ASSESSMENTS OF PHYSIOLOGY AND COGNITION IN HYBRID-REALITY ENVIRONMENTS (APACHE)

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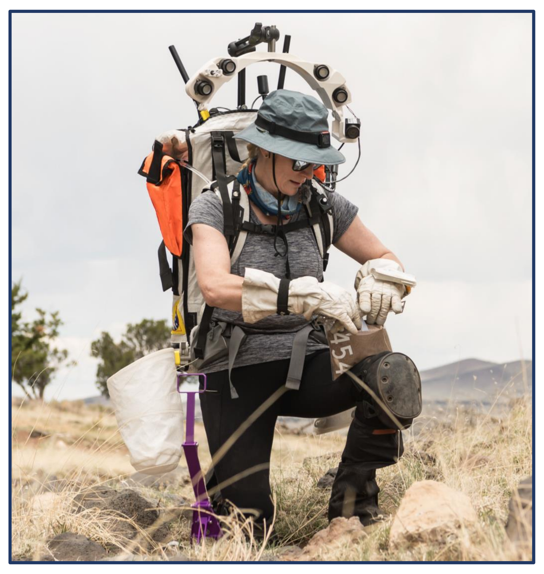
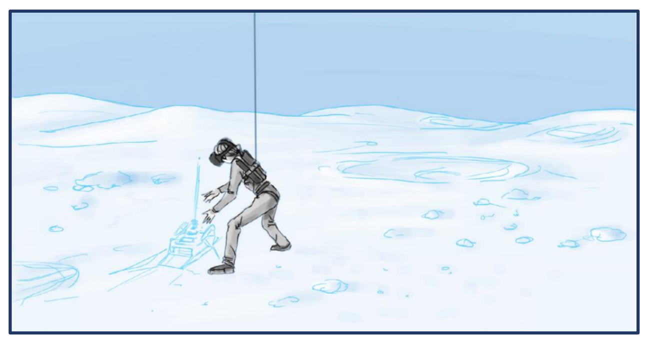
Background

NASA is planning to return to the Moon in the mid-2020s as a steppingstone to Mars missions in the 2030s. Spacewalks, or extravehicular activities (EVAs), performed on the Moon and Mars will differ in a variety of ways from those that have been performed in decades past. NASA has identified multiple risks to human health and performance associated with a crewed mission to Mars, especially those associated with exploration EVAs which are expected to be a primary mission activity. Crew may be expected to conduct up to 24 hours of EVA per person per week, where the likelihood of injury and/or mental mistakes are increased compared to ground-based training or current microgravity EVAs and the consequences of which can be catastrophic.

Current test environments for exploration EVA research and technology development are large, costly facilities that are limited in their availability or capabilities. Space suit testing in a reduced gravity environment such as NASA's Neutral Buoyancy Laboratory (left), while a good representation of the crew's physical workload during exploration EVAs, typically has small datasets and is difficult to integrate physiological sensors or other types of crew performance measures. Meanwhile, scientific field-based testing such as NASA's Joint EVA and Human Surface Mobility Test Team (right) offers an operationally relevant environment for exploration EVAs, particularly for cognitive workload, but is also limited by small datasets, lack of a pressurized spacesuit, and obtrusive measures.



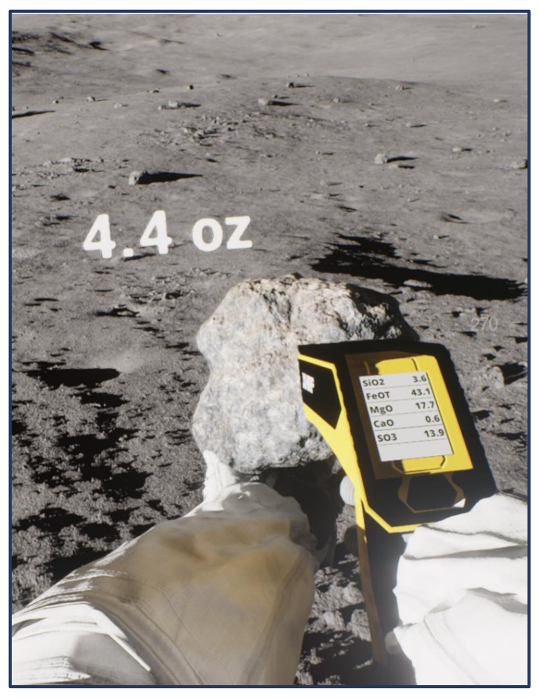
The limitations of these analogs identified a need for a new test environment that could approximate both the physical and cognitive demands associated with exploration EVAs to enable rapid, controlled, and repeatable evaluations of human health and performance risks of exploration missions. In response, the Environmental Physiology Laboratory (EPL) at NASA Johnson Space Center developed APACHE to address these limitations using a combination of virtual, physical, and hybrid reality techniques.



