PLANETARY DRILL PROTOTYPE TESTING AT AN IMPACT STRUCTURE PALAEO-HYDROTHERMAL SITE. B. Glass[1], S. Thompson[1], S. Hanagud[2], S. Statham[2], J. Cohen[3], P. Lee[1], G. Osinski[4], S. Huffman[5]. [1]NASA Ames Research Center, Moffett Field, CA 94305, USA, Email: brian.glass@nasa.gov, [2]Georgia Institute of Technology, Atlanta, GA 30332, USA, [3]Honeybee Robotics, New York, NY 10001, USA, [4]Univ. of Western Ontario, Sudbury, ON, Canada, [5]Stanford University, Stanford, CA 94035, USA.

Introduction: The search for evidence of ancient climates, extinct life, and potential habitats for extant life on Mars, given the desiccated and irradiated conditions near the surface, will require drilling or some other form of subsurface access. A drill or corer becomes both an instrument itself and a means of acquiring fresh unweathered specimens. Given lightspeed time delays (tens of minutes) that are much longer than the time required (seconds) to get a drilling instrument stuck, Earth-based direct teleoperation is not feasible for drilling operations beyond the Moon.

The Drilling Automation for Mars Exploration (DAME) was a NASA project in 2004-07 for developing critical-path drilling software control and automation technologies. The DAME project's purpose was to develop and field-test drilling automation and robotics technologies for projected use in missions in the 2013-18 period [1]. Figure 1 shows a lightweight, planetary-prototype drill, in DAME summer Arctic field testing [2]. DAME included control of the drilling hardware, and state estimation of both the hardware and the lithography being drilled and the state of the hole.

Fig. 1. Planetary-prototype 5m-class DAME drill in summer 2008 field tests in Haughton Crater.

DAME field tests in 2004-2006 were conducted under field conditions in frozen fallback breccia in an impact crater (Haughton Crater) in Arctic Canada [2, 3]. In 2007, tests at a JPL-developed Mars environment drilling testbed [4] were conducted to provide a rigorous repeatable test of drilling automation, and to provide testbed calibration. Under a summer field test grant in 2008 from the NASA Moon And Mars Analog Mission Activities (MMAMA) program, the previous DAME software and planetary-prototype drill hardware were reconditioned and the drill software executive was upgraded to a more fault-tolerant set of controls implemented in Plan Execution Interchange Language (PLEXIL). These were then deployed to the Haughton Crater analog site for field tests in July 2008, acquiring subsurface specimens down to 2m in a palaeo-hydrothermal structure in permafrost.

Objectives – 2008 Field Season: The 2008 drilling test objectives were to demonstrate hands-off automated operations, including fault monitoring, recovery, and execution of nominal drilling and instrument operations, while drilling in a realistic planetary-analog environment. The Honeybee Robotics DAME-prototype 5m augering drill was used for these goals:

(a) Modify both of the existing DAME diagnostic models to reflect the DAME 2007 drill and JPL testbed experience;

(b) Integrate a redesigned DAME executive (in PLEXIL) with the automated monitoring and diagnosis software;

(c) Implement and test the DAME-derived 3-D laser vibrometer design, for detecting axial and torsional vibrations (and hence state changes) of the rotating drill shaft;

(d) Implement and test new drill-state-monitoring graphical displays;

(e) Demonstrate hands-off operations in drilling permafrost, with the integrated automated system.

The 2008 science objectives were to augment ongoing studies of ancient post-impact hydrothermal activity at Haughton Crater [5], drilling 2m into a structure believed to be a past hydrothermal chimney, in permafrost. This was selected both as a Mars-analog and in support of the extant studies of Haughton Crater itself. This was the first documented drilling and acquisition of subsurface samples and cores from a Haughton Crater palaeo-hydrothermal site.

