

JHUSOM CHB Seminar Series

Monitoring and Predicting Crew Status and Risk

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EVA and Environmental Physiology Lab

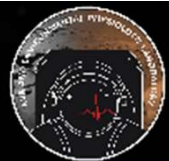
Biomedical Research and Environmental

Sciences Division (SK)

Human Health and Performance Directorate

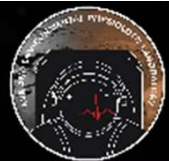
NASA Johnson Space Center (JSC), Houston, TX





Lab Introduction





Biomedical Research and Environmental Sciences (SK)



- The EVA (extravehicular activity) and Environmental Physiology Lab (EEPL) in SK supports several major functions:

- Research

- Human research studies and engineering evaluations
- *Key Projects: Egress Fitness, CO2 Studies, Hi-Tempo EVA*

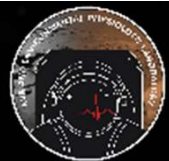
- Technology Development

- Development of EVA-related bioinformatics tools and models
- Development of EVA simulation content (physical and virtual)
- *Key Projects: Hybrid Space Suit Simulator (HS3), Assessments of Physiology And Cognition in Hybrid-reality Environments (APACHE), Crew State and Risk Model (CSRM)*

- Program Support and Operations

- Program requirements, risks and gaps identification
- MEDB metabolic rate reporting and training (NBL, ISLE prebreathe)
- Simulation and test support
- *Key Projects: Exploration Atmosphere*

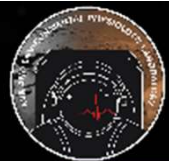




Suited Simulations and Testing

- Support various suited simulation and testing efforts at the Neutral Buoyancy Lab (NBL), Active Response Gravity Offload System (ARGOS), field-based environments, and virtual/hybrid-reality testbeds
- Characterizing human health and performance during partial-g EVA simulations has many elements to consider:
 - Develop appropriate ground-based EVA simulation content (e.g. EVA tasks, tools, and procedures)
 - Characterize relevant health/performance measures and develop capabilities to obtain those measures
 - Identify likely performance decrement injury mechanisms during exploration EVA training pipelines and flight missions.





Key EVA Training, Simulation, and Test Environments



■ NBL

- Suit: Pressurized, high-fidelity
- Offloading: 0g to 1g
- Pros:
 - Dual-EV ops
 - Distributed offload
- Cons:
 - Water (Sensors)
 - Water drag



■ ARGOS

- Suit: Pressurized, high-fidelity
- Offloading: 0g to 1g
- Pros:
 - Easily accessible and configurable
- Cons:
 - Only single-EV ops
 - Limbs not offloaded
 - Limited playspace



■ Field/Rock Yard

- Suit: Simulator
- Offloading: None
- Pros:
 - Realistic environment
 - Rover accessibility
- Cons:
 - Power and data transmission



■ APACHE

- Suit: Simulator
- Offloading: None
- Pros:
 - Highly controllable
 - Immersion
- Cons:
 - Technology-limited (e.g. haptics)
 - Limited space



NBL = Neutral Buoyancy Lab

ARGOS = Active Response Gravity Offload System

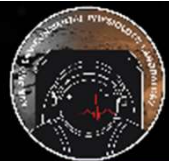
APACHE = Assessments of Physiology and Cognition in Hybrid-reality Environments





Crew State and Risk Model

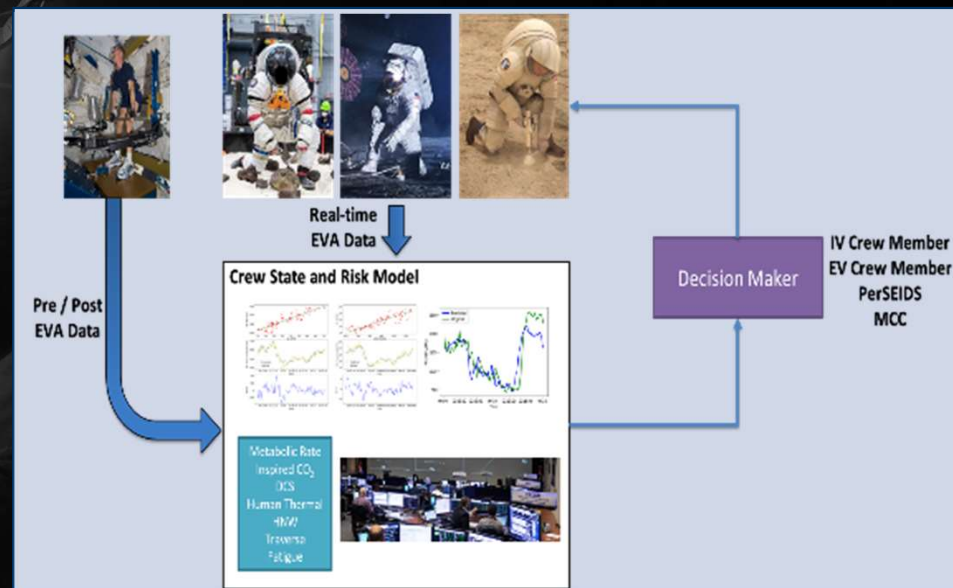


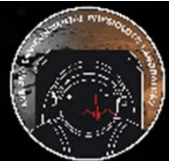


Crew State and Risk Model (CSRM)



- The **CSRM** will provide individualized modeling of the EVA crewmember physical and cognitive parameters, as well as prediction of crew state and associated risk based on the EVA task(s) and scenarios
- Each model will be developed, tested, and validated as **individualized, task-specific models**
- This capability will also be used to provide probabilistic risk estimates and crew state predictions for development of mission architectures and concepts of operation via Personalized EVA and Informatics Decision Support (**PersEIDS**).



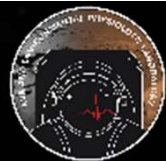


Crew State and Risk Model (CSRM)



