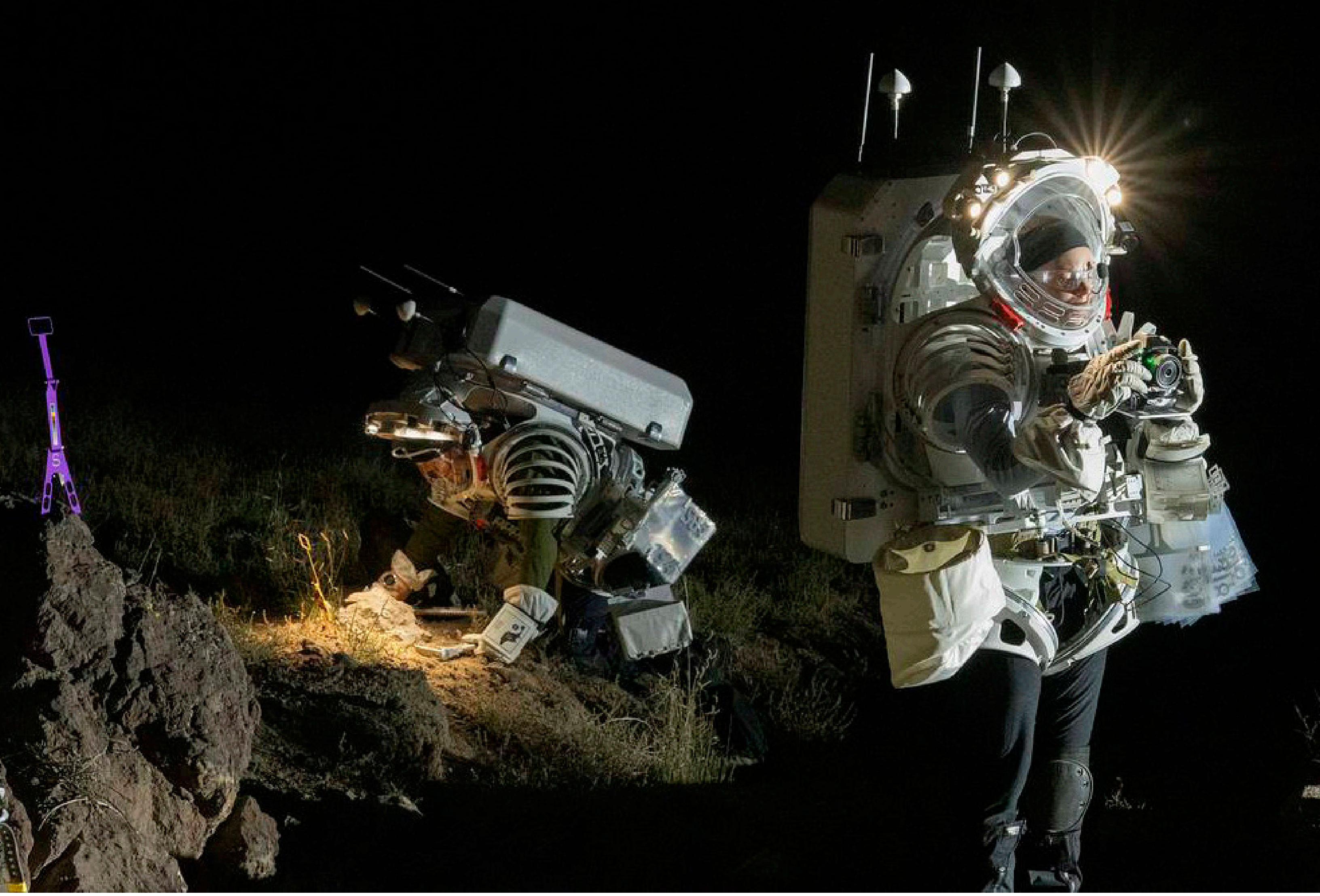

ANALOG OBJECTIVES FOR ARTEMIS (AOA) SPECIFIC ACTION TEAM (SAT) ADDENDUM

Lunar Exploration Analysis Group (LEAG)

June 2023

Cover image: Two Joint Extravehicular Activity Test Team Field Test (JETT3) #3 mission members work on sample collection on the remote, rocky, high-desert terrain of the SP Crater near Flagstaff, Arizona, on Oct. 5, 2022.

