SIMULATION TO EVALUATE AUTONOMOUS BEHAVIORS FOR MOBILE PLANETARY SURFACE SCIENCE MISSIONS. A.F.C. Haldemann, M.C. McHenry, R. Petras, K. Ali, B. Bornstein, R. Castano, J.M. Cameron, T.A. Estlin, T.G. Farr, D. Gaines, A. Jain, C. Lim, I.A. Nesnas, M. Pomerantz, M.W. Powell, R.A. Volpe, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, albert.f.haldemann@jpl.nasa.gov

Introduction: The objective of this paper is to describe recent progress in testing autonomous robotic technologies as they might be used for scientific exploration of planetary surfaces.

The Jet Propulsion Laboratory's Science Operations On Planetary Surfaces (SOOPS) task has as its goal to evaluate, develop and validate methods for increasing the productivity of science operations on planetary surfaces [1]. The highly-integrated spacecraft-instrument payload systems of planetary surface missions create operations constraints that reduce the effective science capability. Technological solutions have been proposed to mitigate the impact to science return from those constraints.

The SOOPS task is developing a method for evaluating alternate rover system improvements within a spectrum of planetary surface science operations scenarios. SOOPS applies this method to selected technologies and scenarios, to enable development and testing by science operations teams. Testing involves a significant effort at simulation of realistic environments and the implementation of a 'Field Test in a Box' (SOOPS-FTB) capability.

SOOPS takes a systems level approach to evaluating and demonstrating the potential benefits of technologies that are already in development at the 'component level'. For example, a rover technology has been demonstrated for automated target approach and contact deployment of an arm-mounted instrument (so-called "single command instrument placement", SCIP) However, its operational benefits have not been tested, nor have operations interfaces to the technology been implemented. SOOPS can integrate this technology and others within a test-operations infrastructure and evaluate the benefits.

More generally, the SOOPS initiative consists of technology developments directed towards specific aspects of the integrated system with the objective of significantly improving the quantity and quality of interactions between a science team and their targets of investigation. These technologies can be tested in key demonstrations and the results can be assessed in terms of potential benefit to future missions.

Simulation of Science Operations: SOOPS Field Test in a Box (SOOPS-FTB) is the integration of ground operations tools (Maestro) [2] that have been used to operate the Mars Exploration Rovers (MER), with on-board control software (CLARAty) [3,4] that is used in rover prototypes, along with simulations of a spacecraft and its environment (ROAMS/SimScape) [5,6,7]. This integrated system provides a "sandbox" in which scientists can conduct simulated field tests for the purposes of strategic planning, training operators, evaluating both new technologies and new operations processes as well as informing subsequent true field tests using a research rover.

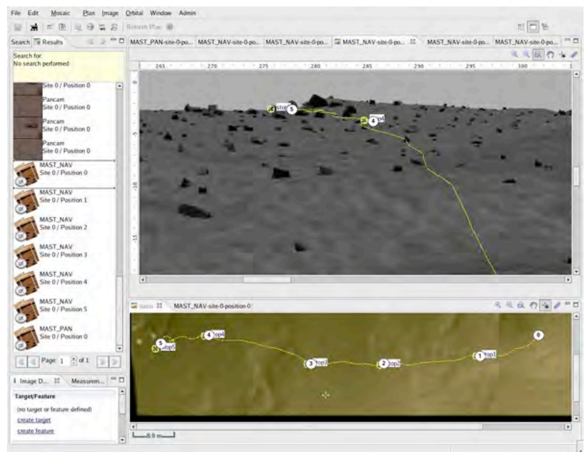

Figure 1. A screen shot of the Maestro user interface data viewer. Traverse planning can be accomplished either in the overhead ('orbital') view, or in the ground view. A separate panel is used to assemble the planned list of activities associated with each waypoint chosen in the landscape with the image viewer.

Figure 2. A test director's view of the simulated prototype rover in a SimScape terrain viewed in ROAMS.

Autonomous Science Experiment: With the completion of the integration of the SOOPS-FTB system, we picked one potential advanced technology to evaluate its use by a science team: OASIS.

OASIS. The Onboard Autonomous Science Investigation System (OASIS) enables detection of, and reaction to science features of interest [8,9,10]. OASIS includes the capability to summarize and prioritize data based on science criteria as well as the capability to perform opportunistic science [11].

