HONEYBEE ROBOTICS PLANETARY DRILL SYSTEMS.
K. Zacny, G. Paulsen, K. Davis, E. Mumm, and S. Gorevan. Honeybee Robotics, New York, NY, [1]zacny@honeybeerobotics.com.

Introduction: In the last decade, Honeybee Robotics Spacecraft Mechanism Corporation has developed over a dozen planetary drill systems. The drills were built to meet specific requirements such as reaching certain depths, exhibiting certain levels of autonomy, acquiring samples of certain sizes and integrity (e.g. core vs. powder). They were built to operate at restricted power and Weight on Bit values. Most of the drills were tested either in the planetary analogs such as the Arctic, and/or laboratory, and/or environmental chambers and for this reason are at different Technology Readiness Levels. This abstract describes some of the drills.

The Coring Abrading Tool (CAT): The integrated coring and abrading tool (CAT), is a hybrid of Honeybee's existing Rock Abrasion Tool (RAT) and Mini-Corer (MC) designs. The Rock Abrasion Tool is a TRL 9 instrument that is currently operating onboard of Mars Exploration Rovers. The CAT is an arm-mounted, stand-alone device, requiring no additional arm actuation once positioned and preloaded. This instrument is capable of autonomously acquiring, retaining and transferring 8 mm in diameter and up to 100 mm long cores of solid and unconsolidated material, abrading and brushing rock surfaces. Changing out bits and end-effectors to perform the coring/abrading operations is also done autonomously. Shown in Figure 1, the CAT weighs less than 4 kg, and can penetrate 100 MPa basalt rock with only 120 Newton of preload (Weight on Bit). The CAT was extensively tested in a vacuum chamber (under simulated Mars atmospheric conditions) and it is currently at TRL of 6.

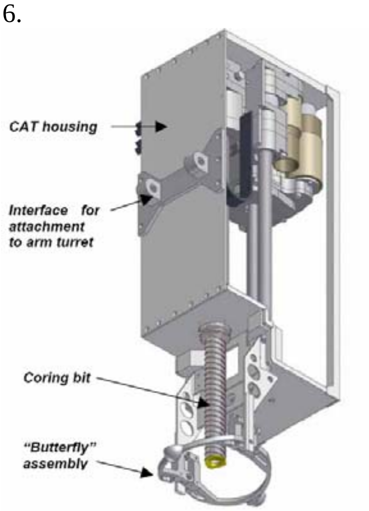

Figure 1. Components of the Corer-Abrader Tool in coring mode.

The SATM drill: The Sample Acquisition and Transfer Mechanism (SATM) is a 1-meter class drill system that features sample handling abilities and sample return containers (Figure 2). A prototype was developed and successfully tested to validate the performance requirements for the NASA ST/4 Champollion mission goals. The SATM was designed to acquire samples at 20 cm and at one meter below the surface with little or no cross-contamination. Depending on the scientific sampling needs, the system can accommodate sample volumes ranging from 0.1-1.0 cc.

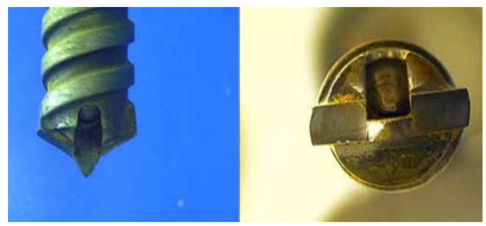

Figure 2: Detail of Sampling Tip (Door Closed) of the Sample Acquisition and Transfer Mechanism (SATM) drill.

The CRUX drill: The Construction and Resource Utilization Explorer (CRUX) drill (seen in Figure 3) was designed as a 2 meter test platform for testing various drill bits, augers, and drilling modes [1]. This drill was designed to use three different drilling modes: rotary, rotary percussive and percussive. The drill has a total linear stroke of 1 meter. The CRUX drill was designed to produce as much as 45 N-m of torque at a rotational speed of 200 rpm. A maximum downforce of 1000 N can be achieved by the linear drive system, which makes the drill ideal for testing large diameter drill bits. The frequency of percussive impact can be varied if needed while rotational speed can be held constant. To control the weight on bit during the drilling process, a load cell is axially aligned with the drill segment to provide accurate feedback of drilling loads to the control system.

