PLANETVAC: REGOLITH SAMPLE CAPTURE AND RETURN USING PNEUMATICS. Kris Zacny[1], Rob Mueller[2], Bruce Betts[3], Magnus Hedlund[1], Phil Chu[1], Gale Paulsen[1], [1]Honeybee Robotics, 398 W Washington Blvd, Suite 200, Pasadena, CA 91103, zacny@honeybeerobotics.com, [2]NASA Kennedy Space Center, rob.mueller@nasa.gov, [3]The Planetary Society, 85 S Grand Ave, Pasadena, CA, bruce.betts@planetary.org.

Introduction: We are entering a new era of space exploration where spacecrafts are becoming smaller and lighter, yet are still expected to return vital scientific and exploration data. No doubt some of the most valuable information includes elemental, chemical, and mineralogical composition data of planetary regoliths, rocks, and volatiles, including water. Acquisition of planetary samples is at the same time, one of the most difficult steps in exploration. Normally, sample capture is done using scoops or drills. Both of these approaches are relatively massive and require several degrees of freedom and actuators, heaters, electronics, smart software and so on. Here we present an alternative to capture of planetary regolith samples.

Pneumatics in space: Pneumatic systems are used every day on earth to transfer powders, soils, and even concrete. Pneumatic systems, in fact, are work horse in many particle transfer applications and are highly reliable and versatile. Every household has a vacuum cleaner. Compressed gas is also easily obtained by compressing terrestrial atmosphere to suitable pressures. Alternatively, a vacuum suction system can produce lower pressure at the back end and use pressure difference to draw atmospheric pressure in.

In space applications, the same principles can apply, depending on atmospheric conditions of a planetary body. Vacuum suction, for example, was used on Venus missions: Venera 13 and 14, to draw drill cuttings into a GCMS instrument. Venus atmospheric pressure is almost 100x greater than on Earth, hence this suction approach was very effective. On Mars, atmospheric pressure is almost $1/100^{th}$ of the terrestrial atmospheric pressure, therefore it is possible to compress this thin atmosphere into gas tanks for later use. Many planetary bodies such as Mars, the Moon, Europa and Enceladus, to mention a few, have large water resources. Water could be excavated and electrolyzed into hydrogen and oxygen. These two gasses could again be used for pneumatic particle excavation and transfer applications. The last resort of course, is to bring a dedicated gas tank with highly pressurized gas. Alternatively, one can tap into pressurant tank that is used to pressurize liquid propellant. In a landed missions, upon touch down, the pressurant is normally vented from tanks – but instead could be used for excavation purposes.

Cold gas propulsion systems use pressurized gas for spacecraft attitude control and other maneuvers. Hence, gas lines, valves, and tanks for space applications could be viewed as commodity. This reduces risks in the case of pneumatic sampling systems.

The major downside of having a tank of gas for performing sample capture, is that the gas is a consumable. Once used up, no further sampling operations can be conducted. However, as has been demonstrated before, gas is an extremely powerful medium in vacuum. Zacny et al. [1] measured efficiency of gas, and found that just 1 gram of gas at <100 kPa absolute, could loft almost 6000 grams of soil (test soil was the JSC-1a lunar soil simulant) at velocities approaching 10 m/s. This very high excavation ratio was attributed to the sonic velocities the gas achieves while exiting the gas tank in vacuum.

PlanetVac: PlanetVac, which stands for Planetary Vacuum, is a succesful implementation and demonstration of a technology and sampling concept developed under the NASA SBIR program [2].

In 2013, The Planetary Society funded the development of a full scale prototype micro-lander, incorporating pneumatic technology for acquisition of planetary regolith for an in-situ analysis and sample return [3]. The main goal of the project was to perform end to end demonstration of landing, sample acquisition and delivery, and launch – all in a 3.5 tall vacuum chamber.

PlanetVac gathers regolith into hollow sample tubes placed underneath the lander footpads. A puff of gas directed at the tube's rim and up the tube can effectively move a plug of regolith through the connecting hose and into a sample return container (or into analytical instruments for in-situ analysis). Redundancy is provided by integrating sampling tubes below each lander footpad, so three tubes could fail and the system could still successfully gather samples (in the case of a four legged lander).

