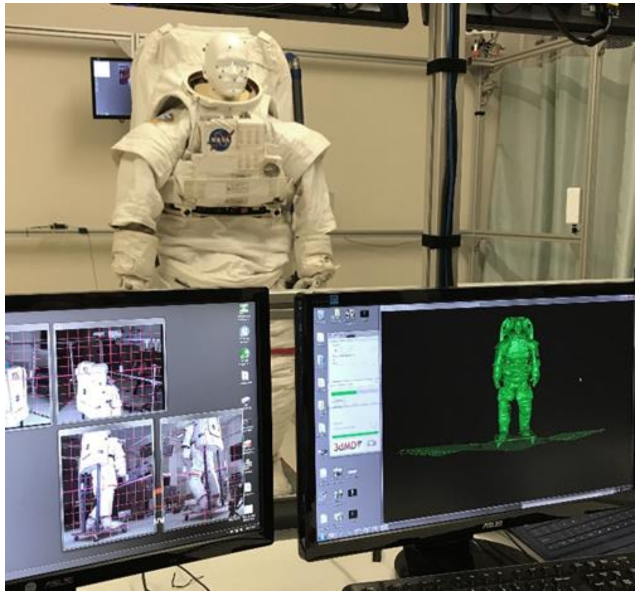
How does Moon 2024 Change Things?

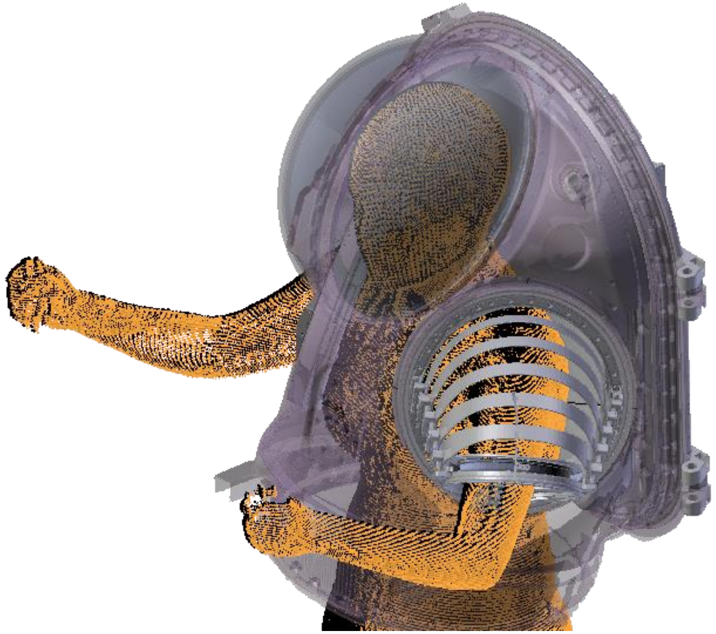
- **Boots-on-the-Moon for < 7 day missions will <u>require</u>:**
  - Prebreathe protocol validation
  - Implementation & verification of HH&P xEMU Requirements (NASA-STD-3001 Rev B)