The OASIS capabilities we chose to incorporate into the FTB for testing were Data Summarization and Image Prioritization. The data summarization consisted of the capability of autonomously generating a rock characterization table and a map onboard the rover. This provides a data summary product that conveys collected data but requires only a small amount of downlink bandwidth. The rock characterization table specifically summarizes data (e.g., location, features) on all identified rocks in image data. A map representing this data can be displayed in Maestro. Image prioritization identifies onboard images containing rocks of high interest based on user specification of key rock features and their associated priorities. Thus image prioritization potentially enables better use of limited downlink bandwidth.

In our test we could select and downlink the top N images with rocks that best match interest parameters set by scientists test teams. The team members are not co-authors of this paper, and are treated, somewhat, as test subjects in a market research sort of way.

Test Scenario. The scenario in which the system was exercised is a rover traverse in which downlink data volume is limited and the rover can collect many more images than it can downlink. In this task, the system was used to summarize and prioritize data based on rocks and their properties.

Four teams were given the goal of characterizing the geology of the terrain in a simulated environment. They were provided with the high-spatial resolution "orbital image" (approximately the resolution of the HiRISE camera on the Mars Reconnaissance Orbiter) shown in the left portion of Figure 3. At the ground level the team was provided with an initial navigation camera (Navcam) panorama. They were to plan a traverse across the 100 m (east-west) by 40 m (north-south) terrain using a fixed downlink budget for a combination of Nav and Pancam images. Each team created two command sequences; one with traditional methods and one with the OASIS onboard autonomous science system. They then compared their post-drive understanding of the terrain based on the data resulting from the two runs.

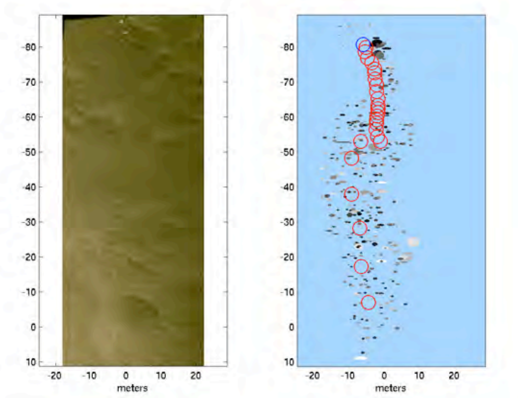

Figure 3. The rock map displayed next to the overhead view. This is the map that resulted from Team 1's OASIS sequence. The red circles show the locations of image acquisitions commanded by the team in their plan. The images are oriented such that North is to the right of the page.

Conclusions: Overall, we are satisfied that the teams felt that the SOOPS environment could be useful for operational testing and tool evaluation. Future experiments should be done over longer periods of time. The existing terrain was not convincing enough for the teams to develop any science story and its lack of fidelity misled them in both the plans and evaluation of returned data. Despite that the environment was realistic enough to evaluate and understand the operational capabilities of the OASIS tool. In fact, some of the approaches the teams took to using the OASIS rock mapping tool had not been previously imagined by the developers, attesting to the strength of the simulation driven tech development approach of SOOPS. With additional instruments, the SOOPS environment can be as good as Mars Yard testing for most applications. The addition of realistic terrain or terrain derived from a real site will make science operations possible.

References: [1] Biesiadecki, J.J. et al. (2006) *IEEE Robot.&Autom.*, *13*, 63. [2] Fox J. et al. (2006) *SpaceOps 2006 Conf.*, Rome, Italy. [3] Nesnas I.A. et al. (2003) *SPIE Aerospace Conf.*, Orlando, Florida. [4] Nesnas I.A. et al. (2006) *Int. J. Adv. Robot. Sys.*, *3*, 023-030. [5] Jain A. et al (2004) *IEEE 2004 Aerospace Conf.*, Big Sky, Montana. [6] Madison R. et al. (2005) *j-SAIRAS 2005*, Munich, Germany. [7] Jain A. et al (2006) *SMC-IT 2006*, Pasadena, Calif. [8] Castano R. et al. (2003) *IEEE 2003 Aerospace Conf.*, Big Sky, Montana. [9] Castano R. et al. (2004) *IEEE 2004 Aerospace Conf.*, Big Sky, Montana. [10] Castano R. et al. (2005) *IEEE 2005 Aerospace Conf.*, Big Sky, Montana. [11] Anderson R.C. et al. (2003) *Eos Trans. AGU*, *84*, Abst.P41B-0408