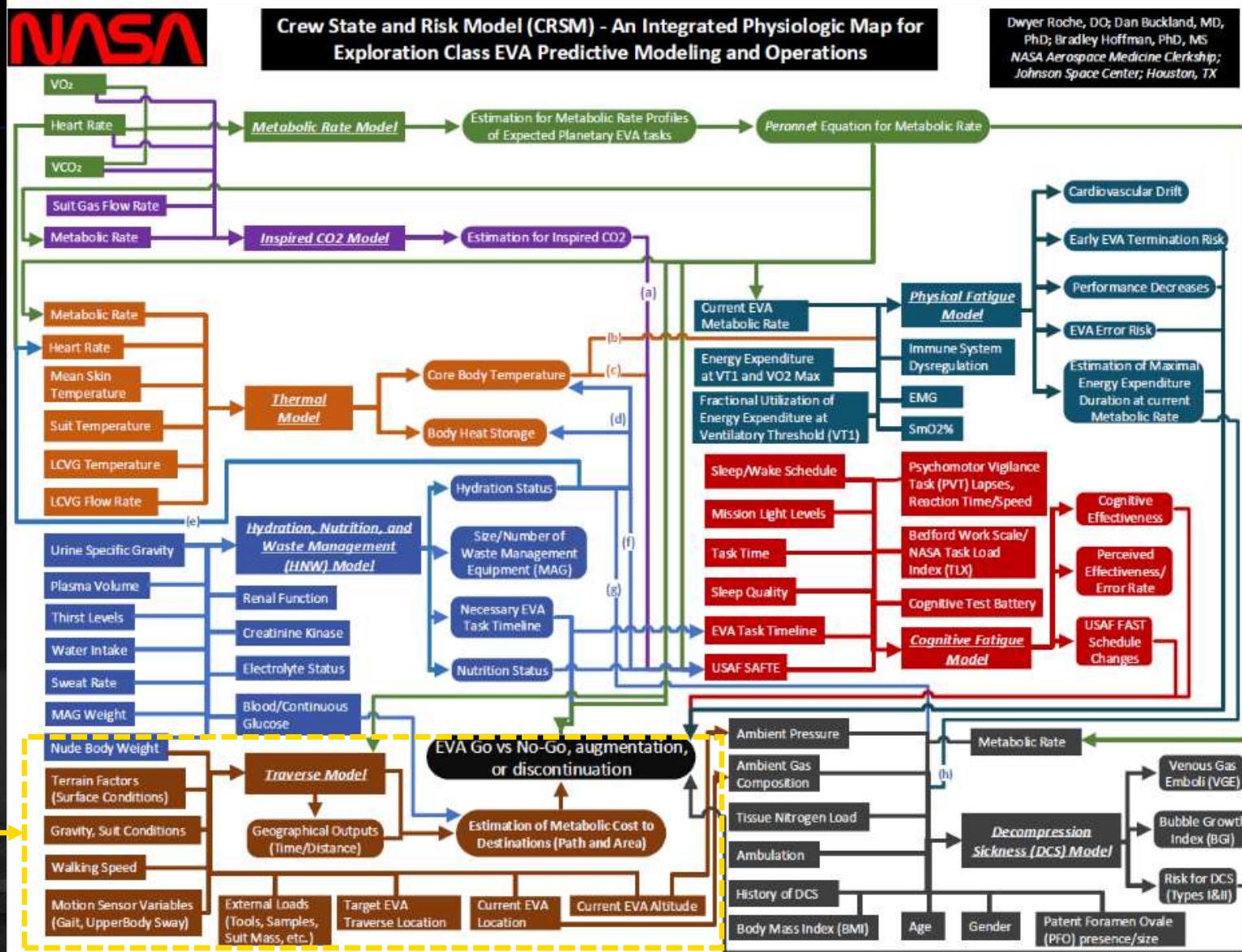
- These parameters will fuel development of core models, which will be developed and validated 1-2 at a time – Baselined physiology models italicized
 - *Metabolic Rate*
 - *Heart Rate*
 - *Inspired CO2*
 - *Human Thermal Regulation*
 - *Hydration, Nutrition, and Waste Management (HNW)*
 - *Decompression Sickness (DCS)*
 - Fatigue (Cognitive and Physical)
 - Traverse (Metabolic cost of ambulation)
- Additional models may be incorporated or developed in the future.

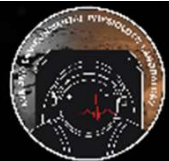




CSRM Map

Traverse model

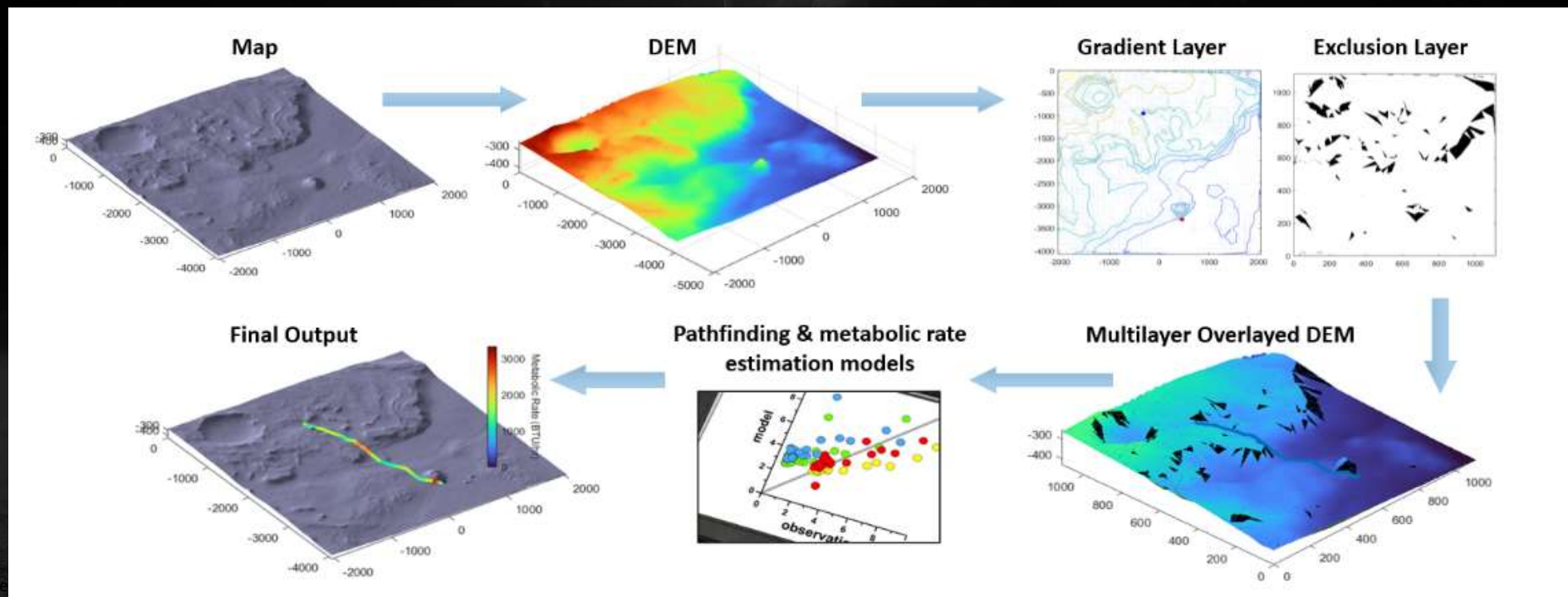




Traverse Model



- *The traverse model aims to*
 - Accurately estimate the metabolic cost of EVA ambulation in simulated exploration EVA environments.