- **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



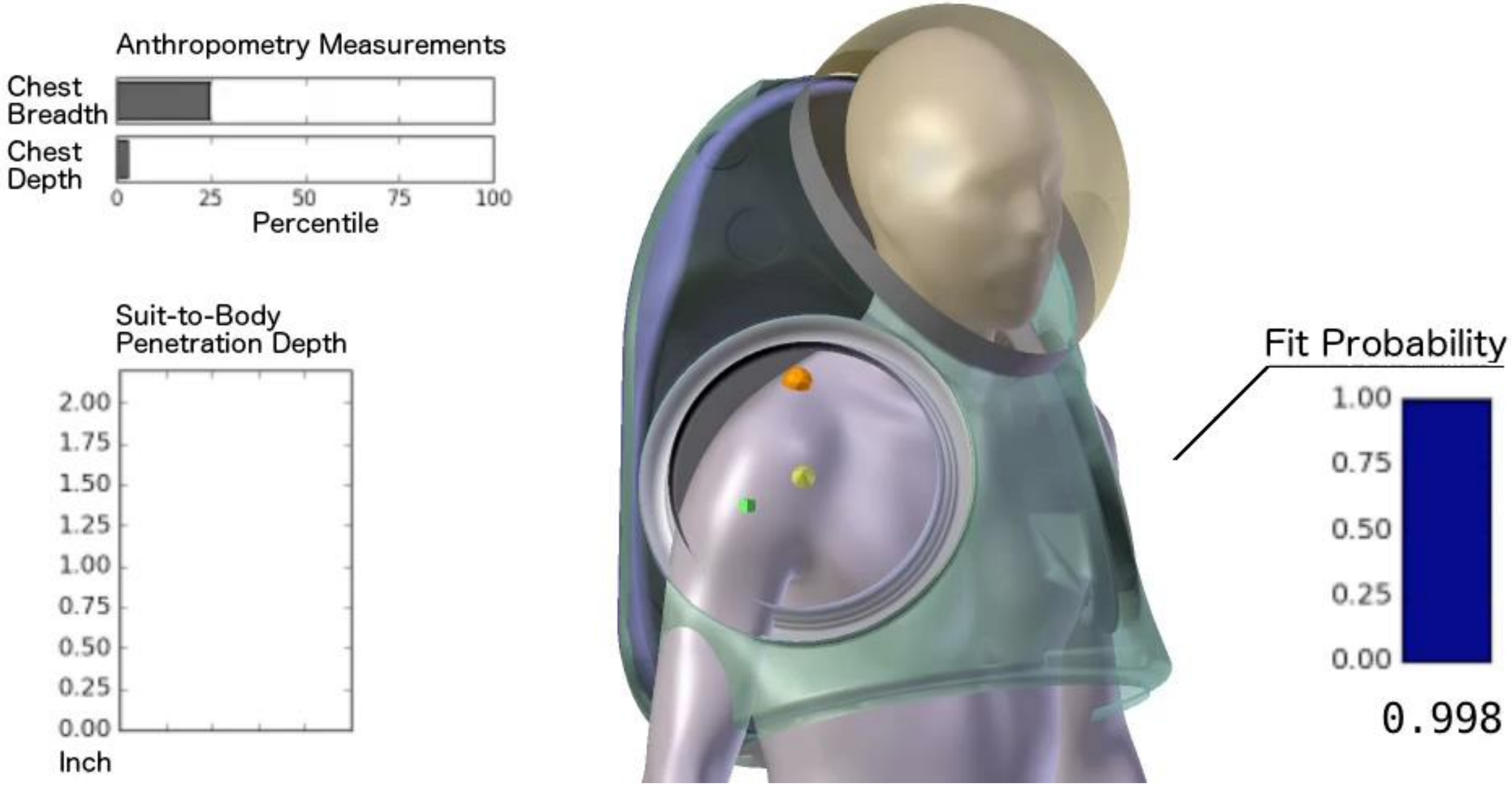


Suited scanning

Full body reach assessment

Suit Fit and Accommodation: Modeling & Validation

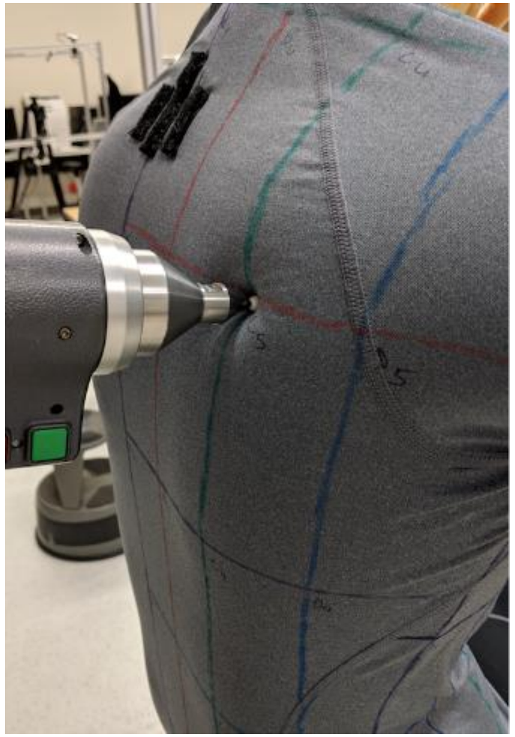
- **A computational model is being developed to predict the probability of suit fit with any person's 3D scan or anthropometry measurements**
  - The model defines the characteristics of the current and future crewmember population accommodated by the suit
  - The model can help identify the key suit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



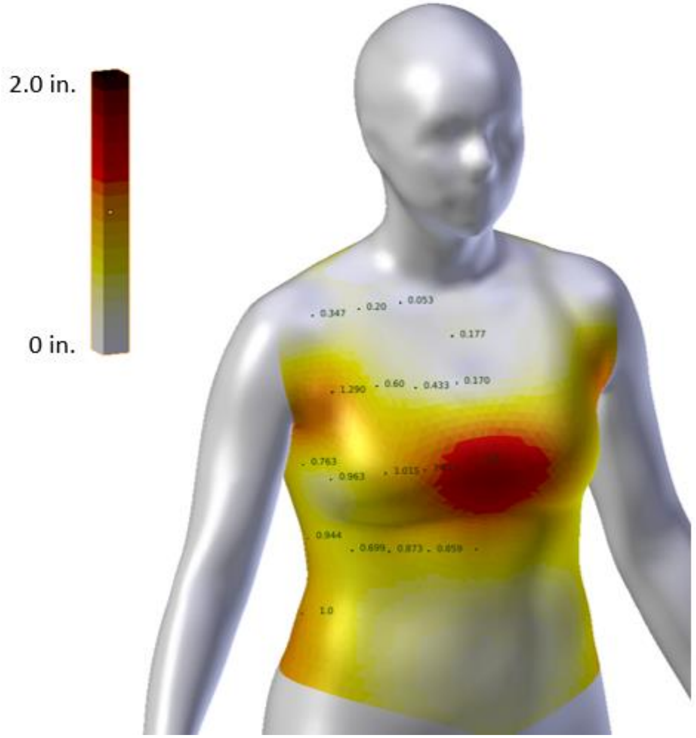
CH&P Gap Title	EVA SMT Gap No
EVA Suit Sizing & Fit	EVA-Gap-90

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

CH&P Gap Title	EVA SMT Gap No
EVA Suit Sizing & Fit	EVA-Gap-90

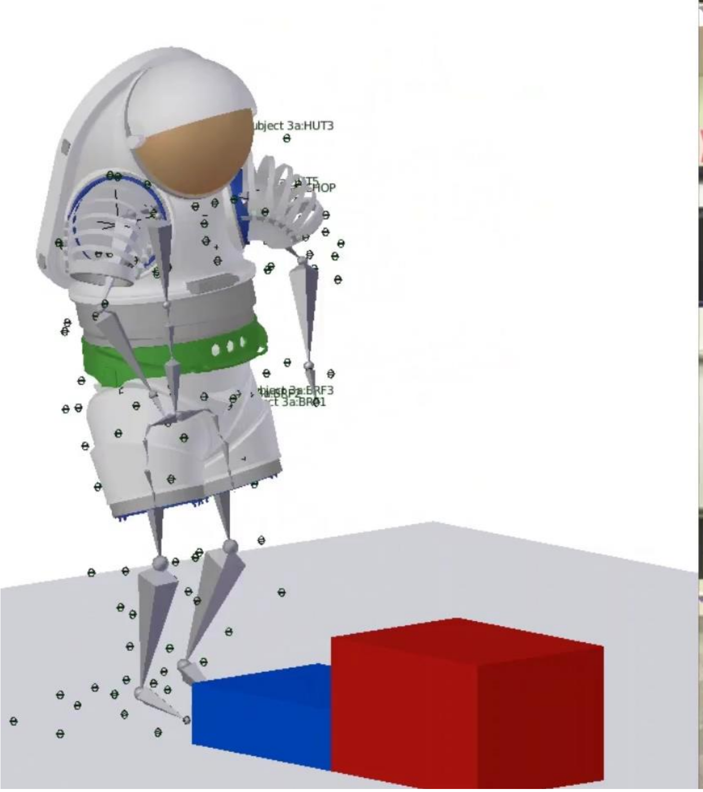
Suited Performance Testing

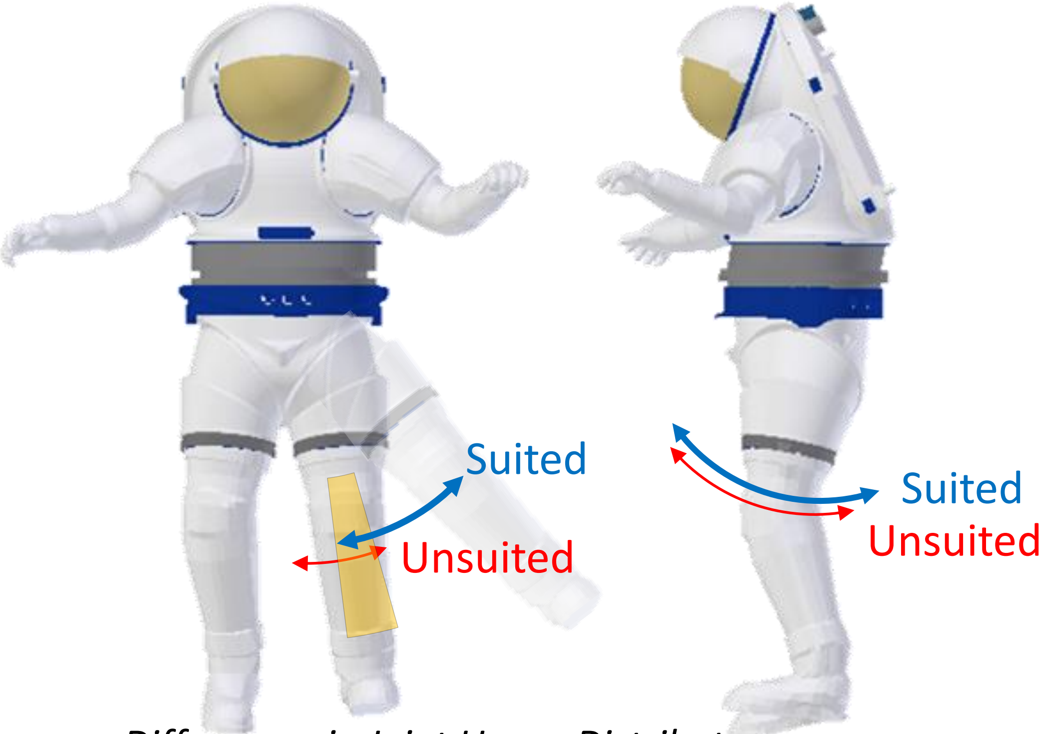
- **Crewmembers across a wide range of size and shape must not only be able to fit in the suit, but also function optimally**
  - In suited performance testing, subjects complete maximal reach envelope testing, on-suit reaches and simulated functional tasks
  - Performance is assessed and compared across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

