LESSONS LEARNED USING THE MISSION CONTROL CENTER (MCC) GEOSCIENCE (GEOSCI) CONSOLE FOR NASA'S NEXTSTEP HABITATION MODULE CREW TESTING (2017-2019).

M. E. Evans[1] (michael.e.evans@nasa.gov), Hung T. Nguyen[1], Debra H. Needham[2], [1]Johnson Space Center, Houston, TX., [2]NASA Marshall Space Flight Center, Huntsville, Al., now at NASA HQ SMD ESSIO, WDC

Overview: From 2017 to 2019, The NASA Next Space Technologies for Exploration Partnerships (NextSTEP) program conducted human "day in the life" ground tests of prototype habitation ("hab") modules in lunar orbit. Two NASA-developed habitation modules and five contractor-developed habitation modules (Lockheed Martin, Northrop Grumman, Boeing, Sierra Nevada, Bigelow) were studied. Overall ground test objectives were developed and assessed on each module [1]. The results provided risk-reduction recommendations for possible NASA lunar architectures [2]; however, the planned NASA lunar program architecture changed profoundly during the test period.

The planned lunar orbit, and functional vehicle elements, changed from Deep Space Gateway (DSG) to Lunar Orbital Program – Gateway (LOP-G) to Gateway to Power Propulsion Element (PPE) with Mini-Hab (MH) aka Habitation and Logistics Outpost (HALO) as components of the Artemis Program [3]. As demonstrated in these tests, reductions in hab hardware components restricts science opportunities.

Test Schedule: The hab testing spanned over two years and required a total of over 40 full days of geoscience support in the MCC. Initial evaluations in 2017 were conducted on the 1st generation hab module built at JSC, followed by initial ground tests on the "Phoebe" hab and the 2nd generation hab connected to the Habitable Air-Lock (HAL), both developed at JSC in 2018. Results from these tests were presented at science conferences in 2018 [4]. The 5 contractor prototypes were evaluated in 2019 with NASA site support teams traveling to the vendor locations and the MCC team remaining at JSC.

MCC Operations: *The first MCC lesson was "Science" is too broad for one console to support.* Specialists developing procedures for human physiology or DNA tests required entirely different skills, equipment and timeline constraints than specialists developing procedures for lunar or cosmic samples, astronomical observations, or telerobotic operations. Thus, the "GeoSci" console evolved to handle activities in the latter category. GeoSci was one of many Subject Matter Expert (SME) teams supporting the NextSTEP tests in the MCC. Some SMEs required training in MCC protocols for voice loop and computer usage, as well as communication hierarchy, before conducting the ground tests with crew in remote habs.

The next lesson learned was that crew execution efficiency was greatly increased with 1) adequate pre-test training, and 2) real-time communication between the GeoSci console and crew (when needed).

Figure 1: GeoSci console ops in MCC

Procedure Development: During the ground tests, 14 geoscience procedures were created and executed; however, not every procedure was executed for each module (depending upon available hardware and timeline). Most procedures evolved with experience (from crew executions) and improvements (to either simulation software or available hab hardware) during the test period. Each SME team developed procedures individually, and crew (both engineering and astronauts) were initially confused by different procedure styles and content in each group. *The third MCC lesson recommends a common methodology for building and testing SME procedures.* Initial guidelines for consistent procedure content, terminology, and format (e.g. execution steps vs. warnings vs. informational instructions) are needed. Procedures should reference stowage locations for needed equipment (if available). Daily messages, uplinked to the crew (as on the International Space Station, ISS) may include instructions to augment or alter procedures. The GeoSci console employed these daily messages to notify crew of desired sample locations or observation targets.

Crew tests revealed that crew sometimes skip steps in procedures, so critical actions should include a verification step (Are you sure?). The NextSTEP test coordinators selected ProX software as a demonstration tool to track and monitor crew inputs using electronic versions of each procedure; however, this software required a dedicated support team to translate and maintain written procedures into electronic format.

Finally, GeoSci observation procedures (for Earth, Moon, or Sun) required a vehicle attitude maneuver, and crew executions demonstrated the need for clearly identified coordinate systems (if there are multiple orbiting vehicles docked together).

Timelines: Integration of all selected SME procedures into a 4-crew daily timeline requires much effort, so *MCC development schedules should set and enforce SME procedure delivery dates.* Daily timelines should include flexible slots for non-critical procedures to fill time gaps created by early completion of scheduled activity.