JSC's rock yard traverse

Mixed terrain

- Three craters (one larger crater (~18 m inner diameter) and two smaller craters, consisting of gravel)
- Sand dunes (soft sand dune area, with a few, short, beach-type dunes)
- Sloped hill (~15 degree grade and a maximum altitude of ~9 m)



Flat terrain with obstacles

- Rock field, a flat field strewn with volcanic rocks/ boulders, ranging from fist-sized to ~3 ft in diameter

Flat terrain

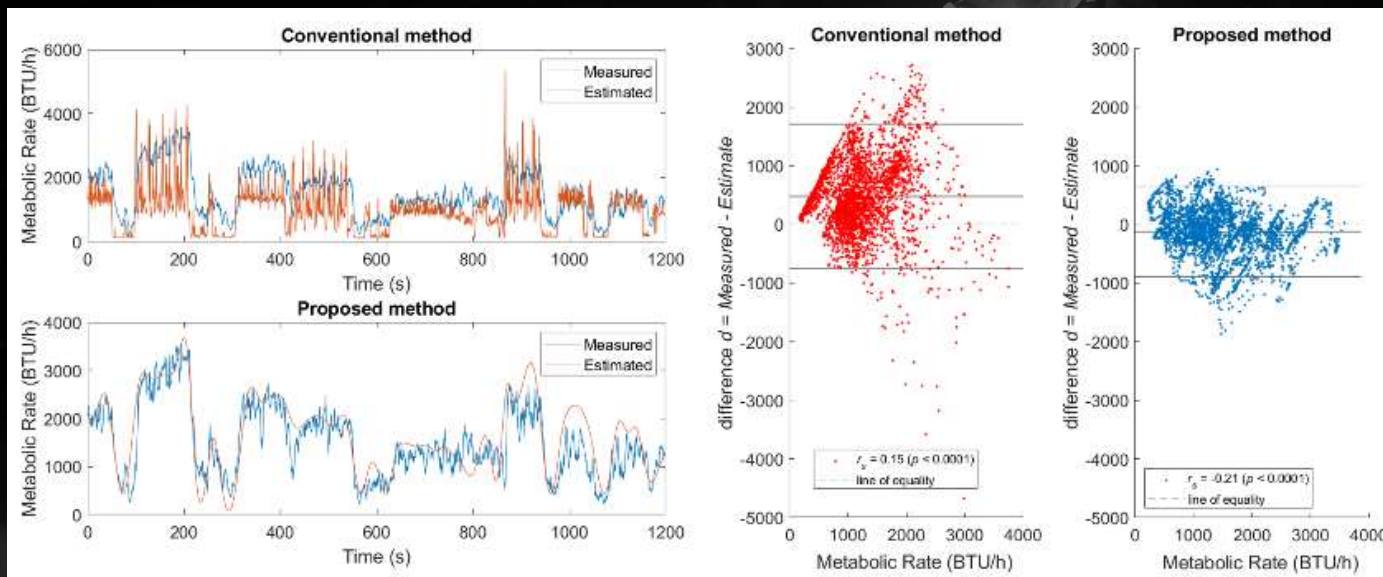
- Consisted of the path as flat as possible to represent the low workload condition





Field Metabolic Rate Estimation

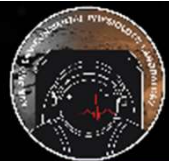
- APACHE dataset to compare estimated metabolic workloads



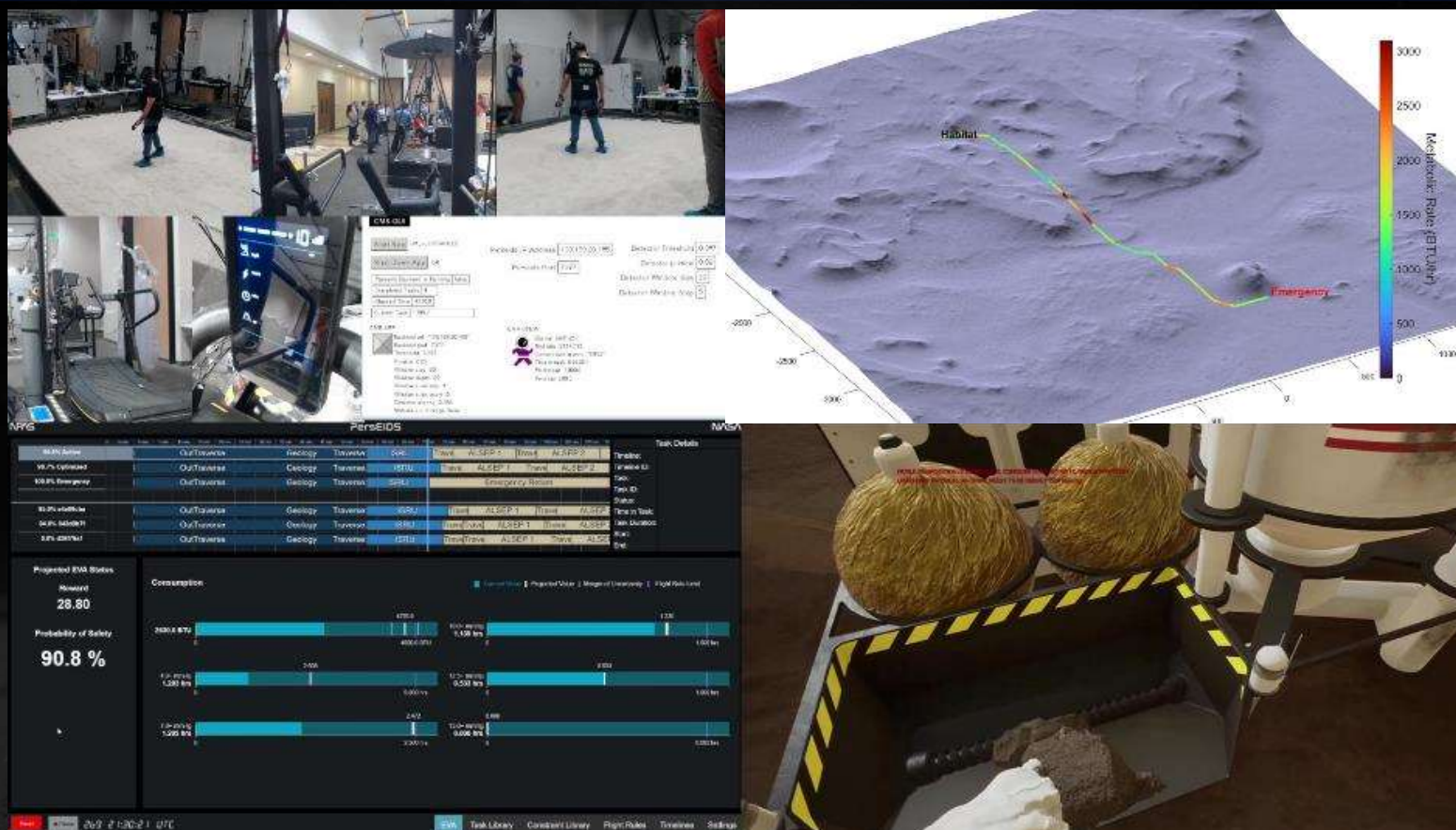
Bland-Altman plots of the conventional Santee model (RED) and the proposed field purpose traverse model (BLUE) based on the modified Pandolf model.

