PLANETARY-PROTOTYPE DRILLING AND SAMPLE ACQUISITION TESTS AT ANALOG SITES.
. B. J. Glass[1], C. McKay[1], A. Dave[1], P. Lee[1], B. Mellerowicz[2], [1]NASA Ames Research Center, Moffett Field, CA 94305, USA, Email: brian.glass@nasa.gov, [3] Honeybee Robotics, 398 W Washington Blvd., Suite 200, Pasadena, CA 91103.

Introduction: Some form of excavation and penetration will be required in order to explore and interrogate the shallow subsurface of Mars from the surface, with drilling being the most mature approach. Looking for organics and signs of past or extant life on Mars will require the ability to search beneath the surface where biomarkers are protected from harmful UV radiation and harsh surface chemicals such as oxidants [1]. Hence, life-detection missions will likely incorporate a rover- or lander-mounted drill (as shown in Figure 1) capable of breaking through up to one meter of ice layers that were a barrier to the Phoenix scoop. Missions to characterize subsurface volatiles on the Moon or Mars will require a similar instrument capability. Given lightspeed delays, teleoperation of a drill and of sample handling beyond the Moon is not feasible and hence must be fully automated. A spacecraft intended to drill on Mars must also be capable of hands-off operation for hours at a time without human oversight or control, as by the time Earth learns of a drilling problem, the drill will be at least several minutes to hours further along and possibly stuck [2,3].

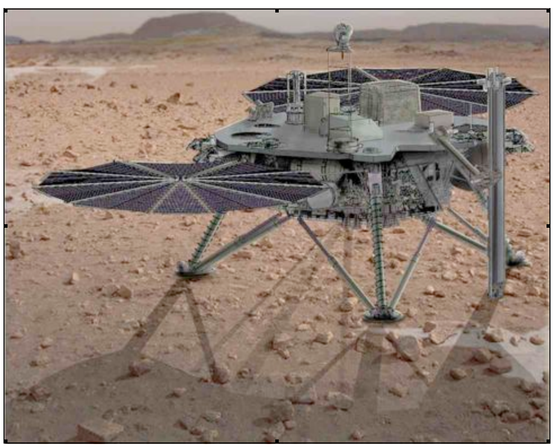

Figure 1. Concept of "Icebreaker" Phoenix-derived polar drilling lander.

Prototype Drill Concepts: A series of 0.5-5m automated rotary and rotary-percussive drills developed over the past decade by NASA Ames and Honeybee Robotics provide a capability that could fly on a Mars surface mission within the next decade. Surface robotics have been integrated for sample transfer to deck instruments, and the Icebreaker sample acquisition system has been tested successfully in Mars chambers and analog field sites to depths between 1-3m.

The Drilling Automation for Mars Exploration (DAME) drill was a lightweight rotary drill developed by Honeybee Robotics and NASA Ames in 2004-05, and tested at Haughton Crater [4]. Along with a similar (MARTE) drill tested with in 2005 with integrated sample transfer [5], these demonstrated downhole and topside automated sample acquisition from the subsurface of Mars and lunar analogs.

Rotary –percussive drill designs have proven to be more energy- and mass-efficient in fracturing ice layers and ice-cemented ground, as well as less prone to getting stuck. The small (5cm) sample acquisition drill on the Mars Science Laboratory rover is a rotary-percussive type.

The Icebreaker drill is a vacuum-rated rotary-percussive drill designed to optimally drill with only 100N downward force (suitable for rovers), using typically 100W or less, to a depth of 1 meter (up to 5m is possible, with additional drill strings). This drill uses three different drilling modes: rotary, rotary percussive and percussive. Decoupling the percussive and rotary actuators means that the frequency of percussive impact (indexing) can be varied. Its rotary and percussive actuators are 200 W each to allow for margins, and the maximum weight on bit (force pushing the drill down) is limited to 100N to simulate drill deployment from a lightweight platform or a rover in low Martian gravity.

Sample Transfer: There are a variety of possible technical approaches for conveying samples from a drill to instruments: among them are manipulator arms, rail or track—conveyor systems, or vibrated tables and bins. Manipulators provide significant advantages in operational flexibility and an arm is used on the MSL rover. Icebreaker uses both active and passive scrapers and brushes that can move drill cuttings from the auger/bit assembly into a sample catchment, while not contacting the sample catcher itself with the brushes. A relatively simple four degree of freedom (DOF) manipulator arm moves the samples from the catchment up to the spacecraft deck with input hoppers, and places the samples in them. The arm itself is powered by servo motors which respond to pulse width modulation signals from the arm interface – two extra servo control channels support the testing of end effectors with up to two actuators.

