# Tech Briefs

## NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

**Technology Focus**

**Electronics/Computers**

**Software**

**Materials**

**Mechanics/Machinery**

**Manufacturing**

**Bio-Medical**

**Physical Sciences**

**Information Sciences**

**Books and Reports**

# INTRODUCTION

Tech Briefs are short announcements of innovations originating from research and development activities of the National Aeronautics and Space Administration. They emphasize information considered likely to be transferable across industrial, regional, or disciplinary lines and are issued to encourage commercial application.

## Additional Information on NASA Tech Briefs and TSPs

Additional information announced herein may be obtained from the NASA Technical Reports Server: **http://ntrs.nasa.gov**.

Please reference the control numbers appearing at the end of each Tech Brief. Information on NASA's Innovative Partnerships Program (IPP), its documents, and services is available on the World Wide Web at **http://www.ipp.nasa.gov**.

Innovative Partnerships Offices are located at NASA field centers to provide technology-transfer access to industrial users. Inquiries can be made by contacting NASA field centers listed below.

# NASA Field Centers and Program Offices

**Ames Research Center**
David Morse
(650) 604-4724
david.r.morse@nasa.gov

**Dryden Flight Research Center**
Ron Young
(661) 276-3741
ronald.m.young@nasa.gov

**Glenn Research Center**
Kimberly A. Dalgleish-Miller
(216) 433-8047
kimberly.a.dalgleish@nasa.gov

**Goddard Space Flight Center**
Nona Cheeks
(301) 286-5810
nona.k.cheeks@nasa.gov

**Jet Propulsion Laboratory**
Dan Broderick
(818) 354-1314
daniel.f.broderick@jpl.nasa.gov

**Johnson Space Center**
John E. James
(281) 483-3809
john.e.james@nasa.gov

**Kennedy Space Center**
David R. Makufka
(321) 867-6227
david.r.makufka@nasa.gov

**Langley Research Center**
Michelle Ferebee
(757) 864-5617
michelle.t.ferebee@nasa.gov

**Marshall Space Flight Center**
Terry L. Taylor
(256) 544-5916
terry.taylor@nasa.gov

**Stennis Space Center**
Ramona Travis
(228) 688-3832
ramona.e.travis@ssc.nasa.gov

## NASA Headquarters

Daniel Lockney,
Technology Transfer Program Executive
(202) 358-2037
daniel.p.lockney@nasa.gov

**Small Business Innovation Research (SBIR) & Small Business Technology Transfer (STTR) Programs**
Rich Leshner, Program Executive
(202) 358-4920
rleshner@nasa.gov

# NASA TECH BRIEFS

## NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

# Technology Focus: Test & Measurement

## ISS Ammonia Leak Detection Through X-Ray Fluorescence

**An astrophysics instrument can be used to detect and localize ISS ammonia leaks.**

*Goddard Space Flight Center, Greenbelt, Maryland*

Ammonia leaks are a significant concern for the International Space Station (ISS). The ISS has external transport lines that direct liquid ammonia to radiator panels where the ammonia is cooled and then brought back to thermal control units. These transport lines and radiator panels are subject to stress from micrometeorites and temperature variations, and have developed small leaks. The ISS can accommodate these leaks at their present rate, but if the rate increased by a factor of ten, it could potentially deplete the ammonia supply and impact the proper functioning of the ISS thermal control system, causing a serious safety risk.

A proposed ISS astrophysics instrument, the Lobster X-Ray Monitor, can be used to detect and localize ISS ammonia leaks. Based on the optical design of the eye of its namesake crustacean, the Lobster detector gives simultaneously large field of view and good position resolu-

tion. The leak detection principle is that the nitrogen in the leaking ammonia will be ionized by X-rays from the Sun, and then emit its own characteristic X-ray signal. The Lobster instrument, nominally facing zenith for its astrophysics observations, can be periodically pointed towards the ISS radiator panels and some sections of the transport lines to detect and localize the characteristic X-rays from the ammonia leaks. Another possibility is to use the ISS robot arm to grab the Lobster instrument and scan it across the transport lines and radiator panels. In this case the leak detection can be made more sensitive by including a focused 100-microampere electron beam to stimulate X-ray emission from the leaking nitrogen. Laboratory studies have shown that either approach can be used to locate ammonia leaks at the level of 0.1 kg/day, a threshold rate of concern for the ISS.

The Lobster instrument uses two main components: (1) a microchannel plate optic (also known as a Lobster optic) that focuses the X-rays and directs them to the focal plane, and (2) a CCD (charge coupled device) focal plane detector that reads out the position and energy of the X-rays, allowing a determination of the leak location. The effective area of the detection system is $\approx 2$ cm$^2$ at 1 keV.

The Lobster astrophysics instrument, designed for monitoring the sky for X-ray transients, gives high sensitivity along with large field of view ($30\times30°$) and good spatial resolution (1 arc min). This offers a significant benefit for detecting ISS ammonia leaks, since the goal is to localize small leaks as efficiently as possible.

## A System for Measuring the Sway of the Vehicle Assembly Building

**Tests have shown that the existing facility is safe.**

*John F. Kennedy Space Center, Florida*

A system was developed to measure the sway of the Vehicle Assembly Building (VAB) at Kennedy Space Center. This system was installed in the VAB and gathered more than one total year of data. The building movement was correlated with measurements provided by three wind towers in order to determine the maximum deflection of the building during high-wind events.

The VAB owners were in the process of obtaining new platforms for use in assembling very tall rockets when analysis of the VAB showed that a high wind could move the building sufficiently that an upper platform might impact a rocket. The problem arises because safety requires a relatively small gap between the platform and the rocket, while a large enough gap is needed to ensure that stacking tolerances prevent

contact between the rocket and the platform. This only leaves an inch or two ($\approx 2$ to 5 cm) of total clearance, so when the analysis showed that more than a couple of inches of motion could occur in a high wind, there was a potential for damaging the rocket. The KSC Applied Physics Laboratory was asked to install a system in the VAB that could measure the motion of the building in high winds to determine the actual building sway.

The motion of the VAB roof under wind load was measured optically, and under analysis, it was determined that a relatively large-aperture optical system would be required to reduce diffraction effects to less than a small fraction of an inch ($\approx$mm) at a distance of 500 ft ($\approx 150$ m). A 10-in. ($\approx 250$ mm) telescope was placed on the floor of the building,

looking at the ceiling. On the ceiling, a flat plate with three white LEDs was mounted in an "L" shape, such that the telescope was essentially looking at three stars. Software was written to track the motion of these three points using an image processing system. This provided a better than 1/10-in. ($\approx 2.5$-mm) 2D measurement faster than once a second. Data was downloaded once a month for comparison with the wind tower data.

The system was fully operational and provided enough data to show that the VAB will only move 1 in. ($\approx 2.5$ cm) at the ceiling under 70-knot winds. Adjustable platforms are not required.

# Fast, High-Precision Readout Circuit for Detector Arrays

**NASA's Jet Propulsion Laboratory, Pasadena, California**

The GEO-CAPE mission described in NASA's Earth Science and Applications Decadal Survey requires high spatial, temporal, and spectral resolution measurements to monitor and characterize the rapidly changing chemistry of the troposphere over North and South Americas. High-frame-rate focal plane arrays (FPAs) with many pixels are needed to enable such measurements.

A high-throughput digital detector readout integrated circuit (ROIC) that meets the GEO-CAPE FPA needs has been developed, fabricated, and tested. The ROIC is based on an innovative charge integrating, fast, high-precision analog-to-digital circuit that is built into each pixel. The 128×128-pixel ROIC digitizes all 16,384 pixels simultaneously at frame rates up to 16 kHz to provide a completely digital output on a single integrated circuit at an unprecedented rate of 262 million pixels per second. The approach eliminates the need for off focal plane electronics, greatly reducing volume, mass, and power compared to conventional FPA implementations. A focal plane based on this ROIC will require less than 2 W of power on a 1×1-cm integrated circuit.

The ROIC is fabricated of silicon using CMOS technology. It is designed to be indium bump bonded to a variety of detector materials including silicon PIN diodes, indium antimonide (InSb), indium gallium arsenide (InGaAs), and mercury cadmium telluride (HgCdTe) detector arrays to provide coverage over a broad spectral range in the infrared, visible, and ultraviolet spectral ranges.

*This work was done by David M. Rider, Bruce R. Hancock, Richard W. Key, Thomas J. Cunningham, Chris J. Wrigley, Suresh Seshadri, Stanley P. Sander, and Jean-Francois L. Blavier of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47320*

# Victim Simulator for Victim Detection Radar

**This simulator can be placed for long periods of time in environments that would be unsafe for a human subject.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Testing of victim detection radars has traditionally used human subjects who volunteer to be buried in, or climb into a space within, a rubble pile. This is not only uncomfortable, but can be hazardous or impractical when typical disaster scenarios are considered, including fire, mud, or liquid waste. Human subjects are also inconsistent from day to day (i.e., they do not have the same radar properties), so quantitative performance testing is difficult. Finally, testing a multiple-victim scenario is difficult and expensive because of the need for multiple human subjects who must all be coordinated.

The solution is an anthropomorphic dummy with dielectric properties that replicate those of a human, and that has motions comparable to human motions for breathing and heartbeat. Two air-filled bladders filled and drained by solenoid valves provide the underlying motion for vinyl bags filled with a dielectric gel with realistic properties. The entire assembly is contained within a neoprene wetsuit serving as a "skin." The solenoids are controlled by a microcontroller, which can generate a variety of heart and breathing patterns, as well as being reprogrammable for more complex activities.

Previous electromagnetic simulators or RF phantoms have been oriented towards assessing RF safety, e.g., the measurement of specific absorption rate (SAR) from a cell phone signal, or to provide a calibration target for diagnostic techniques (e.g., MRI). They are optimized for precise dielectric performance, and are typically rigid and immovable. This device is movable and "positionable," and has motion that replicates the small-scale motion of humans. It is soft (much as human tissue is) and has programmable motions.



The **Victim Simulation System** ("Bob") uses two air-filled bladders sandwiched inside two bags full of a dielectric medium that replicates the properties of humans, within a modified wetsuit to serve as a "skin." An Arduino microcontroller with high-current drivers controls solenoid valves that fill and drain the bladders to simulate human breathing and heartbeat.

This device provides a way to characterize the performance of victim detecting radars objectively and quantitatively. It dramatically reduces the cost of testing in multiple-victim scenarios. The programmable victim simulator can be used to assess the sensitivity of the radar accurately, and can be placed for long periods of time in environments that would be unsafe for a human subject (e.g., buried for 24 to 48 hours in flowing mud, or within a burning building).

# Hydrometeor Size Distribution Measurements by Imaging the Attenuation of a Laser Spot

## Measurement of the DSD's second moment is made by way of the Beer-Lambert law.

*John F. Kennedy Space Center, Florida*

The optical extinction of a laser due to scattering of particles is a well-known phenomenon. In a laboratory environment, this physical principle is known as the Beer-Lambert law, and is often used to measure the concentration of scattering particles in a fluid or gas. This method has been experimentally shown to be a usable means to measure the dust density from a rocket plume interaction with the lunar surface. Using the same principles and experimental arrangement, this technique can be applied to hydrometeor size distributions, and for launch-pad operations, specifically as a passive hail detection and measurement system.

Calibration of a hail monitoring system is a difficult process. In the past, it has required comparison to another means of measuring hydrometeor size and density. Using a technique recently developed for estimating the density of surface dust dispersed during a rocket landing, measuring the extinction of a laser passing through hail (or dust in the rocket case) yields an estimate of the second moment of the particle cloud, and hydrometeor size distribution in the terrestrial meteorological case. With the exception of disdrometers, instruments that measure rain and hail fall make indirect measurements of the drop-size distribution. Instruments that scatter microwaves off of hydrometeors, such as the WSR-88D (Weather Surveillance Radar 88 Doppler), vertical wind profilers, and microwave disdrometers, measure the sixth moment of the drop size distribution (DSD).

By projecting a laser onto a target, changes in brightness of the laser spot against the target background during rain and hail yield a measurement of the DSD's second moment by way of the Beer-Lambert law. In order to detect the laser attenuation within the 8-bit resolution of most camera image arrays, a minimum path length is required. Depending on the intensity of the hail fall rate for moderate to heavy rainfall, a laser path length of 100 m is sufficient to measure variations in optical extinction using a digital camera. For hail fall only, the laser path may be shorter because of greater scattering due to the properties of hailstones versus raindrops. A photodetector may replace the camera in automated installations.

Laser-based rain and hail measurement systems are available, but they are based on measuring the interruption of a thin laser beam, thus counting individual hydrometeors. These systems are true disdrometers since they also measure size and velocity. The method reported here is a simple method, requiring far less processing, but it is not a disdrometer.

# Electronics/Computers

## Quasi-Linear Circuit

*John H. Glenn Research Center, Cleveland, Ohio*

This work involved developing space-qualifiable switch mode DC/DC power supplies that improve performance with fewer components, and result in elimination of digital components and reduction in magnetics. This design is for missions where systems may be operating under extreme conditions, especially at elevated temperature levels from 200 to 300 °C.

Prior art for radiation-tolerant DC/DC converters has been accomplished utilizing classical magnetic-based switch mode converter topologies; however, this requires specific shielding and component de-rating to meet the high-reliability specifications. It requires complex measurement and feedback components, and will not enable automatic re-optimization for larger changes in voltage supply or electrical loading condition.

The innovation is a switch mode DC/DC power supply that eliminates the need for processors and most magnetics. It can provide a well-regulated voltage supply with a gain of 1:100 step-up to 8:1 step down, tolerating an up to 30% fluctuation of the voltage supply parameters.

The circuit incorporates a ceramic core transformer in a manner that enables it to provide a well-regulated voltage output without use of any processor components or magnetic transformers. The circuit adjusts its internal parameters to re-optimize its performance for changes in supply voltage, environmental conditions, or electrical loading at the output.

