**Assessments of Physiology And Cognition in Hybrid-reality Environments (APACHE) – A VR “Sandbox” for Planetary Spacewalk Research**

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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 [1]. 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. Spacesuit testing in a reduced gravity environment such as NASA’s Neutral Buoyancy Laboratory, 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 Desert Research and Technology Studies 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 current analogs for exploration EVAs identify a need for a new test environment that can 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 [2]. In response, the Human Physiology, Performance, Protection, and Operations Laboratory (H-3PO) at NASA Johnson Space Center has developed a hybrid reality exploration EVA analog named the Assessments of Physiology And Cognition in Hybrid-reality Environments (APACHE)[3] to address these limitations using a combination of virtual, physical, and hybrid reality techniques. The APACHE facility resides at NASA Johnson Space Center and serves as a large “sandbox” for EVA research and simulation. At its center is a roughly 15x20ft space surrounded by a 14” tall sandbox partially filled with lunar regolith simulant to emulate the physical feeling of walking on a planetary surface and to allow for simulated geology operations. Nearby, a curved passive treadmill (Skillmill Connect, Technogym, Fairfield, NJ) and an omnidirectional treadmill (Infinadeck, Infinadeck, Rocklin, CA) are included to enable exploration of these large virtual environments while also imposing the physical demands, representative timelines, and cognitive burdens required to navigate and traverse these distances during exploration EVA. A 6DOF motion platform is used to simulate rover operations and supports various human performance evaluations and associated risks. Lastly, APACHE can support two extravehicular (EV) crewmembers working in tandem. A computer workstation is located nearby and also supports an intravehicular (IV) crewmember as part of a full mission simulation. The IV crewmember has direct video and audio communication with the EV crew in VR to provide operational and procedural support.

The software used in APACHE was created by the JSC Engineering Directorate, in partnership with Buendea, powered by a custom Unreal Engine 5 (UE5.3, Epic Games) project. APACHE currently utilizes the HTC Vive Pro Eye in a wireless configuration for VR simulations. There are two virtual environments that subjects can explore within APACHE, a Lunar and Martian surface. The virtual Lunar surface was created from LIDAR data of the Lunar South Pole to create roughly 16 sq km of explorable terrain. The virtual Martian surface contains roughly 400 sq km of explorable terrain derived from Mars Reconnaissance Orbiter LIDAR data of the Jezero Crater. The immersion and related cognitive burdens of conducting a planetary EVA is simulated through a series of EVA-relevant tasks performed in the VR environment, using these high-fidelity visual representations. Additionally, APACHE includes biosensor driven informatics [4], such as real-time heart rate monitoring and/or derived values from model simulations, for active monitoring by the EV crew and added cognitive demand. A “Wizard of Oz” control panel enables test operators to activate contingency events such as simulated spacesuit malfunctions, loss of communications, and/or limited visibility. Embedded performance measures such as accuracy, completeness, and execution time have been developed for various exploration tasks to objectively quantify crew performance during an EVA and compare impacts to performance when different environmental stressors, both physical and cognitive, are added to or removed from the simulation. Additionally, validated cognitive and operational performance measures such as the Digit Symbol Substitution Task [5] have been recreated and embedded in VR for direct and relatively unobtrusive measurement of motor perception.

The APACHE environment currently supports multiple research studies at NASA. Examples include the CHAPEA project [6], a series of simulated year-long missions on Mars by a 4-person crew; and the CO2 Contingency Walk Back Study [7], an investigation of elevated CO2 exposure on crew performance during a contingency EVA scenario. APACHE also provides a test environment to support the development of the Crew State and Risk Model, which is a collection of individualized, mathematical models of crew physical and cognitive state; and the Personalized EVA Informatics and Decision Support system [8], an operational tool for flight controllers, and eventually a self-reliant Martian crew, to make biomedically-informed decisions in real-time to optimize the EVA planning and execution with respect to crew health and performance. Some technical challenges associated with developing the APACHE environment, as well as current limitations, include VR limitless natural walking with a hybrid spacesuit simulator, optimizing performance for wireless PC VR streaming while maintaining a high degree of visual fidelity, and the integration of various physiological (metabolic masks) and psychometric (eye tracking) sensors with the VR headset.

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