CH&P Gap Title	EVA SMT Gap No
EVA Suit Design for Health & Performance	EVA-Gap-89

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



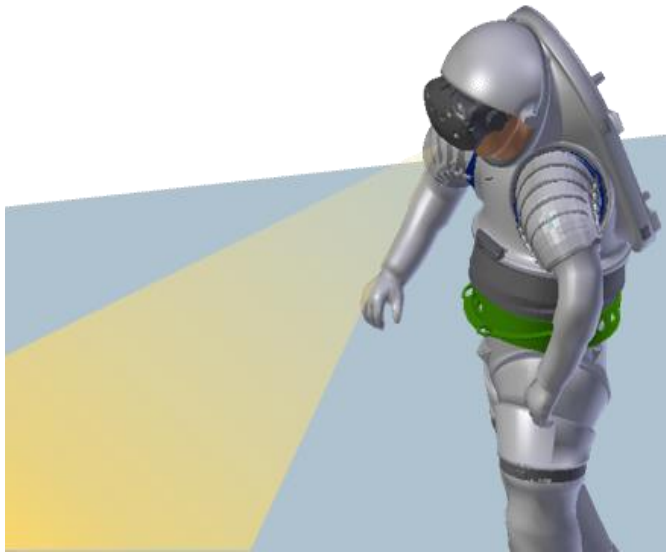


Differences in Joint Usage Distributions

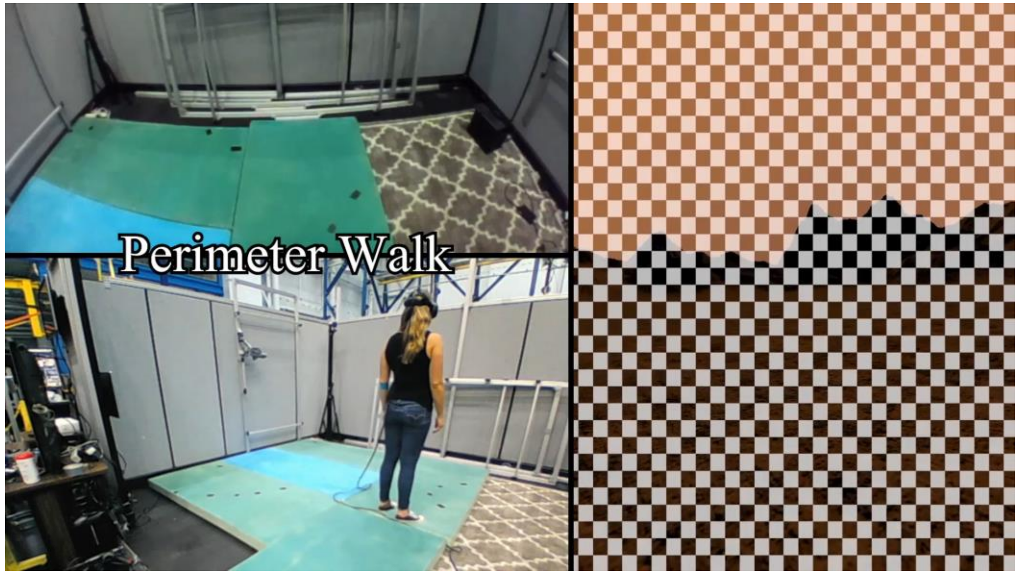
CH&P Gap Title	EVA SMT Gap No
EVA Suit Sizing & Fit	EVA-Gap-90

Building Mockup Suit Test Bed

- **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



Mockup suit and VR headset

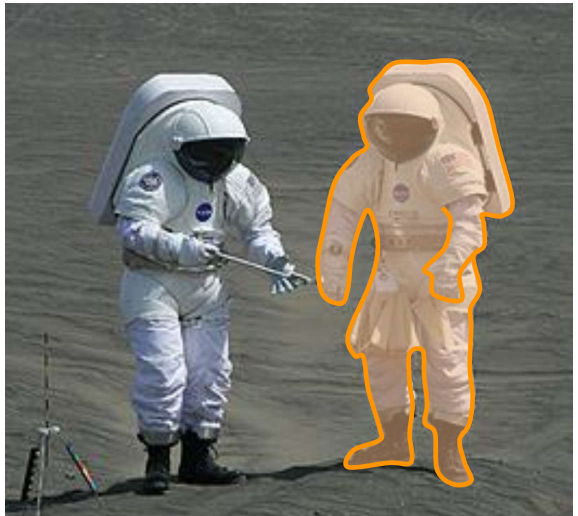


Kinematic and gaze analysis

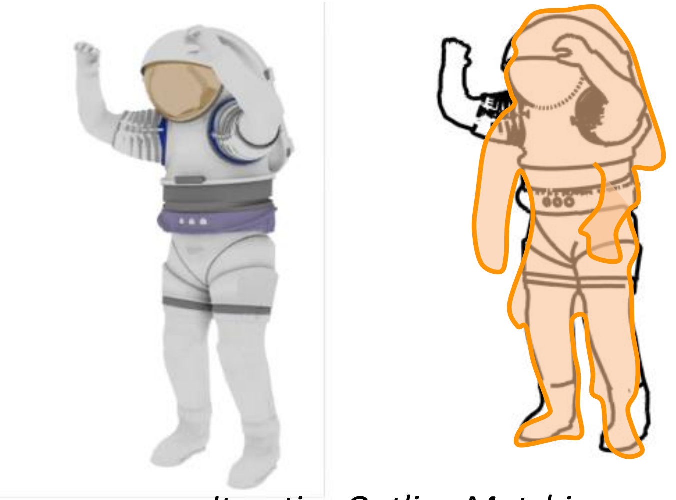
CH&P Gap Title	EVA SMT Gap No
EVA Suit Design for Health & Performance	EVA-Gap-89

