minimally-actuated Axel rover. Axel is a two-wheeled rover platform with a trailing boom that is capable of traversing undulated terrain and overcoming obstacles of a wheel radius in height. It is operated by four motors: one that drives each wheel; a third that controls the rotation of the boom, which orients the body mounted sensors; and a fourth that controls the rover's spool to drive the antenna roller. This low-mass axle-like rover houses its control and communication avionics inside its cylindrical body.

The Axel rover teleoperation software has an auto-spooling mode that allows a user to automatically deploy the thin-film antenna at a rate proportional to the wheel speed as it drives the rover along its trajectory. The software allows Axel to deposit the film onto the ground to prevent or minimize relative motion between the film and the terrain to avoid the risk of scraping and antenna with the terrain.

This work was done by Joseph Lazio, Jaret B. Matthews, Issa A. Nesnas, and Dimitri Zarzhitsky of the Jet Propulsion Laboratory, California Institute of Technology; and Jack C. Morrison for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48887

Counterflow Regolith Heat Exchanger

John F. Kennedy Space Center, Florida

A problem exists in reducing the total heating power required to extract oxygen from lunar regolith. All such processes require heating a great deal of soil, and the heat energy is wasted if it cannot be recycled from processed material back into new material.

The counterflow regolith heat exchanger (CoRHE) is a device that transfers heat from hot regolith to cold regolith. The CoRHE is essentially a tube-in-tube heat exchanger with internal and external augers attached to the inner rotating tube to move the regolith. Hot regolith in the outer tube is moved in one direction by a right-handed auger, and the cool regolith in the inner tube is moved in the opposite direction by a left-handed auger attached to the inside of the rotating tube. In this counterflow arrangement, a large fraction of the heat from the expended regolith is transferred to the new regolith. The spent regolith leaves the heat exchanger close to the temperature of the cold new regolith, and the new regolith is pre-heated close to the initial temperature of the spent regolith. Using the CoRHE can reduce the heating requirement of a lunar ISRU system by 80%, reducing the total power consumption by a factor of two.

The unique feature of this system is that it allows for counterflow heat exchange to occur between solids, instead of liquids or gases, as is commonly done. In addition, in variants of this concept, the hydrogen reduction can be made to occur within the counterflow heat exchanger itself, enabling a simplified lunar ISRU (in situ resource utilization) system with excellent energy economy and continuous non-batch mode operation.

This work was done by Robert Zubrin and Peter Jonscher of Pioneer Astronautics for Kennedy Space Center. For further information, contact the Kennedy Innovative Partnerships Program Office at (321) 861-7158. KSC-13394

Acquisition and Retaining Granular Samples via a Rotating Coring Bit

This device is used in granular sample handling, and as a stand-alone regolith acquisition bit.

NASA's Jet Propulsion Laboratory, Pasadena, California

This device takes advantage of the centrifugal forces that are generated when a coring bit is rotated, and a granular sample is entered into the bit while it is spinning, making it adhere to the internal wall of the bit, where it compacts itself into the wall of the bit. The bit can be specially designed to increase the effectiveness of regolith capturing while turning and penetrating the subsurface. The bit teeth can be oriented such that they direct the regolith toward the bit axis during the rotation of the bit. The bit can be designed with an internal flute that directs the regolith upward inside the bit. The use of both the teeth and flute can be implemented in the same bit. The bit can also be designed with an internal spiral into which the various particles wedge.

In another implementation, the bit can be designed to collect regolith primarily from a specific depth. For that implementation, the bit can be designed such that when turning one way, the teeth guide the regolith outward of the bit and when turning in the opposite direction, the teeth will guide the regolith inward into the bit internal section. This mechanism can be implemented with or without an internal flute.

The device is based on the use of a spinning coring bit (hollow interior) as a means of retaining granular sample, and the acquisition is done by inserting the bit into the subsurface of a regolith, soil, or powder. To demonstrate the concept, a commercial drill and a coring bit were used. The bit was turned and inserted into the soil that was contained in a bucket. While spinning the bit (at speeds of 600 to 700 RPM), the drill was lifted and the soil was retained inside the bit. To prove this point, the drill was turned horizontally, and the acquired soil was still inside the bit. The basic theory behind the process of retaining unconsolidated mass that can be acquired by the centrifugal forces of the bit is determined by noting that in order to stay inside the interior of the bit, the frictional force must be greater than the weight of the sample.

The bit can be designed with an internal sleeve to serve as a container for granular samples. This tube-shaped component can be extracted upon completion of the sampling, and the bottom can be capped by placing the bit onto a corklike component. Then, upon removal of the internal tube, the top section can be sealed. The novel features of this device are:

- A mechanism of acquiring and retaining granular samples using a coring bit without a closed door.
- An acquisition bit that has internal structure such as a waffle pattern for compartmentalizing or helical internal flute to propel the sample inside the bit and help in acquiring and retaining granular samples.
- A bit with an internal spiral into which the various particles wedge.
- A design that provides a method of testing frictional properties of the granular samples and potentially segregating particles based on size and density. A controlled acceleration or deceleration may be used to drop the least-frictional particles or to eventually shear the unconsolidated material near the bit center.

This work was done by Yoseph Bar-Cohen, Mircea Badescu, and Stewart Sherrit of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47606

Very-Low-Cost, Rugged Vacuum System

Applications include portable analytical instruments such as mass spectrometers and leak detectors.

Goddard Space Flight Center, Greenbelt, Maryland

NASA, DoD, DHS, and commercial industry have a need for miniaturized, rugged, low-cost vacuum systems. Recent advances in sensor technology have led to the development of very small mass spectrometer detectors as well as other miniature analytical instruments. However, the vacuum systems to support these sensors remain large, heavy, and power-hungry. To meet this need, a miniaturized vacuum system was created based on a very small, rugged, and inexpensive-to-manufacture molecular drag pump (MDP). The MDP is enabled by the development of a miniature, very-high-speed, rugged, low-power, brushless DC motor optimized for wide temperature operation and long life. Such a pump represents an order-of-magnitude reduction in mass, volume, and cost over current, commercially available, state-of-the-art vacuum pumps.

The vacuum system consists of the MDP coupled to a ruggedized rough pump (for terrestrial applications or for planets with substantial atmospheres). The rotor in the MDP consists of a simple smooth cylinder of aluminum spinning at approximately 200,000 RPM inside an outer stator housing. The pump stator comprises a cylindrical aluminum housing with one or more specially designed grooves that serve as flow channels. To minimize the length of the pump, the gas is forced down the flow channels of the outer stator to the base of the pump. The gas is then turned and pulled toward the top through a second set of channels cut into an inner stator housing that surrounds the motor. The compressed gas then flows down channels in the motor housing to the exhaust port of the pump. The exhaust port of the pump is connected to a diaphragm or scroll pump. This pump delivers very high performance in a very small envelope. The design was simplified so that a smaller compression ratio, easier manufacturing process, and enhanced ruggedness can be achieved at the lowest possible cost.

The machining of the rotor and stators is very simple compared to that necessary to fabricate TMP (turbo molecular pump) rotor and stator blades. Also, the symmetry of the rotor is such that dynamic balancing of the rotor is greatly simplified. Finally, because of the simplified design, the number of parts in the unit is cut by nearly a factor of three. In fact, there are only five parts, not counting the motor and off-the-shelf screws and O-rings. This reduces the amount of machining and also makes fit-up much simpler while allowing the maintenance of close tolerances.

This work was done by Robert Kline-Schoder, Paul Sorensen, Christian Passow, and Steve Bilski of Creare Inc. for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16695-1