



Mechanics/Machinery

UltraSail CubeSat Solar Sail Flight Experiment

Solar sail will feature new approaches that will result in larger sail areas and larger payloads.

Marshall Space Flight Center, Alabama

UltraSail is a next-generation, high-risk, high-payoff sail system for the launch, deployment, stabilization, and control of very large (km² class) solar sails enabling high payload mass fractions for interplanetary and deep space spacecraft. UltraSail is a non-traditional approach to propulsion technology achieved by combining propulsion and control systems developed for formation-flying microsatellites with an innovative solar sail architecture to achieve controllable sail areas approaching 1 km², sail subsystem area densities approaching 1 g/m², and thrust levels many times those of ion thrusters used for comparable deep space missions. UltraSail can achieve outer planetary rendezvous, a deep-space capability now reserved for high-mass nuclear and chemical systems.

There is a twofold rationale behind the UltraSail concept for advanced solar sail systems. The first is that sail-and-boom systems are inherently size-limited. The boom mass must be kept small, and column buckling limits the boom length to a few hundred meters. By eliminating the boom, UltraSail not only offers larger sail area, but also lower areal density, allowing larger payloads and

shorter mission transit times. The second rationale for UltraSail is that sail films present deployment handling difficulties as the film thickness approaches one micrometer. The square sail requires that the film be folded in two directions for launch, and similarly unfolded for deployment.

The film is stressed at the intersection of two folds, and this stress varies inversely with the film thickness. This stress can cause the film to yield, forming a permanent crease, or worse, to perforate. By rolling the film as UltraSail does, creases are prevented. Because the film is so thin, the roll thickness is small. Dynamic structural analysis of UltraSail coupled with dynamic control analysis shows that the system can be designed to eliminate longitudinal torsional waves created while controlling the pitch of the blades, while using solar photon pressure to slew the spin axis. Vacuum tests have also verified that electrostatic and molecular adhesion forces can substantially be eliminated by making the film electrically conductive, reducing the peel force of the film off the storage roll to levels of 100s of micro-N.

The innovation demonstrated the capability of deploying a six-micron alu-

minum-coated film from a reel through a slit in vacuum. The innovation also demonstrated a spin-stabilized method for deploying a long reel of solar sail film using solar pressure to spin-up and orbit raise the satellite, and also a gravity gradient method for deploying a long reel of solar sail film using solar pressure to orbit raise the satellite.

The solar sail mass fraction of 25% is consistent with high specific impulse ion systems, but without the added weight and cost of a power source and processing unit. The large sail area, coupled with low film density, is giving UltraSail a high payload fraction. The UltraSail deployment scheme unrolls a micrometer-scale reflection-coated polyimide film from a storage mandrel to a maximum length of several kilometers with the aid of a blade tip satellite.

This work was done by David Carroll and Rodney Burton of CU Aerospace L.L.C., Victoria Coverstone of the University of Illinois at Urbana-Champaign, and Gary Swenson of the University of Illinois for Marshall Space Flight Center. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32949-1.

Mechanism for Deploying a Long, Thin-Film Antenna From a Rover

The deployment mechanism consists of two rollers to automatically deploy the antenna at a rate proportional to the wheel speed.

NASA's Jet Propulsion Laboratory, Pasadena, California

Observations with radio telescopes address key problems in cosmology, astrophysics, heliophysics, and planetary science including the first light in the Universe (Cosmic Dawn), magnetic fields of extrasolar planets, particle acceleration mechanisms, and the lunar ionosphere. The Moon is a unique science platform because it allows access to radio frequencies that do not penetrate the Earth's ionosphere and because its far side is shielded from intense terrestrial emissions. A

radio antenna can be realized by using polyimide film as a substrate, with a conducting substance deposited on it. Such an antenna can be rolled into a small volume for transport, then deployed by unrolling, and a robotic rover offers a natural means of unrolling a polyimide film-based antenna. An antenna deployment mechanism was developed that allows a thin film to be deposited onto a ground surface, in a controlled manner, using a minimally actuated rover.

The deployment mechanism consists of two rollers, one driven and one passive. The antenna film is wrapped around the driven roller. The passive roller is mounted on linear bearings that allow it to move radially with respect to the driven roller. Springs preload the passive roller against the driven roller, and prevent the tightly wrapped film from unspooling or "bird's nesting" on the driven spool. The antenna deployment mechanism is integrated on the

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 an-

tenna 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 ex-

change 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