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



Common Digital Photographs

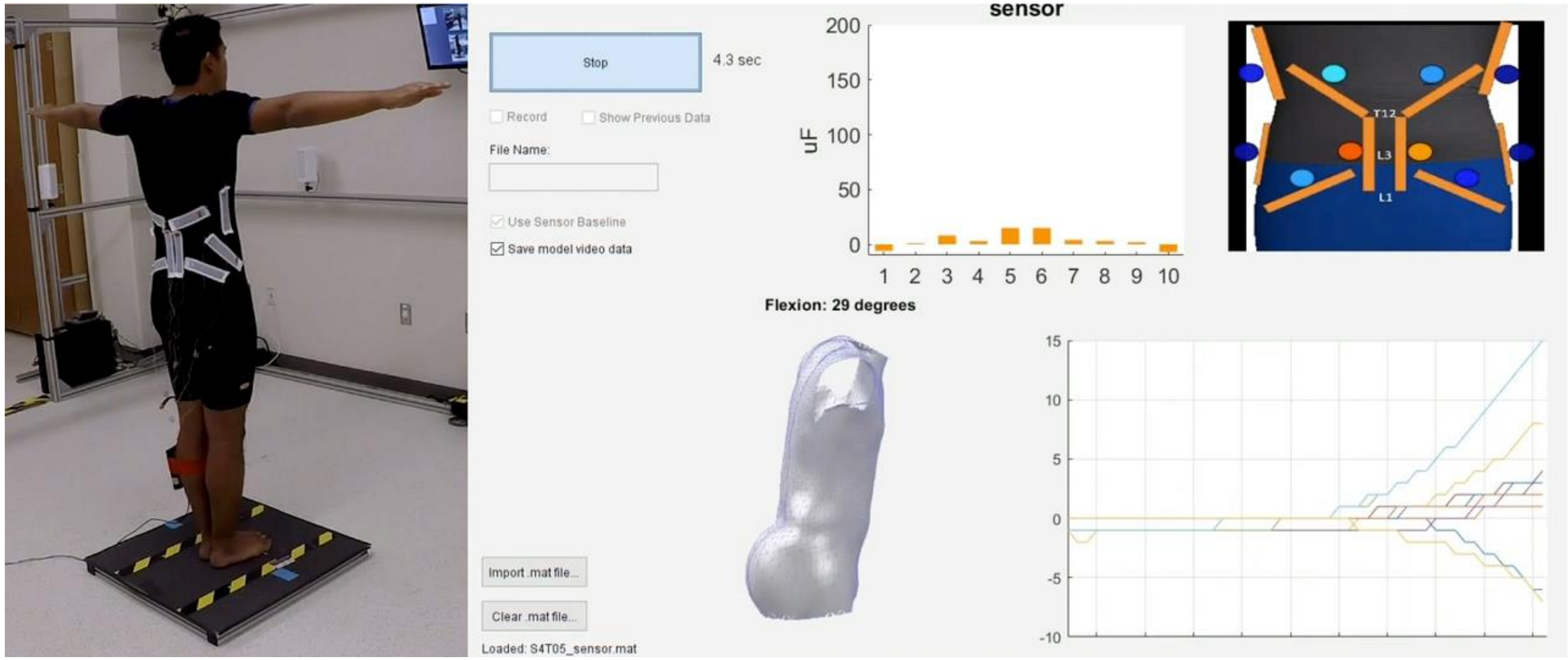


Iterative Outline Matching

CH&P Gap Title	EVA SMT Gap No
EVA Suit Design for Health & Performance	EVA-Gap-89

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

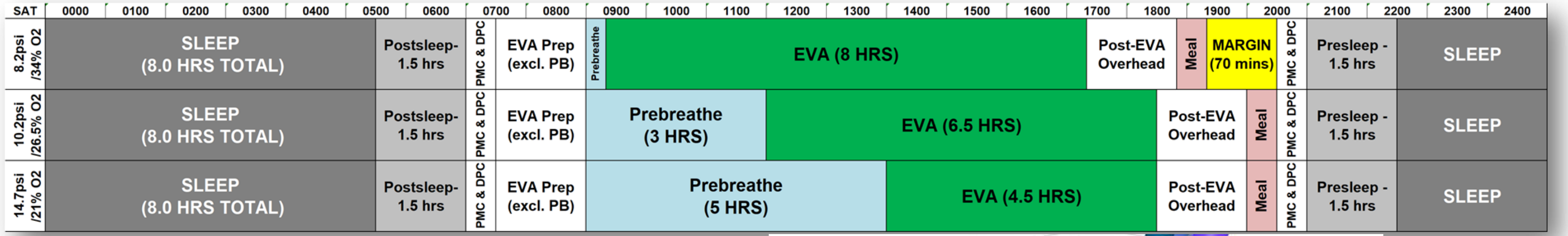


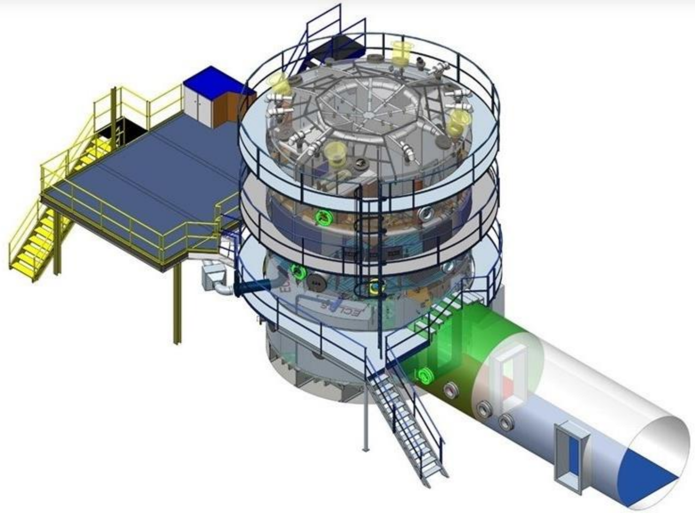
Shape prediction from sensor garment signal

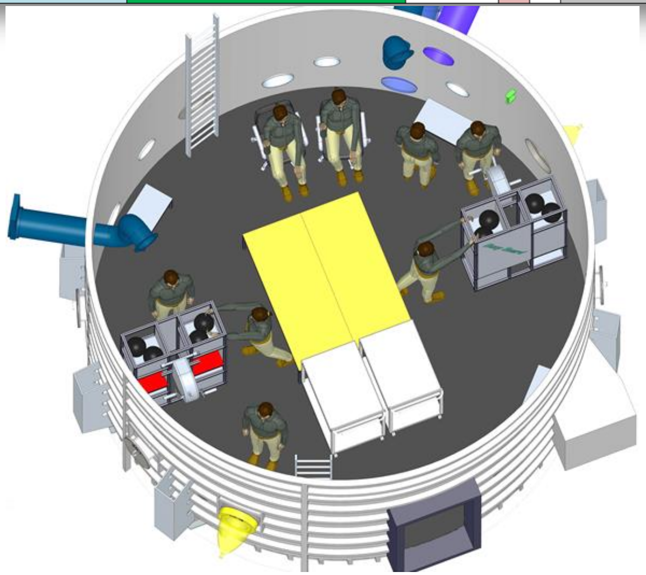
CH&P Gap Title	EVA SMT Gap No
EVA Injury Risk & Mitigation	EVA-Gap-94

