A MODULAR EQUIPMENT TRANSPORT SYSTEM FOR PLANETARY SURFACE OPERATIONS.
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Introduction: Like the six Apollo surface missions, future planetary surface exploration will include Extravehicular Activities (EVAs) designed to explore the area around a landing site. EVAs will include exploration, pioneering and construction, sample collection, and in situ data collection. Efficient transportation, access, and stowage of tools, hardware, science instruments, and sampling equipment is critical for increased output during planetary surface EVAs [1,2,4]. A team at the National Aeronautics and Space Administration (NASA) Johnson Space Center (JSC) has been rethinking the way tools, equipment, and samples are transported with the intention of increasing the efficiency of EVAs during planetary surface operations. This abstract briefly summarizes the hardware development process, discusses the operational concept of this modular system, and highlights some of the key takeaways from operational evaluation of this concept.

Hardware Development: The Modular Equipment Transport System (METS) was developed to transport equipment from one location to another utilizing the knowledge of the planned EVA traverse, activities, and the tools required to accomplish each task in order to group hardware into Modules. This concept was designed for and tested at the NASA Extreme Environment Mission Operations (NEEMO) 22 Mission utilizing Aquarius, the world's only operational undersea research station, in June 2017. The primary goal for the EVA team at NEEMO was to explore the interplay of end-to-end concepts of operations, engineering hardware, and science objectives for Exploration class destinations in a mission-like environment [1,3]. This platform was ideal to assess the operational benefits of the METS concept by providing a realistic analog to future Exploration missions.

The METS includes a four-wheeled transporter and Modules of hardware to be used on an EVA. To understand how to group the hardware into Modules, it was important to first understand the planned EVA tasks and all of the hardware needed to complete them. Once a complete list of hardware was compiled, they were grouped based on the frequency of use and the EVA task requirements. These groupings were called Modules and ranged in size and shape to best fit their use. For example, the Temporary Tag Module, used to label potential sampling sites, is a pouch that could be carried or worn around the waist, whereas the Drill Module is a rigid box with handles that sits inside the METS cart.

Along with the Modules inside the wheeled transporter, there were two crew-worn Modules: one on the forearm and one on the thigh. These held small, lightweight, standard tools and their location allowed for easy access. The METS cart is maneuvered by a handle and was outfitted with additional features to assist with EVA efficiency and capability. A camera mount was built on one corner of the METS cart to hold a situational awareness camera which gave the Mission Control team and Intravehicular Activity (IVA) crewmember an additional view of the operation. Another mount was built to hold a tablet in an underwater housing. This tablet showed traverse paths, procedures, data about potential samples, and other information for the crew. The mount has a flexible arm for variable positioning and allowed for the removal of the tablet if needed. The METS cart was also designed to keep the handle from falling to the ground when not in use, reducing the effort needed in a suit when grabbing the handle. Figure 1 shows the METS in use at NEEMO 22.

Figure 1: The METS including camera and tablet mounts and Modules loaded inside the cart.

Operational Concept: The modular concept was developed to increase EVA efficiency and capability, along with reducing crew exertion. The operations start with the crew egressing the habitat and going to a staging area where all Modules are housed when not in use. Based upon the planned EVA tasks for that day, the crew loads the METS cart with only the Modules needed. The crew then pulls the METS cart along their EVA traverse path until they reach their destination. The METS cart can be parked in a single location near where the work is to be completed. The crew members can then take the Modules out of the METS cart that correspond to the type of activity they are required to perform at that stop. This reduces the amount of back and forth trips the crew members have to make to the METS cart, saving crew time, and prevents the crew from having to move the cart directly next to the worksite, circumventing potential navigation issues in more challenging terrain. Furthermore, the Modules can be taken to areas the larger cart cannot reach and allows for multiple activities to be performed at the same time. Once the tasks are complete, the crew loads up the METS and traverses back to the staging area where they unload the METS and store samples, and finally ingress the habitat. This operational concept was evaluated each day at NEEMO 22 to assess its feasibility and efficiency. Figure 2 shows the crew at the staging area loading up the METS.

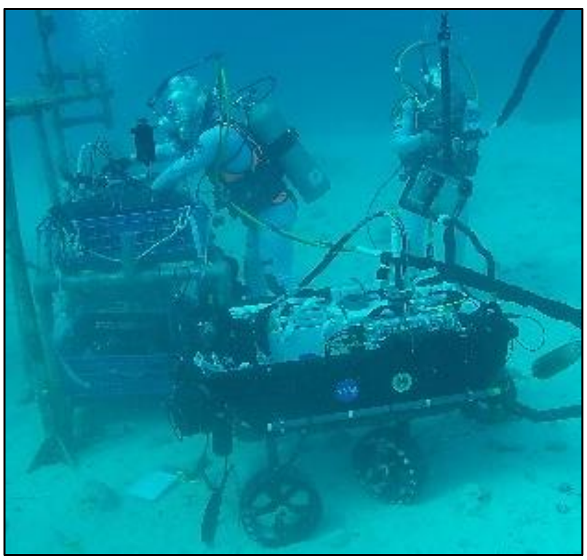

Figure 2: Staging area and METS.

Key Takeaways: Testing the METS concept at NEEMO enabled valuable feedback from astronauts, scientists, and engineers. It was determined that the METS concept of putting tools into Modules has the potential to provide efficiencies and capabilities during EVAs, but could become over-constraining if not well thought through. It requires close integration between EVA hardware engineers, planetary scientists, EVA operation experts, and anyone else involved in EVAs to ensure all pieces of equipment are accounted for when populating and arranging the Modules. This makes it hard to incorporate pieces of equipment that are added last minute and minimizes the ability for crews to adjust the contents of each Module mid-mission as each Module is tightly constrained. It's also important to think through potential contingencies and ensure operational flexibility [3].

Small, lightweight, generic tools could be carried on the forearm, torso, and other locations to provide easy access. Small tools carried on the suit forearm work well and enabled crew easy visibility and access to the tools. Carrying tools on the thigh (or other areas not easily visible) was challenging due to lack of visibility [3].

The positive and constructive feedback from the evaluations at NEEMO will drive further prototype iterations to expand on this modular concept to move closer to a flight design.

References: [1] Todd *et al.* (2017) NASA Extreme Environment Mission Operations. [2] Young K.E. et al. (2013) *Acta Astronaut.*, *90*, 332-343. [3] Coan, D. (2017) NEEMO 22 EVA Overview & Debrief. [4] Coan D. (2017) Exploration EVA System Concepts of Operations.