- The treadmill-based estimation models predicted metabolic rate with less accuracy in actual field-based conditions.
- The traverse model included factors for compensating model input sensitivities and metabolic adaptation delays.
- Our study showed that the proposed traverse model predicts the metabolic rate of open-field ambulation against the rates measured by COSMED K5 with the highest accuracy.*

* Kyoung Jae Kim et al (2025) A Consolidated Tool for Planning and Analyzing Simulated Exploration Traverses and Associated Metabolic Workload, ICES, Accepted



VR Applications for PersEIDS



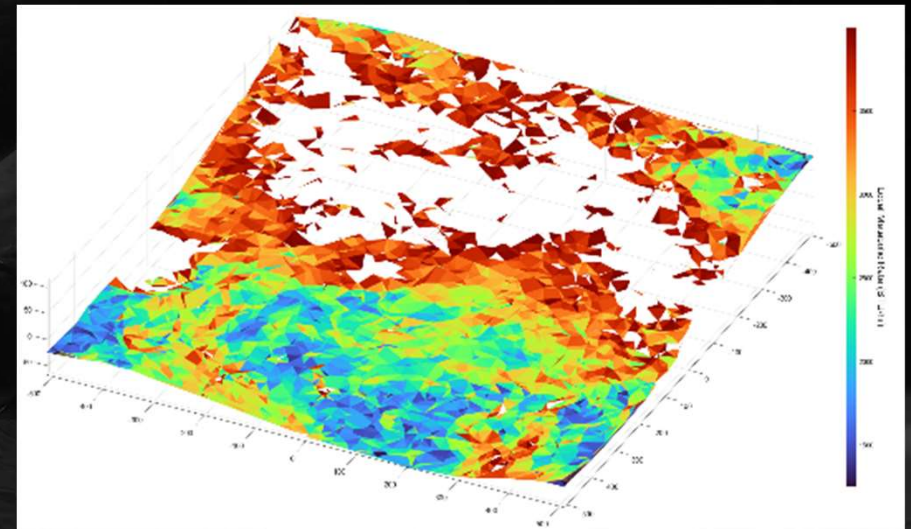
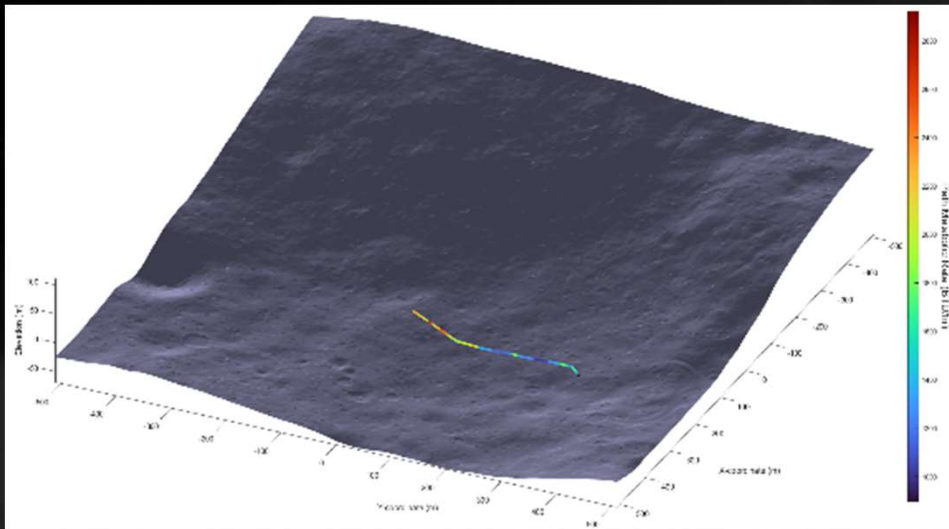


Spatial Estimation & Visualization

- Expanding the path-based metabolic rate to the local (spatial) metabolic rate

Path metabolic rate

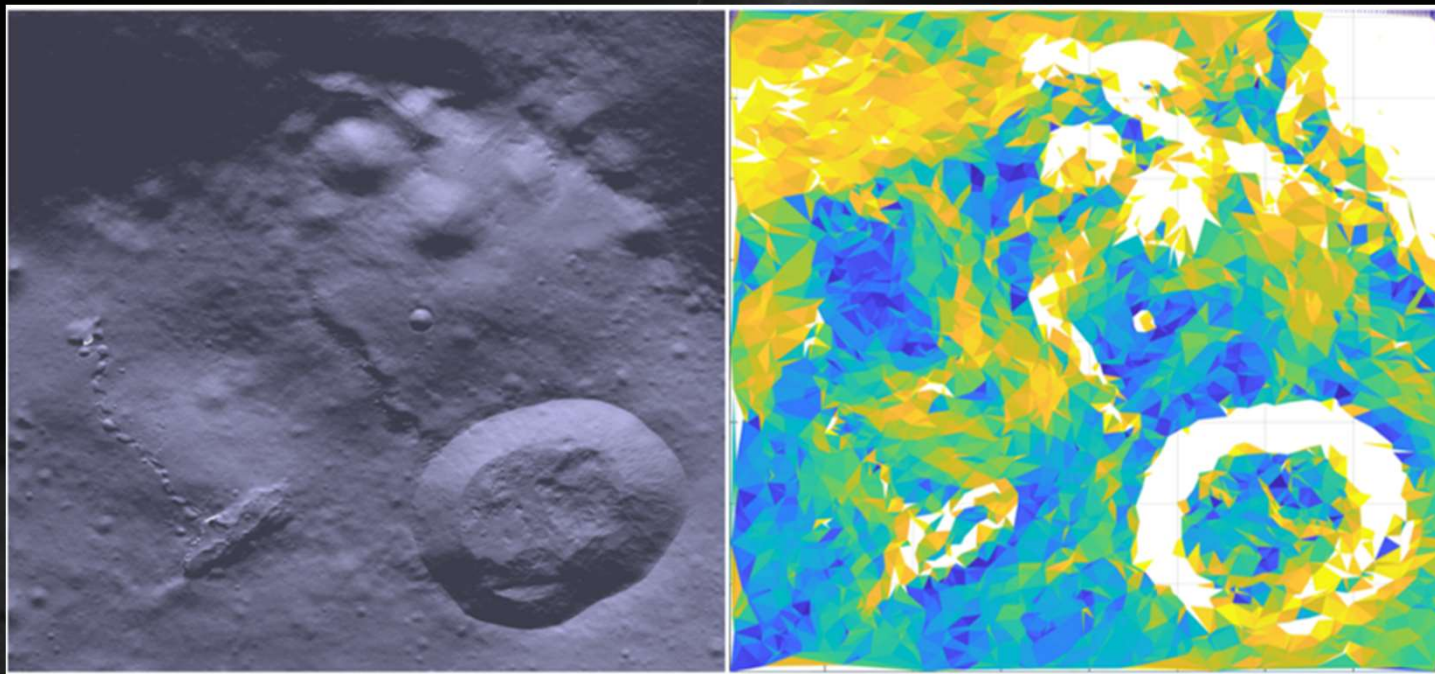
Local metabolic rate





Spatial Estimation & Visualization

- Site04: Shackleton environment. The traverse model identifies regions that correspond to low intensity (blue zone) and high intensity (yellow zone) based on the desired threshold. The empty white areas are surfaces with a slope $> 20^\circ$ and a slope $< -20^\circ$, which are inaccessible.