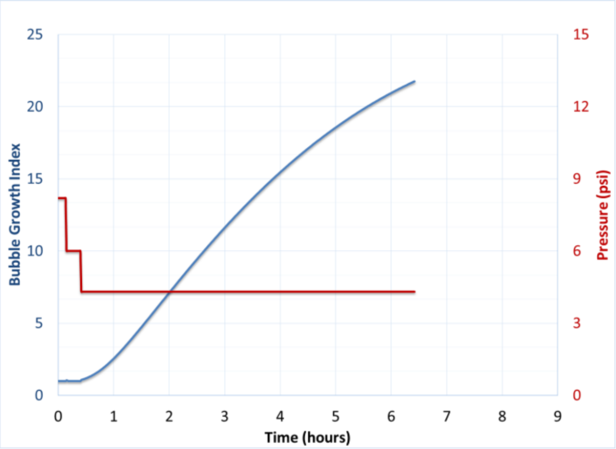
Exploration Atmosphere Prebreathe Validation

- **The exploration atmosphere (8.2 psia, 34% O_2) 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 F_IO_2 environment will be evaluated









- 6 Subjects + 2 Doppler Technicians
- Planetary EVA Simulation

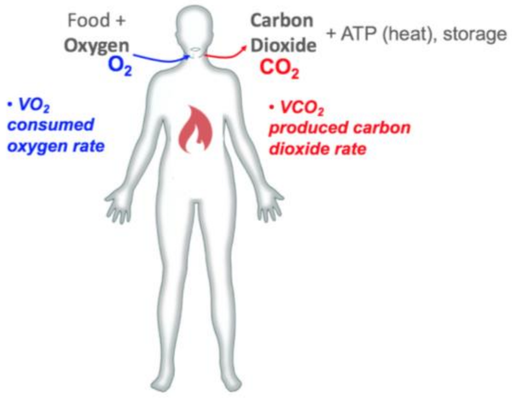
Day 1	3hr @ 100% O2, 14.7 psia; Ascend to 8.2psia / 34% O2; Equilibrate
Day 2	
Day 3	Prebreathe; 6hr EVA @ 4.3 psia, 85% O2
Day 4	Rest & Hypoxia Characterization
Day 5	Prebreathe; 6hr EVA @ 4.3 psia, 85% O2
Day 6	Rest & Hypoxia Characterization
Day 7	Prebreathe; 6hr EVA @ 4.3 psia, 85% O2
Day 8	Rest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

CH&P Gap Title	EVA SMT Gap No
EVA Exploration Prebreathe	EVA-Gap-95

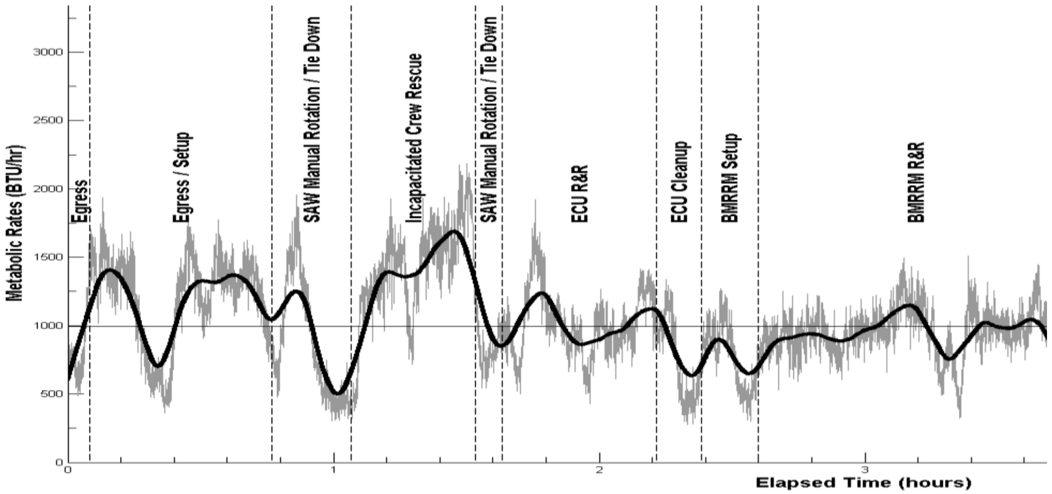
NBL Informatics

- 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

Physical Workload --> Metabolic Rate



Training Feedback and EVA Planning:



Task Timeline Tracking:

Task Analysis:

Task	Category			
EVA setup/cleanup	EVA Setup (Free-Float)	EVA Cleanup (Free-Float)		
Worksite setup/cleanup	Worksite Setup (Free-Float)	Worksite Cleanup (Free-Float)		
Other work	Miscelanous Work (Free-Float)	Cable routing (Free-Float)		
Bolts	Bolts (Free-Float)	Bolts (BRT)	Bolts (APFR)	Bolts (On SSRMS)
Fluid Connectors	Fluid Connectors (Free-Float)	Fluid Connectors (BRT)	Fluid Connectors (APFR)	Fluid Connectors (On SSRMS)
Electrical Connectors	Electrical Connectors (Free-Float)	Electrical Connectors (BRT)	Electrical Connectors (APFR)	Electrical Connectors (On SSRMS)
R&R (or install) work	R&R work (Free-Float)	R&R work (BRT)	R&R work (APFR)	R&R work (On SSRMS)

CH&P Gap Title

EVA Informatics for Health & Performance

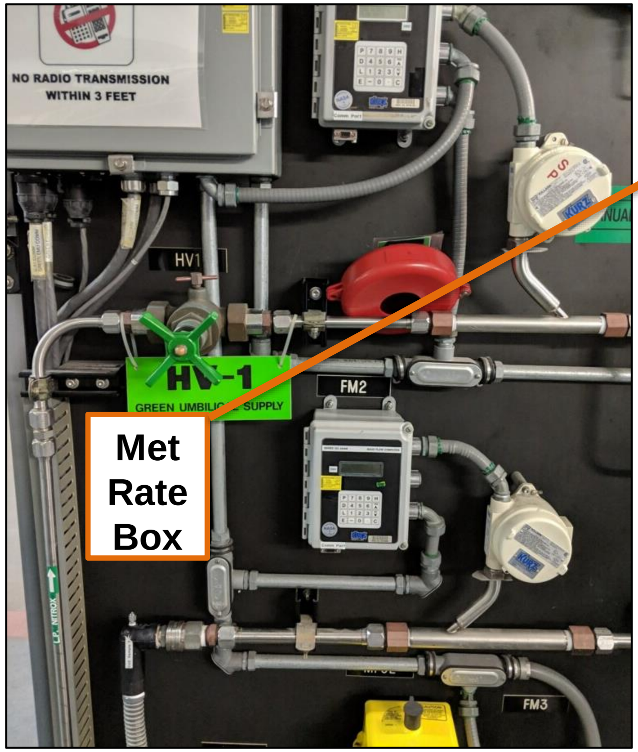
EVA SMT Gap No

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)

