PLANETVAC: SAMPLE ACQUISITION AND DELIVERY SYSTEM FOR INSTRUMENTS AND SAMPLE RETURN. Z.Fitzgerald[1], K.Zacny[1], R.Mueller[2], P.Morrison[1], M.McCormick[1], A.Wang[1], L.Thompson[1], H.Jung[1], J.Hernandez[1], K.Leucht[2], M.Dupuis[2]. [1]Honeybee Robotics, 2408 Lincoln Ave. Altadena, CA 91101, KAZacny@honeybeerobotics.com. [2]NASA KSC, rob.mueller@nasa.com

Introduction: PlanetVac is a revolutionary technology for acquiring and transferring regolith from almost any planetary body to instruments (for in situ analysis) or sample returned container (for sample return missions) [1-4].

PlanetVac uses a robust and dust tolerant pneumatic approach, similar to traditional pneumatic based powder delivery technologies used on Earth. The main difference is the sources of gas: PlanetVac uses a standalone gas canister to provide the working fluid. Numerous surface missions (Viking, Mars Phoenix, MSL Curiosity, Venera, Luna etc.) have proven that sample acquisition and delivery is one of the most difficult aspects of the mission. Several missions, such as Venera, did not meet their scientific goals because of sample delivery system failure. In Mars Pheonix's case, some of its instrument suite was left unused because of difficulty in sample delivery (**Figure 1**).

Figure 1. The Mars Phoenix's Icy Soil Acquisition Device (ISAD) encountered problems when delivering cohesive samples. Poor control of scoop placement resulted in sample being spilled onto adjacent cups.

The range of instrument types and mission goals has driven complexity of sample delivery approaches. Some instruments require 50 micrograms of sample delivered into small cups (GCMS), some instruments require 10 cc of sample delivery into a cylindrical cup (MS), while others want a sample spread across a flat surface (Raman, LIBS, LDMS). Exploration and In-Situ Resource Utilization missions would likely want larger quantities of specific relevant materials (e.g., fines that contain specific minerals, such as ilmenite). Some sample return missions want rocklets (for geochronology) while others may require 10 cc of representative regolith sample. PlanetVac is versatile and can be adapted to meet any of these requirements. The PlanetVac pneumatic approach is gravity agnostic (it can work in strong or no gravity field) and it works with non-cohesive or cohesive materials (the latter materials have been the most difficult to deal with on prior missions, especially in low gravitational fields).

Reduced gravity flights (**Figure 2**) using lunar simulants has demonstrated that because of its high cohesion, lunar regolith will bridge which may make delivery to an instrument cup or sample return container difficult or impossible. During this testing Mueller et al., used JSC-1A lunar soil simulant in an hourglass hopper assembly and measured time required for the simulant to flow down. Without limited shaking (airplane provided some vibrations), at 1/6th g, the simulant flow was very slow and in some cases stopped altogether. The assembly had to be tapped on, shaken, bounced, and hammered to motivate the flow. JSC-1A is not the best simulant because it does not have agglutinates which make lunar soil extremely cohesive. As such, the situation on the Moon, with real lunar soil and in hard vacuum (which only increase cohesion because of electrostatic forces) will be more severe.

Figure 2. Testing at lunar g demonstrated difficulty of 'gravity' moving soil simulant – JSC-1A [5].

PlanetVac: PlanetVac, in the baseline design, is attached to a footpad (or footpads if more than one PlanetVac is used) of a lander or deployed (e.g., using 5th leg/boom). It is connected to instruments or sample return containers via a pneumatic transfer hose. The exact location of the instruments and sample container is irrelevant since the transfer hose can be routed around other systems.

Figure 3 shows operation steps of PlanetVac. The gas jets inside the sampling head are pointed down to sweep and loft regolith into a transfer tube. The capture system separates the sample from the flow and delivers it to the instrument. This process is incredibly resource efficient. Gas acts like an explosive in vacuum, meaning only a small volume of gas is required to move sample, agnostic of gravity. Sample collection occurs in a matter of seconds after single valve opening command. As a result, total power draw is virtually non-existent given the brief operation. In addition, no operator in the loop is required for collection.

The main advantage of the pneumatic transfer is that the point of acquisition and point of delivery can be anywhere on the spacecraft. Unlike scoops deployed by robotic arms which are constrained by kinematic position of the arm and the location of instruments, pneumatic transfer lines can instead be routed around potential obstacles. As such, sample acquisition hardware can be placed where it is best for sample acquisition, and instruments can be placed in the best location for performing analysis.