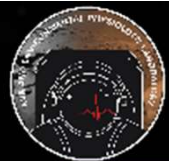




Considerations for Lunar and Mars Environments

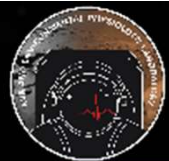


- Reduction in weight/gravity should be factored into the model when estimating metabolic rates.
- Spacesuits may also affect an astronaut's movement and increase energy consumption. Our investigation found that the estimated metabolic rate was underpredicted when the pressurized suit condition was not considered compared to when it was.
- Walk-run transition
 - Apollo astronauts reported that walking heel-to-toe in 0.17 g was more challenging and energy-consuming, especially when they had to transition at a faster speed.
 - Walking and running incur different metabolic costs, and in reduced gravity environments (< 0.5 g), running uses less energy per unit distance than walking.
 - Spacesuits adversely impact the metabolic cost of walking more severely than running, likely due to the spring-like nature of space suit pressure forces.
 - Apollo space suits were 100% self-supporting in 0.17 g.
 - How will new exploration spacesuits relate?

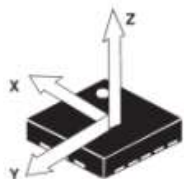


Motion Monitoring for Physiological Analysis



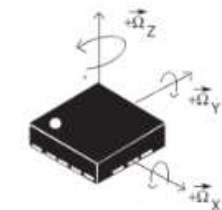


Inertial Measurement Units (IMU)



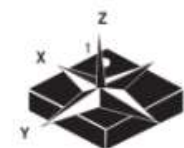
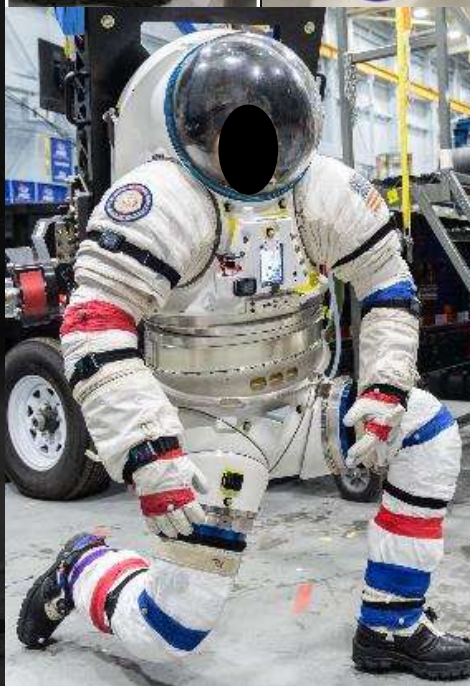
Accelerometer

Measuring acceleration
Including acceleration
due to gravity



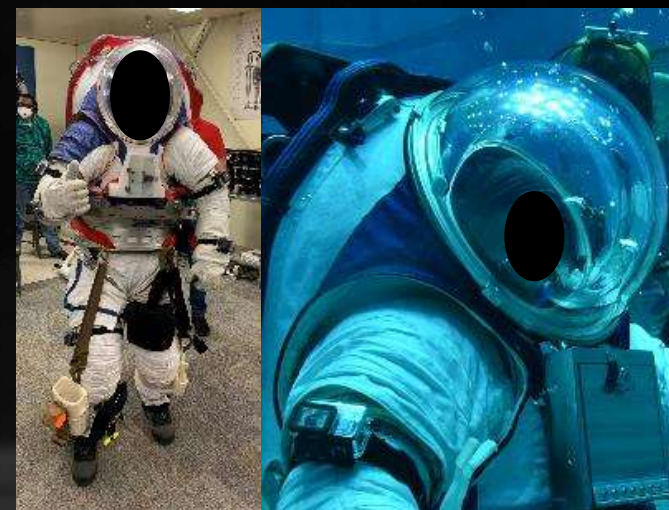
Gyroscope

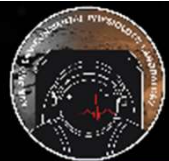
Measuring angular
velocity



Magnetometer

Direction of magnetic
north



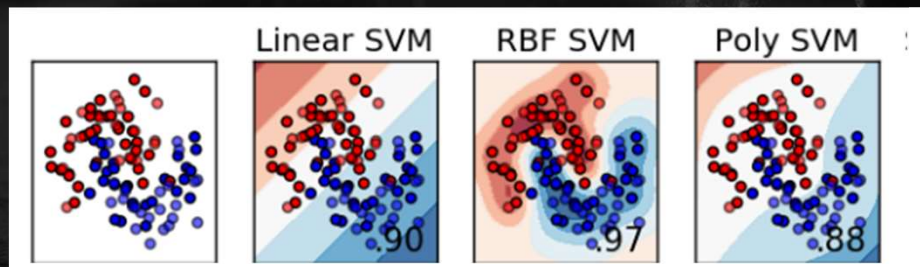


Machine Learning Classifier

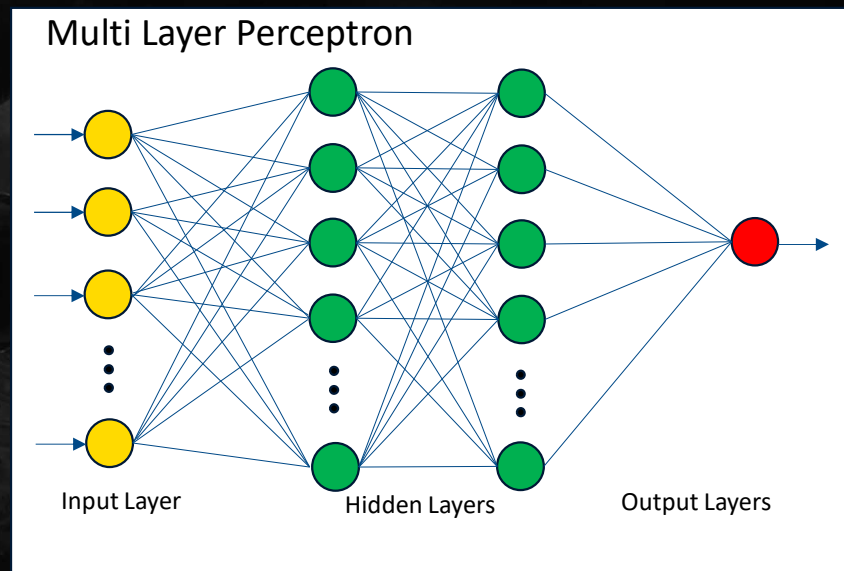
- Binary and multi-class
- Random under sampling