Current System



Upgraded System

System Components:

CO2 sensor
- Vaisala GMP 252

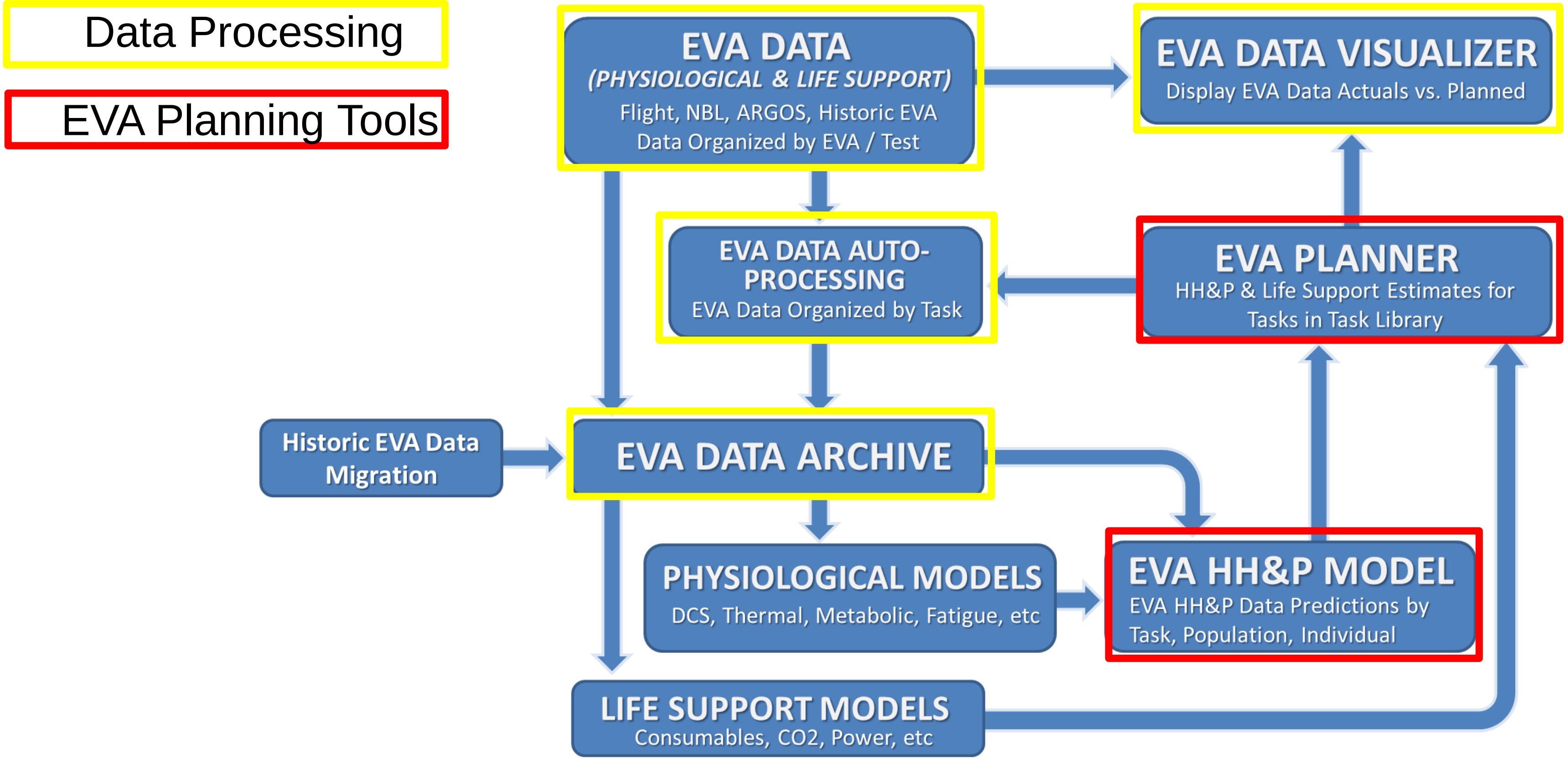
Data Acquisition
- Raspberry Pi

Connectivity
- IT Security
- Cloud Services
- Real-Time Access

CH&P Gap Title	EVA SMT Gap No
EVA Informatics for Health & Performance	EVA-Gap-93

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

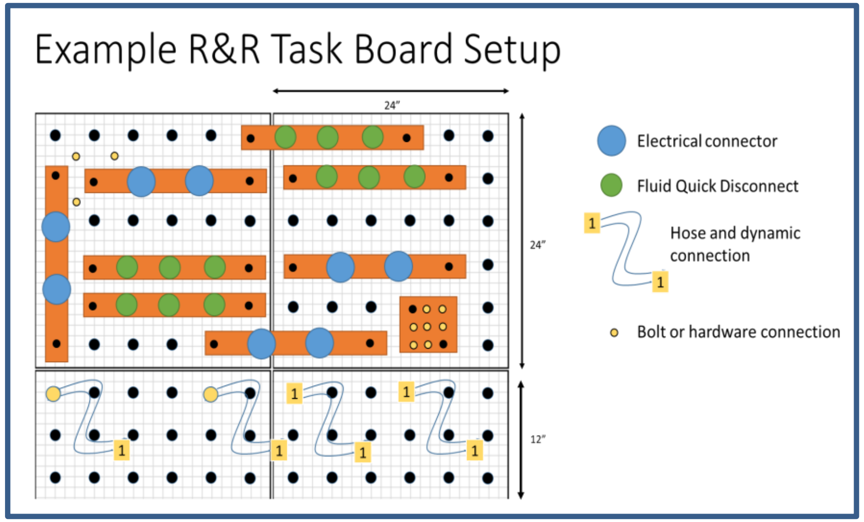


CH&P Gap Title	EVA SMT Gap No
EVA Informatics for Health & Performance	EVA-Gap-93

Planetary EVA Metabolic Task Characterization

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.