JETT3 was the third simulated moonwalk in preparation for future Artemis missions; during Artemis III, astronauts will visit the lunar South Pole region, which has never been explored by humans. The SP Crater has unique terrain and geology, as well as minimal communications infrastructure that make it a great location for an analog mission.

Image Credit: NASA/Bill Stafford

ORIGINAL AOA SAT REPORT

https://www.lpi.usra.edu/leag/reports/analog-objectives-report-02142022.pdf

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TABLE OF CONTENTS

Introduction

In late 2021 the NASA Science Mission Directorate (SMD) and the Lunar Exploration Analysis Group (LEAG) commissioned a Specific Action Team (SAT) to define Analog Objectives for Artemis (AOA). The task of the AOA SAT was to catalog and prioritize the objectives for science and science operations in preparation for Artemis human missions that can be achieved through analog testing. The AOA SAT report was released in February 2022 (document linked above). The report defines 45 Objectives in 11 different categories and, for each objective, listed Priority, Time Criticality, and Candidate Analog Scenario(s).

Since the AOA SAT report was released, Artemis plans have continued to evolve, and the community has carried out analog tests to address both the AOA SAT Objectives and other Artemis knowledge gaps and risks. SMD commissioned this AOA SAT Addendum to inform the lunar community about relevant activities and updates during the time since AOA SAT publication, including reflections on how those updates impact AOA SAT Objectives and Priorities.

Relevant Artemis Updates

In the time since the original AOA SAT report was released, several Artemis elements have evolved that could have a bearing on community analog testing and baseline parameters. We outline several of these updates here and encourage the community to familiarize themselves with them to make their analog testing as applicable as possible to NASA's current direction.

DRIVING DOCUMENTS RELEASED

NASA recently completed an initial Architecture Concept Review (ACR) with an expectation of completing a yearly review cycle. This process links to two critical products:

- Moon to Mars Objectives: *https://www.nasa.gov/sites/default/files/atoms/files/m2m-objectives-exec-summary.pdf*
- Architecture Definition Document (ADD), summary, and white papers located at *https://www.nasa.gov/MoonToMarsArchitecture*

These documents are a powerful resource by which the community can understand NASA's current direction, and Artemis plans. Analog tests that map to these critical documents will be sure to be aligned with NASA's current goals.

CANDIDATE LANDING REGIONS

In August 2022, NASA released 13 candidate landing regions for Artemis III, all near the lunar South Pole: *https://www.nasa.gov/press-release/nasa-identifies-candidate-regions-for-landing-next-americans-on-moon*

ARTEMIS LANDER UPDATES

NASA has made two Human Landing System (HLS) selections for early Artemis missions: SpaceX and Blue Origin. Selection and vehicle details can be found in public information, but each HLS has characteristics that could be relevant for analog testing.

LTV RFP RELEASED

The final Request for Proposals (RFP) for the Lunar Terrain Vehicle Services contract was issued in Spring 2023. The Lunar Terrain Vehicle (LTV) will provide increased mobility for astronauts on the lunar surface.

PAYLOAD OPPORTUNITIES

NASA recently (May 2023) released a call for deployed payloads for Artemis III: *https://nspires.nasaprs.com/external/solicitations/summary!init.do?solId=%7b76053627-8933-47CD-B627-C5DCDD474076%7d&path=open*

NASA has also announced plans to solicit for additional payloads (including both deployed and handheld) for Artemis IV and LTV.

STRUCTURE OF ARTEMIS SCIENCE TEAMS

NASA has provided additional information about the make-up of each Artemis mission's Science Team, which will consist of NASA internal scientists as well as solicited teams and scientists. Artemis III Geology Team proposals were submitted at the end of April 2023, and Team selection is expected to be announced in Fall 2023, with the selected Team beginning work in January 2024. For each Artemis mission, a Geology Team will be selected. It will integrate with other entities of the overall Artemis Science Team, such as the Artemis Internal Science Team, Participating Scientists, Deployed Instrument Teams, and Curation, among others.

