Three General Lunar Regolith Conveyance Systems Tested in Atmosphere and Vacuum Conditions. Jason B. Noe[1], Paul van Susante[2], Laurent Sibille[3], Parker Bradshaw[4], Eli Sierra[5], and Ben Wiegand[6], [1,2,4,,5,6]Planetary Surface Technology Development Laboratory, Michigan Technological University, 1400 Townsend Dr, Houghton, MI 49931, USA, (contact pjvansus@mtu.edu), [3]Southeastern Universities Research Association (SURA), Swamp Works Granular Mechanics and Regolith Operations, NASA Kennedy Space Center, Florida 32899, USA, laurent.sibille-1@nasa.gov

Introduction: A maintained presence in space requires a constant supply of resources, with NASA's vision for a permanent base on the moon, a lot of research is required to determine the best way to do this. In-Situ Resource Utilization, or ISRU, is the process of taking local resources and using/transforming them to sustain missions instead of transporting all the resources from Earth. Lunar regolith, for example, is a local resource that can be used for the construction of roads, berms, rocket landing pads, tool manufacturing, insulation, oxygen production, metal production, and habitat construction. To take full advantage of lunar regolith, machines and tools must be developed to efficiently mine, convey and process this resource.

One large area that has received little attention is the conveyance of lunar regolith, point to point delivery. This field needs to be thoroughly researched to determine the most efficient way to move lunar regolith in different scenarios. Originally, this research was part of a NASA GCD grant for the development of a Regolith Delivery System (RDS) for a Molten Regolith Electrolysis (MRE) reactor. For this project three different methods of conveying regolith were looked at: screw conveyance, piston conveyance, and vibratory conveyance. These conveyance systems would have to meet the requirements set by the project, a mass flow rate of 100 kg delivered in 20 min (83.3 g/s), plus or minus 250 grams. All conveyors underwent extensive testing in both atmospheric conditions and vacuum conditions. These tests were conducted at MTU's Planetary Surface Technology Development Lab (PSTDL).

Screw Conveyor: The first method of conveyance that was researched was a screw conveyor. An image of a screw conveyor can be seen in figure 1 and 2. It is a system that consists of a trough, a screw/auger, and a motor. The screw usually rests concentrically in the trough with the motor mounted on a shaft that extends outside of the trough. Material, in this case lunar regolith simulant, is poured into the trough and is pushed by the auger to the other end of the trough, where it can be passed on to another system. The main objectives of this conveyor is to determine mass flow rate of material and the power needed to push the regolith to meet the requirements listed above. The independent variables in this test were RPM of the motor and regolith simulant fill height in the trough. For the system built, it was found that an RPM of 12, at a 50% trough fill was sufficient to meet the set requirements and had an average mass flow rate of 298 g/s in the atmosphere and 216 g/s in vacuum. Additionally, results indicated the average power draw for the atmosphere was lower than the vacuum, 27 W compared to 34 W respectively. Several other tests were done to parameterize the system listed here.

Fig. 1. Empty Screw Conveyor.

Fig. 2. Screw and Piston Conveyors in DTVAC.

Piston Conveyor: In some situations the environment in which conveyance occurs, especially in an MRE reactor, may prove too harsh for some conveyance system. The piston conveyor was a novel approached designed to handle these conditions (temperatures up to 1700 C°) focusing on simplicity to limit points of failure. The piston designed for this project, seen in figure 3 and 4, consisted of a chamber, push blade, and a motor to drive the blade. The system works by first retracting the blade, filling the chamber with regolith, and then pushing the blade back out which pushes the regolith to its next location. Again, the objective of testing this conveyor was to determine mass flow rate and the power required to meet the requirements of 83.3 g/s. The variables of this conveyor were regolith mass and piston speed. Results indicated that a chamber with a regolith simulant mass of roughly 3 kg, and a blade speed of 10 mm/s was sufficient to meet the requirement, a mass flow rate of 94.8 g/s at 28 W in atmosphere and a mass flow rate of 103.3 g/s at 26 W in vacuum. For an empty piston conveyor, there was little difference in power consumption in the atmosphere compared to the vacuum, suggesting that there are differences in regolith properties in the vacuum compared to in the atmosphere.