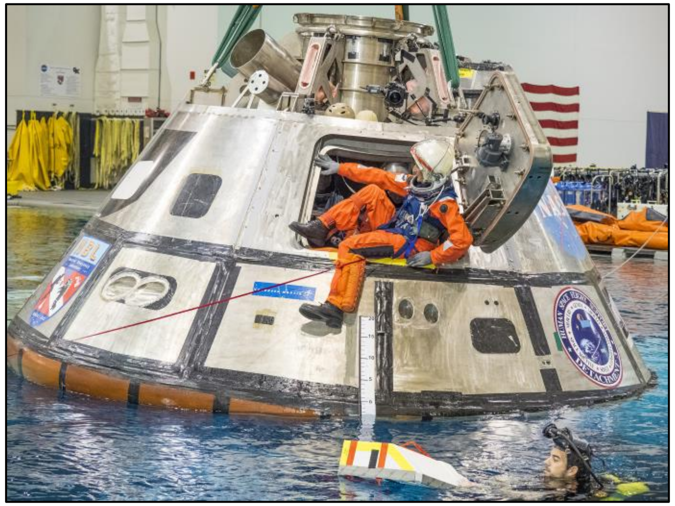
CH&P Gap Title	EVA SMT Gap No
EVA Suit Design for Health & Performance	EVA-Gap-89

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.



CH&P Gap Title	EVA SMT Gap No
EVA Crew Required Capabilities	EVA-Gap-88

Impaired EVA – Part II Early EVA

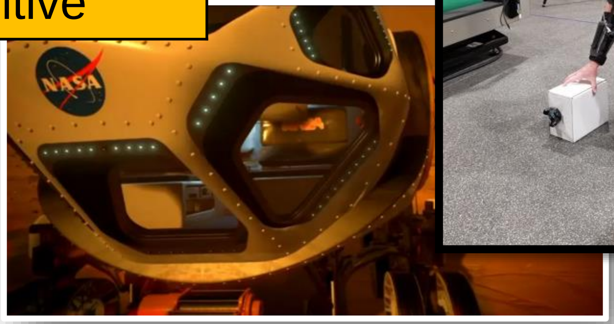
- **Tested EVA Capabilities**
  - First 24 Hours
    - Ingress EVA suit
    - Translate through hatch
    - Ladder descent
    - Walk & connect supply umbilicals
    - Object translation
    - Align with rear entry donning stand
    - Egress EVA suit
  - Additional Tasks Done Pre and Later Post-landing
    - Agility obstacle course
    - Jump down and stabilize
    - Incline/decline ambulation and instrument deploy

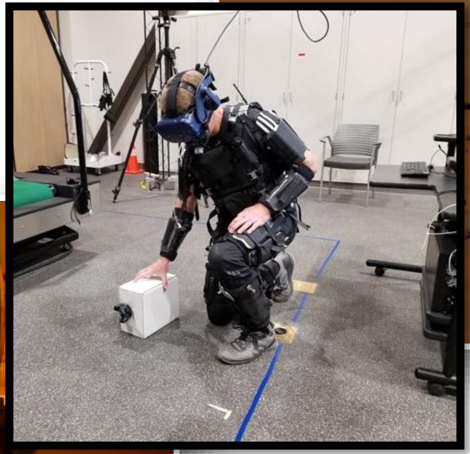
CH&P Gap Title	EVA SMT Gap No
EVA Crew Required Capabilities	EVA-Gap-88

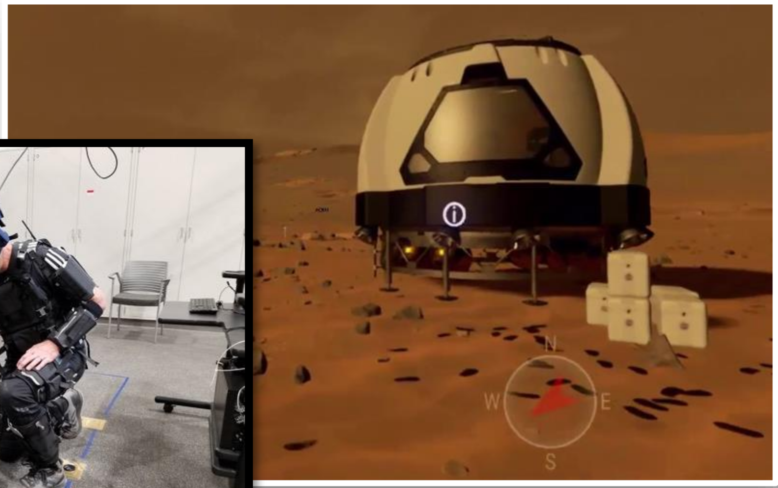
APACHE: Assessments of Physiology And Cognition in Hybrid-reality Environments

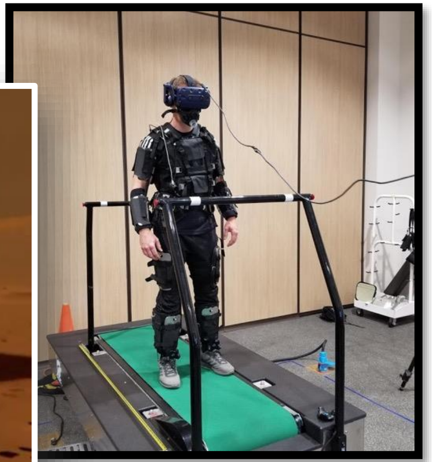
- APACHE is a **new** lab environment in the Building 21 high bay that uses a variety of techniques (Virtual/Hybrid reality, weighted suits, treadmills, audio/video communication loops) to model the physical and cognitive stress of the EVA environment.
- The lab employs a suite of data interfaces to 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.

High Physical Low Cognitive	High Physical High Cognitive
Low Physical Low Cognitive	Low Physical High Cognitive









CH&P Gap Title	EVA SMT Gap No
EVA Informatics for Health & Performance	EVA-Gap-93

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

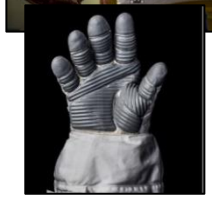
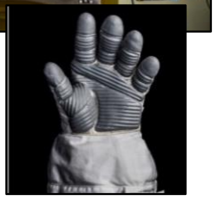
Subject Characteristics
- Age, Sex
- Anthropometry
- Strength
- Fitness

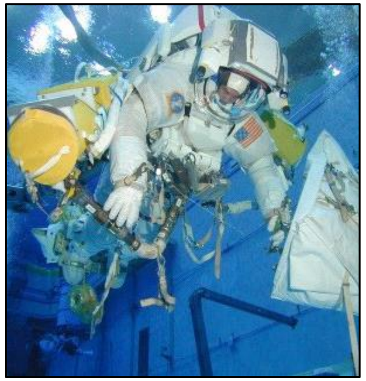
Spacesuit
- Type
- Sizing
  - Prime vs Secondary
- Pressure

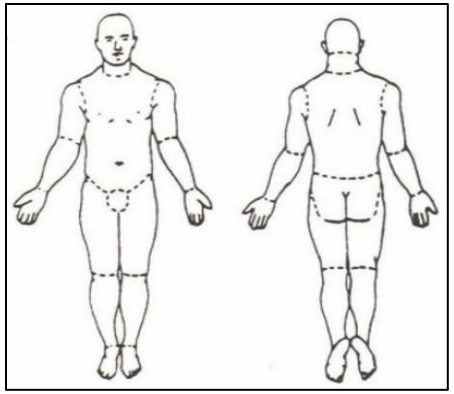
Task Characteristics
- Training
- Flight
- Research
- Facility