What is APACHE?

The goal of APACHE is to create a planetary EVA simulation environment that provides a representative physical and cognitive workload approximation using a combination of virtual reality (VR), physical reality, and hybrid reality (HR) techniques.

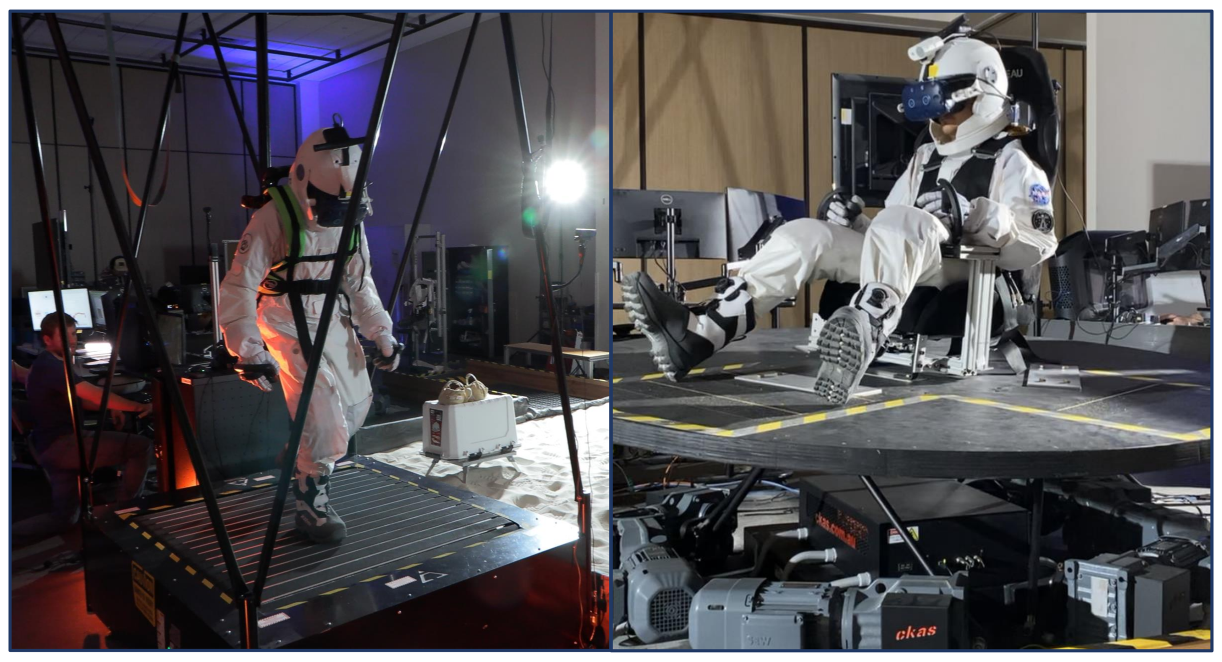
Physical workload is approximated using the VR treadmills, space suit simulators, and hybrid-reality objects integrated into the VR simulation. Physical workload is primarily quantified using a combination of physiological and kinematic sensors as well as metabolic analyzers.



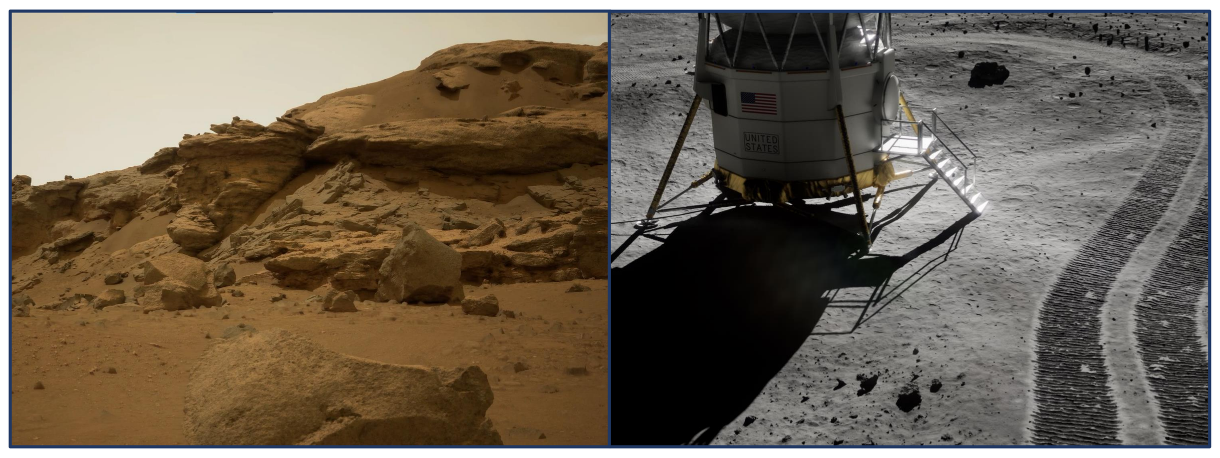
Cognitive workload is simulated via high-fidelity VR environments and flight-like operational tasks. Cognitive workload is typically measured via subjective surveys, but APACHE is currently evaluating unobtrusive measures such as task-specific embedded performance metrics and wearable biosensors.