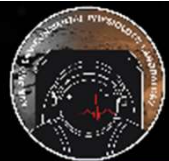


- Support Vector Machine (SVM) – sorting based on hyperplane division
 - Linear – low time complexity
 - Polynomial kernel – degree 3
 - Radial basis function (RBF) kernel – gamma scale



- Multi-layer perceptron (MLP) – neural network
 - Commonly used for non-linear classification
 - Used 2 hidden layers (with 64 and 32 neurons), ReLu activation function, and max 500 iterations of forward/ back propagation





Posture Classification



Label: **Not Kneeling**

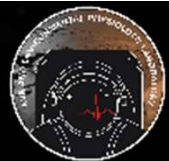
Prediction: **Not Kneeling**



Label: **Kneeling**

Prediction: **Kneeling**

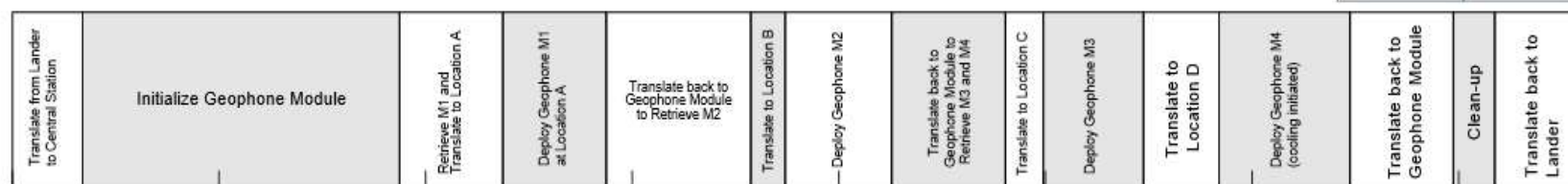
Kyoung Jae Kim, et al. (2023) Development of an Inertial Sensor-Based Methodology for Spacesuited Lunar Geology Task Assessments, *IEEE Aerospace Conference*



