ROTARY-PERCUSSIVE DRILL FOR PLANETARY EXPLORATION AND A 3.5 m VACCUM CHAMBER ENABLING FULL SCALE TESTING. K. Zacny[1], G. Paulsen[1], M. Szczesiak[1], B. Glass[2], C. McKay[2], J. Wilson[1], J. Craft[1], [1]Honeybee Robotics Spacecraft Mechanism Corp. (zacny@honeybeerobotics.com), [2]NASA ARC

Introduction to Drilling Technology: Minimizing push force on the drill, or so called Weight on Bit (WOB), in low gravity environments such as on Mars or the Moon is of paramount importance. This is especially true if the mass of the drill platform (rover or a lander) is also very low [1]. For this reason, we designed and built a Rotary-Percussive drill called the CRUX drill. This drill was built to determine the exact reduction in WOB and also improvement in drilling efficiency produced by the rotary-percussive action while drilling in various formations such as ice, ice with perchlorate (as found at the Phoenix landing site), icy-soils, and rocks.

Rotary-Percussive Drill: The CRUX drill is a rotary percussive drill designed as a highly capable test-bed platform (Figure 1). The actuators for rotation, percussion and preload are large enough to allow testing to large depths with minimal concern of the drill getting stuck and having to be manually pulled out. This capability allows for quantifying various drill faults such as auger choking. The drill has been used to determine power, energy (power x time), and Weight on Bit (WOB) required to drill in various formations such as ice, limestone, basalt, and frozen Arctic Devon Island breccia. The drill includes the following capabilities:

- Rotary Percussive Drill head with two separate actuators enabling the following drilling modes:
  - Rotary
  - Percussive
  - Rotary Percussive
- Auger drive capabilities of 2 kW
- Percussive drive capabilities of 200 W
- Weight on Bit (WOB) capability of 1100 N
- Depth Range > 1 m with a single drill string
- Electrical feed throughs for down hole sensors such as a thermocouple
- A dedicated Torque and Temperature sensors for measuring torque and temperature of the bit only. This data decouples torque due to cuttings removal from the torque due to rock breaking and supports drill automation.
- Window in drill string for down-hole camera

Test Results: Though there have been other studies comparing rotary to rotary-percussive drilling [2], data presented in this abstract specifically compares drilling tests performed by the CRUX drill (rotary-percussive) and the DAME drill (rotary only) in the Canadian High Arctic. Another notable difference between these drills is the diameter of the drill bit: 1.86 inch for DAME and 1.5 inch for CRUX. The data for WOB, Rate of Penetration (ROP), and Specific Energy for the two drill systems are shown in Table 1. To help in the data comparison, the DAME drill data has been normalized to a 1.5 inch diameter (the diameter of the CRUX drill). In particular, the WOB, Rate of Penetration, and Energy were reduced by the ratio of the drill bit areas. It can be seen that when using the CRUX drill, the WOB and the Specific Energy was lower, while the ROP was higher. In particular, the WOB was ~453 N, which was two times less than that for the corrected DAME rotary drill data; the Specific Energy was 203 J/cc, which is a third of the energy used by the DAME drill; and the penetration rate of the CRUX drill was 0.35 mm/s, which is almost an order of magnitude higher than that for the DAME drill. Note however, that because the CRUX drill used additional mechanism (percussor), the total power was in fact higher than that for the DAME drill (150 Watt vs. 50-100 Watt). Also note that the reduction in WOB and Energy, and an increase in ROP and Power would be different for different materials and thus the numbers presented in Table 1, should not be applied to other formations.

Table 1: Rotary vs. Rotary-Percussive drill.

Description	CRUX	DAME	Ratio: CRUX / DAME
Drill Type	Rotary-Percussive	Rotary	
Bit diameter	1.5in	1.86in but data was normalized to 1.5in.	
WOB* (N)	453	945	0.5
ROP** (mm/s)	0.35	0.03	12
Power (Watt)	150	50-100	2
SE*** (J/cm^3)	203	759	0.26

*Weight on Bit; ** Rate of Penetration; *** Specific Energy

Introduction to Vacuum Chamber: In order to bring the sampling technologies into the required

Technology Readiness Level (TRL) of 6, the hardware has to be extensively tested under relevant environmental conditions. These conditions are always much different than the conditions we find on Earth, and the exact conditions depend on where (what extraterrestial body) the system will be deployed. For example, if the target planet is Venus, the hardware has to be tested at ~90 bar pressure, CO2 atmosphere, and 460 °C temperature. For Mars, the conditions are more benign: low pressure of 1-11 torr and temperature of the order of -80°C to +25°C.

Simulating accurate environmental conditions not only is required for demonstrating the hardware, but also to investigate how a sample is behaving during a sample acquisition. Sticking of sample onto the scoop surface on the Mars Phoenix lander would not have occur if the same sampling system was deployed on the Moon, for example.

In addition to atmospheric conditions (pressure, gas, temperature), it is also important to simulate the appropriate formation (soil, rock, ice). For example, drilling into icy-soils will be different than drilling into icy-soils containing salts (as found by the Phoenix lander). Salts depress the freezing point of water and in turn make the sample stickier at even sub-freezing temperatures. Sample acquisition of icy-soils will also be different than sample acqusition of rocks.

In order to address environmental testing of drills, diggers, and penetrometers for Mars applications (and to some extent the Moon, and the Asteroids) we developed a large environmental chamber system.

Vacuum Chamber Description: The Vacuum chamber consists of two smaller chambers assembled on top of each other in such a way that the inner walls are flush (Figure 1). The bottom chamber is 84 in tall by 38 in x 38 in, while the top chamber is 48 in by 38 in x 38 in. Having two chambers instead of one allows the two smaller chambers to be used independently of each other.

The chamber has 20 inch flanges on the top and the bottom. This allows inserting an additional cylindrical vacuum extension on top to accommodate a longer penetrometer stage. Putting a similar 20 in diameter cylindrical extension at the bottom, allows the vacuum chamber to extend below the floor (into a trench, for example). A rock or a soil sample could be placed in this lower cylindrical section.

The chamber reached 0.01 torr with two pumps. Current pumping system allows the chamber to reach ~1 torr with just one rouging pump. This was proven even when the chamber was filled with sand (Figure 1). A pressure of 5 torr (Mars pressure) can be reached in just under 15 minutes. The cooling of sample is achieved via a closed loop cooling system.

The chamber so far has been used to test different Mars and Lunar drill systems to a depth of >1 meter. The chamber was also placed in a horizontal position (Figure 2) to test a lunar mining system.

Figure 1. Rotary-Percussive drill inside vacuum chamber in an upright position. The chamber allows testing to >1m depth under Mars low pressure, low temperature and CO2 atmospheric conditions. The chamber can also be used for testing drills under partial lunar like conditions, because, the lowest pressure it can reach is 0.01 torr.

Figure 2. Vacuum chamber in a horizontal position for testing lunar mining systems. Shows is a lunar pneumatic excavator prior to testing in the GRC-1 lunar soil simulant.

References: [1] Bar Cohen, Y., and K. Zacny, Drilling in Extreme Environments: Penetration and Sampling on Earth and other Planets, Wiley-VCH (Sept 15, 2009). [2] Izzo, M., Down-hole Hammering Mechanism Bread Board Model Summary Report," Galileo Avionica Report, DHM-SA-GA-015.