INTEGRATED SCIENCE AND FLIGHT OPERATIONS. David A. Kring[1,2,3], Barbara A. Janoiko[2,4], Christopher A. Looper[2,5], Zane A. Ney[2,6], Kelsey E. Young[3,7], Dean B. Eppler[8], and Trevor G. Graff[9], [1]Lunar and Planetary Institute, USRA, 3600 Bay Area Blvd., Houston TX 77058 (kring@lpi.usra.edu), [2]LPI-JSC Center for Lunar Science and Exploration, [3]NASA Solar System Exploration Research Virtual Institute, [4]Exploration Mission Planning Office, Johnson Space Center, Houston TX 77058, [5]Space Exploration Division, Johnson Space Center, Houston TX 77058, [6]Flight Operations Division, Johnson Space Center, Houston TX 77058, [7]Geology, Geophysics, and Geochemistry Lab, Goddard Space Flight Center, [8]The Aerospace Corporation, 2525 Bay Area Boulevard, Houston TX 77058, [9]Astromaterials Research and Exploration Science, Johnson Space Center, Houston TX 77058.

Introduction: The lessons of Apollo were reviewed during the initial phase of the Constellation program when designing systems that land at the lunar south pole and explore a circumpolar region. One of the Apollo lessons was to develop integrated lunar mission simulations, which Constellation Lunar Surface Systems and the Directorate Integration Office implemented through the Desert Research and Technology Studies program.

Integrated Mission Simulations: The simulations drew on the Apollo finding that field-based simulations should engage all those who will be involved in missions, so staff were drawn from the Flight Operations Directorate's Astronaut Office and Extravehicular Activity (EVA) Group, Human Factors, and the science community. Furthermore, the simulations utilized and developed flight-like hardware, including mobility assets, technical adaptations to suits, and a flight control room that integrated flight and science personnel supporting lunar surface activities.

Integrated Flight Control Room: An important advance made during those simulations was the integrated science and flight operations control room. The flight control room for the first remote field simulation was in JSC Bldg. 9, evolved to a field-deployed Mobile Mission Control Center (MMCC) (Fig. 1, top) and was finally installed in a next-generation flight control room in JSC Bldg. 30, NASA's Mission Control Center (Fig. 1, bottom). From those flight control rooms, crew missions were conducted at Moses Lake, WA (2008) and the Black Point Lava Flow, AZ (2008-2011). The latter site provided a lunar-like terrain where realistic science activities under demanding field conditions could be conducted.

During a simulated mission, a Flight Director, CAPCOM, and supporting console staff managed flight operations, including egress from a small pressurized rover (SPR). When crew stepped off the vehicle to conduct science station activities or a traverse, operations were picked up by a Science Leader (SCILEAD), Science Communication (SCICOM), and supporting console staff. Operations sequenced back to flight operations personnel at the end of an EVA or if any anomalies occurred. The simulations demonstrated that an integrated flight and science operations architecture greatly enhances mission productivity and provides crew with lunar surface expertise when engaged in lunar surface activities.

Figure 1. *(top) Integrated flight control room in a Mobile Mission Control Center. (bottom) Integrated flight control room in JSC Building 30. Note that Artemis Astronaut Jessica Watkins, then a student, is sitting at an EV2 camera science console in the flight control room.*

The transition from flight operations personnel to science operations personnel also occurred during rover traverses when crew were making intravehicular activity (IVA) observations. This was particularly effective when utilizing a SPR that provided productive IVA capabilities.

Science operations staff provided crew with a daily pre-traverse briefing and a post-traverse debriefing.

Figure 2. *(top) EV1 and EV2 collecting a soil sample and photo-documenting the site. (bottom) EV1, Stan Love, describing and photo-documenting a sample for the science operations staff.*

Potentially, a day's traverse results may prompt re-planning of the following day's traverse. In those cases, modified plans were presented to and discussed with crew at the next day's pre-traverse briefing. The simulations investigated continuous communication and twice-a-day communication scenarios. Continuous communication produced the best results.

Primary Constellation Mission Simulation Field Site: The Black Point Lava Flow was selected from several Apollo mission training sites as an ideal location to develop mission capabilities for the lunar south pole. Black Point geology is not directly relevant to that at the south pole, but it provides a good range of geologic and topographic diversity for mission systems. The site contains a volcanic terrain and a layered terrain. The site also contains a field of craters produced explosively during the Apollo era.

The test site was eventually expanded from the Black Point Lava Flow to Colton and SP craters, providing ~25 km of terrain, comparable to distances envisioned for an initial phase of lunar exploration. While Meteor Crater east of Flagstaff is the world's best training facility for impact-cratered terrains on the Moon, Colton Crater is a 1.2 diameter explosive volcanic crater with topographic properties that can be used to simulate an impact crater.

Utilizing that terrain, missions could be conducted with flight-light surface activities (Fig. 2) with flight-like schedules (Fig. 3) over periods of days to weeks.

Artemis Integrated Simulations: Additional field-based integrated simulations will be needed to develop and test other parameters for Artemis lunar surface operations, including trades among communication protocols, mobility options, surface imaging systems, and sample documentation. Both Apollo and Constellation taught us that science and flight operations staff should work with crew and hardware providers to develop the skills necessary to work as a team during a lunar surface mission.

Importantly for Artemis goals, the Constellation simulations should be expanded to include a greater variety of *in situ* resource utilization (ISRU) operations. Artemis simulations should also explore the consequences of rover operations that replace dual SPR with a Lunar Terrain Vehicle (LTV) and Habitable Mobility Platform (HMP) system.

Conclusions: An integrated science and flight operations room provides crew with lunar expertise during lunar surface operations. The smooth functioning of that team with crew and hardware elements will require field-based mission simulations prior to flight.

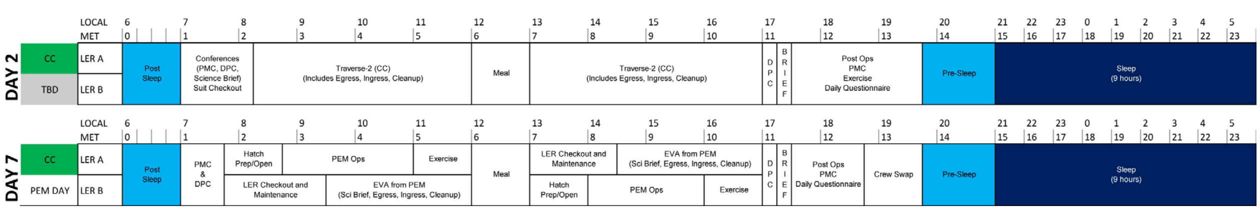

Figure 3. *Crew schedules for days 2 and 7 of a 14-day-long mission simulation. These 24-hour schedules illustrate timelines for days with traverses (top) and days with equipment-related tasks (bottom). This particular set of timelines were for a dual-SPR (LER A and LER B) mission simulation prompted by the design of a 28-day-long mission around the Moon's Malapert massif.*