*This work was done by William Bradley, Ross Bird, Dennis Eldred, Jon Zook, and Gareth Knowles of QorTek. Inc. for Glenn Research Center. For more information, contact kimberly.a.dalgleish@nasa.gov.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18995-1.*

## High-Speed, High-Resolution Time-to-Digital Conversion

*Goddard Space Flight Center, Greenbelt, Maryland*

This innovation is a series of time-tag pulses from a photomultiplier tube, featuring short time interval between pulses (e.g., 2.5 ns). Using the previous art, dead time between pulses is too long, or too much hardware is required, including a very-high-speed demultiplexer. A faster method is needed.

The goal of this work is to provide circuits to time-tag pulses that arrive at a high rate using the hardwired logic in an FPGA — specifically the carry chain — to create what is (in effect) an analog delay line. High-speed pulses travel down the chain in a "wave." For instance, a pulse train has been demonstrated from a 1-GHz source reliably traveling down the carry chain. The size of the carry chain is over 10 ns in the time domain. Thus, multiple pulses will travel down the carry chain in a wave simultaneously. A register clocked by a low-skew clock takes a "snapshot" of the wave. Relatively simple logic can extract the pulses from the snapshot picture by detecting the transitions between logic states.

The propagation delay of CMOS (complementary metal oxide semiconductor) logic circuits will differ and/or change as a result of temperature, voltage, age, radiation, and manufacturing variances. The time-to-digital conversion circuits can be calibrated with test signals, or the changes can be nulled by a separate on-die calibration channel, in a closed loop circuit.

*This work was done by Richard Katz, Igor Kleyner, and Rafael Garcia of Goddard Space Flight Center. For further information, contact the Goddard Innovative Partnerships Office at (301) 286-5810. GSC-16242-1*

## Li-Ion Battery and Supercapacitor Hybrid Design for Long Extravehicular Activities

**Batteries with supercapacitors can be used as more compact packages for extended work in space.**

*Lyndon B. Johnson Space Center, Houston, Texas*

With the need for long periods of extravehicular activities (EVAs) on the Moon or Mars or a near-asteroid, the need for long-performance batteries has increased significantly. The energy requirements for the EVA suit, as well as surface systems such as rovers, have increased significantly due to the number of applications they need to power at the same time. However, even with the best state-of-the-art Li-ion batteries, it is not possible to power the suit or

the rovers for the extended period of performance. Carrying a charging system along with the batteries makes it cumbersome and requires a self-contained power source for the charging system that is usually not possible. An innovative method to charge and use the Li-ion batteries for long periods seems to be necessary and hence, with the advent of the Li-ion supercapacitors, a method has been developed to extend the performance period of the Li-ion power system for future exploration applications.

The Li-ion supercapacitors have a working voltage range of 3.8 to 2.5 V, and are different from a traditional su-percapacitor that typically has a working voltage of 1 V. The innovation is to use this Li-ion supercapacitor to charge Li-ion battery systems on an as-needed basis. The supercapacitors are charged using solar arrays and have battery systems of low capacity in parallel to be able to charge any one battery system while they provide power to the application. Supercapacitors can safely take up fast charge since the electrochemical process involved is still based on charge separation rather than the intercalation process seen in Li-ion batteries, thus preventing lithium metal deposition on the anodes. The lack of intercalation and eliminating wear of the supercapacitors allows for them to be charged and discharged safely for a few tens of thousands of cycles.

The Li-ion supercapacitors can be charged from the solar cells during the day during an extended EVA. The Li-ion battery used can be half the capacity required for a nominal EVA. The small Li-ion battery can be divided into two parallel modules with independent charging ports that would allow the supercapacitors to charge one battery while the other is providing power to the rover or suit.

*This work was done by Judith Jeevarajan of Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-25223-1*

# Ultrasonic Low-Friction Containment Plate for Thermal and Ultrasonic Stir Weld Processes

*Marshall Space Flight Center, Alabama*

The thermal stir welding (TSW) process is finding applications in fabrication of space vehicles. In this process, workpieces to be joined by TSW are drawn, by heavy forces, between "containment plates," past the TSW tool that then causes joining of the separate plates. It is believed that the TSW process would be significantly improved by reducing the draw force, and that this could be achieved by reducing the friction forces between the workpieces and containment plates.

Based on use of high-power ultrasonics in metal forming processes, where friction reduction in drawing dies has been achieved, it is believed that ultrasonic vibrations of the containment plates could achieve similar friction reduction in the TSW process. By applying ultrasonic vibrations to the containment plates in a longitudinal vibration mode, as well as by mounting and holding the containment plates in a specific manner such as to permit the plates to acoustically float, friction between the metal parts and the containment plates is greatly reduced, and so is the drawing force.

The concept was to bring in the ultrasonics from the sides of the plates, permitting the ultrasonic hardware to be placed to the side, away from the equipment that contains the thermal stir tooling and that applies clamping forces to the plates.

Tests demonstrated that one of the major objectives of applying ultrasonics to the thermal stir system, that of reducing draw force friction, should be achievable on a scaled-up system.

*This work was done by Karl Graff and Matt Short of the Edison Welding Institute for Marshall Space Flight Center. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32900-1.*

# High-Powered, Ultrasonically Assisted Thermal Stir Welding

**This method has the potential to increase the longevity of hardware in the auto industry, especially in bearing wear.**

*Marshall Space Flight Center, Alabama*

This method is a solid-state weld process capable of joining metallic alloys without melting. The weld workpieces to be joined by thermal stir welding (TSW) are drawn, by heavy forces, between containment plates past the TSW stir tool that then causes joining of the weld workpiece.

TSW is similar to friction stir welding (FSW) in that material is heated into a plastic state (not melted) and stirred using a stir rod. The FSW pin tool is an integrated geometrical structure consisting of a large-diameter shoulder, and a smaller-diameter stir pin protruding from the shoulder. When the pin is plunged into a weld workpiece, the shoulder spins on the surface of the weld workpiece, thus inducing frictional heat into the part. The pin stirs the fraying surfaces of the weld joint, thus joining the weld workpiece into one structure. The shoulder and stir pin of the FSW pin tool must rotate together at a desired rotational speed. The induced frictional energy control and stir pin control of the

pin tool cannot be de-coupled. The two work as one integrated unit.

TSW, on the other hand, de-couples the heating and stirring of FSW, and allows for independent control of each process element. A uniquely designed induction coil heats the weld workpiece to a desired temperature, and once heated, the part moves into a stir rod whose RPM is also independently controlled. As the weld workpiece moves into the stir rod, the piece is positioned, or sandwiched, between upper and lower containment plates. The plate squeezes together, thus compressing the upper and lower surfaces of the weld workpiece. This compressive force, also called consolidation force, consolidates the plastic material within the weld nugget material as it is being stirred by the stir rod. The stir rod is positioned through the center of the top containment plate and protrudes midway through the opposite lower containment plate where it is mechanically captured. The upper and lower containment plates are separated by a distance equal to the thickness of the material being welded.

The TSW process can be significantly improved by reducing the draw forces. This can be achieved by reducing the friction forces between the weld workpieces and the containment plates. High-power ultrasonic (HPU) vibrations of the containment plates achieve friction reduction in the TSW process. Furthermore, integration of the HPU energy into the TSW stir rod can increase tool life of the stir rod, and can reduce shear forces to which the stir rod is subjected during the welding process.

TSW has been used to successfully join 0.500-in (≈13-mm) thick commercially pure (CP) titanium, titanium 6AL-4V, and titanium 6AL-4V ELI in weld joint lengths up to 9 ft (≈2.75-m) long. In addition, the TSW process was used to fabricate a sub-scale hexagonally shaped gun turret component for the U.S. Navy. The turret is comprised of six 0.5000-in (≈13-mm) thick angled welds. Each an-

gled weld joint was prepared by machining the mating surfaces to 120°. The angled weld joint was then fixtured using an upper and lower containment plate of the same geometry of the angled weld joint. The weld joint was then stirred by the stir rod as it and the upper and lower containment plates traverse through the angled joint prep.

*This work was done by Robert (Jeff) Ding for Marshall Space Flight Center. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov.*

*This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Marshall Space Flight Center. Refer to MFS-32895-1.*

# Next-Generation MKIII Lightweight HUT/Hatch Assembly
## Applications for general aviation include the insulation around fuel tanks, especially wing-located tanks.

*Lyndon B. Johnson Space Center, Houston, Texas*

The MK III (H-1) carbon-graphite/ epoxy Hard Upper Torso (HUT)/Hatch assembly was designed, fabricated, and tested in the early 1990s. The spacesuit represented an 8.3 psi (≈58 kPa) technology demonstrator model of a zero pre-breathe suit. The basic torso shell, brief, and hip areas of the suit were composed of a carbon-graphite/epoxy composite lay-up. In its current configuration, the suit weighs approximately 120 lb (≈54 kg). However, since future planetary suits will be designed to operate at 0.26 bar (≈26 kPa), it was felt that the suit's re-designed weight could be reduced to 79 lb (≈35 kg) with the incorporation of lightweight structural materials.

Many robust, lightweight structures based on the technologies of advanced honeycomb materials, revolutionary new composite laminates, metal matrix composites, and recent breakthroughs in fullerene fillers and nanotechnology lend themselves well to applications requiring materials that are both light and strong.

The major problem involves the reduction in weight of the HUT/ Hatch assembly for use in lunar and/or planetary applications, while at the same time maintaining a robust structural design. The technical objective is to research, design, and develop manufacturing methods that support fabrication of a lightweight HUT/Hatch assembly using advanced material and geometric redesign as necessary. Additionally, the lightweight HUT/Hatch assembly will interface directly with current MK III hardware.

Using the new operating pressure and current MK III (H-1) interfaces as a starting block, it is planned to maximize HUT/Hatch assembly weight reduction through material selection and geometric redesign. A hard upper torso shell structure with rear-entry closure and corresponding hatch will be fabricated. The lightweight HUT/Hatch assembly will retrofit and interface with existing MK III (H-1) hardware elements, providing NASA with immediate "plug-and-play" capability.

NASA crewmembers will have a lightweight, robust, life-support system that will minimize fatigue during extraterrestrial surface sojourns. Its unique feature is the utilization of a new and innovative family of materials used by the aerospace industry, which at the time of this reporting has not been used for the proposed application.

*This work was done by Mike McCarthy and Ralph Toscano of Air-Lock, Inc. for Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-23941-1*

# Centrifugal Sieve for Gravity-Level-Independent Size Segregation of Granular Materials

**Centrifugal force can significantly shorten the time to segregate feedstock into a set of different-sized fractions.**

*John H. Glenn Research Center, Cleveland, Ohio*

Conventional size segregation or screening in batch mode, using stacked vibrated screens, is often a time-consuming process. Utilization of centrifugal force instead of gravity as the primary body force can significantly shorten the time to segregate feedstock into a set of different-sized fractions. Likewise, under reduced gravity or microgravity, a centrifugal sieve system would function as well as it does terrestrially. When vibratory and mechanical blade sieving screens designed for terrestrial conditions were tested under lunar gravity conditions, they did not function well. The centrifugal sieving design of this technology overcomes the issues that prevented sieves designed for terrestrial conditions from functioning under reduced gravity.

These sieves feature a rotating outer (cylindrical or conical) screen wall, rotating fast enough for the centrifugal forces near the wall to hold granular material against the rotating screen. Conventional centrifugal sieves have a stationary screen and rapidly rotating blades that shear the granular solid near the stationary screen, and effect the sieving process assisted by the airflow inside

the unit. The centrifugal sieves of this new design may (or may not) have an inner blade or blades, moving relative to the rotating wall screen. Some continuous flow embodiments would have no inner auger or blades, but achieve axial motion through vibration. In all cases, the shearing action is gentler than conventional centrifugal sieves, which have very high velocity differences between the stationary outer screen and the rapidly rotating blades. The new design does not depend on airflow in the sieving unit, so it will function just as well in vacuum as in air.

One advantage of the innovation for batch sieving is that a batch-mode centrifugal sieve may accomplish the same sieving operation in much less time than a conventional stacked set of vibrated screens (which utilize gravity as the primary driving force for size separation). In continuous mode, the centrifugal sieves can provide steady streams of fine and coarse material separated from a mixed feedstock flow stream. The centrifugal sieves can be scaled to any desired size and/or mass flow rate. Thus, they could be made in sizes suitable for small robotic ex-

ploratory missions, or for semi-permanent processing of regolith for extraction of volatiles of minerals.

An advantage of the continuous-mode system is that it can be made with absolutely no gravity flow components for feeding material into, or for extracting the separated size streams from, the centrifugal sieve. Thus, the system is capable of functioning in a true microgravity environment. Another advantage of the continuous-mode system is that some embodiments of the innovation have no internal blades or vanes, and thus, can be designed to handle a very wide range of feedstock sizes, including occasional very large oversized pieces, without jamming or seizing up.

*This work was done by Otis R. Walton of Grainflow Dynamics, Inc.; Christopher Dreyer of the Colorado School of Mines; and Edward Riedel of Ned Riedel Engineering, LLC for Glenn Research Center. For more information, contact kimberly.a.dalgleish@nasa.gov.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-19033-1.*

# Ion Exchange Technology Development in Support of the Urine Processor Assembly

**Resins can filter gypsum out of urine, improving the water recovery rate.**

*Lyndon B. Johnson Space Center, Houston, Texas*

The urine processor assembly (UPA) on the International Space Station (ISS) recovers water from urine via a vacuum distillation process. The distillation occurs in a rotating distillation assembly (DA) where the urine is heated and subjected to sub-ambient pressure. As water is removed, the original organics, salts, and minerals in the urine become more

concentrated and result in urine brine. Eventually, water removal will concentrate the urine brine to super saturation of individual constituents, and precipitation occurs. Under typical UPA DA operating conditions, calcium sulfate or gypsum is the first chemical to precipitate in substantial quantity. During preflight testing with ground urine, the

UPA achieved 85% water recovery without precipitation.