To demonstrate this approach, a PlanetVac lander with two sampling tubes has been designed, built, and tested. Two of the four landing pads were not used, to reduce development cost and schedule. Testing has been performed in a 3.5 m tall vacuum chamber and with two planetary simulants: Mars Mojave Simulant (MMS) and lunar regolith simulant JSC-1A. One sampling system within a footpad was connected to an earth return rocket, while the second sampling system integrated with another footpad was connected to a deck mounted "instrument" (clear box for easy viewing). Demonstrations included: 1. lander drop from a height of ~50 cm onto the bed of regolith simulant, 2. confirmation of touch down event by a sensor below the footpad, 3. deployment of sampling tubes using pre-stressed spring, activated by a burn wire, 3. determination of soil volume in a sampling tube using custom capacitive sensor, 4. opening of a gas tank and transfer of captured regolith sample using compressed gas into a rocket and an instrument, 5. confirmation of acquisition of regolith into an instrument (sample container) and the rocket, 6. launch of the rocket. A total of nine tests were conducted of which four were successful. The remaining five had various faults related to electrical and mechanical subsystems.

In all four successful tests, approximately 20 grams of sample was delivered to the regolith box and approximately 5 grams of regolith was delivered into a rocket each time. It was found that 1 gram of gas at approximately 160 kPa could loft over 1000 grams of soil.

PlanetVac video can be watched here: https://www.youtube.com/watch?v=DjJXvtQk6no

Figure 1. PlanetVac suspended within a vacuum chamber above Mars Mojave Simulant. Number 1 indicates cyclone separator connected to an instrument, while the number 2 cyclone is connected to a rocket. The major subsystems are also shown on both sides.

Discussion: The entire system performed satisfactorily in that the regolith samples were acquired into the sampling container and the rocket.

However, we also observed that the spring deployment of the soil tube was unreliable and prone to jamming. In one case we noted that during the landing, some soil still managed to get pushed up into the soil tube and, upon injection of compressed gas, captured in the soil bin.

A possible solution to sampling tube problem is a different approach to sample capture as shown in Figure 2. In this case, the compressed gas is injected into the soil from a gas tube. The gas mixes with the soil and then blows back up into the sampling tube. This approach was built and has already successfully demonstrated Mars conditions [2].

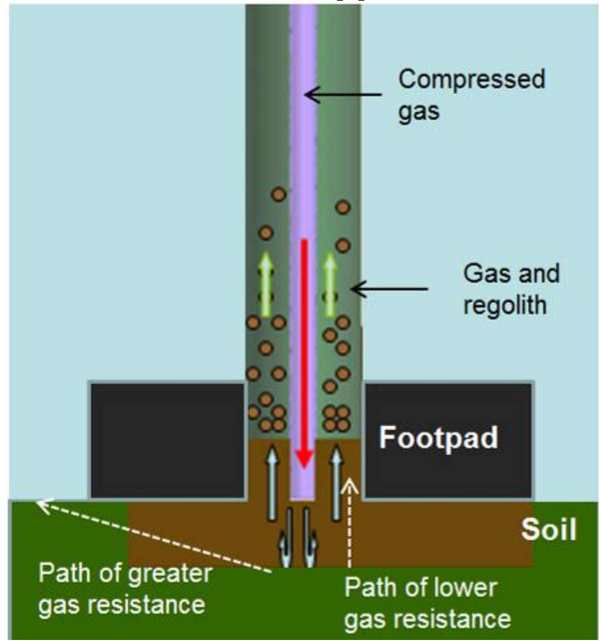

Figure 2. Sampling system without deployable tube.

References: [1] Zacny K., J. Craft; M. Hedlund; P. Chu; G. Galloway; R. Mueller, (2010), Investigating the Efficiency of Pneumatic Transfer of JSC-1a Lunar Regolith Simulant in Vacuum and Lunar Gravity During Parabolic Flights. AIAA Space 2010, AIAA-2010-8702, Aug 31-Sep 2, 2010, Anaheim, CA, [2] Zacny, K., G. Mungas, C. Mungas, D. Fisher, and M. Hedlund, (2008), Pneumatic Excavator and Regolith Transport System for Lunar ISRU and Construction, Paper No: AIAA-2008-7824 and Presentation, AIAA SPACE 2008 Conference & Exposition, 9 - 11 Sep 2008, San Diego Convention Center, San Diego, California, [3] Zacny, K., B. Betts, M. Hedlund, P. Long, M. Gramlich, K. Tura, P. Chu, A. Jacob, A. Garcia, (2014), PlanetVac: Pneumatic Regolith Sampling System, IEEE Aerospace Conference, 3-7 march 2014, Big Sky, MT