PNEUMATIC DRILL AND EXCAVATOR FOR PLANETARY EXPLORATION. K. Zacny[1], G. Mungas[2], L. Parrington[1], C. Mungas[2], and D. Fisher[2]. [1]Honeybee Robotics (zacny@honeybeerobotics.com), [2]Firestar Engineering.

Introduction: We have been investigating a method for penetrating into the regolith and mining of the regolith using a gas powered (pneumatic) drill and 'jet-lift' method respectively. It is believed, that the coupled propulsion/pneumatic system for excavation and prospecting may enable robust, rapid subsurface access into an in-situ medium that may cover a wide range of mechanical and thermophysical properties. Such architecture would allow subsurface access and mining without requiring solar illumination, potentially large nuclear power systems, or potentially complicated distributed power systems.

Pneumatic drilling. Analogous to terrestrial high power, hydraulic and pneumatic drilling using chemical fuel (i.e. gasoline and air) and fluids for cutting removal, the proposed pneumatic drill derives it's mechanical power from a high energy density chemical monopropellant (precombined fuel and oxidizer with stored energy density of ~1400 Whr/kg). After combustion and mechanical power extraction, the relatively low temperature exhaust gases are used to fluidize cuttings for removal during drilling (Figure 1).

Figure 1. Pneumatic drill concept. The telescopic drill is being driven by a cooled exhaust gases. As the gas exits the drill, it lifts the cuttings out of the hole. Pneumatic drill makes an auger absolute and enables telescopic mechanism for drill extension.

There are a number of significant benefits to using a pneumatic system, as opposed to a more conventional electro-mechanical planetary drill. Gas circulation can be used effectively as a means of lifting the drill cuttings to the surface [1]. Clearing the cuttings from a drill hole has many advantages that include significantly lower operating drill power (as much as an order of magnitude lower at 2 meter depth) and cooling of the drilled formation, which tends to heat up from bit friction [2]. Since there is no need for an auger to remove the cuttings, the drill can be made to extend telescopically, which reduces its mechanical complexity, volume and mass. Furthermore, gas pressure can be used as a dust mitigation mechanism for seals and joints. Finally, a pneumatic system can be made smaller and lighter, and its components can tolerate a much larger temperature range due to the absence of electronic components.

Pneumatic mining. The mining method uses an analogous jet-lift dredging method for mining the top few centimeters of lunar regolith using. This method uses a concentrated high-speed stream of gas to draw adjacent material into a delivery pipe connected to a receiving container [3]. The system has very few moving parts and is thus well suited for the planetary application.

Source of gas. Rocket propulsion requires an inherently large reservoir of energy and gas generation capability, given that propulsive mobility, although required for exploration of the Moon and Mars, is an inherently energy and mass inefficient process. Therefore, even very small residual portions of propellant typically budgeted for margin in lander operations carry very large energy and gas reserves. These reserves coupled with existing propulsion system infrastructure can be tapped for carrying out high power pneumatic operations with minimal additional hardware. Pressurized gas generation for the pneumatic drill will be provided by partial decomposition of a new, high Isp, non-toxic, low freezing point, NOFB monopropellant previously developed by Firestar Engineering under the NASA Mars Advanced Technology program. The temperature of the pneumatic gas can be regulated by adjusting the percent decomposition of the monopropellant, allowing additional capabilities, such as thawing out drill string segments that become frozen into low temperature ice-ridden ground. The dual use of propellant represents an innovative, economical exploitation of reserve resources in meeting NASA's exploration needs.

Preliminary mining tests and result: Figure 2 shows the design concept for the mining test stand. In this design, gas at atmospheric pressure was introduced into a low pressure chamber via a narrow nozzle that sits above, or is inserted into, a container of simulated regolith. The nozzle was surrounded by a tube or larger diameter that had one end that also sits on or below the regolith surface, and also bifurcates into a u-shape that terminates in a collection container. The higher pressure gas from the nozzle was intended to excavate regolith from the simulant container, and transfer it to the collection container.