However, on ISS, it is possible that crewmember urine can be significantly more concentrated relative to urine from ground donors. As a result, gypsum precipitated in the DA when operating at water recovery rates at or near 85%, causing the failure and subsequent re-

placement of the DA. Later investigations have demonstrated that an excess of calcium and sulfate will cause precipitation at water recovery rates greater than 70%. The source of the excess calcium is likely physiological in nature, via crewmembers' bone loss, while the excess sulfate is primarily due to the sulfuric acid component of the urine pretreatment. To prevent gypsum precipitation in the UPA, the Precipitation Prevention Project (PPP) team has focused on removing the calcium ion from pretreated urine, using ion exchange resins as calcium removal agents. The selectivity and effectiveness of ion exchange resins are determined by such factors as the mobility of the liquid phase through the polymer matrix, the density of functional groups, type of functional groups bound to the matrix, and the chemical characteristics of the liquid phase (pH, oxidation potential, and ionic strength).

Previous experience with ion exchange resins has demonstrated that the most effective implementation for an ion exchange resin is a cartridge, or column, in which the resin is contained. Based on the results of equilibrium and sub-scale dynamic column testing, a possible solution for mitigating the calcium precipitation issue on the ISS has been identified. From an original pool of 13 ion exchange resins, two candidates have been identified that demonstrate substantial calcium removal on the sub-scale. The dramatic reduction in resin performance from published calcium uptake demonstrates the need for thorough evaluation of resins at the low pH and strong oxidizing environment present in the UPA. Chemical variations in the influent (calcium concentrations and pretreatment dosing) appear to have a noticeable impact on the calcium capacity of the resin. Low calcium concentrations and high pretreatment dosing will likely result in a decrease in calcium capacity. Conversely, low pretreatment dosing will likely result in an increase in calcium capacity. In contrast, investigations at a variety of flow rates, length-to-diameter ratios, resin volumes, and flow regimes (continuous versus pulsed) show that changes in physical parameters do not have substantial impacts on resin performance in the very low specific velocity ranges of interest. This result is particularly useful because most commercial applications at higher specific velocities do show a relatively strong relationship between flow and capacity. The lack of a strong relationship will allow more flexibility in the implementation of an ion exchange bed for flight. Verification of subscale tests with flight-scale resin beds is recommended prior to implementation in the on-orbit UPA.

*This work was done by Julie Mitchell, James Broyan, and Karen Pickering of Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-25338-1*

# Nickel-Graphite Composite Compliant Interface and/or Hot Shoe Material

**This innovation is a technique for joining various thermoelectric materials into segmented device architectures.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Next-generation high-temperature thermoelectric-power-generating devices will employ segmented architectures and will have to reliably withstand thermally induced mechanical stresses produced during component fabrication, device assembly, and operation. Thermoelectric materials have typically poor mechanical strength, exhibit brittle behavior, and possess a wide range of coefficient of thermal expansion (CTE) values. As a result, the direct bonding at elevated temperatures of these materials to each other to produce segmented leg components is difficult, and often results in localized microcracking at interfaces and mechanical failure due to the stresses that arise from the CTE mismatch between the various materials. Even in the absence of full mechanical failure, degraded interfaces can lead to increased electrical and thermal resistances, which adversely impact conversion efficiency and power output.

The proposed solution is the insertion of a mechanically compliant layer, with high electrical and thermal conductivity, between the low- and high-temperature
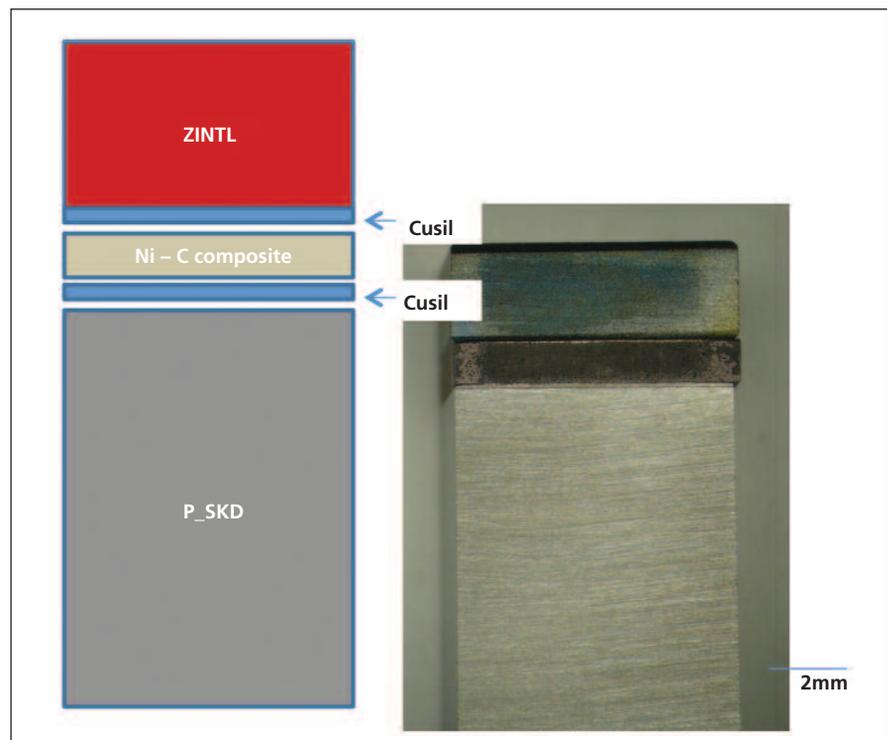


The freestanding segmented Zintl/skutterudite leg fabricated using a **Nickel-Graphite Composite-Based Compliant Layer** brazed to the metalized surfaces of the Zintl and skutterudite (SKD) segments.

segments to relieve thermomechanical stresses during device fabrication and operation. This composite material can be used as a stress-relieving layer between the thermoelectric segments and/or between a thermoelectric segment and a hot- or cold-side interconnect material. The material also can be used as a compliant hot shoe.

Nickel-coated graphite powders were hot-pressed to form a nickel-graphite composite material. A freestanding thermoelectric segmented leg was fabricated by brazing the compliant pad layer between the high-temperature p-Zintl and low-temperature p-SKD TE segments using Cu-Ag braze foils. The segmented leg stack was heated in vacuum under a compressive load to achieve bonding.

The novelty of the innovation is the use of composite material that reduces the thermomechanical stresses encountered in the construction of high-efficiency, high-temperature thermo-electric devices. The compliant pad enables the bonding of dissimilar thermoelectric materials while maintaining the desired electrical and thermal properties essential for efficient device operation. The modulus, CTE, electrical, and thermal conductances of the composite can be controlled by varying the ratio of nickel to graphite.

*This work was done by Samad A. Firdosy, Billy Chun-Yip Li, Vilupanur A. Ravi, Jean-*

# 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 ($km^2$ 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 $km^2$, sail subsystem area densities approaching 1 $g/m^2$, 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 aluminum-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.

# 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, astrobiology, 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 nonbatch 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 seg-

regating 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*

# Medicine Delivery Device With Integrated Sterilization and Detection

**This automated medicine delivery device would ensure that patients receive medication on schedule and at the right dosage level.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Sterile delivery devices can be created by integrating a medicine delivery instrument with surfaces that are coated with germicidal and anti-fouling material. This requires that a large-surface-area template be developed within a constrained volume to ensure good contact between the delivered medicine and the germicidal material. Both of these can be integrated using JPL-developed silicon nanotip or cryo-etch black silicon technologies with atomic layer deposition (ALD) coating of specific germicidal layers.

The application of semiconductor processing techniques and technologies to the problems of fluid manipulation and delivery has enabled the integration of chemical, electrical, and mechanical manipulation of samples all within a single microfluidic device. This approach has been successfully applied at JPL to the automated processing, detection, and analysis of minute quantities (parts per trillion level) of biomaterials to develop instruments for *in situ* exploration or extraterrestrial bodies. The same nanofabrication techniques that are used to produce a microfluidics device are also capable of synthesizing extremely high-surface-area templates in precise locations, and coating those surfaces with conformal films to manipulate their surface properties. This methodology has been successfully applied at JPL to produce patterned and coated silicon nanotips (also known as black silicon) to manipulate the hydrophilicity of surfaces to direct the spreading of fluids in microdevices. JPL's ALD technique is an ideal method to produce the highly conformal coatings required for this type of application.

Certain materials, such as $TiO_2$, have germicidal and anti-fouling properties when they are illuminated with UV light. The proposed delivery device contacts medicine with this high-surface-area black silicon surface coated with a thin-film germicidal deposited conformally with ALD. The coating can also be illuminated with ultraviolet light for the purpose of sterili-
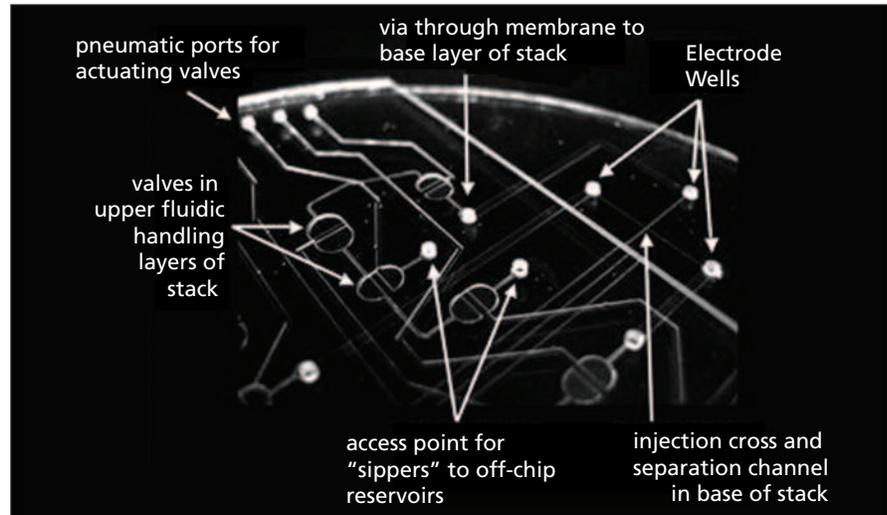


Figure 1. **JPL's Microfluidic Chip** for sample preparation, delivery, and analysis.
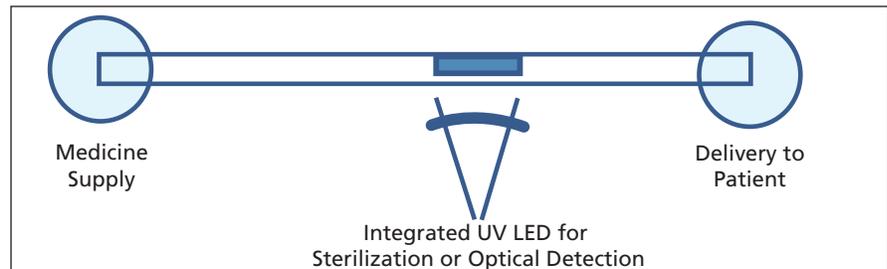


Figure 2. Schematic of a **Microchannel** in the medicine delivery device with integrated sterilization or analysis on an extremely high-surface-area template.

zation or identification of the medicine itself. This constrained volume that is located immediately prior to delivery into a patient, ensures that the medicine delivery device is inherently sterile.

An additional benefit to integrating a high-surface-area template within the fluid channel of a medicine delivery device is that one can envision a number of different functional coatings that could facilitate the capture and analysis of either microbial contaminants or the medicine itself. For example, one could attach antibodies or some other binding agent with a specific affinity to the silicon nanotip template. Once a target mole-

cule or microbe is bound to the high-surface-area template, one could use an optical analytical technique such as fluorescence or adsorption to determine the identity and potentially the concentration of the species of interest. By illuminating the bound species from the back, it may also be possible to probe only the molecules with an evanescent wave, making detection of the species from the front side of the device much simpler.

*This work was done by Michael J. Shearn, Harold F. Greer, and Harish Manohara of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47972*

# FRET-Aptamer Assays for Bone Marker Assessment, C-Telopeptide, Creatinine, and Vitamin D

**Applications include assessment of osteoporosis, and aptamer assays for veterinary analytes, infectious disease, food- and water-borne pathogens, and chemical/biological threats.**

*Lyndon B. Johnson Space Center, Houston, Texas*

Astronauts lose 1.0 to 1.5% of their bone mass per month on long-duration spaceflights. NASA wishes to monitor the bone loss onboard spacecraft to develop nutritional and exercise countermeasures, and make adjustments during long space missions. On Earth, the same technology could be used to monitor osteoporosis and its therapy.

Aptamers bind to targets against which they are developed, much like antibodies. However, aptamers do not require animal hosts or cell culture and are therefore easier, faster, and less expensive to produce. In addition, aptamers sometimes exhibit greater affinity and specificity vs. comparable antibodies. In this work, fluorescent dyes and quenchers were added to the aptamers to enable pushbutton, one-step, bind-and-detect fluorescence resonance energy transfer (FRET) assays or tests that can be freeze-dried, rehydrated with body fluids, and used to quantitate bone loss of vitamin D levels with a handheld fluorometer in the spacecraft environment.

This work generated specific, rapid, one-step FRET assays for the bone loss marker C-telopeptide (CTx) when extracted from urine, creatinine from urine, and vitamin D congeners in diluted serum. The assays were quantified in nanograms/mL using a handheld fluorometer connected to a laptop computer to convert the raw fluorescence values into concentrations of each analyte according to linear standard curves.

DNA aptamers were selected and amplified for several rounds against a 26-amino acid form of CTx, creatinine, and vitamin D. The commonalities between loop structures were studied, and several common loop structures were converted into aptamer beacons with a fluorophore and quencher on each end. In theory, when the aptamer beacon binds its cognate target (CTx bone peptide, creatinine, or vitamin D), it is forced open and no longer quenched, so it gives off fluorescent light (when excited) in proportion to the amount of target present in a sample. This proportional increase in fluorescence is called a "lights on" FRET response. The vitamin D aptamer beacon gives a "lights off" or inversely proportional fluorescence response to the amount of vitamin D present in diluted serum.