PlanetVac has been selected as part of the NASA Lunar Surface Instrument and Technology Payloads (LSITP) program to fly to the Moon's Mare Crisium in 2023 onboard Firefly Blue Ghost lander. **Figure 4** shows PlanetVac being deployed using a 5th leg (a boom) underneath the lander.

PlanetVac is suitable as a complement or backup sampling system for a range of landers to the Moon, Mars, or any other body covered in regolith. With low mass and minimal complexity, it can reduce the risks associated with surface sampling, and reliably collect soil using the type of pressurized gas often already onboard landing vehicles. Previously, the pneumatic system was successfully tested in a vacuum chamber at simulated lunar gravity (on zero-g airplane) and lifted 60 grams of JSC-1a lunar regolith simulant with just 10 milligrams of pressurized nitrogen gas.

Sample capture is characterized by separating particles from a gas stream; that is particles need to be captured into a container while gas needs to be vented to the outside. During this step, sample bias could occur since it might be very difficult to capture all of the particles. The sample bias will disfavor fine particles (microns in size, and less), which are difficult to remove from the airstream. Sample capture approaches are a function of a mission profile (in-situ analysis vs sample return) as well as the type of instruments that require a sample.

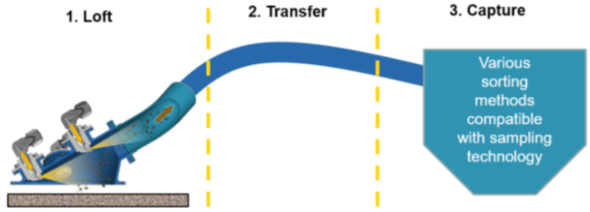

Figure 3. PlanetVac sample acquisition and capture.

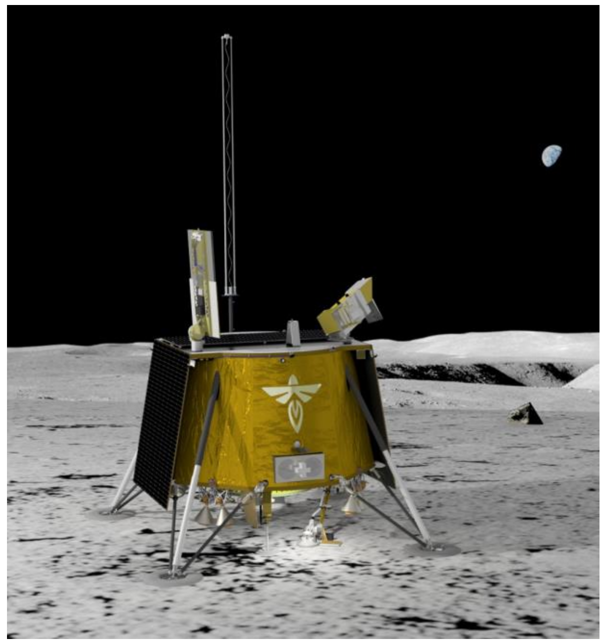

Figure 4. PlanetVac will launch to the Moon as part of CLPS 19D. Shown is PlanetVac deployed by a boom (5th leg) on Firefly Blue Ghost lander.

PlanetVac system can provide samples from known locations for science, exploration, and commercial missions. As such, it also meets STMD goals.

References: [1] Zacny et al., (2020) Pneumatic Sampler (P-Sampler) for the Martian Moons eXploration (MMX) Mission, IEEE Aerospace Conf. [2] Spring et al., (2019), PlanetVac Xodiac: Lander Foot Pad Integrated Planetary Sampling System, IEEE Aerospace Conf., [3] Zacny et al., (2019), Application of Pneumatics in Delivering Samples to Instruments on Planetary Missions, IEEE Aerospace Conf., [4] Zacny et al., (2-14), PlanetVac: Pneumatic Regolith Sampling System, IEEE Aerospace Conf. [5] Mueller, R., et al, (2010) AIAA Space 2010, AIAA-2010-8900, Aug 31-Sep 2, 2010, Anaheim, CA

Acknowledgments: PlanetVac is being funded under NASA Lunar Surface Instrument and Technology Payloads (LSITP) program.