Technology Development

At the heart of APACHE is "The Sandbox", a large pit filled with Lunar Regolith Simulant. Users perform simulated geology, payload deployment, and repair tasks in either virtual or hybrid reality while feeling the Lunar surface underfoot.



Treadmills, either a curved passive treadmill or the Infinadeck omni-directional treadmill (left), are used for traversing out to and between task sites. Simulating the physical exertion and navigations of walking out to a site is critical to determining what the physical and cognitive demands of an EVA task can be. Users can also simulate driving out to a site in a rover using a 6DOF motion platform (right).



APACHE uses two simulated planetary exploration environments. The Lunar environment (right) is modeled on satelite data of the Shackleton Crater, a potential Artemis landing site. The Martian environment (left) is based on Belva Crater, the exploration site of the Perseverance Mars rover.

Funding & References

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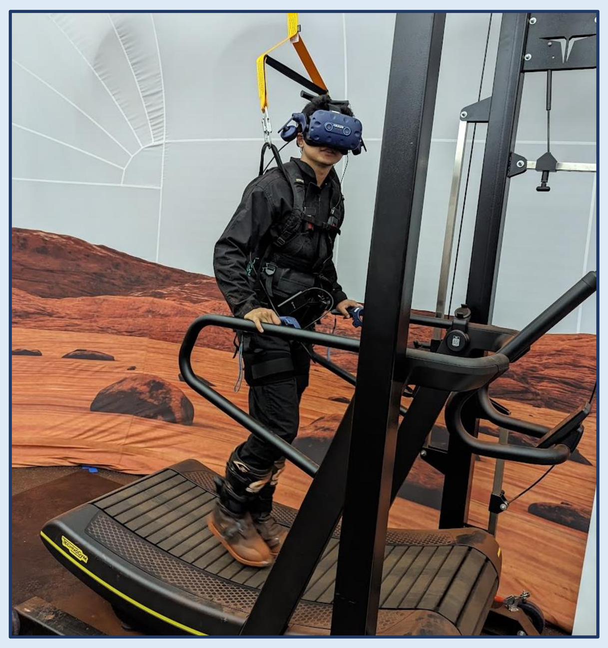
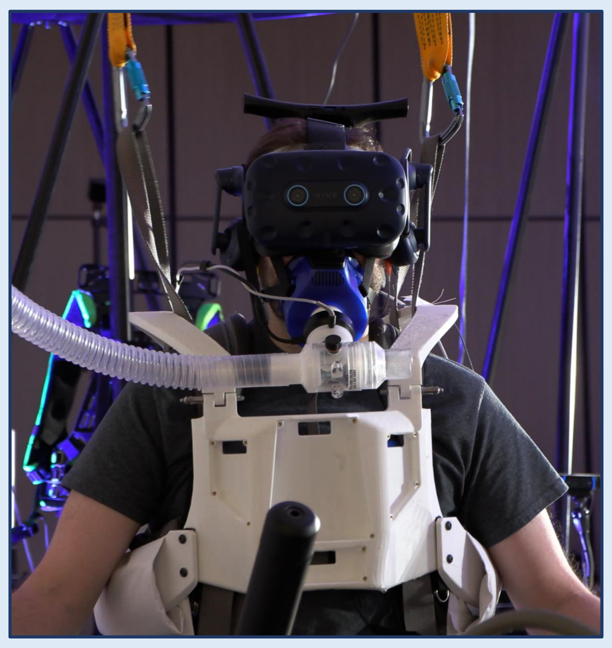
Current and Future Research