These FRET-aptamer assays are rapid (<30 minutes), sensitive (low ng/mL detection limits), and quite easy to carry out (add sample, mix, and detect in the handheld reader). Benefits include the speed of the assays as well as the small amount of space taken up by the handheld reader and cuvette assays.

The aptamer DNA sequences represent novel additional features of the existing (patent-pending) FRET-aptamer assay platform.

# Multimode Directional Coupler for Utilization of Harmonic Frequencies From TWTAs

**The design is easily scaled to higher frequency TWTAs.**

*John H. Glenn Research Center, Cleveland, Ohio*

A novel waveguide multimode directional coupler (MDC) intended for the measurement and potential utilization of the second and higher order harmonic frequencies from high-power traveling wave tube amplifiers (TWTAs) has been successfully designed, fabricated, and tested. The design is based on the characteristic multiple propagation modes of the electrical and magnetic field components of electromagnetic waves in a rectangular waveguide.

The purpose was to create a rugged, easily constructed, more efficient waveguide-based MDC for extraction and exploitation of the second harmonic signal from the RF output of high-power TWTs used for space communications. The application would be a satellite-based beacon source needed for Q-band and V/W-band atmospheric propagation studies. The MDC could function as a CW narrow-band source or as a wideband source for study of atmospheric group delay effects on high-data-rate links.

The MDC is fabricated from two sections of waveguide — a primary one for the fundamental frequency and a secondary waveguide for the second harmonic — that are joined together such that the second harmonic higher order modes are selectively coupled via precision-machined slots for propagation in the secondary waveguide.

In the TWTA output waveguide port, both the fundamental and the second harmonic signals are present. These signals propagate in the output waveguide as the dominant and higher order modes, respectively. By including an appropriate mode selective waveguide directional coupler, such as the MDC presented here at the output of the TWTA, the power at the second harmonic can be sampled and amplified to the power level needed for atmospheric propagation studies.

The important conclusions from the preliminary test results for the multimode directional coupler are: (1) the second harmonic (Ka-band) can be measured and effectively separated from the fundamental (Ku-band) with no coupling of the latter, (2) power losses in the fundamental frequency are negligible, and (3) the power level of the extracted second harmonic is sufficient for further amplification to power levels needed for practical applications. It was also demonstrated that third order and potentially higher order harmonics are measurable with this device. The design is frequency agnostic, and with the appropriate choice of waveguides, is easily scaled to higher frequency TWTs. The MDC has the same function but with a number of important advantages over the conventional diplexer.

*This work was done by Rainee N. Simons and Edwin G. Wintucky of Glenn Research Center. Further information is contained in a TSP (see page 1).*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-19045-1.*

# Dual-Polarization, Multi-Frequency Antenna Array for use with Hurricane Imaging Radiometer

**New approach promises to be more cost effective and can reduce on-station aircraft time.**

*Marshall Space Flight Center, Alabama*

Advancements in common aperture antenna technology were employed to utilize its proprietary genetic algorithm-based modeling tools in an effort to develop, build, and test a dual-polarization array for Hurricane Imaging Radiometer (HIRAD) applications. Final program results demonstrate the ability to achieve a lightweight, thin, higher-gain aperture that covers the desired spectral band.

NASA employs various passive microwave and millimeter-wave instruments, such as spectral radiometers, for a range of remote sensing applications, from meas-

urements of the Earth's surface and atmosphere, to cosmic background emission. These instruments such as the HIRAD, SFMR (Stepped Frequency Microwave Radiometer), and LRR (Lightweight Rainfall Radiometer), provide unique data accumulation capabilities for observing sea surface wind, temperature, and rainfall, and significantly enhance the understanding and predictability of hurricane intensity. These microwave instruments require extremely efficient wideband or multiband antennas in order to conserve space on the airborne platform.

In addition, the thickness and weight of the antenna arrays is of paramount importance in reducing platform drag, permitting greater time on station.

Current sensors are often heavy, single-polarization, or limited in frequency coverage. The ideal wideband antenna will have reduced size, weight, and profile (a conformal construct) without sacrificing optimum performance. The technology applied to this new HIRAD array will allow NASA, NOAA, and other users to gather information related to hurricanes and other tropical storms

more cost effectively without sacrificing sensor performance or the aircraft time on station.

The results of the initial analysis and numerical design indicated strong potential for an antenna array that would satisfy all of the design requirements for a replacement HIRAD array. Multiple common aperture antenna methodologies were employed to achieve exceptional gain over the entire spectral frequency band while exhibiting superb VSWR (voltage standing wave ratio) values.

Element size and spacing requirements were addressed for a direct replacement of the thicker, lower-performance, stacked patch antenna array currently employed for the HIRAD application. Several variants to the multiband arrays were developed that exhibited four, equally spaced, high efficiency, "sweet spot" frequency bands, as well as the option for a high-performance wideband array. The 0.25-in. (≈6.4-mm) thickness of the antenna stack-up itself was achieved through the application of specialized antenna techniques and meta-materials to accomplish all design objectives.

# Complementary Barrier Infrared Detector (CBIRD) Contact Methods

*NASA's Jet Propulsion Laboratory, Pasadena, California*

The performance of the CBIRD detector is enhanced by using new device contacting methods that have been developed. The detector structure features a narrow gap adsorber sandwiched between a pair of complementary, unipolar barriers that are, in turn, surrounded by contact layers. In this innovation, the contact adjacent to the hole barrier is doped n-type, while the contact adjacent to the electron barrier is doped p-type.

The contact layers can have wider bandgaps than the adsorber layer, so long as good electrical contacts are made to them. If good electrical contacts are made to either (or both) of the barriers, then one could contact the barrier(s) directly, obviating the need for additional contact layers. Both the left and right contacts can be doped either n-type or p-type. Having an n-type contact layer next to the electron barrier creates a second p-n junction (the first being the one between the hole barrier and the adsorber) over which applied bias could drop. This reduces the voltage drop over the adsorber, thereby reducing dark current generation in the adsorber region.

# Autonomous Control of Space Nuclear Reactors

**Autonomous operation and safety are addressed simultaneously.**

*John H. Glenn Research Center, Cleveland, Ohio*

Nuclear reactors to support future robotic and manned missions impose new and innovative technological requirements for their control and protection instrumentation. Long-duration surface missions necessitate reliable autonomous operation, and manned missions impose added requirements for failsafe reactor protection. There is a need for an advanced instrumentation and control system for space-nuclear reactors that addresses both aspects of autonomous operation and safety.

The Reactor Instrumentation and Control System (RICS) consists of two functionally independent systems: the Reactor Protection System (RPS) and the Supervision and Control System (SCS). Through these two systems, the RICS both supervises and controls a nuclear reactor during normal operational states, as well as monitors the operation of the reactor and, upon sensing a system anomaly, automatically takes the appropriate actions to prevent an unsafe or potentially unsafe condition from occurring. The RPS encompasses all electrical and mechanical devices and circuitry, from sensors to actuation device output terminals.

The SCS contains a comprehensive data acquisition system to measure continuously different groups of variables consisting of primary measurement elements, transmitters, or conditioning modules. These reactor control variables can be categorized into two groups: those directly related to the behavior of the core (known as nuclear variables) and those related to secondary systems (known as process variables). Reliable closed-loop reactor control is achieved by processing the acquired variables and actuating the appropriate device drivers to maintain the reactor in a safe operating state. The SCS must prevent a deviation from the reactor nominal conditions by managing limitation functions in order to avoid RPS actions.

The RICS has four identical redundancies that comply with physical separation, electrical isolation, and functional independence. This architecture complies with the safety requirements of a nuclear reactor and provides high availability to the host system. The RICS is intended to interface with a host computer (the computer of the spacecraft where the reactor is mounted).

The RICS leverages the safety features inherent in Earth-based reactors and also integrates the wide range neutron detector (WRND). A neutron detector provides the input that allows the RICS to do its job. The RICS is based on proven technology currently in use at a nuclear research facility. In its most basic form, the RICS is a ruggedized, compact data-acquisition and control system that

could be adapted to support a wide variety of harsh environments. As such, the RICS could be a useful instrument outside the scope of a nuclear reactor, including military applications where fail-safe data acquisition and control is required with stringent size, weight, and power constraints.

*This work was done by John Merk of Aurora Flight Sciences for Glenn Research Center. For more information, contact kimberly.a.dalgleish@nasa.gov.*

# High-Power, High-Speed Electro-Optic Pockels Cell Modulator

*Goddard Space Flight Center, Greenbelt, Maryland*

Electro-optic modulators rely on a change in the index of refraction for the optical wave as a function of an applied voltage. The corresponding change in index acts to delay the wavefront in the waveguide. The goal of this work was to develop a high-speed, high-power waveguide-based modulator (phase and amplitude) and investigate its use as a pulse slicer. The key innovation in this effort is the use of potassium titanyl phosphate (KTP) waveguides, making the high-power, polarization-based waveguide amplitude modulator possible. Furthermore, because it is fabricated in KTP, the waveguide component will withstand high optical power and have a significantly higher RF modulation figure of merit (FOM) relative to lithium niobate.

KTP waveguides support high-power TE and TM modes — a necessary requirement for polarization-based modulation as with a Pockels cell.

High-power fiber laser development has greatly outpaced fiber-based modulators in terms of its maturity and specifications. The demand for high-performance nonlinear optical (NLO) devices in terms of power handling, efficiency, bandwidth, and useful wavelength range has driven the development of bulk NLO options, which are limited in their bandwidth, as well as waveguide based LN modulators, which are limited by their low optical damage threshold.

Today, commercially available lithium niobate (LN) modulators are used for laser formatting; however, because of photorefractive damage that can reduce transmission and increase requirements on bias control, LN modulators cannot be used with powers over several mW, dependent on wavelength.

The high-power, high-speed modulators proposed for development under this effort will enable advancements in several exciting fields including lidar-based remote sensing, atomic interferometry, free-space laser communications, and others.

*This work was done by Justin Hawthorne and Philip Battle of AdvR, Inc. for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16559-1*

## Covariance Analysis Tool (G-CAT) for Computing Ascent, Descent, and Landing Errors

*NASA's Jet Propulsion Laboratory, Pasadena, California*

G-CAT is a covariance analysis tool that enables fast and accurate computation of error ellipses for descent, landing, ascent, and rendezvous scenarios, and quantifies knowledge error contributions needed for error budgeting purposes. Because G-CAT supports hardware/system trade studies in spacecraft and mission design, it is useful in both early and late mission/proposal phases where Monte Carlo simulation capability is not mature, Monte Carlo simulation takes too long to run, and/or there is a need to perform multiple parametric system design trades that would require an unwieldy number of Monte Carlo runs.

G-CAT is formulated as a variable-order square-root linearized Kalman filter (LKF), typically using over 120 filter states. An important property of G-CAT is that it is based on a 6-DOF (degrees of freedom) formulation that completely captures the combined effects of both attitude and translation errors on the propagated trajectories. This ensures its accuracy for guidance, navigation, and control (GN&C) analysis. G-CAT provides the desired fast turnaround analysis needed for error budgeting in support of mission concept formulations, design trade studies, and proposal development efforts.
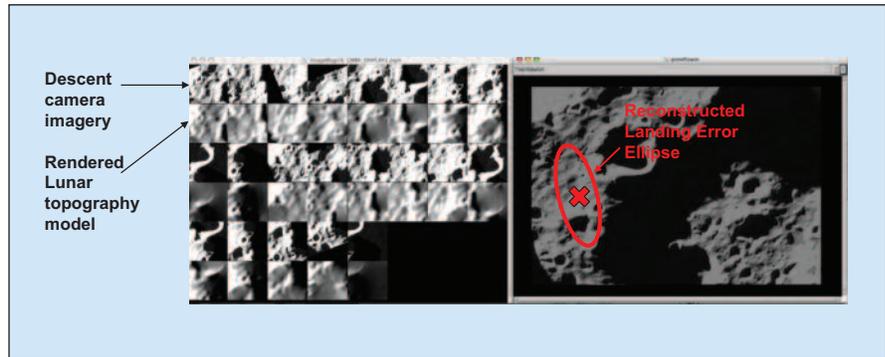


**Landing Site Reconstruction** based on descent camera imagery. *Copyright 2010 California Institute of Technology. Government sponsorship acknowledged.*

The main usefulness of a covariance analysis tool such as G-CAT is its ability to calculate the performance envelope directly from a single run. This is in sharp contrast to running thousands of simulations to obtain similar information using Monte Carlo methods. It does this by propagating the "statistics" of the overall design, rather than simulating individual trajectories.

G-CAT supports applications to lunar, planetary, and small body missions. It characterizes onboard knowledge propagation errors associated with inertial measurement unit (IMU) errors (gyro and accelerometer), gravity errors/dispersions (spherical harmonics, mass-cons), and radar errors (multiple altimeter beams, multiple Doppler velocimeter beams). G-CAT is a standalone MATLAB-based tool intended to run on any engineer's desktop computer.

*This work was done by Dhemetrios Boussalis and David S. Bayard of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-47854.*

## Enigma Version 12

*Lyndon B. Johnson Space Center, Houston, Texas*

Enigma Version 12 software combines model building, animation, and engineering visualization into one concise software package. Enigma employs a versatile user interface to allow average users access to even the most complex pieces of the application. Using Enigma eliminates the need to buy and learn several software packages to create an engineering visualization. Models can be created and/or modified within Enigma down to the polygon level. Textures and materials can be applied for additional realism. Within Enigma, these models can be combined to create systems of models that have a hierarchical relationship to one another, such as a robotic arm. Then these systems can be animated within the program or controlled by an external application programming interface (API). In addition, Enigma provides the ability to use plug-ins. Plug-ins allow the user to create custom code for a specific application and access the Enigma model and system data, but still use the Enigma drawing functionality.