The drill platform was designed to accommodate a downhole neutron spectrometer for measuring the amount of hydrated material in the area surrounding the borehole [2], as well as downhole temperature sensors, accelerometers, and electrical properties tester.

The Tungsten Carbide (WC) and PCD bits and augers designed specifically for this drill were extensively tested in various rock types and lunar regolith simulants with water contents ranging from 0 to

10%wt. Testing was done with rotary and rotary-percussive drilling modes.

Figure 3. Honeybee CRUX drill was designed for three different drilling modes: rotary, rotary-percussive and percussive. The augers and drill bits are not shown.

The MARTE drill: The Honeybee Robotics MARTE drill was part of the Mars Astrobiology Research and Technology Experiment (MARTE), shown in Figure 4, which was a Mars research platform that has investigated robotic drilling to 10 meter depths [3].

The MARTE drill is a highly automated 10 meter class drill system. The 10-axis system is designed for subsurface core capture, break off, recovery and hand-off as well as autonomous assembly and disassembly of drill strings. The MARTE drill produces rock cores 27 mm in diameter and 250 mm long while creating a 48 mm diameter borehole. A core hand-off sub-system delivers a core to a core clamp for sample preparation and delivery to scientific instruments. The drill strings interfaces allow for power and data transfer to embedded instruments. The system is designed to operate below 150 Watts average. Highly integrated sensor feedback control on all drilling axes allows for future integration of intelligent drilling algorithms and fully autonomous operation. The drill was field tested in California limestone quarry and Rio Tinto, Spain and is at TRL 5-6.

The DAME drill: The DAME drill (Drilling Automation for Mars Exploration) shown in Figure 5, is a 10 meter class drill system designed specifically to investigate methods of automated drilling and fault recovery [4]. To achieve that, the drill includes seven sensors: a load cell is used to measure the drilling down force or Weight On Bit (WOB); two optical encoders are used to track and control the position and velocity of the Z axis and the auger; a torque sensor is built into the lead drill string to measure the torque directly at the bit (cutting torque); a thermistor is also built into the lead drill string to measure the bit temperature; and two current sensors are used to measure the current draw from the auger and Z axis motors. With this suite of sensors, the drill can 'sense' its state and adjust drilling parameters or drilling sequence accordingly. It can also identify up to seven drilling faults and use pre-coded sequence to recover from them. The drill was deployed three times in the Arctic and it is at TRL of 4-5.

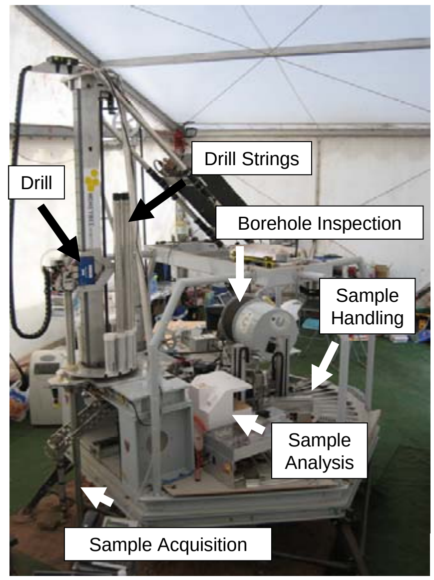

Figure 4. The MARTE (Mars Astrobiology Research and Technology Experiment) science package with all the instruments and a drill.

Figure 5. The DAME drill was deployed three times in the Arctic field tests (2004, 2005 and in 2006) on Devon. The drill uses 1.75 inch full faced bit forcutting material and auger for cuttings removal.

References: [1] Zacny K. et al. (2006) Earth and Space. [2] Elphic R. et al. (2006) LPSC *XXXVII*, Abstract #1677. [3] Stoker C. et al. (2003) LPSC *XXXVI*, Abstract #2025. [4] Glass B. et al. (2006) LPSC *XXXVII*, Abstract #2300.