EXTRAVEHICULAR ACTIVITY (EVA) AND MISSION SUPPORT CENTER (MSC) DESIGN ELEMENTS FOR FUTURE HUMAN SCIENTIFIC EXPLORATION OF OUR SOLAR SYSTEM. M. J. Miller[1], A. F. J. Abercromby[2], S. Chappell[2], K. Beaton[2], S. Kobs Nawotniak[3], A. L. Brady[4], W. B. Garry[5] and D. S. S. Lim[6,7]. [1]Department of Aerospace Engineering, 270 Ferst Dr, Georgia Institute of Technology, Atlanta, GA 30313, matthew.j.miller-1@nasa.gov; [2]NASA Johnson Space Center, 2101 NASA Parkway, Houston, TX 77058; [3]Department of Geosciences, Idaho State University, 921 S. 8th Ave, M-S 8072, Pocatello, ID 83209; [4]McMaster University, 1280 Main Street West, Hamilton, Ontario, Canada; [5]NASA Goddard Space Flight Center, 8800 Greenbelt Road, Greenbelt, MD, 20771; [6]Bay Area Environmental Research Institute, 625 2nd St Ste. 209, Petaluma, CA 94952; [7]NASA Ames Research Center, Moffett Field, CA 94035, Darlene.lim@nasa.gov

Introduction: NASA's Journey to Mars outlines a vision that includes sending humans to an asteroid by 2025 and to Mars in the 2030s. While it is expected that most of the design elements for prospective capabilities and operational concepts will focus on issues concerning astronaut safety and planetary protection, we also envision mission architectures that are strongly driven by scientific requirements that fully leverage the presence of human assets in deep space.

While the development of operational concepts and capabilities needed to send humans to Mars is underway [1]-[3], high-fidelity testing is still required to identify which concepts of operations (ConOps) and capabilities enable high-value scientific return under the operational constraints of working on Mars. One critical consideration in designing for human-robotic missions to Mars is the unavoidable communication delays that will occur between Mars and Earth. Latencies ranging from 4-22 minutes one-way light time are expected. No longer will ground personnel be able to support astronauts as they execute tasks or troubleshoot disturbances through immediate, or realtime, communications. Thus, we must examine how human spaceflight could be successful under communication latency, where crew will operate while managing asynchronous Mission Support Center (MSC) inputs.

Extra-Vehicular Activity (EVA) Design Elements: EVA is defined as "any space operation or activity performed outside the protective environment of a spacecraft therefore requiring supplemental or independent life support equipment for the astronaut [4, p. 5]." EVAs will likely be a primary mechanism for human scientific exploration within future missions. However, EVA experiences to-date have been devoted to maintenance, installation, and construction of engineered hardware – e.g. satellites and the International Space Station (ISS) [5] – and involve large contingents of ground-based support personnel [6], [7]. Few EVAs dedicated to scientific exploration have ever been performed with the exception of those that occurred during the Apollo program, where on the lunar surface communication latencies were ~1 second.

How then will we have to evolve EVAs to enable flexibility that supports scientific exploration? Exploration involves peering into the unknown and reacting to the observed. The quest for scientific discovery is an iterative and ceaseless process, as answers to research questions reveal more refined and sometimes unexpected research questions. In stark contrast, current EVA execution is highly scripted, with procedures arranged as a prioritized set of tasks, configured to maximize the likelihood of accomplishing the *a priori* set of task objectives while maintaining crew safety. Flexibility in the context of EVA execution is typically minimized because this can lead to unpredictability, which can potentially jeopardize both crew safety and the successful completion of EVA objectives. As experienced during Apollo, the operational constraints greatly shaped what was feasible to perform during EVA. Out of the 44 planned stations to be explored during Apollo, only 30 were successfully reached. Fourteen stations were forced to be dropped from the plans, mainly due to time constraints [8]. As a whole, scientific exploration and exploratory processes have served as a secondary objective on human spaceflight missions [9]. Therefore, for future missions, there is a need to better understand how we can merge EVA operations concepts with the established purpose of performing scientific exploration.

Mission Support Center (MSC) Design Elements: Deep-space operations impose a fundamental limitation on how controllable astronauts' actions are from Earth. For the past 50 years, the Mission Control Center located at Johnson Space Center has served as the central nervous system of human spaceflight, controlling and influencing all crew activities. However, for any dynamics that occur more quickly than the time it takes to complete one round-trip communication between crew and Earth, the astronauts will by default need to control their own situations, devoid of immediate input from support personnel. Sustained human presence in deep space will necessitate a profound shift in the way mission operations is conducted. We define here the concept of an MSC as a first step towards realizing this shift in operations from a control oriented focus to one that supports crew activities, leaving more authority and responsibility for the crew to make their own decisions.

The MSC concept has been recently explored in a number of analog field deployments: BASALT (Biologic Analog Science Associated with Lava Terrains) 1 & 2 and NEEMO (NASA Extreme Environment Mission Operations) 20 & 21. The MSC focus to-date has emphasized enabling the exchange of scientific expertise and preferences between Earth and crew *during* EVA operations. Crew will undoubtedly be well trained in future missions, however, they will unlikely be the experts in the multitude of scientific fields planned for future missions. In addition, these scientific disciplines will likely require a breadth of science teams, all competing for their scientific objectives to be prioritized and satisfied. The management and organization of these scientific teams will need careful thought and consideration, especially when we deal with human-scale operations. Even with the time-delay constraint, the pace of scientific EVA operations will be much greater than ever before. To-date, Martian robotic operations conduct operations on the time-scales of 24 hours to direct robotic actions. Human EVA operations will be much more dynamic, thereby necessitating a quicker turn-around capability for scientists to receive, synthesize, discuss, and formulate opinions within the MSC. If humans are to be leveraged in scientific exploration, they must be supported to achieve the highest-possible scientific return and the MSC will play a key role in providing that support.

Science-driven ConOps and Capabilities Development through analog studies: Conducting real (non-simulated) field science under simulated deep space and Mars mission conditions will directly address knowledge gaps associated with the design and development of architectures that enable scientific return, exploration and discovery under the variable communication latencies. Through these efforts we can identify the Concepts of Operations (ConOps) (defined as operational design elements that guide the organization and flow of hardware, personnel, communications, and data products through the course of a mission implementation) and supporting capabilities (functionalities that can take the form of hardware or software) that will balance operational constraints with scientific return, and manage decision-making conditions that involve astronaut crew members and MSC personnel who will be separated by both physical (space, time) and experiential factors.

BASALT, PLRP (Pavilion Lake Research Project) and NEEMO analog research programs conduct non-simulated field science under simulated planetary mission conditions. These programs are low risk, high-impact opportunities to help identify ConOps and capabilities requirements for enabling efficient and effective traverse planning and re-planning, crew scheduling, *in situ* instrument development for sample high-grading, among many other elements. However, these missions are only scratching the surface in terms of inter-disciplinary opportunities that could integrate terrestrial field science and operations/exploration research to design human missions that enable scientific return and discovery. As an example, the Ocean Exploration community has well-honed scientific operational expertise that could provide a high-fidelity analog to deep space operations. Capturing best practices associated with these and other communities will enable NASA to efficiently build a library of ops concepts and capabilities that can then be used to evolve current mission design elements related to human scientific exploration of our Solar System.

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