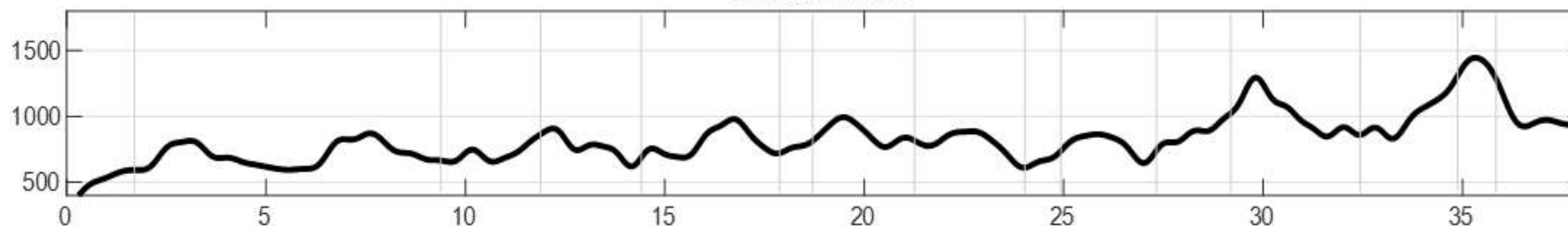
Posture-based Physiological Analysis



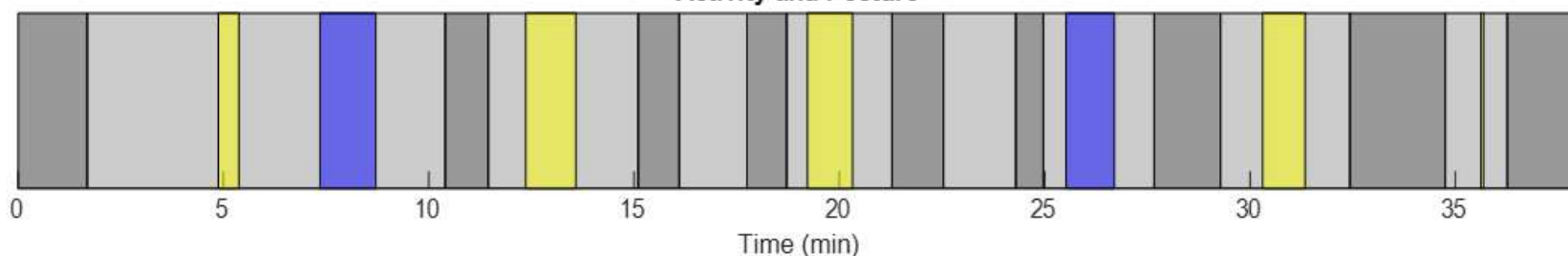
Task Label



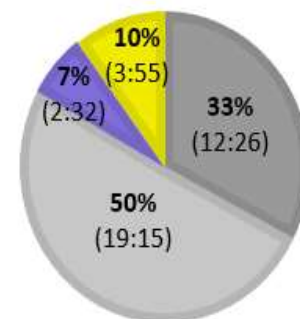
Metabolic Rate



Activity and Posture

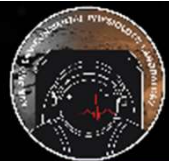


% (cumulative time) of Activity and Posture

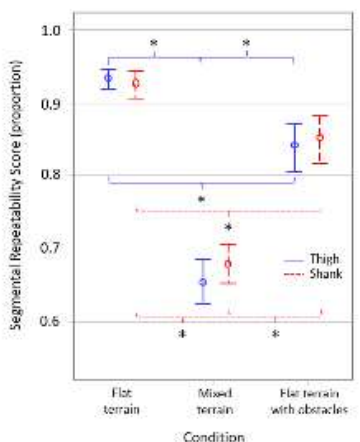
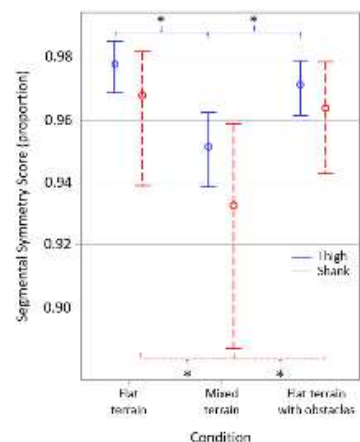
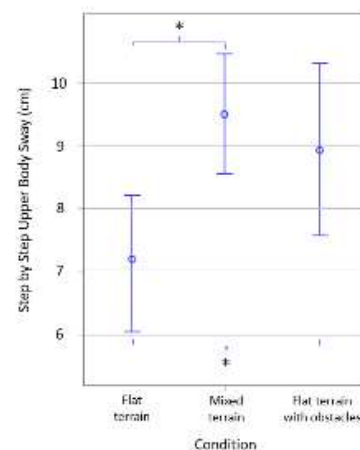
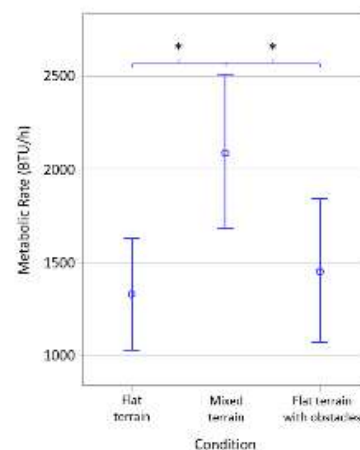


*Total duration: 38m 9s

- Translation (ambulation)
- Functional activities with the standing postures
- Functional activities with non-standing postures (kneeling down with one knee)
- Functional activities with non-standing postures (kneeling down with both knees)

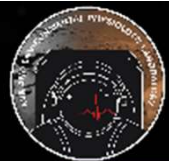


Field Motion Analysis



- The gait regularity and upper body sway parameters are more sensitive than total energy expenditure in discriminating between different terrain environments.
- Wearable technologies can be essential tools in planetary EVA simulations that aid in characterizing physical workloads for future lunar EVAs, inform crewmembers of potentially hazardous movements, and allow the prediction of metabolic burden.





Considerations for Lunar and Mars Environments



- Integration with a real-time data streaming and monitoring app for live classification of posture based on wearable sensors.
- Supporting the CSRM's traverse model by monitoring and evaluating the motion-based physiological data of crewmembers
- Will be necessary for future autonomous operations and decision-making when communication delays prevent real-time communications with mission control, as with missions to Mars.



*A Next-generation spacesuit for the Artemis astronauts (Credit: Axiom Space).



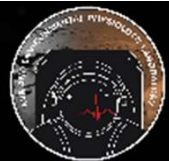


Thank you!

The presented efforts were funded by Mars Campaign Office (MCO).

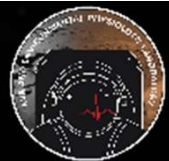
Contact: kyoungjae.kim@nasa.gov



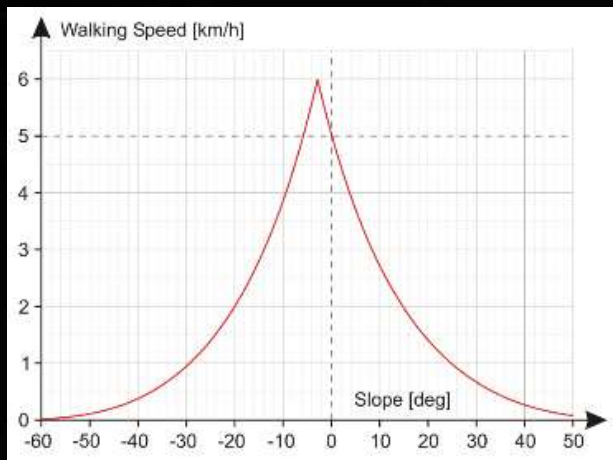


Backup





Walking Speed Model

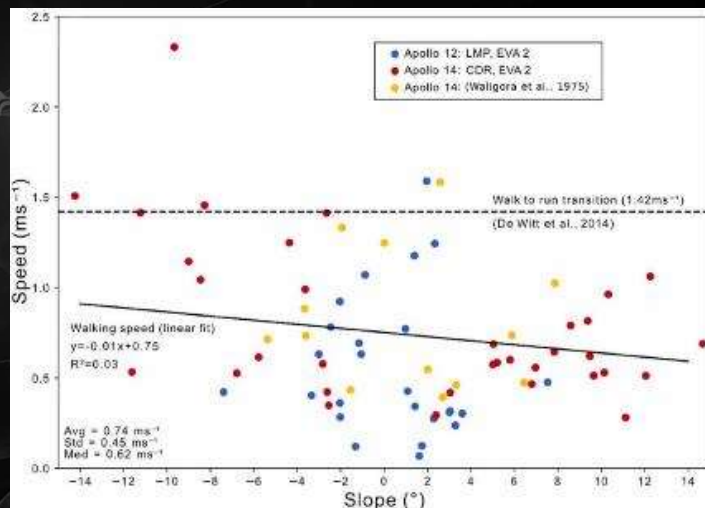


Earth Walking Speed Model (exponential fit)

$$W = 6 \cdot e^{-3.5 \left| \frac{dh}{dx} + 0.05 \right|}, \frac{dh}{dx} = S = \tan \theta$$

where the model variables are walking velocity (W in km/h), elevation difference (dh), distance (dx), slope (S), angle of slope (θ , inclination).

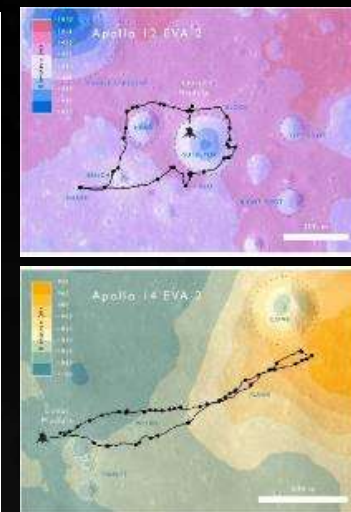
Tobler, W., 1993. Three presentations on geographical analysis and modeling: Non-isotropic geographic modeling speculations on the geometry of geography global spatial analysis. NCGIA Technical Report. 93 (1), pp. 1-26.



Lunar Walking Speed Model (linear fit)

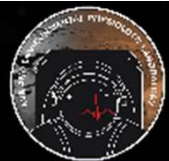
$$V = -0.01 \cdot S + 0.75$$

where the model variables are walking speed (V in m/s) and slope grade (S).