CAD files can be imported into Enigma and combined to create systems of computer graphics models that can be manipulated with constraints. An API is available so that an engineer can write a simulation and drive the computer graphics models with no knowledge of computer graphics. An animation editor allows an engineer to set up sequences of animations generated by simulations or by conceptual trajectories in order to record these to high-quality media for presentation.

Commercially, because it is so generic, Enigma can be used for almost any project that requires engineering visualization, model building, or animation. Models in Enigma can be exported to many other formats for use in other applications as well. Educationally, Enigma is being used to allow university students to visualize robotic algorithms in a simulation mode before using them with actual hardware.

# Micrometeoroid and Orbital Debris (MMOD) Shield Ballistic Limit Analysis Program

*Lyndon B. Johnson Space Center, Houston, Texas*

This software implements penetration limit equations for common micrometeoroid and orbital debris (MMOD) shield configurations, windows, and thermal protection systems. Allowable MMOD risk is formulated in terms of the probability of penetration (PNP) of the spacecraft pressure hull.

For calculating the risk, spacecraft geometry models, mission profiles, debris environment models, and penetration limit equations for installed shielding configurations are required. Risk assessment software such as NASA's BUMPER-II is used to calculate mission PNP; however, they are unsuitable for use in shield design and preliminary analysis studies.

The software defines a single equation for the design and performance evaluation of common MMOD shielding configurations, windows, and thermal protection systems, along with a description of their validity range and guidelines for their application. Recommendations are based on preliminary reviews of fundamental assumptions, and accuracy in predicting experimental impact test results.

The software is programmed in Visual Basic for Applications for installation as a simple add-in for Microsoft Excel. The user is directed to a graphical user interface (GUI) that requires user inputs and provides solutions directly in Microsoft Excel workbooks.

# Spitzer Telemetry Processing System

*NASA's Jet Propulsion Laboratory, Pasadena, California*

The Spitzer Telemetry Processing System (SirtfTlmProc) was designed to address objectives of JPL's Multi-mission Image Processing Lab (MIPL) in processing spacecraft telemetry and distributing the resulting data to the science community. To minimize costs and maximize operability, the software design focused on automated error recovery, performance, and information management.

The system processes telemetry from the Spitzer spacecraft and delivers Level 0 products to the Spitzer Science Center. SirtfTlmProc is a unique system with automated error notification and recovery, with a real-time continuous service that can go quiescent after periods of inactivity.

The software can process 2 GB of telemetry and deliver Level 0 science products to the end user in four hours. It provides analysis tools so the operator can manage the system and troubleshoot problems. It automates telemetry processing in order to reduce staffing costs.

# Planetary Protection Bioburden Analysis Program

*NASA's Jet Propulsion Laboratory, Pasadena, California*

This program is a Microsoft Access program that performed statistical analysis of the colony counts from assays performed on the Mars Science Laboratory (MSL) spacecraft to determine the bioburden density, 3-sigma biodensity, and the total bioburdens required for the MSL prelaunch reports. It also contains numerous tools that report the data in various ways to simplify the reports required. The program performs all the calculations directly in the MS Access program. Prior to this development, the data was exported to large Excel files that had to be cut and pasted to provide the desired results. The program contains a main menu and a number of submenus. Analyses can be performed by using either all the assays, or only the accountable assays that will be used in the final analysis.

There are three options on the first menu: either calculate using (1) the old MER (Mars Exploration Rover) statistics, (2) the MSL statistics for all the assays, or

(3) the MSL statistics for only the accountable assays. Other options on the main menu include a data editing form and utility programs that produce various reports requested by the microbiologists and the project, and tools to generate the groupings for the final analyses.

The analyses can be carried out in three ways: Each assay can be treated separately, the assays can be collectively treated for the whole zone as a group, or the assays can be collected in groups designated by the JPL Planetary Protection Manager. The latter approach was used to generate the final report because assays on the same equipment or similar equipment can be assumed to have been exposed to the same environment and cleaning. Thus, the statistics are improved by having a larger population, thereby reducing the standard deviation by the square root of $N$.

For each method mentioned above, three reports are available. The first is a detailed report including all the data. This version was very useful in verifying the calculations. The second is a brief report that is similar to the full detailed report, but does not print out the data. The third is a grand total and summary report in which each assay requires only one line. For the first and second reports, most of the calculations are performed in the report section itself. For the third, all the calculations are performed directly in the query bound to the report. All the numerical results were verified by comparing them with Excel templates, then exporting the data from the Planetary Protection Analysis program to Excel.

# ◆ Wing Leading Edge RCC Rapid Response Damage Prediction Tool (IMPACT2)

*Lyndon B. Johnson Space Center, Houston, Texas*

This rapid response computer program predicts Orbiter Wing Leading Edge (WLE) damage caused by ice or foam impact during a Space Shuttle launch (Program "IMPACT2"). The program was developed after the Columbia accident in order to assess quickly WLE damage due to ice, foam, or metal impact (if any) during a Shuttle launch. IMPACT2 simulates an impact event in a few minutes for foam impactors, and in seconds for ice and metal impactors.

The damage criterion is derived from results obtained from one sophisticated commercial program, which requires hours to carry out simulations of the same impact events. The program was designed to run much faster than the commercial program with prediction of projectile threshold velocities within 10 to 15% of commercial-program values. The mathematical model involves coupling of Orbiter wing normal modes of vibration to nonlinear or linear spring-mass models.

IMPACT2 solves nonlinear or linear impact problems using classical normal modes of vibration of a target, and nonlinear/linear time-domain equations for the projectile. Impact loads and stresses developed in the target are computed as functions of time.

This model is novel because of its speed of execution. A typical model of foam, or other projectile characterized by material nonlinearities, impacting an RCC panel is executed in minutes instead of hours needed by the commercial programs. Target damage due to impact can be assessed quickly, provided that target vibration modes and allowable stress are known.

# ◆ ISSM: Ice Sheet System Model

*NASA's Jet Propulsion Laboratory, Pasadena, California*

In order to have the capability to use satellite data from its own missions to inform future sea-level rise projections, JPL needed a full-fledged ice-sheet/ice-shelf flow model, capable of modeling the mass balance of Antarctica and Greenland into the near future. ISSM was developed with such a goal in mind, as a massively parallelized, multi-purpose finite-element framework dedicated to ice-sheet modeling.

ISSM features unstructured meshes (Tria in 2D, and Penta in 3D) along with corresponding finite elements for both types of meshes. Each finite element can carry out diagnostic, prognostic, transient, thermal 3D, surface, and bed slope simulations. Anisotropic meshing enables adaptation of meshes to a certain metric, and the 2D Shelfy-Stream, 3D Blatter/Pattyn, and 3D Full-Stokes formulations capture the bulk of the ice-flow physics. These elements can be coupled together, based on the Arlequin method, so that on a large scale model such as Antarctica, each type of finite element is used in the most efficient manner.

For each finite element referenced above, ISSM implements an adjoint. This adjoint can be used to carry out model inversions of unknown model parameters, typically ice rheology and basal drag at the ice/bedrock interface, using a metric such as the observed InSAR surface velocity. This data assimilation capability is crucial to allow spinning up of ice flow models using available satellite data.

ISSM relies on the PETSc library for its vectors, matrices, and solvers. This allows ISSM to run efficiently on any parallel platform, whether shared or distrib-

uted. It can run on the largest clusters, and is fully scalable. This allows ISSM to tackle models the size of continents.

ISSM is embedded into MATLAB and Python, both open scientific platforms. This improves its outreach within the science community. It is entirely written in C/C++, which gives it flexibility in its design, and the power/speed that C/C++ allows. ISSM is svn (subversion) hosted, on a JPL repository, to facilitate its development and maintenance.

ISSM can also model propagation of rifts using contact mechanics and mesh splitting, and can interface to the Dakota software. To carry out sensitivity analysis,
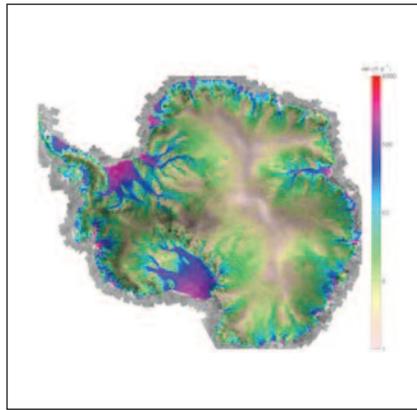


**Modeled Antarctic Surface Velocity** using ISSM.

mesh partitioning algorithms are available, based on the Scotch, Chaco, and Metis partitioners that ensure equal area mesh partitions can be done, which are then usable for sampling and local reliability methods.

*This work was done by Eric Larour and John E. Schiermeier of Caltech, and Helene Seroussi and Mathieu Morlinghem of Ecole Centrale Paris for NASA's Jet Propulsion Laboratory. For more information, see http://issm.jpl.nasa.gov/.*

*This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48164.*

---

# ✿ Automated Loads Analysis System (ATLAS)

*Lyndon B. Johnson Space Center, Houston, Texas*

ATLAS is a generalized solution that can be used for launch vehicles. ATLAS is used to produce modal transient analysis and quasi-static analysis results (i.e., accelerations, displacements, and forces) for the payload math models on a specific Shuttle Transport System (STS) flight

using the shuttle math model and associated forcing functions. This innovation solves the problem of coupling of payload math models into a shuttle math model. It performs a transient loads analysis simulating liftoff, landing, and all flight events between liftoff and landing.

ATLAS utilizes efficient and numerically stable algorithms available in MSC/NASTRAN.

*This work was done by Stephen Gardner, Scot Frere, and Patrick O'Reilly of The Boeing Company for Johnson Space Center. For further information, contact the JSC Innovation Partnerships Office at (281) 483-3809. MSC-24987-1*

---

# ✿ Integrated Main Propulsion System Performance Reconstruction Process/Models

*Lyndon B. Johnson Space Center, Houston, Texas*

The Integrated Main Propulsion System (MPS) Performance Reconstruction process provides the MPS post-flight data files needed for post-flight reporting to the project integration management and key customers to verify flight performance. This process/model was used as the baseline for the currently ongoing Space Launch System (SLS) work.

The process utilizes several methodologies, including multiple software programs, to model integrated propulsion system performance through space shuttle ascent. It is used to evaluate integrated propulsion systems, including propellant tanks, feed systems, rocket engine, and pressurization systems performance throughout ascent based on flight pressure and temperature data. The latest re-

vision incorporates new methods based on main engine power balance model updates to model higher mixture ratio operation at lower engine power levels.

*This work was done by Eduardo Lopez, Katie Elliott, Steven Snell, and Michael Evans of The Boeing Company for Johnson Space Center. For further information, contact the JSC Innovation Partnerships Office at (281) 483-3809. MSC-25066-1*

---

# 〰 Phoenix Telemetry Processor

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Phxtelemproc is a C/C++ based telemetry processing program that processes SFDU telemetry packets from the Telemetry Data System (TDS). It generates Experiment Data Records (EDRs) for several instruments includ-

ing surface stereo imager (SSI); robotic arm camera (RAC); robotic arm (RA); microscopy, electrochemistry, and conductivity analyzer (MECA); and the optical microscope (OM). It processes both uncompressed and compressed teleme-

try, and incorporates unique subroutines for the following compression algorithms: JPEG Arithmetic, JPEG Huffman, Rice, LUT3, RA, and SX4.

This program was in the critical path for the daily command cycle of the

Phoenix mission. The products generated by this program were part of the RA commanding process, as well as the SSI, RAC, OM, and MECA image and science analysis process. Its output products were used to advance science of the near polar regions of Mars, and were used to prove that water is found in abundance there.

Phxtelemproc is part of the MIPL (Multi-mission Image Processing Laboratory) system. This software produced Level 1 products used to analyze images returned by *in situ* spacecraft. It ultimately assisted in operations, planning, commanding, science, and outreach.

# Contact Graph Routing Enhancements Developed in ION for DTN

*NASA's Jet Propulsion Laboratory, Pasadena, California*

The Interplanetary Overlay Network (ION) software suite is an open-source, flight-ready implementation of networking protocols including the Delay/Disruption Tolerant Networking (DTN) Bundle Protocol (BP), the CCSDS (Consultative Committee for Space Data Systems) File Delivery Protocol (CFDP), and many others including the Contact Graph Routing (CGR) DTN routing system. While DTN offers the capability to tolerate disruption and long signal propagation delays in transmission, without an appropriate

routing protocol, no data can be delivered.

CGR was built for space exploration networks with scheduled communication opportunities (typically based on trajectories and orbits), represented as a contact graph. Since CGR uses knowledge of future connectivity, the contact graph can grow rather large, and so efficient processing is desired. These enhancements allow CGR to scale to predicted NASA space network complexities and beyond.

This software improves upon CGR by adopting an earliest-arrival-time cost metric and using the Dijkstra path selection algorithm. Moving to Dijkstra path selection also enables construction of an earliest-arrival-time tree for multicast routing. The enhancements have been rolled into ION 3.0 available on sourceforge.net.

# GFEChutes Lo-Fi

*Lyndon B. Johnson Space Center, Houston, Texas*

NASA needed to provide a software model of a parachute system for a manned re-entry vehicle. NASA has parachute codes, e.g., the Descent Simulation System (DSS), that date back to the Apollo Program. Since the space shuttle did not rely on parachutes as its primary descent control mechanism, DSS has not been maintained or incorporated into modern simulation architectures such as Osiris and Antares, which are used for new mission simulations. GFEChutes Lo-Fi is an object-oriented implementation of conventional parachute codes designed for use in modern simulation environments.