XEVAS CONTRACT

The spacesuits Artemis astronauts will utilize for lunar surface exploration will be provided through NASA's Exploration Extravehicular Activity Services (xEVAS) contract. In June 2022, Axiom Space and Collins Aerospace were selected as the two potential vendors to provide services for next-generation spacesuits and associated systems via competitive task orders. In September 2022, Axiom Space was awarded the task order to provide the lunar surface spacesuits and tools for the Artemis III lunar landing. These commercial partners are responsible for all design, development, qualification, certification, and production of the spacesuits and support equipment. The Artemis III xEVAS contract will also provide lunar surface exploration tools, including the geology tools required for sample collection, transportation, and storage.

Summary of Analog Testing from February 2022–June 2023

Below is a non-exhaustive list of analog tests with Artemis-relevant science objectives that have occurred since the release of the AOA SAT. The table includes the AOA SAT Objective(s) they addressed (both primary and secondary), a high-level description of the test, and any implications to AOA SAT Objectives apparent from available information about the tests. This list is not meant to be exhaustive; we recognize other analog testing is ongoing. We provide this initial list as an indication of the types of analog testing that have been recently conducted. The intent is only to communicate to the community how recent analog testing may have impacted AOA SAT priorities so that future analog testing may be as timely and relevant as possible. We note that we have identified a gap in lack of clarity of the full breadth of analog testing in the community, making it challenging to track closure or addressing of AOA SAT Objectives sufficiently. Future work could address how the community can best understand the full breadth of Artemis and AOA SAT-relevant analog testing.

Test Name and Dates	AOA SAT Obj #'s	Test Focus Area(s)
JETT1 (April 2022)	Primary: C.1, C.3, I.3 Secondary: C.2, C.4, F.7, I.1, I.2	Field test focused on the initial deployment of EVA field mockup suit and “at-station” operations to test prototype tools and early Artemis ConOps. Evaluated initial field lighting concepts, tool and tool management, imagery, and instrument deployment methods. Field Site = Kilbourne Hole, NM.
JETT2 (July 2022)	Primary: E.1, E.2, F.1, F.2, F.3, F.5, F.6, G.1, G.2, G.3, G.4, H.1, H.3, I.1, I.2 Secondary: H.4	Field test that evaluated the xEVA System capabilities and further developed the EVA ConOps for early Artemis missions. Conducted mission scale EVA ops in a high-fidelity lunar-like environment using the current tool and field suit mockups available. Objectives focused on mitigating risk and identifying technology gaps for low-illumination lighting, lunar navigation, and tool transport and management. Field Site = Iceland Highlands.
JETT3 (October 2022)	Primary: A.1, A.4, B.1, B.2, B.3, E.1, E.2, F.1, F.2, F.3, F.5, F.6, F.9, G.1, G.2, G.3, H.1, H.3, I.1, I.2, K.1 Secondary: A.6, B.4, K.2	High-fidelity Artemis III mission simulation with full Science Team embedded in pre-mission planning and mission execution, including a full Science Evaluation Room (SER). Lighting, navigation, tool and tool management, imagery, and informatics objectives were also tested. Field Site = San Francisco Volcanic Field, AZ
JETT4 (May 2023)	Primary: E.1, E.2, E.3, G.1, G.2, G.3, H.1, H.3 Secondary: C.2, F.1, F.5, F.6	Field test focused on the deployment of a revised EVA field mockup suit in a full-scale early Artemis mission scenario. Conducted end-to-end EVA traverses in and around the unique craters at this field location. Field Site = Nevada National Security Site
JETT5 (Test planned for Fall 2023))	Details TBD (pre-test preparatory work in progress as of May 2023)	High-fidelity Artemis III mission simulation being planned for Fall 2023 with full Science Team embedded in pre-mission planning and mission execution. Detailed objectives are still being defined at publication of this Addendum, but science operations objectives will focus on two daily operational shifts and associated science operational products. Field Site = San Francisco Volcanic Field, AZ