Preliminary tests were performed in fine to medium-grained, washed sand, to determine the overall performance of the test stand. The tests performed were either 5 or 10 seconds in duration at a gas (air) flow rate of 6 l/sec. We determined that nozzle location in relation to the outer tube, the depth of the tube below the surface of the sand, as well as test duration greatly affected the mass of excavated sand. The fastest mining, in excess of 80 g/sec, was achieved when the nozzle was extended an inch below the tube, while the tube was buried 4 inches into the sand. For the air supply of 6 l/min at 760 torr, this means that 1 kg of air at 760 torr and 300 K could potentially provide enough gas flow to mine 660 kg of sand.

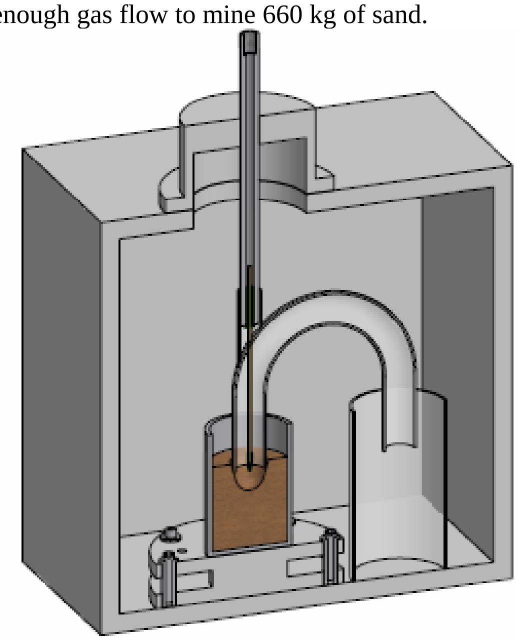

Figure 2. Experimental layout for the mining tests using an analogous jet-lift technique.

Composition of exhaust gasses of NOFB monopropellant: Firestar Engineering performed a study of exhaust gases from NOFB monopropellant and found that its main constituents include ~50% Nitrogen (~50%), ~27% Carbon monoxide, ~9% H_2O, ~8% H_2, and ~7% CO_2.Lower volatile water could be cold-filtered or molecular-sieved prior to injection into the ground.

Converting chemical energy to mechanical work: Firestar Engineering completed a preliminary trade space study of candidate energy extraction devises for use in gas and power generation for excavation systems. The goal was to identify a method for converting the chemical energy within a NOFB monopropellant into mechanical work and an exhaust gas suitable for use as a fluid for lifting cuttings from the bore hole (exhaust gas temperature ~0˚C). A trade space examination revealed two methods for extracting chemical energy from a NOFB monopropellant; a) axial turbine (based on the Brayton cycle), and b) reciprocating piston cycle (modified Otto cycle). The two cycles were examined with regard to; i) material limitations, and ii) thermal efficiency.

It was found that the efficiency of a multi-stage axial turbine was slightly greater than the efficiency of a reciprocating piston cycle operating on a modified Otto cycle (where backpressure is negligible). However, this advantage in thermal efficiency is offset by the material limitations that occur with the operation of a turbine at elevated temperatures. Lowering the inlet temperature of combusted NOFB by roughly a factor of 2 was found to be impractical, thus eliminating an axial turbine as a means of extracting the chemical energy from a NOFB monopropellant. With current automobile engines offering a compelling analogous existence proof for a mechanical power system operating on adiabatic flame temperatures significantly above material limitations, a reciprocating piston cycle was chosen as the best means for extracting the chemical energy from a NOFB monopropellant.

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References: [1] Zacny K. et al., (2005a) JGR, 109, E07S16. [2] Zacny K. et al., 2005b) JGR, 110, E04002. [3] Zacny K. et al., (2004) RASC-AL, Cocoa Beach, FL.