The GFE (Government Furnished Equipment), low-fidelity (Lo-Fi) parachute model (GFEChutes Lo-Fi) is a software package capable of modeling the effects of multiple parachutes, deployed concurrently and/or sequentially, on a vehicle during the subsonic phase of re-entry into planetary atmosphere. The term "low-fidelity" distinguishes models

that represent the parachutes as simple forces acting on the vehicle, as opposed to independent aerodynamic bodies. GFEChutes Lo-Fi was created from these existing models to be clean, modular, certified as NASA Class C software, and portable, or "plug and play."

The GFE Lo-Fi Chutes Model provides basic modeling capability of a sequential series of parachute activities. Actions include deploying the parachute, changing the reefing on the parachute, and cutting away the parachute. Multiple chutes can be deployed at any given time, but all chutes in that case are assumed to behave as individually isolated chutes; there is no modeling of any interactions between deployed chutes. Drag characteristics of a deployed chute are based on a coefficient of drag, the face area of the chute, and the local dynamic pressure only. The orientation of the chute is approximately modeled for purposes of obtaining torques on the vehicle, but the dy-

namic state of the chute as a separate entity is not integrated — the treatment is simply an approximation.

The innovation in GFEChutes Lo-Fi is to use an object design that closely followed the mechanical characteristics and structure of a physical system of parachutes and their deployment mechanisms. Software objects represent the components of the system, and use of an object hierarchy allows a progression from general component outlines to specific implementations. These extra chutes were not part of the baseline deceleration sequence of drogues and mains, but still had to be simulated. The major innovation in GFEChutes Lo-Fi is the software design and architecture.

# Advanced Strategic and Tactical Relay Request Management for the Mars Relay Operations Service

*NASA's Jet Propulsion Laboratory, Pasadena, California*

This software provides a new set of capabilities for the Mars Relay Operations Service (MaROS) in support of Strategic and Tactical relay, including a highly interactive relay request Web user interface, mission control over relay planning time periods, and mission management of allowed strategic vs. tactical request parameters. Together, these new capabilities expand the scope of the system to include all elements critical for Tactical relay operations.

Planning of replay activities spans a time period that is split into two distinct phases. The first phase is called Strategic, which begins at the time that relay opportunities are identified, and concludes at the point that the orbiter generates the flight sequences for onboard execution. Any relay request changes from this point on are called Tactical.

Tactical requests, otherwise called Orbiter Relay State Changes (ORSC), are highly restricted in terms of what types of changes can be made, and the types of parameters that can be changed may differ from one orbiter to the next. For example, one orbiter may be able to delay the start of a relay request, while another may not. The legacy approach to ORSC management involves exchanges of e-mail with "requests for change" and "acknowledgement of approval," with no other tracking of changes outside of e-mail folders.

MaROS Phases 1 and 2 provided the infrastructure for strategic relay for all supported missions. This new version, 3.0, introduces several capabilities that fully expand the scope of the system to include tactical relay. One new feature allows orbiter users to manage and "lock" Planning Periods, which allows the or-

biter team to formalize the changeover from Strategic to Tactical operations. Another major feature allows users to interactively submit tactical request changes via a Web user interface. A third new feature allows orbiter missions to specify allowed tactical updates, which are automatically incorporated into the tactical change process. This software update is significant in that it provides the only centralized service for tactical request management available for relay missions.

*This work was done by Daniel A. Allard, Michael N. Wallick, Roy E. Gladden, Paul Wang, and Franklin H. Hy of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.*

*This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48337.*

# Software for Generating Troposphere Corrections for InSAR Using GPS and Weather Model Data

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Atmospheric errors due to the troposphere are a limiting error source for spaceborne interferometric synthetic aperture radar (InSAR) imaging. This software generates tropospheric delay maps that can be used to correct atmospheric artifacts in InSAR data. The software automatically acquires all needed GPS (Global Positioning System), weather, and Digital Elevation Map data, and generates a tropospheric correction map using a novel algorithm for combining GPS and weather information while accounting for terrain.

Existing JPL software was prototypical in nature, required a MATLAB license, required additional steps to acquire and ingest needed GPS and weather data, and did not account for topography in interpolation. Previous software did not achieve a level of automation suitable for integration in a Web portal. This software overcomes these issues.

GPS estimates of tropospheric delay are a source of corrections that can be used to form correction maps to be applied to InSAR data, but the spacing of GPS sta-
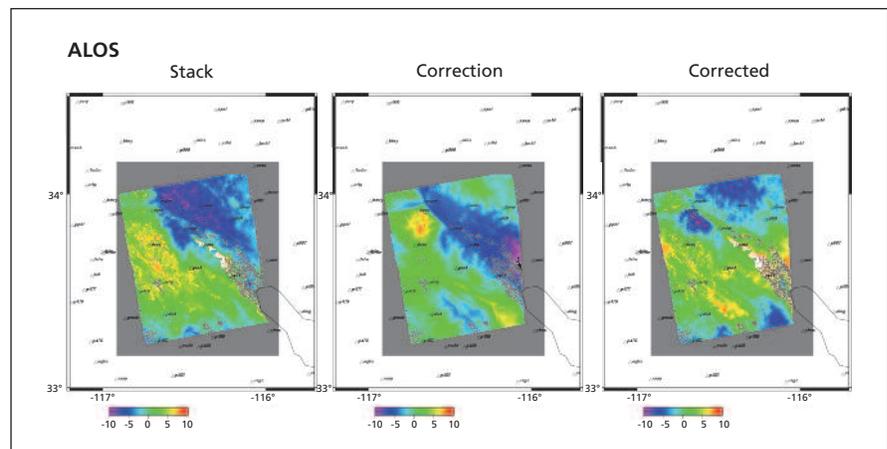


**Advanced Land Observing Satellite** (ALOS) Data. At left, the original stack of 33 interferograms. Center: The stacked correction maps, showing typical distribution of moisture in the Coachella Valley, CA. At right, the corrected stacked image.

tions is insufficient to remove short-wavelength tropospheric artifacts. This software combines interpolated GPS delay with weather model precipitable water vapor (PWV) and a digital elevation model to account for terrain, increasing the spatial resolution of the tropospheric

correction maps and thus removing short-wavelength tropospheric artifacts to a greater extent. It will be integrated into a Web portal request system, allowing use in a future L-band SAR Earth radar mission data system. This will be a significant contribution to its technology readiness,

building on existing investments in *in situ* space geodetic networks, and improving timeliness, quality, and science value of the collected data.

*This work was done by Angelyn W. Moore, Frank H. Webb, Evan F. Fishbein, Eric J. Field-ing, Susan E. Owen, and Stephanie L. Granger of Caltech; Fredrik Björndahl and Johan Löfgren of Chalmers University of Technology; and Peng Fang, James D. Means, Yehuda Bock, and Xiaopeng Tong of UC San Diego's Scripps Institution of Oceanography for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48556.*

# Ionospheric Specifications for SAR Interferometry (ISSI)

*NASA's Jet Propulsion Laboratory, Pasadena, California*

The ISSI software package is designed to image the ionosphere from space by calibrating and processing polarimetric synthetic aperture radar (PolSAR) data collected from low Earth orbit satellites. Signals transmitted and received by a PolSAR are subject to the Faraday rotation effect as they traverse the magnetized ionosphere. The ISSI algorithms combine the horizontally and vertically polarized (with respect to the radar system) SAR signals to estimate Faraday rotation and ionospheric total electron content (TEC) with spatial resolutions of sub-kilometers to kilometers, and to derive radar system calibration parameters. The ISSI software package has been designed and developed to integrate the algorithms, process PolSAR data, and image as well as visualize the ionospheric measurements.

A number of tests have been conducted using ISSI with PolSAR data collected from various latitude regions using the phase array-type L-band synthetic aperture radar (PALSAR) onboard Japan Aerospace Exploration Agency's Advanced Land Observing Satellite mission, and also with Global Positioning System data. These tests have demonstrated and validated SAR-derived ionospheric images and data correction algorithms.

*This work was done by Xiaoqing Pi, Bruce D. Chapman, Anthony Freeman, Walter Szeliga, Sean M. Buckley, Paul A. Rosen, and Marco Lavalle of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.*

*This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48351.*

# Implementation of a Wavefront-Sensing Algorithm

*Goddard Space Flight Center, Greenbelt, Maryland*

A computer program has been written as a unique implementation of an image-based wavefront-sensing algorithm reported in "Iterative-Transform Phase Retrieval Using Adaptive Diversity" (GSC-14879-1), *NASA Tech Briefs,* Vol. 31, No. 4 (April 2007), page 32. This software was originally intended for application to the James Webb Space Telescope, but is also applicable to other segmented-mirror telescopes.

The software is capable of determining optical-wavefront information using, as input, a variable number of irradiance measurements collected in defocus planes about the best focal position. The software also uses input of the geometrical definition of the telescope exit pupil (otherwise denoted the pupil mask) to identify the locations of the segments of the primary telescope mirror. From the irradiance data and mask information, the software calculates an estimate of the optical wavefront (a measure of performance) of the telescope generally and across each primary mirror segment specifically. The software is capable of generating irradiance data, wavefront estimates, and basis functions for the full telescope and for each primary-mirror segment. Optionally, each of these pieces of information can be measured or computed outside of the software and incorporated during execution of the software.

*This program was written by Jeffrey S. Smith, Bruce Dean, and David Aronstein of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15399-1*

# Sally Ride EarthKAM — Automated Image Geo-Referencing Using Google Earth Web Plug-In

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Sally Ride EarthKAM is an educational program funded by NASA that aims to provide the public the ability to picture Earth from the perspective of the International Space Station (ISS). A computer-controlled camera is mounted on the ISS in a nadir-pointing window; however, timing limitations in the system cause inaccurate positional metadata. Manually correcting images within an orbit allows the positional metadata to be improved using mathematical regressions. The manual correction process is time-consuming and thus, unfeasible for a large number of images.

The standard Google Earth program allows for the importing of KML (keyhole markup language) files that previ-

ously were created. These KML file-based overlays could then be manually manipulated as image overlays, saved, and then uploaded to the project server where they are parsed and the metadata in the database is updated. The new interface eliminates the need to save, download, open, re-save, and upload the KML files. Everything is processed on the Web, and all manipulations go directly into the database. Administrators also have the control to discard any single correction that was made and validate a correction.

This program streamlines a process that previously required several critical steps and was probably too complex for the average user to complete suc-

cessfully. The new process is theoretically simple enough for members of the public to make use of and contribute to the success of the Sally Ride EarthKAM project.

Using the Google Earth Web plug-in, EarthKAM images, and associated metadata, this software allows users to interactively manipulate an EarthKAM image overlay, and update and improve the associated metadata. The Web interface uses the Google Earth JavaScript API along with PHP-PostgreSQL to present the user the same interface capabilities without leaving the Web. The simpler graphical user interface will allow the public to participate directly and mean-

ingfully with EarthKAM. The use of similar techniques is being investigated to place ground-based observations in a Google Mars environment, allowing the MSL (Mars Science Laboratory) Science Team a means to visualize the rover and its environment.

*This work was done by Paul M. Andres of Caltech, Dennis K. Lazar of Purdue University, and Robert Q. Thames of Loyola Marymount University for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48800.*

# Trade Space Specification Tool (TSST) for Rapid Mission Architecture (Version 1.2)

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Trade Space Specification Tool (TSST) is designed to capture quickly ideas in the early spacecraft and mission architecture design and categorize them into trade space dimensions and options for later analysis. It is implemented as an Eclipse RCP Application, which can be run as a standalone program. Users rapidly create concept items with single clicks on a graphical canvas, and can organize and create linkages between the ideas using drag-and-drop actions within the same graphical view. Various views such as a trade view, rules view, and architecture view are provided to help users to visualize the trade space.

This software can identify, explore, and assess aspects of the mission trade space, as well as capture and organize

linkages/dependencies between trade space components. The tool supports a user-in-the-loop preliminary logical examination and filtering of trade space options to help identify which paths in the trade space are feasible (and preferred) and what analyses need to be done later with executable models. This tool provides multiple user views of the trade space to guide the analyst/team to facilitate interpretation and communication of the trade space components and linkages, identify gaps in combining and selecting trade space options, and guide user decision-making for which combinations of architectural options should be pursued for further evaluation.

This software provides an environment to capture mission trade space ele-

ments rapidly and assist users for their architecture analysis. This is primarily focused on mission and spacecraft architecture design, rather than general-purpose design application. In addition, it provides more flexibility to create concepts and organize the ideas. The software is developed as an Eclipse plug-in and potentially can be integrated with other Eclipse-based tools.

*This work was done by Yeou-Fang Wang, Mitchell Schrock, Chester S. Borden, and Robert C. Moeller of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48158.*

# Acoustic Emission Analysis Applet (AEAA) Software

*John H. Glenn Research Center, Cleveland, Ohio*

NASA Glenn Research and NASA White Sands Test Facility have developed software supporting an automated pressure vessel structural health monitoring (SHM) system based on acoustic emissions (AE). The software, referred to as the Acoustic Emission Analysis Applet (AEAA), provides analysts with a tool that can interrogate data collected on Digital Wave Corp. and Physical Acoustics Corp. software

using a wide spectrum of powerful filters and charts. This software can be made to work with any data once the data format is known. The applet will compute basic AE statistics, and statistics as a function of time and pressure (see figure). AEAA provides value added beyond the analysis provided by the respective vendors' analysis software. The software can handle data sets of unlimited size.

A wide variety of government and commercial applications could benefit from this technology, notably requalification and usage tests for compressed-gas and hydrogen-fueled vehicles. Future enhancements will add features similar to a "check engine" light on a vehicle. Once installed, the system will ultimately be used to alert International Space Station crewmembers to critical structural instabilities, but will have lit-

The **Front Panel** is divided into the following main sections: (1) Run-time menu; File, Options, Help; (2) AE & Fast Fourier Transform graphs; (3) AE analysis settings; and (4) AE statistics.