DRATS (October 2022)	Primary: H.3 Secondary: A.2, A.3, A.5, .1, B.2, B.3, B.4, C.1, C.2, D.1, D.2, D.3, E.1, E.2, E.3, F.2, F.3, F.4, F.5, F.9, G.1, G.2, H.1, K.1, K.2	Field test of NASA's Pressurized Rover (PR) with objectives on defining rover requirements, lighting operational implications of EVA/rover interactions, and early integration of a Flight Control Team (including science representation) into PR surface operations. Field Site = Black Point Lava Flow, AZ
GEODES SSERVI	Primary: C1, C2 Secondary: M2, O1, O2	Testing geophysical methods & instruments to probe regolith and near subsurface. Investigating ConOps with deployed and portable geophysical instrumentation. Investigating ability to inform EVA with real-time or near real-time data analysis. Field Sites = San Francisco Volcanic Field, Flagstaff, AZ; Medicine Lake Volcano Region, Northern CA; Potrillo Volcanic Field/Kilbourne Hole, NM.
TREX SSERVI	Primary: C1, D1, D2, D3, J1, J4, N1 Secondary: A1, F7, G1, G2, G3, L1	Testing (software & hardware) for rover-based autonomous science operations, incorporating real-time rover-based science instrument data, tests also included astronaut EVAs to assess efficiencies with autonomous rover capabilities. Field Site = Yellow Cat, UT.
RESOURCE SSERVI	Primary: C1, C2, C3, C4, E3, F1, F2, F4, J1, J3, O1 Secondary: B1, B3, E1, F5, J2, M2, M3, O2	Instrument field testing (3D depth camera imaging system for science and operations, functions in both illuminated and shadowed terrain); data visualization & VR/AR/XR for science & ops. Field Sites = Marblehead, MA & Svalbard plus NASA / SSERVI Regolith Testbed.
RISE2 SSERVI	Primary: B1, B3, C1, C2, C3, F3, F4, F7, F9 Secondary: J2, M2, O1, O2	Handheld field instrument testing to support real-time science operations; data visualization software for science & ops. Field Site = Kilbourne Hole, NM.
JSC Rock Yard Series	B1, C1, C3, E1, E2, F1, F2, F3, F4, F6, G1, G2, G3, H1, H3, J1	Handheld field instrument testing, lighting tests. Atlas mockup suit mobility, tools integration. Camera conops, suit stowage, performance in low light. Sampling conops, sample markers. JARVIS display testing.
JSC-Based VR Tests	B1, B2, B3, E1, E2, G1, G2, H1, H2, L1	EVA planning using map products. Simulated lighting systems. Simulated tools and sampling.

Table 1. Analog Tests and Relevance to AOA-SAT Objectives

Reflections on Updated AOA SAT Priorities

As summarized above, the analog testing community has been hard at work over the last 18 months completing tests to inform Artemis development. Additionally, programmatic updates have provided updated guidance on architecture, planned hardware, and team structure. Listed here are several thoughts on how recent progress impacts the priorities and objectives outlined in the AOA SAT report.

A SCIENCE SUPPORT ROOM INTEGRATION AND STRUCTURE

Science Support Room: The Artemis Science Support Room will be called the Science Evaluation Room (SER), consistent with current NASA human spaceflight Mission Control nomenclature. JETT3 testing (which built on the findings from many years of analog testing and human spaceflight missions that came before it) resulted in the delivery of SER requirements to relevant groups for development and construction of the Artemis SER, which will be completed and ready for Science Team use prior to Artemis III. These physical infrastructure requirements include recommendations on SER available physical space, IT resources, communications capabilities, physical layout, and more. The AOA SAT team, therefore, recommends that analog testing focusing on SER operations concentrates on areas beyond these physical infrastructure requirements (resulting in a lower priority for AOA SAT Obj. A.4). However, additional recommendations for updates to these requirements and how they dictate SER operations are always valuable.