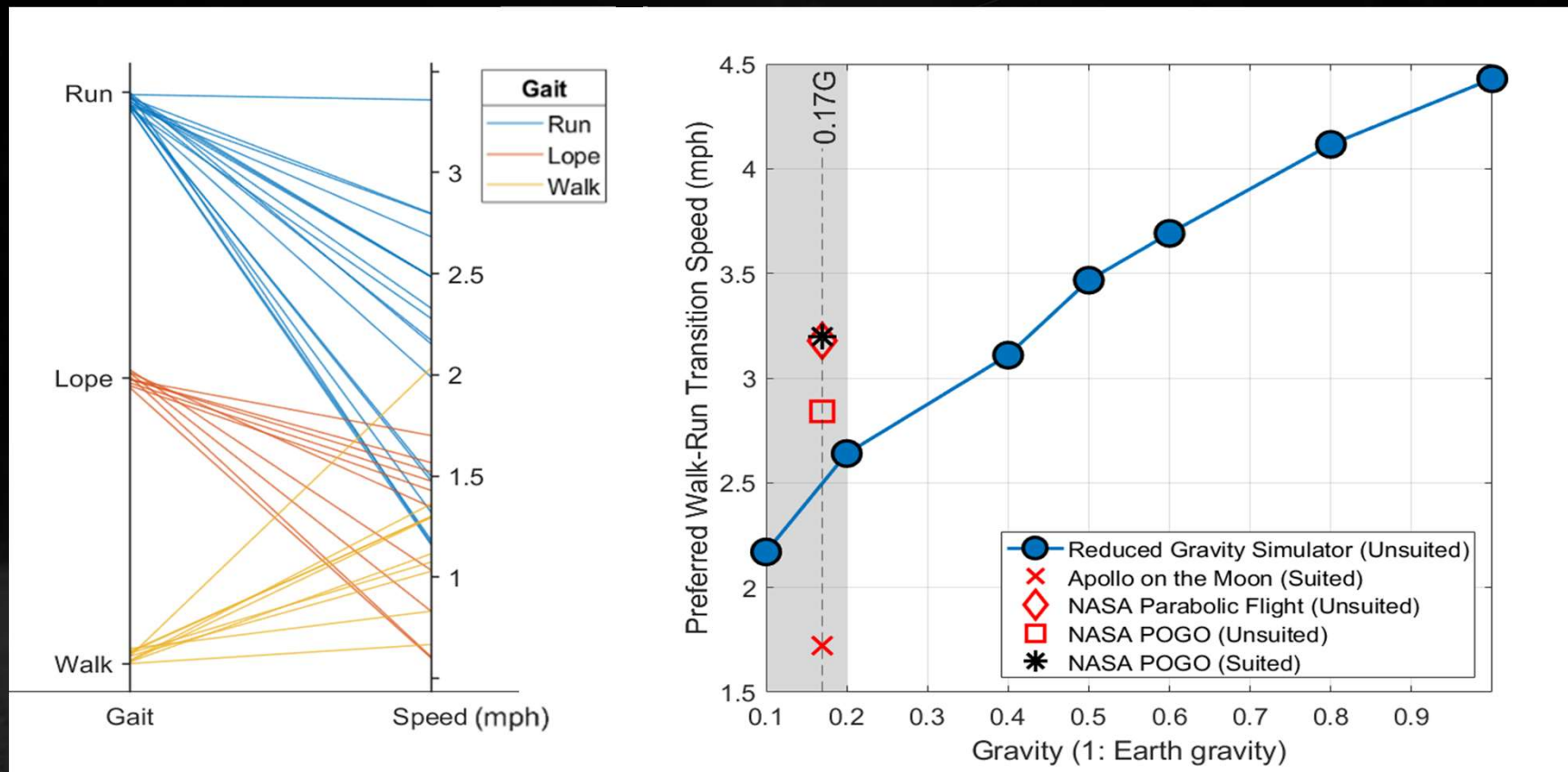


Peña-Asensio, E., Sutherland, J., Tripathi, P., Mason, K., Goodwin, A., Bickel, V.T. and Kring, D.A., 2024. Automated astronaut traverses with minimum metabolic workload: Accessing permanently shadowed regions near the lunar south pole. *Acta Astronautica*, 214, pp.324-342.



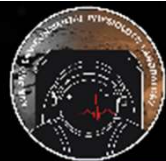


Walk-Run Transition



• Sources: Apollo Lunar Surface Journal, Analysis of Apollo XI lunar EVA (Mobility Evaluation), Apollo 15 time and motion study, Apollo 16 time and motion study, NASA's POGO & Parabolic Study, NASA WRT study.





Model Equations



	Model Equations
Terrestrial	$M_F = \text{Hilbert}[(M_P - CF) * DF] \text{ (where * is being convoluted.)}$ $M_P = 3.41 \cdot [1.5 \cdot W + 2.0 \cdot (W+L) \cdot (L/W)^2 + \eta \cdot (W+L) \cdot (1.5V^2 + 0.35 \cdot V \cdot S)]$ $CF = 3.41 \cdot \eta \cdot [(S \cdot (W+L) \cdot V) / 3.5 - ((W+L) \cdot (S+6)^2) / W + (25 - V^2)]$ $V = 0.28 \cdot 6 \cdot e^{-3.5 \cdot S+0.05 }$ $DF = (1/D) \cdot e^{-(1/D)}$
Lunar	$M_F = \rho \cdot \text{Hilbert}[(M_P - CF) * DF] + \sigma \text{ (where * is being convoluted.)}$ $M_P = 3.41 \cdot [1.5 \cdot W \cdot G + 2.0 \cdot G \cdot (W+L) \cdot (L/W)^2 + \eta \cdot G \cdot (W+L) \cdot (1.5V^2 + 0.35 \cdot V \cdot S)]$ $CF = 3.41 \cdot \eta \cdot [(S \cdot G \cdot (W+L) \cdot V) / 3.5 - ((W+L) \cdot (S+6)^2) / W + (25 - V^2)]$ $V = -0.01 \cdot \tan^{-1}(S/100) + 0.75$ $DF = (1/D) \cdot e^{-(1/D)}$
Heuristics (cost functions)	$C_z = \ s_2^* - s_1^*\ , \text{ where } s_2^* = [x_i \ y_i \ z_i \ w]$ $C_{slope} = \begin{cases} \ s_2 - s_1\ + w * \langle s_2 - s_1 , g_x \ g_y \rangle & \text{if } slope < slope_{max} \\ e^{\langle s_2 - s_1 , g_x \ g_y \rangle} & \text{else} \end{cases}$ $C_{roll} = \begin{cases} \ s_2 - s_1\ + w * \langle s_2 - s_1 , g_y \ g_x \rangle & \text{if } slope < slope_{max} \\ e^{\langle s_2 - s_1 , g_y \ g_x \rangle} & \text{else} \end{cases}$
Local metabolic rate (for 3-D metabolic rate output)	The 3-D slope function, which returns magnitudes of slope of a surface, is required. For example, <code>slope = slope2(x,y,z)</code> returns a gridded local slope field for the surface z. The inputs x and y can be either vectors corresponding to the dimensions of z or a <u>meshgrid</u> of vectors corresponding to the dimensions of z. This function does not require x spacing to equal y spacing, however, it does assume uniform spacing in x and uniform spacing in y (e.g., Computation of Slope, University of Texas at Austin, https://www.caee.utexas.edu/prof/maidment/giswr2012/docs/Slope.pdf)