# Memory-Efficient Onboard Rock Segmentation

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Rockster-MER is an autonomous perception capability that was uploaded to the Mars Exploration Rover Opportunity in December 2009. This software provides the vision front end for a larger software system known as AEGIS (Autonomous Exploration for Gathering Increased Science), which was recently named 2011 NASA Software of the Year. As the first step in AEGIS, Rockster-MER analyzes an image captured by the rover, and detects and automatically identifies the boundary contours of rocks and regions of outcrop present in the scene. This initial segmentation step reduces the data volume from millions of pixels into hundreds (or fewer) of rock contours. Subsequent stages of AEGIS then prioritize the best rocks according to scientist-defined preferences and take high-resolution, follow-up observations (see figure). Rockster-MER has performed robustly from the outset on the Mars surface under challenging conditions.

Rockster-MER is a specially adapted, embedded version of the original Rockster algorithm ("Rock Segmentation Through Edge Regrouping," (NPO-44417) *Software Tech Briefs*, September 2008, p. 25). Although the new version performs the same basic task as the original code, the software has been (1) significantly upgraded to overcome the severe onboard resource limitations (CPU,
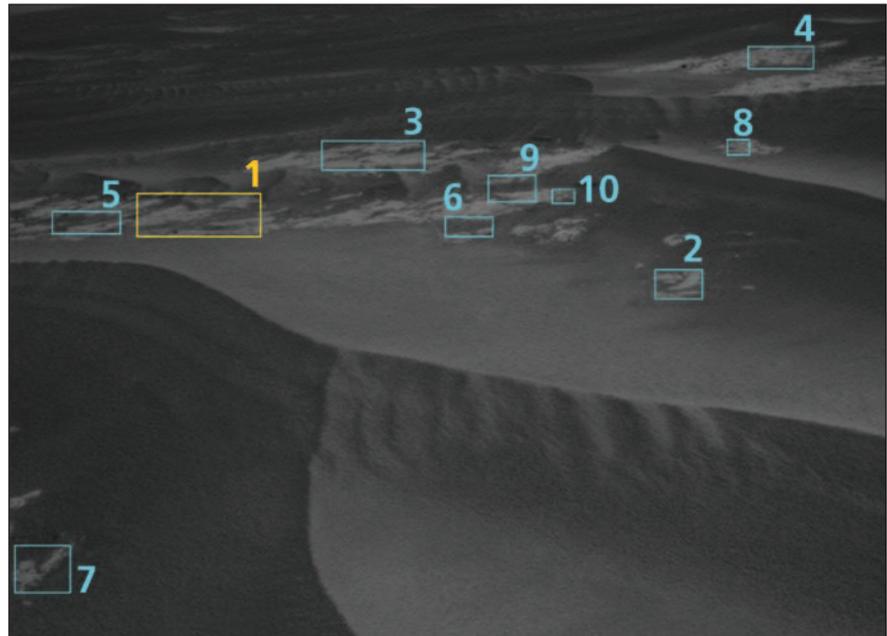


The **top ten objects** detected by Rockster-MER running onboard the Opportunity rover on Sol 2221. Note: Rockster-MER detects and segments the objects; the ranking is provided by AEGIS according to a set of scientist-specified attribute weightings.

memory, power, time) and (2) "bullet-proofed" through code reviews and extensive testing and profiling to avoid the occurrence of faults. Because of the limited computational power of the RAD6000 flight processor on Opportunity (roughly two orders of magnitude

slower than a modern workstation), the algorithm was heavily tuned to improve its speed. Several functional elements of the original algorithm were removed as a result of an extensive cost/benefit analysis conducted on a large set of archived rover images. The algorithm was also re-

quired to operate below a stringent 4MB high-water memory ceiling; hence, numerous tricks and strategies were introduced to reduce the memory footprint. Local filtering operations were re-coded to operate on horizontal data stripes across the image. Data types were reduced to smaller sizes where possible. Binary-valued intermediate results were squeezed into a more compact, one-bit-per-pixel representation through bit packing and bit manipulation macros.

An estimated 16-fold reduction in memory footprint relative to the original Rockster algorithm was achieved. The resulting memory footprint is less than four times the base image size. Also, memory allocation calls were modified to draw from a static pool and consolidated to reduce memory management overhead and fragmentation.

Rockster-MER has now been run onboard Opportunity numerous times as part of AEGIS with exceptional

performance. Sample results are available on the AEGIS website at http://aegis.jpl.nasa.gov.

# Advanced Multimission Operations System (ATMO)

*NASA's Jet Propulsion Laboratory, Pasadena, California*

The HiiHat toolbox developed for CAT/ENVI provides principal investigators direct, immediate, flexible, and seamless interaction with their instruments and data from any location. Offering segmentation and neutral region division, it facilitates the discovery of key endmembers and regions of interest larger than a single pixel.

Crucial to the analysis of hyperspectral data from Mars or Earth is the removal of unwanted atmospheric signatures. For Mars and the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM), residual atmospheric $CO_2$ absorption is both directly problematic and indicative of processing errors with implications to the scientific utility of any particular image region. Estimating this residual error becomes key both in selecting regions of low distortion, and also to select mitigating methods, such as neutral region division. This innovation, the ATMO estimator, provides a simple, 0-1 normalized scalar that estimates this distortion (see figure). The metric is defined as the coefficient of determination of a quadratic fit in the region of distorting atmospheric absorption ($\approx 2$ µm). This mimics the behavior of existing CRISM
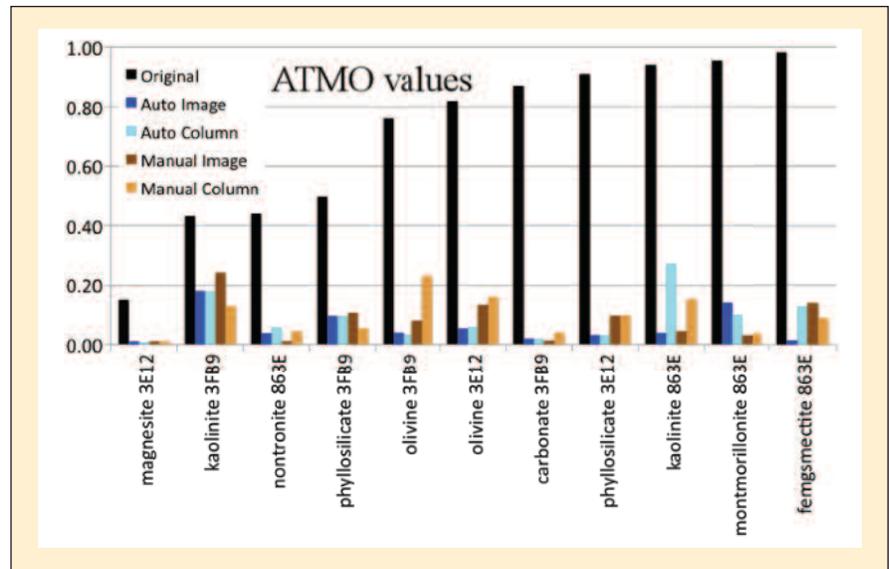


**Automatic Method** matches manual for atmospheric correction.

team mineralogical indices to estimate the presence of known, interesting mineral signatures. This facilitates the ATMO metric's assimilation into existing planetary geology workflows.

# Robot Sequencing and Visualization Program (RSVP)

*NASA's Jet Propulsion Laboratory, Pasadena, California*

The Robot Sequencing and Visualization Program (RSVP) is being used in the Mars Science Laboratory (MSL) mission for downlink data visualization and command sequence generation. RSVP reads and writes downlink data products from the operations data server (ODS)

and writes uplink data products to the ODS. The primary users of RSVP are members of the Rover Planner team (part of the Integrated Planning and Execution Team (IPE)), who use it to perform traversability/articulation analyses, take activity plan input from the Science

and Mission Planning teams, and create a set of rover sequences to be sent to the rover every sol (see figure).

The primary inputs to RSVP are downlink data products and activity plans in the ODS database. The primary outputs are command sequences to be placed in
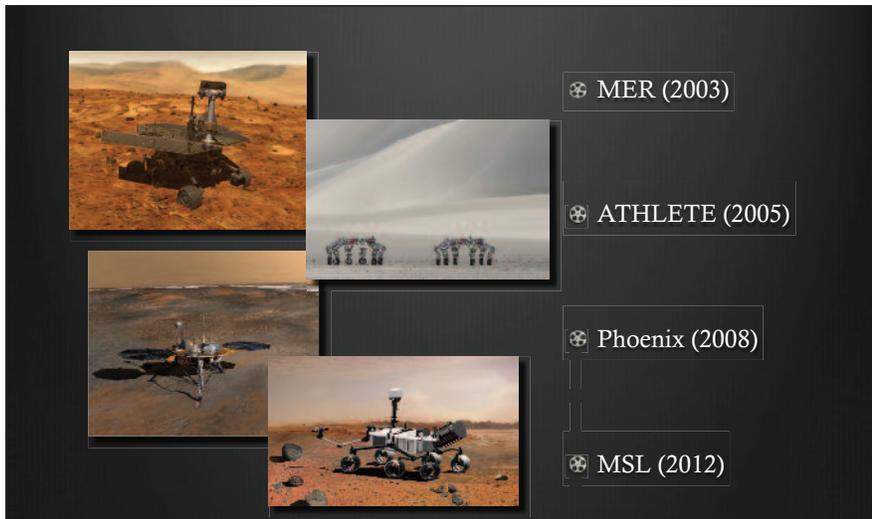
**Missions** using RSVP.

the ODS for further processing prior to uplink to each rover. RSVP is composed of two main subsystems. The first, called the Robot Sequence Editor (RoSE), understands the MSL activity and command dictionaries and takes care of converting incoming activity level inputs into command sequences. The Rover Planners use the RoSE component of RSVP to put together command sequences and to view and manage command level resources like time, power, temperature, etc. (via a transparent real-time connection to SEQGEN).

The second component of RSVP is called HyperDrive, a set of high-fidelity computer graphics displays of the Martian surface in 3D and in stereo. The Rover Planners can explore the environment around the rover, create commands related to motion of all kinds, and see the simulated result of those commands via its underlying tight coupling with flight navigation, motor, and arm software. This software is the evolutionary replacement for the Rover Sequencing and Visualization software used to create command sequences (and visualize the Martian surface) for the Mars Exploration Rover mission.

*This work was done by Brian K. Cooper, Scott A. Maxwell, Frank R. Hartman, John R. Wright, Jeng Yen, Nicholas T. Toole, and Zareh Gorjian of Caltech; and Jack C. Morrison of Northrop Grumman for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48690.*

# Automating Hyperspectral Data for Rapid Response in Volcanic Emergencies

*NASA's Jet Propulsion Laboratory, Pasadena, California*

In a volcanic emergency, time is of the essence. It is vital to quantify eruption parameters (thermal emission, effusion rate, location of activity) and distribute this information as quickly as possible to decision-makers in order to enable effective evaluation of eruption-related risk and hazard. The goal of this work was to automate and streamline processing of spacecraft hyperspectral data, automate product generation, and automate distribution of products.

The software rapidly processes hyperspectral data, correcting for incident sunlight where necessary, and atmospheric transmission; detects thermally anomalous pixels; fits data with model black-body thermal emission spectra to determine radiant flux; calculates atmospheric convection thermal removal; and then calculates total heat loss. From these results, an estimation of effusion rate is made. Maps are generated of thermal emission and location (see figure). Products are posted online, and relevant parties notified. Effusion rate data are added to historical record and



2 May 2010 – VIS          2 May 2010 – SWIR          4 May 2010 - SWIR
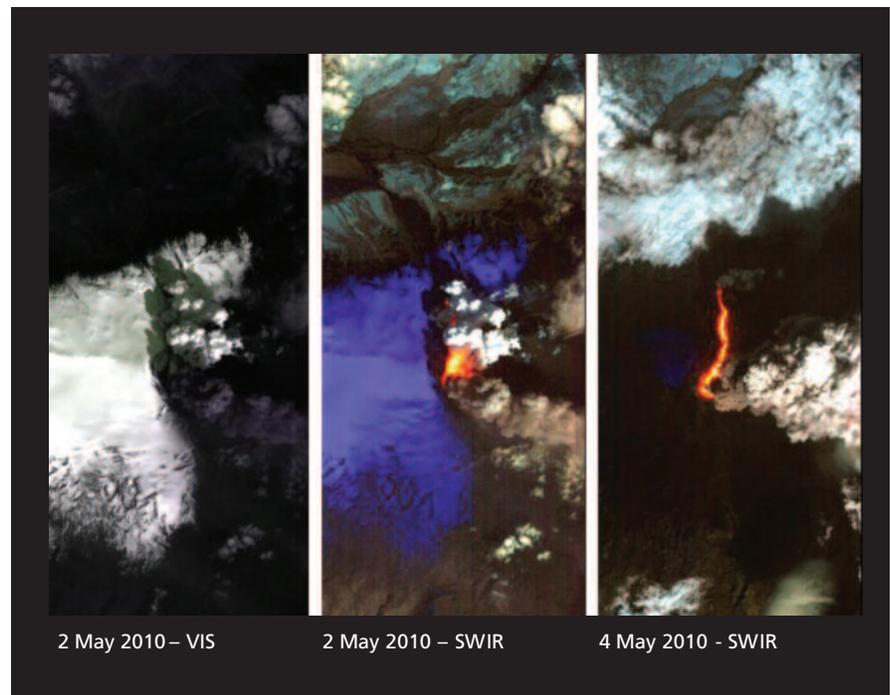
**Visible and Short-Wave Infrared Images** of volcanic eruption in Iceland in May 2010.

plotted to identify spikes in activity for persistently active eruptions. The entire process from start to end is autonomous.

Future spacecraft, especially those in deep space, can react to detection of transient processes without the need to communicate with Earth, thus increasing science return. Terrestrially, this removes the need for human intervention.

