**DRILLING AND PNEUMATIC TRANSFER OF TITAN SURFACE MATERIALS** R. D. Lorenz[1], J. Sparta[2], T. Costa[2], V. Sanigepalli[2], D. Yu[2], P. Ng[2], J. Bailey[2], B. Yen[2], F. Rehnmark[2], K. Zacny[2]. [1]Johns Hopkins Applied Physics Laboratory, Laurel MD, USA. (ralph.lorenz@jhuapl.edu) [2]Honeybee Robotics Exploration Technologies Group, Pasadena CA, USA

**Introduction:** Titan [1] presents a rich and accessible inventory of organic materials on its surface and in its atmosphere. Honeybee Robotics working with APL has developed an integrated sampling system for deployment to Titan which uses a drill to excavate material from the subsurface and pneumatic transfer to deliver it to internal instruments. The system has been tested in a cryogenic environment.

**Background:** Although Titan's materials present a major opportunity in the long term for in-situ resource utilization (not least as propellant – as described in Arthur C. Clarke's novel "Imperial Earth" in 1976), the more immediate application for acquisition and transport is in scientific sampling to measure the composition and ascertain the degree of prebiotic chemical evolution that has taken place on this organic-rich icy moon. Scientific interest in the "Ocean Worlds" (Titan, Enceladus, Europa) is high, and of these bodies, Titan's surface is in fact the most accessible due to its thick atmosphere.

**Figure 1**: The Dragonfly lander sitting on an interdune plain: the MMRTG is the cylinder at left, and the high gain antenna is deployed for direct-to-Earth communication. Each skid features a sampling drill and sensors to measure surface properties.

Currently, NASA is evaluating a proposal, "Dragonfly" [2,3; fig.1] for the New Frontiers 4 opportunity to launch in 2025. Dragonfly is a relocatable lander, using a set of 8 rotors to soft-land at multiple locations. Dragonfly is powered by a MultiMission Radioisotope Thermoelectric Generator (MMRTG) which trickle-charges a battery for flight. Dragonfly would use a pair of rotary-percussive drills (one on each landing skid) and a pneumatic sample transfer system to acquire surface samples.

**Titan Sampling System:** Our sampling system [4] employs a stream of gas to convey material (i.e. pneumatics) from a planetary surface to a sample cup for presentation to science instruments. We have paired our pneumatic system with a custom rotary-hammer drill to penetrate materials such as water ice, paraffin wax, ammonia-rich ice, etc. [5] that are expected to be found on Titan (the drill is conical in shape to avoid the potential for sticking). Fine-grained cuttings produced by the drill, or granular material that may be present in the landscape such as Titan's abundant organic sand dunes [1], is ingested with ambient Titan air through a suction inlet (figure 2) mounted near the drill. The airstream, driven by a simple ~700W blower (not unlike a commercial shop-vac) lifts the particles and conveys them through pneumatic tubing at 30 m/s. Once ingested, material is deposited into a self-metering sample cup in < 0.2 s. This approach not only minimizes heat transfer to the sample but also minimizes sample cross-contamination.

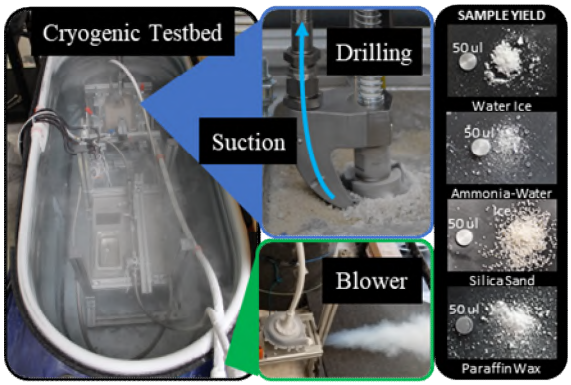


**Figure 2**: Sampling system under cryogenic test at Honeybee Robotics' Pasadena facility. The large bath is maintained with a bottom pool of liquid nitrogen : the continuous boiloff leads to a thick layer of cold gas (~80-100K, 1 bar) close to Titan conditions (94K, 1.46 bar). The open environment facilitates much more rapid test turnaround and access than a closed chamber, while the continuous boiloff helps prevent Earth-ambient moisture from freezing onto equipment.

**Material Capture:** The system developed for Dragonfly specifically uses 'diverter cups' to capture solids from the loaded airstream. These cups permit the small amount of material for analysis to be reliably metered and transferred to a science instrument. The capture efficiency of this approach is small (most of the ingested material is ejected through the blower) which is unimportant in this application. For in-situ resource utilization, where larger amounts of material might be transferred and a higher efficiency may be desired, a cyclone separator could be used instead, and our testing program has explored a variety of designs [4].

**Conclusion:** A combination drill and pneumatics sampling system is an excellent means for sampling the Ocean Worlds. Honeybee Robotics has designed and tested such a system for deployment to Titan.

**References:** [1] Lorenz, R. (2010) *Lifting Titan's Veil*, Princeton [2] Turtle E.P. *et al.* (2018) *LPSC 49*. #1641 [3] Lorenz R.D. *et al.* (2018) *APL Tech Digest*, 34(3), 374–387 [4] Zacny K. et al (2019) IEEE Aerospace Conference. [5] Sparta, J. et al. (2018) Experimental Studies of the Outer Solar System (ExoSS) Abstract #3008, Lunar and Planetary Institute Contrib. 2094

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