Science Team Integration into Flight Operations: The senior science officer in the Flight Control Team will be called the Exploration Science Officer (ESO). The current structure for the Artemis EVA Flight Control Team (FCT) is included below (Figure 1). Analog activities seeking to test science integration into real-time science support structure would benefit from reviewing this architecture. The ESO and SER architecture is solidified, especially for early Artemis missions, but the community can also accommodate for the additional exploration hardware and resources that will be available and possible resulting recommendations that analog testing could inform about this increased operational complexity.

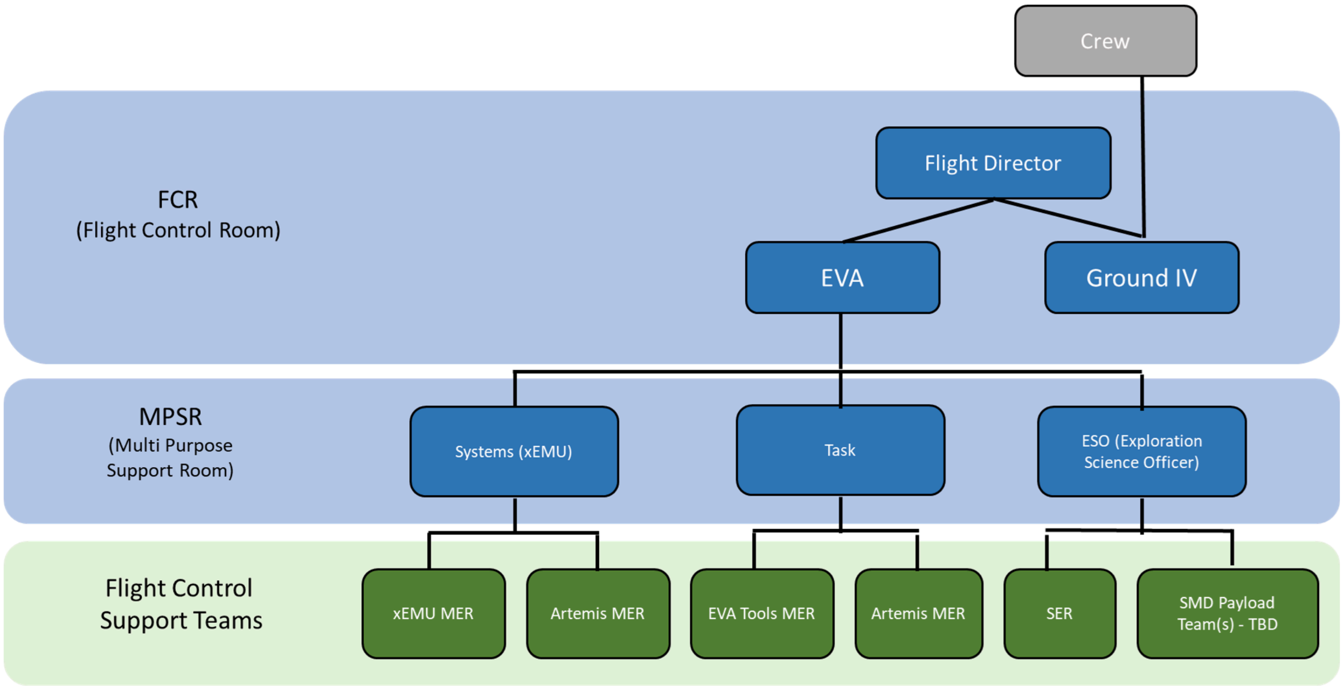

Figure 1: Current Artemis EVA FCT Structure. Additional console positions will exist (e.g., numerous other FCR positions); this chart focuses on EVA-relevant positions. Acronyms: Ground IV - person responsible for communicating with EVA crew; xEMU - Exploration Extravehicular Mobility Unit (lunar spacesuit); MER - Mission Evaluation Room (support backrooms).