Telerobotic Procedures: GeoSci procedures tested telerobotic operations of an attached vehicle arm and a lunar surface rover (including time lags). These procedures could be executed by crew in lunar orbit, on the lunar surface, or on Earth. *For the arm, the hab should include a window for crew safety and visual monitoring of activity*. For the rover, camera capability should include rotating the driver view left and right, and allow viewing under the rover chassis to avoid "high centering" on rocks. *Adding display capability for a laser pointer/range finder and an overhead "Gods-Eye" view aided crew in surface relative navigation beyond vehicle cameras.* For the simulated environment, GeoSci input facilitated more realistic activity by adding visual field boundaries, and known lunar properties for rock size distributions, terrain slope, and lighting at the rover site. An untested, but desired, ability to test rover sample collection using a rover arm was planned for development in future tests.

Observation Procedures: GeoSci procedures for astronomy observations utilized both an externally attached hab telescope and crew photography from a hab science window, perhaps a cupola (like on ISS). One procedure monitored a lunar surface meteorite impact to capture volatile signatures in the plume. *As the tests progressed, the solar observation procedure was enhanced to allow crew monitoring of solar flares and Corona Mass Ejections (CMEs).* If witnessed, these triggered emergency protection procedures such as construction of a hab radiation storm shelter.

Unique Lunar Orbit Procedures: A lunar orbital vehicle offers unique science opportunities unlike anything available on the lunar surface or in Earth orbit. *A GeoSci procedure created an instrument prototype, the "Gateway Interstellar Dust Collector" (GIDC), to demonstrate a method to capture dust samples outside the Earth's magnetic field* [5]. This requires a hab with a robotic arm and science airlock to attach and detach the experiment from the hull.

Lunar sample transfer procedures developed by GeoSci demonstrate hardware requirements for the hab and Earth return vehicles. These procedures evaluated the hab prototypes using robotic arm transfer of a Sample Return Canister (SRC) from a free-flying vehicle to the science airlock. This SRC could contain lunar surface, asteroid, or other planetary material. The SRC was then "double-bagged" to add a second layer of protection - either robotically in the airlock, or by crew using a glove box - then crew transferred to the pressurized volume in Orion. These tests revealed a need for both 1) cold volatile storage in the pressurized volume of Orion, and 2) unpressurized sample storage on the exterior or Orion or other crewed Earth return vehicles.

Finally, *lunar orbit microgravity experiments, such as the Hermes regolith settling experiment inside ISS [6], or materials exposure experiments (such as the Exposed Facility on ISS [7]), were contemplated as future GeoSci test procedures* but no sufficient hab hardware was available on any of the developed prototypes.

Summary: The testing of multiple prototype lunar orbit habitation modules generated lessons learned using procedures specifically targeting geoscience activities.

1. Science procedures for geologic and astronomy observation activities can be well managed with a dedicated GEOSCI console in the MCC.
2. All MCC SME procedures should follow a consistent format and include common features.
3. GEOSCI procedure execution is significantly improved with sufficient crew training, as well as direct communications between crew and the GEOSCI console during procedure execution
4. MCC timeline generation requires fixed delivery dates for SME procedures.
5. Robotic arm operations and crew safety are enhanced with crew monitoring via a window
6. Driving a lunar surface rover remotely requires navigation aids (beyond driver cameras) to maintain crew positional awareness.
7. Crew monitoring of solar flares and CMEs from lunar orbit facilitates early warning for emergency radiation protection procedures
8. A robust cosmic dust experiment can be added to the orbiting lunar vehicle outfitted with a robotic arm and science airlock
9. Lunar orbit sample transfer procedures drive requirements for a vehicle robotic arm and science airlock, and also for Earth return vehicle(s) with cold and unpressurized lunar sample storage
10. Lunar orbit microgravity regolith settling experiments and materials exposure experiments require more hardware than provided with prototype lunar orbit hab modules

References: [1] Gernhardt, M.L. (2018), *IEEE Aerospace Conference*, [2] Chinga, M. (2019) *IAC*, [3] Smith, M., (2020), *IEEE Aerospace Conference*, [4] Evans, M.E. (2018), *LPSC and LPI Lunar Science Workshop*, [5] Evans, M.E. (2020), *Acta Astronautica 177*, [6] Dove, A., (2019), *EPSC*, [7] Kawasaki, K. (2008), *Proceedings of the RIKEN Symposium*