Field Test: The Haughton-Mars Project operates a research station in the Canadian Arctic adjacent to Haughton Crater, on Devon Island, Nunavut at 75.2N, 89.7W, jointly supported by NASA and the Canadian Space Agency. The DAME drill and newly-revised

automation software and laser vibrometers were deployed to the HCRS in July 2008. The drilling site selected (Figure 2) was on top of one of a group of palaeo-hydrothermal chimneys believed to be along the original edge of the impact crater melt sheet. A large 5m-diameter dome tent covered the drill and support equipment. A portable generator provided power, although the drill itself was constrained to use no more than 150W peak. A communications relay to HCRS base camp provided data access back to NASA Ames for remote monitoring and technical support.

Fig. 2. 2008 Drilling Site in Haughton Crater, Devon Island, Canada.

All drilling 2008 technical test goals were completed successfully. Five of six known primary drill hardware faults were encountered naturally in the course of drilling. These drilling faults or state changes were correctly identified, corrective actions were taken and the drilling continued. Figure 3 shows the detection and automated response to hard material while drilling, as an example. It shows that the condition was triggered, then recovery actions made enough progress to return to nominal drilling, and then it was triggered again. There are 4 subplots - depth is on top, then there are 3 subplots for the parameters that were controlled by the executive (penetration rate, downward force, and auger rotational speed).

A total of 32 hours of autonomous, hands-off drilling was accomplished over five days. And a total depth of 2.76m was reached (a 74cm pilot borehole was used for debugging and parameter adjustments with the new software, followed by a 202cm "production" borehole), into the frozen chimney structure, with cores and cuttings obtained in 25cm sampling intervals.

Two of the three DAME diagnostic methods (rule-based, and vibration-neural-net) were used together and demonstrated robust, reliable monitoring and analysis of the drill and drilling operations. The model-based diagnostics did not function and were disabled in the field, but the drilling automation responded adequately given the improvements in the other parallel diagnostic methods. The 3-D laser vibrometer and its interpretative neural net was able to detect changes from shifts in natural frequencies and mode shapes of both torsional and axial shaft vibrations.

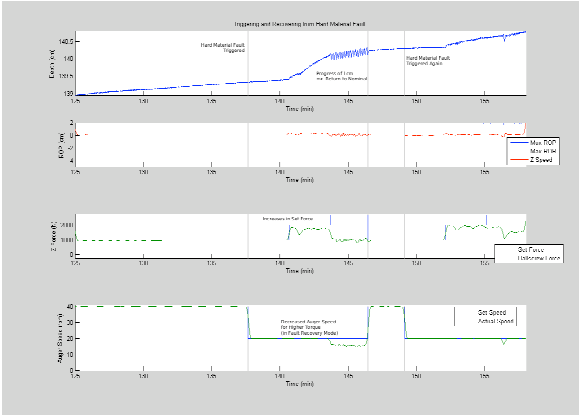

Fig. 3. Drill Automation Response to an Ice Lens.

Conclusions: This 2008 drilling automation field test effort successfully updated and replaced major components of the DAME drilling control software and completed a series of field tests in a relevant planetary analog environment, leading to drilling automation maturation suitable for consideration in future missions. On very short notice (2 months), a successful major overhaul of core DAME automation and its executive and GUI was implemented and field-tested. We found that the 3-D vibrometer/neural-net is now as reliable and responsive as rule-based diagnostics, while still being a non-contact method requiring no downhole sensors. Cores and cuttings were successfully retrieved and archived at roughly 25cm intervals, profiling an ancient post-impact hydrothermal chimney for the first time at the Haughton Crater site. Future work is needed to deploy and test drilling control from flight-prototype avionics boards, and to bring together the DAME-derived drilling automation with topside sample handling and curation as an integrated whole.

Acknowledgements: The authors would like to thank Kelly Snook of the Moon and Mars Analog Missions Program for her support of this 2008 analog field test project, as well as the DAME team at Honeybee, NASA and Georgia Tech and Les Addison for deployment logistics support.

References:[1]Glass, B. et al. (2008) *Astrobiology.* [2]Paulsen, G.L. et al. (2006), *LPSC XXXVII,* Abstract 2358. [3]Glass, B. et al. (2006) *LPSC XXXVII*, Abstract 2300. [4]Glass, B. et al. (2008) *LPSC XXXIX*, Abstract 2126. [5] Osinski, G. R. and Spray, J. G. (2005) *Meteoritics & Planet. Sci.*