B SOFTWARE TO SUPPORT REAL-TIME OPERATIONS

NASA has developed a suite of tools called EVA Mission System Software (EMSS) that enable surface EVA operations. These tools integrate science traceability into the operational objectives of EVA targets and tasks. Since 2019, the EMSS initiative has been incrementally building three core software solutions *(Figure 2)*. Collaborative Operations Data Activation (CODA) exists for the purpose of putting mission data into horizontally integrated mission context to enable current and future NASA missions, as inspired by the functionality demonstrated in the Apollo in Real Time application *(https://apolloinrealtime.org/)*. Maestro aims to digitize EVA procedure authoring and execution. In doing so, coordinated EVA activity can be associated, recorded, and shared in new ways among the Flight Control Team. Artemis EVA Geographic Information System (AEGIS) strives to enable spatiotemporal awareness for EVA procedure authoring and execution. The EMSS suite of applications leverages a common technical architecture. The solidification of EMSS indicates that AOA SAT Obj. B.2 should be retired as AEGIS satisfies this need. For more information, see Miller, M.J., Charney, D., Feist, B., Pittman, C., Rynearson, D., Vu, J., Montalvo., Heinemann, K., Davis, T., Lin, S., Baig, O., (2023) Supporting Exploration Missions by Enabling Exploration Mission System Software, 52nd International Conference on Environmental Systems ICES-2023-242, 16-20 July 2023, Calgary, Canada.

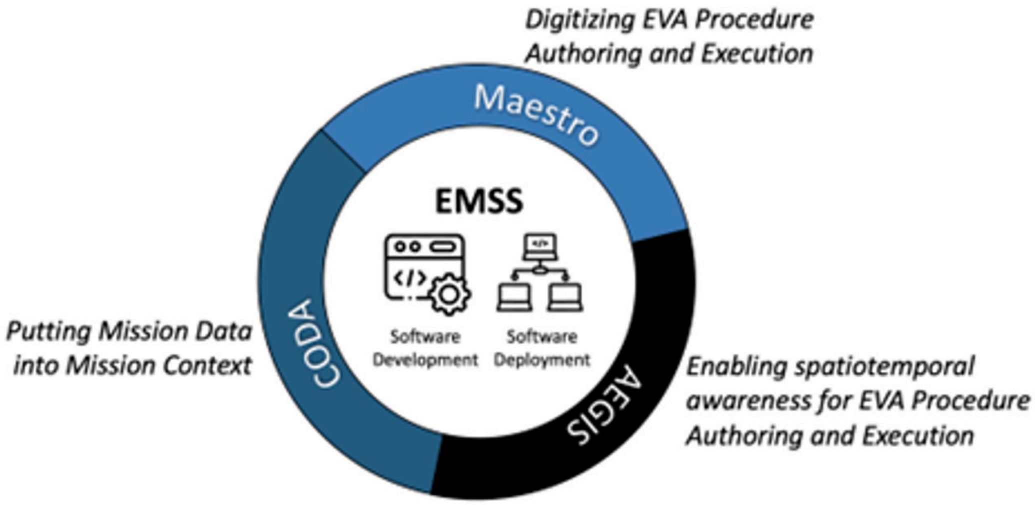

Figure 2: EMSS portfolio.

C INSTRUMENTATION

Refer to the SMD-released Artemis III Deployed Instruments call and the planned Artemis IV and LTV payload calls for NASA's current instrumentation plans. Multiple SSERVI teams are evaluating field instrumentation and their impact on surface exploration (see Table 1 for details), so refinements to these objectives may be forthcoming.

D HUMAN/ROBOTIC PARTNERSHIPS

As discussed above, the RFP for LTVS has been released. The community is encouraged to keep track of the results of this solicitation for updates to planned Artemis robotic assets.

E OPERATIONS IN COMPLEX LIGHTING ENVIRONMENTS

Numerous NASA test events and facility developments are aimed at reducing the risks associated with operating in the challenges associated with the low-angle lighting environment at the lunar South Pole. This integrated challenge has high priority across numerous components of the Artemis campaign. Effective strategies for science operations in complex lighting environments *(AOA SAT Obj. E.1)* have been tested at numerous JETT field tests and at NASA facilities (VR Labs, NBL and lighting labs). Lighting system requirements *(AOA SAT Obj. E.2)* and advanced technologies *(AOA SAT Obj. E.3)* have also been evaluated during recent analog testing events. We encourage the science and analog communities to contribute to further evaluations and strategies for conducting lunar operations in complex lighting environments.