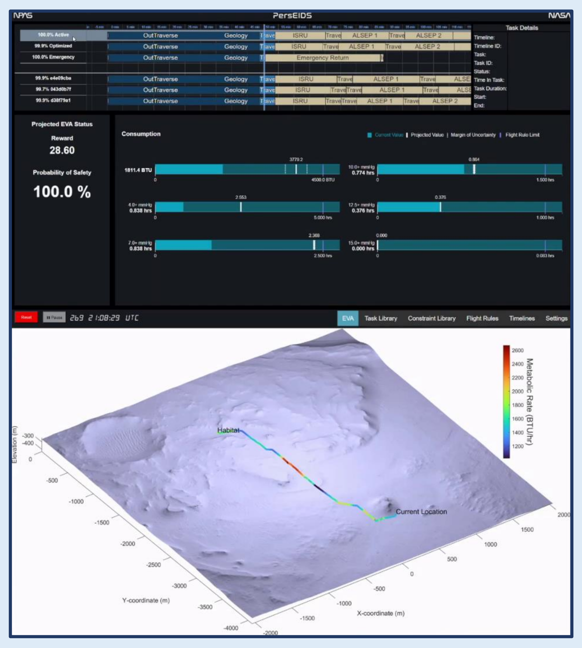
Crew Health And Performance Exploration Analog (CHAPEA) is a year-long simulated Mars exploration mission. APACHE provided 8x unique VR EVAs for the crew to perform during their mission. The physical demands and cognitive measures embedded in these VR EVAs allow scientists to evaluate potential Martian food systems and related countermeasures for any impacts to crew performance.

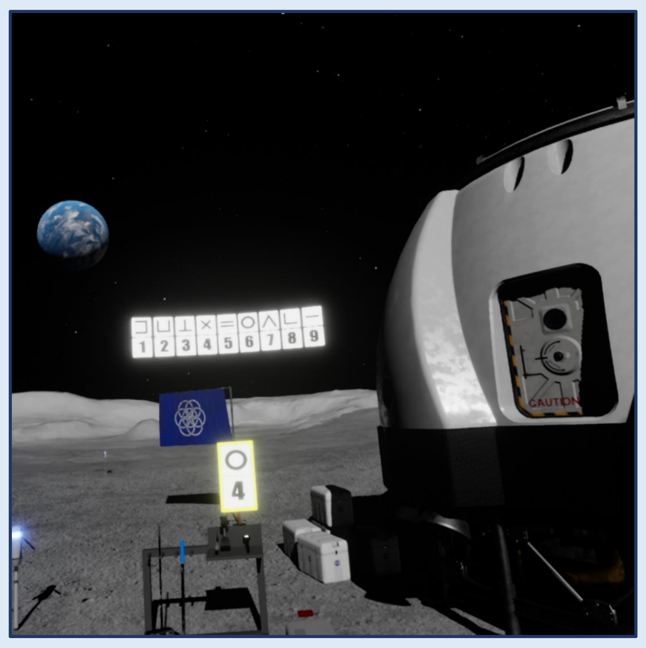




CO2 Contingency Walk Back is a study to evaluate the impact to crew performance in scenarios where CO_2 levels may become elevated during EVA. APACHE provides an operationally relevant simulation of a contingency return-to-lander scenario with embedded physiologic and cognitive measures to evaluate subject performance impacts under various levels of CO_2 exposures ranging from 0 to 30 mmHg.

Personalized EVA Informatics & Decision Support (PersEIDS) is a software package that provides biomedical decision-making during EVA planning and execution. APACHE provides the test environment to quickly and easily evaluate different iterations of PersEIDS, UI concepts, and associated features. Physiological data are streamed through APACHE to PersEIDS and provide updated predictions and monitoring by an intravehicular crewmember.





Cognitive Workload Study is a study that aims to evaluate APACHE's novel cognitive measures, ideally to characterize cognitive workload at different levels of EVA task difficulty. Task-specific performance measures, embedded cognitive tests like the DSST (left), and biometric data from wearable sensors will be compared against traditional subjective surveys while a user completes a high-fidelity exploration EVA task.

Limitations

APACHE is constantly seeking out new technologies to improve visual fidelity, haptic immersion, and overall simulation quality. While developing the environment, the following limitations and/or project needs were identified with current COTS XR headsets, hardware, and technologies:

- Pupillometry and other psychophysiological measurement capabilities are unavailable due to lack of sensor hardware or limited access to raw data.
- Interactions between VR headsets and metabolic masks are often uncomfortable or actively break immersion. Low-profile headsets are desirable.
- Wireless PC VR can be unstable and limits the bandwidth available to produce high fidelity visuals while collecting data from the headset in real time.
- Lack of depth-corrected full color passthrough for mixed reality applications.
- VR walking platforms don't fully replicate natural workload due to altered gait, vestibular disruption, or not replicating terrain during ambulation.

XOSS VR Software Demo Video