Development of a Pneumatic Sample Transport System for Ocean Worlds. Joseph Sparta[1], Tighe Costa[1], Fredrik Rehnmark[1], Jameil Bailey[1], Kris Zacny[1], and Ralph Lorenz[2], [1]Honeybee Robotics, Pasadena CA, USA (jsparta@honeybeerobotics.com), [2]Johns Hopkins Applied Physics Laboratory, Laurel, MD 20723, USA (Ralph.Lorenz@jhuapl.edu).

Introduction: A pneumatic sample transport system is being developed under the NASA COLDTech program for the transfer of cryogenic material from a planet's surface to a vehicle's on-board science instruments. This project focuses on the design of a pneumatic transport system for the exploration of Titan; it is feasible, however, that such a system could be used to explore other destinations.

Titan is geologically diverse (with methane lakes and rivers, sand dunes, craters, and cryovolcanoes) [1], and its surface conditions are likely to be similarly diverse. Initial testing accounts for this diveristy by including a wide variety of Titan mechanical analogs with ranging physical properties. An overview of the current status of the project follows.

Background: Sensitive scientific instruments deployed to ocean worlds to search for traces of past or extant biological activity will almost certainly be housed in a thermally controlled environment within the vehicle. A sample acquisition and delivery system presenting surface material to these instruments must be capable of operating at cryogenic temperatures (Titan's surface temperature is 94K) and in reduced gravity (Titan's surface gravity is 0.14g).

A vacuum cleaner uses airflow to pickup, transport, and collect loose material. The same applies to the pneumatic conveying of drill cuttings and surface material from the ground to an instrument for analysis. The process is simple and fast, and transport takes only a fraction of a second. Conveying material with a fast-moving air stream has a dual benefit of reducing the risk of adhesion along the transport path and minimizing temperature rise of the sample.

Pneumatic transport was successfully performed on Venus during the Venera 13, 14 and Vega 2 missions [2]. Pneumatic sample transport is also possible on airless worlds using a supply tank of gas and a manifold to seal around the target sample: injecting gas into the manifold pushes the sample through the pneumatics, as demonstrated by Honeybee's proposed PlanetVac sampling system [3].

Modeling: The pneumatic conveyors used in terrestrial process industries are typically designed to transport a specific dry material, such as grain or cement, under controlled conditions. Pneumatic transport involves complex, two-phase dynamic interactions between gas and solid particles and even three-phase flow (if the material being conveyed is wet). Consequently, the physics of pneumatic transport are not completely understood and existing models are largely empirical [4]. While these models can provide a useful starting point for design, testing is required to properly size and characterize the performance of any pneumatic transport system.

Experiments: The goal of current testing efforts is to characterize the transport of Titan simulants in a system with an architecture analogous to the flight design. These tests will determine the baseline fluid velocity for high sample collection efficiencies ([mass deposited in the sample cup] / [total mass of sample ingested]) of the target simulants in STP air. Operating at high collection efficiencies reduces buildup of material in the lines, helps prevent clogging, and minimizes crosstalk between samples. Tests are performed at standard room conditions using a sample transport testbed powered by a commercial vacuum cleaner (**Figure 1**). Future testing will be performed in environments more representative of Titan's atmosphere.

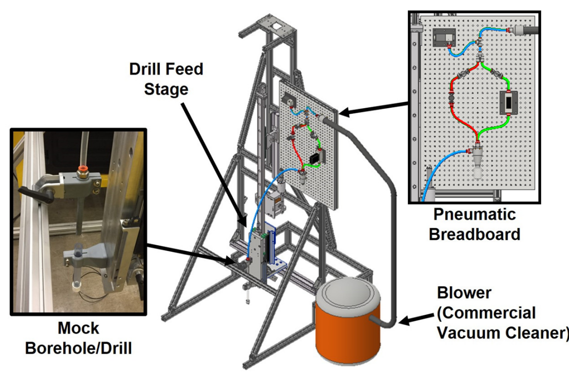

Figure 1. Pneumatic sample transport testbed.

Design: The first prototype will be designed for terrestrial operation and used for higher-fidelity simulant transport testing. The system will then be scaled for operation in Titan atmosphere.

The accepted models for pickup, choking, and saltation velocities account for the fluid properties of the carrying medium. [5] Comparison of the predictions for transport velocities on Titan to those on Earth show that the fluid velocity required to pneumatically convey a certain sample on Titan is approximately 4-5x lower than that required on Earth. This prediction will be tested with the Titan-scaled design at relevant conditions (cyrogenic GN2 at 1.5atm).

The Titan blower will be designed for the baseline fluid velocity determined in Earth atmosphere tests (adjusted for the different atmosphere and with an added margin). The scaling of the blower will be guided by the fan affinity laws, which describe the relationships of fan speed, fan size, and air density to pressure drop, flow rate, and power consumption.

The Titan cyclone separator will be scaled from the Earth atmosphere prototype according to Lapple's model of cut diameter, which accounts for fluid properties and flow rate. [6] The geometry may be fine-tuned for improved separation of sticky materials: Titan simulant transport results have so far shown that standard cyclone geometries (designed to work with dry materials) are not optimized for separation of wet and cohesive materials.

Conclusions and Future Work: This work represents a critical first step toward the design and qualification of a pneumatic sample transport system for ocean worlds. A custom blower will be designed and tested at room temperature based on the initial test results. Eventually, the design will be scaled for a Titan environment and tested at Titan temperature, pressure and atmospheric composition.

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References: [1] Lorenz, R. et al, (2017) APL Tech Digest. [2] Badescu, V. and Zacny, K., (2015) *Inner Solar System: Prospective Energy and Resources*, 193-194. [3] Zacny et al, (2014) *IEEE Aerospace*. [4] Klinzing, G. (2018) *KONA Powder and Particle 35*, 150-159. [5] Klinzing, G. et al, (2010) *Pneumatic Conveying of Solids*. [6] Dirgo, J. and Leith, D., (1985) *Aerosol Science and Technology, 4, 401-415*.