F IMAGING

Early Artemis surface missions are expected to include one handheld camera per EVA crewmember. Analog testing need not be limited to these imaging platforms if additional capabilities are desired. Continued efforts are encouraged to exercise the capabilities of cameras similar to those baselined for Artemis in a range of lighting conditions, particularly including low-light conditions expected for Permanently Shadowed Regions (PSRs) *(AOA SAT Obj. F1)*. Integrated tests including a science team (in both tactical and strategic roles), are needed to exercise how to best use imagery telemetered to Earth in real-time as well as post-/between EVAs, including handling and processing potentially large volumes of digital imagery at various timescales during an EVA and surface mission stay *(AOA SAT Obj. F2)*. Tests to establish best practices for astronauts' use of the handheld camera on the lunar surface for context photography, sample curation, etc. have been done and are continuing *(AOA SAT Obj. F3)*. There is a remaining need to establish science requirements, expectations, and use cases for astronaut-deployed and/or autonomous camera systems (e.g., mounted to rovers, vehicles) to monitor and record EVA activities *(AOA SAT Obj. F4)*. There is also a remaining need to establish workflows (both field and SER) for obtaining image data for specialized use cases (e.g., 3D photogrammetry, gigapixel resolution panoramic/macro images, construction of digital twins/virtual outcrops, etc.) *(AOA SAT Obj. F5)*. The Government Reference Design set of Artemis geology tools includes sample markers with image scale/calibration capabilities; test efforts can exercise the utility of these tools and establish whether there is a remaining need for other/different calibration targets for photometry, spatial ground control, etc. *(AOA SAT Obj. F6)*. There is a remaining need to establish science requirements, expectations, and use cases for multispectral camera systems, LiDAR, and other imaging technologies *(AOA SAT Obj. F7)*. Image stabilization *(AOA SAT Obj. F8)* may be important for video imagery obtained with LTV and xEVAS spacesuit mounted camera systems. Training *(AOA SAT Obj. F9)* continues to be included in a variety of past and ongoing analog test efforts.

G SAMPLING

Sampling ConOps (AOA SAT Objective G.2): An Artemis ConOps for sampling has been developed, matured, and implemented in NASA's JETT tests. Recommendations on specific requirements for documentation are welcomed from the analog testing community.

H TOOL AND TOOL/SAMPLE/PAYLOAD/MANAGEMENT

JETT field testing has directly contributed to developing a Government Reference Design set of Artemis geology tools. The tool maturation and lessons learned over numerous tests were captured and provided to the industry partners developing the Artemis tools via the xEVAS contract.

I DOCUMENTATION

No updates.

J ADVANCED TECHNOLOGIES

No updates.

K COMMUNICATIONS ARCHITECTURE

AOA SAT Objective K.1: As shown in Figure 1, the SER will communicate with the rest of the Flight Control Team through the ESO. Details of this structure were tested during JETT3, and additional testing is being planned for JETT5. As AOA SAT Objective K.1 includes SER internal and external communication, the addition of the ESO position could be considered in future analog testing.

L CREW AUTONOMY

No updates.

M ANALOG SCIENCE TRAINING

AOA SAT Objective M.1: As discussed above, each mission's Artemis Science Team will consist of internal NASA Scientists, competed geology teams, Participating Scientists, and instrument teams. This architecture should be considered given Obj. M.1's focus on building a productive and inclusive team environment for SER members.

AOA SAT Objective M.3: The Artemis Internal Science Team has provided updates in community meetings about current training plans for Artemis astronauts and flight controllers. Community members are encouraged to review these plans in considering analog testing designed to develop and test training activities and protocols.

N LOCATION/NAVIGATION

Navigation strategies *(AOA SAT Objective N.1)* and requirements for science *(AOA SAT Objective N.2)* have been matured through JETT and VR test events. Testing solutions from paper maps to advanced software and technologies have contributed to the planning and phased approach for navigation knowledge and capabilities. Navigation remains a significant challenge for Artemis surface missions, and testing continues to address this challenge.

O TEST DESIGN

No updates.