Objective and Metrics: Possible use of a rotary-percussive drill in a future Mars mission requires technical maturity and demonstrated operations in relevant environments. Objectives for the 2012-13 Haughton Crater and Dry Valleys tests were therefore to test the Icebreaker drill in frozen ice-consolidated material and ice layers that are texturally similar to Martian conditions; to meet or exceed the maximum depth drilled by earlier tests in 2011 (3m cumulatively); to demonstrate integrated sample-acquisition operations with a coordinated drill and sample-transfer manipulator, in a realistic setting; to demonstrate the expected fault modes of the drill, for use in failure detection and automated control; to operate remotely with periodic uploaded batch-mode commands similar to Mars operations; and to compare the required energy and downward forces needed to make headway, compared with previous drill designs tested at the same location.

Field Test Sites: The Haughton Crater test site in the Canadian Arctic is on Devon Island, Nunavut at 75.2N, 89.7W, at the Drill Hill impact breccia deposit inside the 22km-diameter impact structure . The Haughton Crater Research Station base provides seasonal logistical support for up to 40 researchers and staff working in or around the 22-km wide Haughton Crater impact site during summer months.

Tests in 2010 and in 2012-13 in Antarctica were held in one of the Dry Valleys (University Valley) as well as locations on Ross Island near McMurdo Station.

Results: Icebreaker was tested under manual control in Antarctica (near McMurdo Station) in late 2010 as an initial shakedown of the hardware. Drill control automation was integrated and tested successfully with Icebreaker at Haughton Crater in the summer of 2011. Fig. 2 shows an example of the successful detection, recovery, and resumption of drilling by the Icebreaker during an episode of downhole jamming.

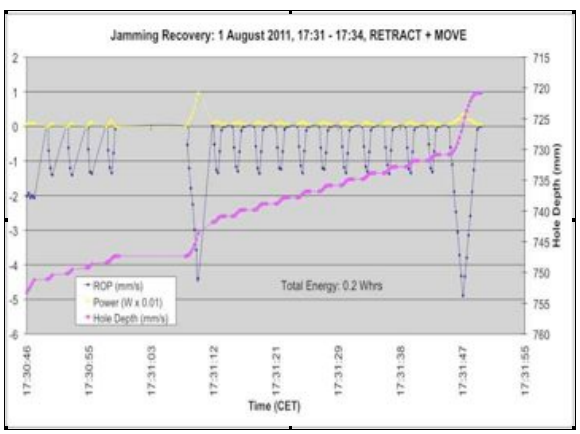

Figure 2. Automated detection and recovery of a downhole jam by Icebreaker.

In summer 2012 tests at Haughton Crater, a cumulative 4.1m was drilled in several boreholes, with the deepest at 1.3m. Four of six major fault modes occurred naturally in the course of drilling operations (corkscrew, binding, bit inclusion, choking) while two had to be induced with assistance due to the drill's robustness (jamming, hard material/bit wearout).

The sample transfer arm was integrated and tested as part of overall drilling and sample acquisition operations. Samples were retrieved (without direct arm contact with the drill itself, for planetary-protection) and deposited in mockup instruments with full-scale inlet ports on a simulated Phoenix-sized spacecraft deck. Figure 3 shows the tested system in August 2012 at Haughton Crater. These tests are planned to be repeated at a different analog site, in January-February 2013 in Antarctica at McMurdo and University Valley.

Fig. 3. Icebreaker integrated sample acquisition test configuration in August 2012 at Haughton Crater.

Conclusions: A series of 0.5-5m automated rotary and rotary-percussive drills developed over the past decade by NASA Ames and Honeybee Robotics provide a capability that could fly on a Mars or lunar surface mission within the next decade. Surface robotics have been integrated for sample transfer to deck instruments, and the Icebreaker sample acquisition system has been tested successfully in the laboratory and analog field sites to depths between 1-3m.

Acknowledgements: The authors would like to thank Dr. Mary Voytek of the Astrobiology Science And Technology For Exploring Planets (ASTEP) and Dr. Michael New of the Astrobiology Instrument Development (ASTID) programs at NASA Headquarters for their support of this combined effort.

References: [1] Navarro-González, R., et al, (2010) *JGR*, 115, E12010. [2] Blacic, J., et al (2000) *AIAA Space 2000*, AIAA-2000-5301. [3] Y. Bar-Cohen and K. Zacny (2009) *Drilling in Extreme Environments*, Wiley & Sons. [4] Glass, B. et al, (2008) *Astrobiology*. [5] Stoker, C. et al. (2004) *LPSC XXXV*, Abstract 2025.