Crew/Robot Coordinated Planetary EVA Operations at a Lunar Base Analog Site. M. A. Diftler[1], R. O. Ambrose[1], W. J. Bluethmann[1], F. J. Delgado[1], E. Herrera[1], J. J. Kosmo[1], B. A. Janoiko[1], B. H. Wilcox[2], J. A. Townsend[2], J. B. Matthews[2], T. W. Fong[3], M. G. Bualat[3], S. Y. Lee[3], J. T. Dorsey[4], and W. R. Doggett[4], [1]Johnson Space Center, 2101 NASA Road One, Houston, TX 77058 (myron.a.diftler@nasa.gov), [2]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, [3]Ames Research Center, Moffett Field CA 94035, [4]Langley Research Center, Hampton, VA 23681 .

Summary: Under the direction of NASA's Exploration Technology Development Program, robots and space suited subjects from several NASA centers recently completed a very successful demonstration of coordinated activities indicative of base camp operations on the lunar surface. For these activities, NASA chose a site near Meteor Crater, Arizona close to where Apollo Astronauts previously trained. The main scenario demonstrated crew returning from a planetary EVA (extra-vehicular activity) to a temporary base camp and entering a pressurized rover compartment while robots performed tasks in preparation for the next EVA. Scenario tasks included: rover operations under direct human control and autonomous modes, crew ingress and egress activities, autonomous robotic payload removal and stowage operations under both local control and remote control from Houston, and autonomous robotic navigation and inspection. In addition to the main scenario, participants had an opportunity to explore additional robotic operations: hill climbing, maneuvering heaving loads, gathering geological samples, drilling, and tether operations. In this analog environment, the suited subjects and robots experienced high levels of dust, rough terrain, and harsh lighting.

Introduction: In preparation for a return to the Moon and then to Mars, NASA is investigating a range of planetary operational scenarios. One class of scenarios covers combined human/robot EVA operations. In developing these combined operations, NASA is assessing which types of tasks can be performed by robots in an effort to off-load crew. By demonstrating these tasks in Lunar/Martian analog environments, system developers and operations personnel can refine both the robots and the division of labor with significantly better data than is available in a laboratory environment.

Analog Environment: The Meteor Crater area provides a range of terrain and a soil composition that makes it a good Lunar Analog environment. The fine dust that covers the area is especially good for demonstrating the effectiveness of dust mitigation techniques. The privately owned Bar-T-Bar Ranch site chosen for this testing is adjacent to Meteor Crater and provides a large plain-like area for testing out operational scenarios in a realistic environment not available at NASA centers. The Meteor Crater area was effectively used for testing during the Apollo Era and over the last decade, the adjacent Bar-T-Bar Ranch location has been utilized for advanced planetary prototype Space Suit evaluations.

Participants: Two suited subjects, four robots and a mock-up of a pressurized rover compartment participated in the demonstration. The Johnson Space Center provided the two space suits and the suit subjects, the two person SCOUT (Science Crew Operations and Utility Testbed) rover, and the dexterous humanoid Centaur robot. The K-10 robot from the Ames Research Center performed inspection activities and the Jet Propulsion Laboratory ATHLETE (All-Terrain Hex-Limbed Extra-Terrestrial Explorer) robot maneuvered and supported the simulated pressurized rover compartment provided by the Langley Research Center.

Coordinated Operations Scenario: This scenario, referred to as the Coordinated Field Demonstration (CFD), covers operations that could occur after the crew returns from a "typical" planetary EVA on the SCOUT rover to a lunar base site. At the base site, three robots are stationed to support post lunar sortie operations: ATHLETE equipped with a modular Pressurized Rover Compartment (PRC), Robonaut in its mobile Centaur configuration, and the K-10 inspection robot. This scenario consists of the following steps (Figures 1-4) which were successfully demonstrated multiple times under various lighting conditions at the Analog Site:

- EVA crew drives the SCOUT rover in from the "field" to the "Lunar" base site and parks it for unloading, inspection and maintenance.
- EVA crew dismount SCOUT and walk to a kneeling ATHLETE.
- EVA crew climbs aboard ATHLETE and enters the PRC
- Centaur approaches SCOUT, unloads payload from the vehicle, and delivers it to a predetermined area.
- K-10 approaches SCOUT and performs a visual inspection of the vehicle
- SCOUT returns to the field without crew under supervised autonomy

Results: Extensive testing and coordination prior to arrival at the analog site, resulted in both the suited subjects and robots all performing extremely well throughout the two week desert test period. During the first week, participants verified compatible Radio Frequency (RF) communications, adjusted their systems for lighting and terrain conditions unique to the test site, and refined final operation procedures.

Figure 1: Crew drive to base camp on SCOUT

Figure 2: Crew enter PRC (on ATHLETE)

During the second week, the participants practiced and documented the scenario, evaluating technologies key to future planetary operations. The K-10 high-resolution, high-dynamic-range (HDR) image panoramas produced excellent inspection images of the SCOUT overcoming both shadowing and wash out effects in desert lighting. Dust mitigation techniques for all robots were effective. The Centaur robot performed its supervised autonomous payload operations under both local control and remote control from Houston via satellite. As expected, using remote control initially resulted in task times on the order of 3-6 times longer, but with the addition of a predictive display, tasks times were reduced to approximately 2.5 times over local control. In addition, all participants had the opportunity to explore other potential cooperative operational scenarios. For example, Figure 5 shows Centaur assisting ATHLETE with a rappelling line.

Figure 3: Centaur autonomously removes and stows a sample box

Figure 4: K-10 robot inspects SCOUT prior to SCOUT departing under supervised autonomy

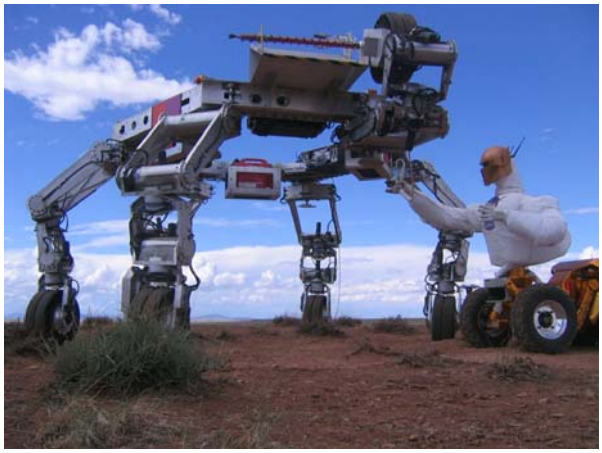

Figure 5: ATHLETE preparing to drill and Centaur removing a tether hook from ATHLETE