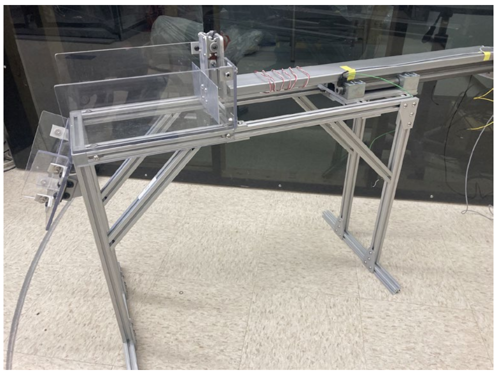

Fig. 3 Empty Piston Conveyor.

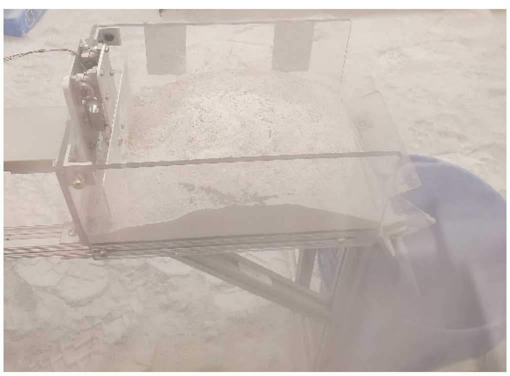

Fig. 4 Filled Piston Conveyor.

Vibratory Conveyor: A vibratory conveyor shown in figure 5 uses a vibration mechanism, in this case, an eccentric mass motor system, to oscillate a bed back and forth which is situated on angled leaf springs to move regolith in one direction. The vibrations required to move regolith is dependent on how much regolith mass is on the conveyor which increases the complexity. For this conveyor, regolith mass, amplitude, and frequency were the variables tested to find the highest mass flow rate and lowest power draw whilst also meeting the requirements. Results showed that a two-eccentric mass system, filled to 3 kg at 1 cm depth and operating at 3.5 Hz, verified via accelerometer, was able to meet the criteria while being the most efficient in power. In these conditions, in atmosphere, the vibratory conveyor operated at a mass flow rate of 93.3 g/s at 6.6 W while in a vacuum it had a higher mass flow rate of 209.86 g/s at 5.7 W.

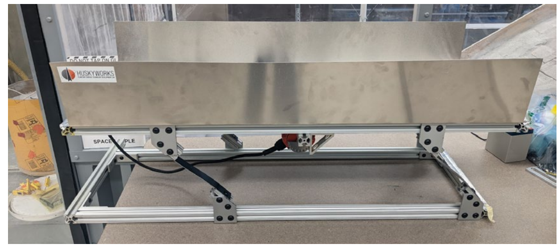

Fig. 5 Empty Vibratory Conveyor.

Future Testing: Although these initial tests are promising, the full parameterization of these systems has not been completed. To beter understand how these systems operate under lunar conditions for longer periods of time, a long duration test was designed, specifically for the screw conveyor. The test setup can be seen in figure 6 and is set to be completed in April-May. This test will run for a minimum of 24 hours and up to weeks, in which two screw conveyor will perpetual feed into each other in vacuum. Power will be monitored for the duration of the test and samples of the regolith simulant, MTU-LHT-1A, will be taken before and after the test to understand the long term effects of conveyance on the shape of the granules. Pieces of the conveyor will be studied for wear/abrasion before and after the test to look at the rate of wear.

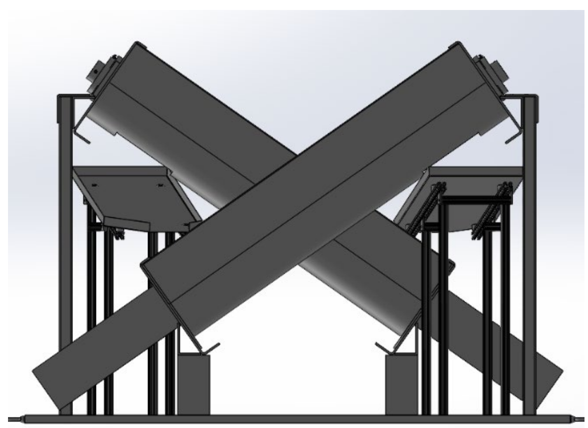

Fig. 6 Lond Duration Screw Conveyor Setup.

References: [1] M. E. Fayed and T. S. Skocir, *Mechanical conveyors: selection and operation*. Lancaster; Basel: Technomic Publ., Cop, 1997.