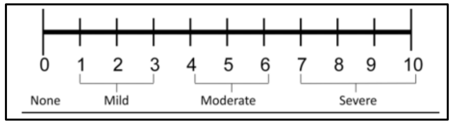
Suit Related Injury
- Yes
  - Type
  - Location
  - Severity
- No









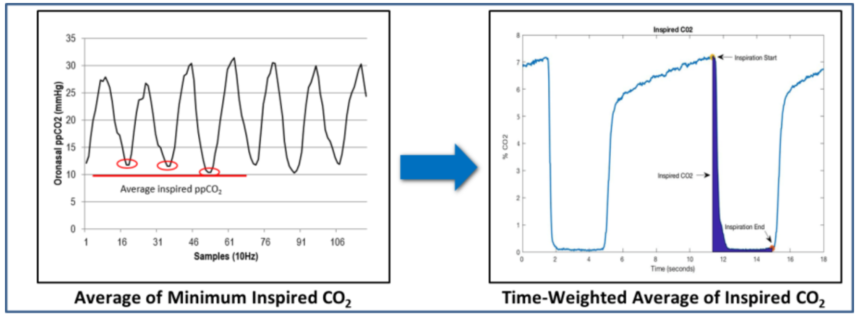
Suited Injury Likelihood & Consequence

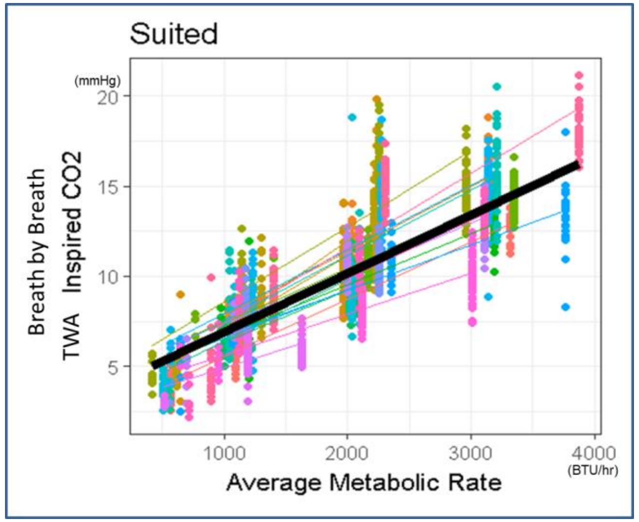
DRM Categories	Mission Duration	LxC OPS	Risk Disposition	LxC LTH	Risk Disposition
Low Earth Orbit	6 Months	3 x 1	Accepted	3 x 3	Accepted
	1 Year	3 x 1	Accepted	3 x 3	Accepted
Deep Space Sortie	1 Month	3 x 2	Accepted / Optimize	3 x 3	Accepted / Optimize
Lunar Visit/ Habitation	1 Year	3 x 3	Requires Mitigation	3 x 3	Requires Mitigation
Deep Space Journey/ Habitation	1 Year	3 x 2	Accepted / Optimize	3 x 3	Accepted / Optimize
Planetary	3 Year	3 x 3	Requires Mitigation	2 x 4	Requires Mitigation

CH&P Gap Title	EVA SMT Gap No
EVA Injury Risk & Mitigation	EVA-Gap-94

Inspired CO_2 Standard and xEMU Requirement

- Characterized historical EMU CO_2 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 CO_2 exposure limits for acute exposures during EVA





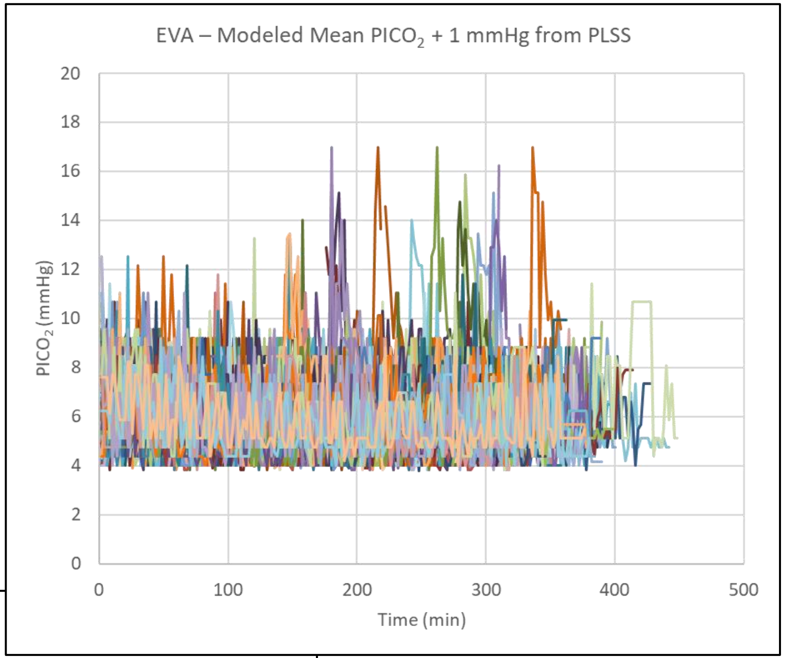
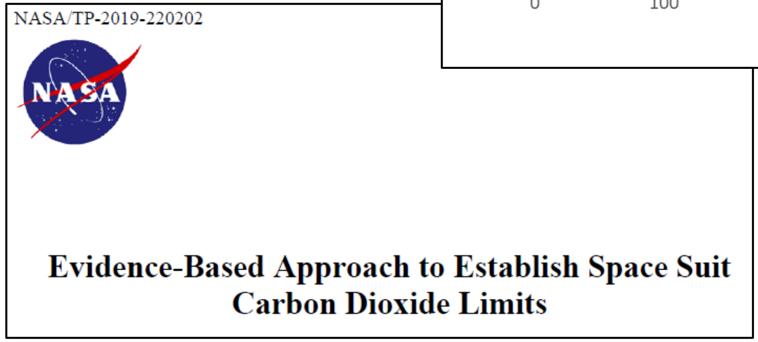


Table 1. xEMU P_ICO_2 Limits.

P_ICO_2 † (mmHg)	Allowable Cumulative Duration †† (hours per day)
> 15.0	Do Not Exceed
> 12.5	≤ 0.5
> 10.0	≤ 1.0
> 7.0	≤ 2.5
> 4.0	≤ 7.0
≤ 4.0	≤ 14.0


NASA/TP-2019-220202

Evidence-Based Approach to Establish Space Suit Carbon Dioxide Limits

CH&P Gap Title	EVA SMT Gap No
EVA Physiological Inputs and Outputs	EVA-Gap-91

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