*This work was done by Ashley G. Davies, Joshua R. Doubleday, and Steve A. Chien of Caltech for NASA's Jet Propulsion Lab-*

*oratory. Further information is contained in a TSP (see page 1).*

*This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48123.*

# Raster-Based Approach to Solar Pressure Modeling
## Combinations of simple geometry yield answers to complex light pressure problems.

*John H. Glenn Research Center, Cleveland, Ohio*

An algorithm has been developed to take advantage of the graphics processing hardware in modern computers to efficiently compute high-fidelity solar pressure forces and torques on spacecraft, taking into account the possibility of self-shading due to the articulation of spacecraft components such as solar arrays. The process is easily extended to compute other results that depend on three-dimensional attitude analysis, such as solar array power generation or free molecular flow drag.

The impact of photons upon a spacecraft introduces small forces and moments. The magnitude and direction of the forces depend on the material properties of the spacecraft components being illuminated. The parts of the components being lit depends on the orientation of the craft with respect to the Sun, as well as the gimbal angles for any significant moving external parts (solar arrays, typically). Some components may shield others from the Sun.

The purpose of this innovation is to enable high-fidelity computation of solar pressure and power generation effects of illuminated portions of spacecraft, taking self-shading from spacecraft attitude and movable components into account. The key idea in this innovation is to compute results dependent upon complicated geometry by using an image to break the problem into thousands or millions of sub-problems with simple geometry, and then the results from the simpler problems are combined to give high-fidelity results for the full geometry.

This process is performed by constructing a 3D model of a spacecraft using an appropriate computer language (OpenGL), and running that model on a modern computer's 3D accelerated video processor. This quickly and accurately

a

b
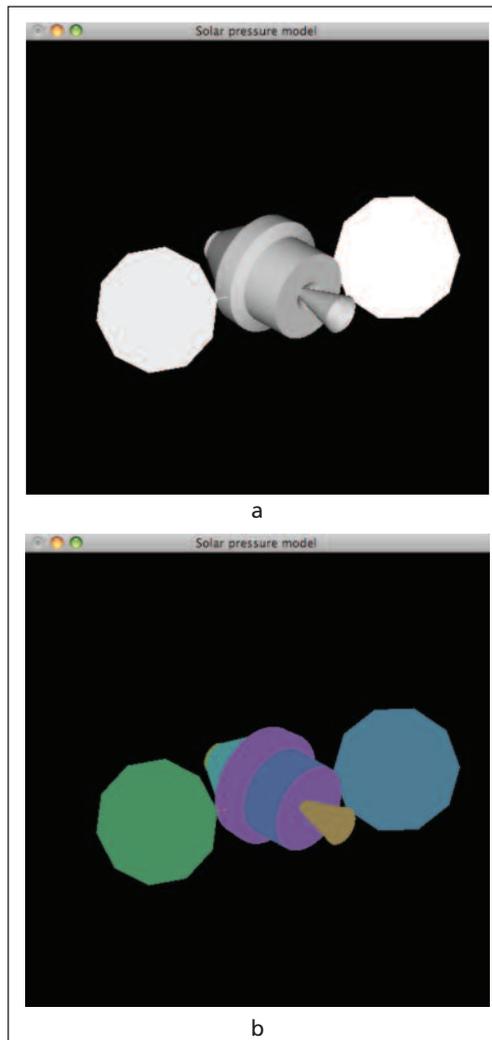
A typical view (a) of the **Crew Exploration Vehicle** (CEV) with the solar array gimbals optimized to point the arrays in the Sun direction, and (b) a view of the CEV with surfaces color-coded to help identify spacecraft material properties.

generates a view of the model (as shown on a computer screen) that takes rotation and articulation of spacecraft components into account. When this view is interpreted as the spacecraft as seen by the Sun, then only the portions of the craft visible in the view are illuminated.

The view as shown on the computer screen is composed of up to millions of pixels. Each of those pixels is associated with a small illuminated area of the spacecraft. For each pixel, it is possible to compute its position, angle (surface normal) from the view direction, and the spacecraft material (and therefore, optical coefficients) associated with that area. With this information, the area associated with each pixel can be modeled as a simple flat plate for calculating solar pressure. The vector sum of these individual flat plate models is a high-fidelity approximation of the solar pressure forces and torques on the whole vehicle.

In addition to using optical coefficients associated with each spacecraft material to calculate solar pressure, a power generation coefficient is added for computing solar array power generation from the sum of the illuminated areas. Similarly, other area-based calculations, such as free molecular flow drag, are also enabled.

Because the model rendering is separated from other calculations, it is relatively easy to add a new model to explore a new vehicle or mission configuration. Adding a new model is performed by adding OpenGL code, but a future version might read a mesh file exported from a computer-aided design (CAD) system to enable very rapid turnaround for new designs

# Space Images for NASA JPL Android Version

*NASA's Jet Propulsion Laboratory, Pasadena, California*

This software addresses the demand for easily accessible NASA JPL images and videos by providing a user friendly and simple graphical user interface that can be run via the Android platform from any location where Internet connection is available. This app is complementary to the iPhone version of the application. A backend infrastructure stores, tracks, and retrieves space images from the JPL Photojournal and Institutional Communications Web server, and
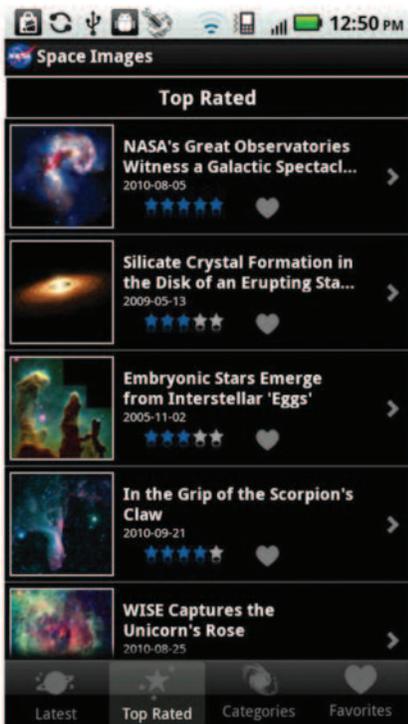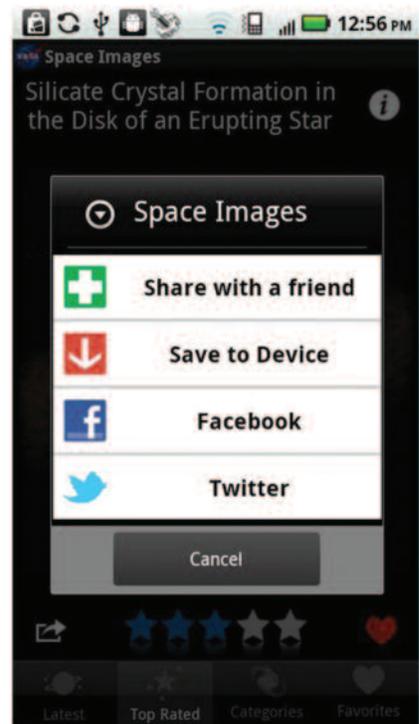


**Sample Screen Shots of the Space Images Android Application**: The feature graphic (a) is displayed on Google Play Android Market. The title and image thumbnails (b) are scrollable lists. When clicked, it will show the images in detail, as well as a caption describing the image (c). The user can rate the images by giving a star rating from 1 to 5. In addition, there is an option to share the image by e-mail, Facebook/Twitter, or save it to the user's Android device (d).

catalogs the information into a streamlined rating infrastructure.

This system consists of four distinguishing components: image repository, database, server-side logic, and Android mobile application. The image repository contains images from various JPL flight projects. The database stores the image information as well as the user rating. The server-side logic retrieves the image information from the database and categorizes each image for display. The Android mobile application is an interfacing delivery system that retrieves the image information from the server for each Android mobile device user. Also created is a reporting and tracking system for charting and monitoring usage.

Unlike other Android mobile image applications, this system uses the latest emerging technologies to produce image listings based directly on user input. This allows for countless combinations of images returned. The backend infrastructure uses industry-standard coding and database methods, enabling future software improvement and technology updates. The flexibility of the system design framework permits multiple levels of display possibilities and provides integration capabilities. Unique features of the software include image/video retrieval from a selected set of categories, image Web links that can be shared among e-mail users, sharing to Facebook/Twitter, marking as user's favorites, and image metadata searchable for instant results.

# ⟩ Kinect Engineering with Learning (KEWL)

*Lyndon B. Johnson Space Center, Houston, Texas*

According to a Nielsen survey at the time of this reporting, 41% of all households have a game console. This is one market in which NASA has been absent from education and outreach efforts. Kinect Engineering with Learning (KEWL) is made to enter into that market and bring NASA education and outreach to a very familiar venue. KEWL creates an education and outreach experience that is more participatory, both in a school and museum environment.

KEWL is a set of applications that runs on an Xbox 360 (see Figure 1) using the Kinect controller used for education and outreach. These applications currently include: Train R2 (see Figure 2), a visual simulation of Robonaut 2 that allows students to control a virtual R2 in a game environment; Drive R2, an interface using the Xbox 360 and Kinect controller that allows students to control the real R2 using the methods they learned playing Train R2; ISS experience, a visual tour of the interior of the International Space Station where students use their body to fly through the virtual ISS; Gravity Ball, a simulation of throwing balls in the gravity of different planets; Solar Array repair, a simulation of the simplified STS-121 solar array repair mission; and PlaySpace, a Mars/Moon application that allows students to experience different aspects of Mars/Moon.

Users can "fly through" the ISS using their body, allowing an experience similar to what an astronaut would have on orbit. In PlaySpace, users can fly over the surface of Mars and view surface data obtained by Mars rovers. Users of Train R2



Figure 1. The **Xbox 360** is one of the most recognized gamng consoles.



Figure 2. In **Train R2**, the student learns to control a simulated R2 using simple poses.

and Drive R2 can experience what it is like to control a robot over a distance with a time delay, simulating the time delay that would occur between ground control and an on-orbit robot. The initial ISS experiences were built using parts of code from the NASA Enigma software. The models used in these experiences were also from the Integrated Graphics Operations and Analysis Lab model database. The PlaySpace experience incorporates surface data obtained from NASA rovers and satellites and was built by NASA JPL.

*This work was done by Sharon Goza and David Shores of Johnson Space Center;*

# Spacecraft 3D Augmented Reality Mobile App

*NASA's Jet Propulsion Laboratory, Pasadena, California*

The Spacecraft 3D application allows users to learn about and interact with iconic NASA missions in a new and immersive way using common mobile devices (see figure). Using Augmented Reality (AR) techniques to project 3D renditions of the mission spacecraft into real-world surroundings, users can interact with and learn about Curiosity, GRAIL, Cassini, and Voyager. Additional updates on future missions, animations, and information will be ongoing.

Using a printed AR Target and camera on a mobile device, users can get up close with these robotic explorers, see how some move, and learn about these engineering feats, which are used to expand knowledge and understanding about space.

The software receives input from the mobile device's camera to recognize the presence of an AR marker in the camera's field of view. It then displays a 3D rendition of the selected spacecraft



**Spacecraft 3D Application** allows one to interact and learn about different missions.

in the user's physical surroundings, on the mobile device's screen, while it tracks the device's movement in relation to the physical position of the spacecraft's 3D image on the AR marker.

# MPST Software: grl_pef_check

*NASA's Jet Propulsion Laboratory, Pasadena, California*

This innovation is a tool used to verify and validate spacecraft sequences at the predicted events file (PEF) level for the GRAIL (Gravity Recovery and Interior Laboratory, see http://www.nasa.gov/mission_pages/grail/main/index.html) mission as part of the Multi-Mission Planning and Sequencing Team (MPST) operations process to reduce the possibility for errors. This tool is used to catch any sequence related errors or issues immediately after the seqgen modeling to streamline downstream processes.

This script verifies and validates the seqgen modeling for the GRAIL MPST

process. A PEF is provided as input, and dozens of checks are performed on it to verify and validate the command products including command content, command ordering, flight-rule violations, modeling boundary consistency, resource limits, and ground commanding consistency. By performing as many checks as early in the process as possible, grl_pef_check streamlines the MPST task of generating GRAIL command and modeled products on an aggressive schedule.

By enumerating each check being performed, and clearly stating the criteria and assumptions made at each step,

grl_pef_check can be used as a manual checklist as well as an automated tool. This helper script was written with a focus on enabling the user with the information they need in order to evaluate a sequence quickly and efficiently, while still keeping them informed and active in the overall sequencing process. grl_pef_check verifies and validates the modeling and sequence content prior to investing any more effort into the build. There are dozens of various items in the modeling run that need to be checked, which is a time-consuming and error-prone task. Currently, no software exists that provides this functionality. Com-

pared to a manual process, this script reduces human error and saves considerable man-hours by automating and streamlining the mission planning and sequencing task for the GRAIL mission.

# Real-Time Multimission Event Notification System for Mars Relay

*NASA's Jet Propulsion Laboratory, Pasadena, California*

As the Mars Relay Network is in constant flux (missions and teams going through their daily workflow), it is imperative that users are aware of such state changes. For example, a change by an orbiter team can affect operations on a lander team. This software provides an ambient view of the real-time status of the Mars network.

The Mars Relay Operations Service (MaROS) comprises a number of tools to coordinate, plan, and visualize various aspects of the Mars Relay Network. As part of MaROS, a feature set was developed that operates on several levels of the software architecture. These levels include a Web-based user interface, a back-end "ReSTlet" built in Java, and databases that store the data as it is received from the network. The result is a real-time event notification and management system, so mission teams can track and act upon events on a moment-by-moment basis.

This software retrieves events from MaROS and displays them to the end user. Updates happen in real time, i.e., messages are pushed to the user while logged into the system, and queued when the user is not online for later viewing. The software does not do away with the e-mail notifications, but augments them with in-line notifications. Further, this software expands the events that can generate a notification, and allows user-generated notifications.

Existing software sends a smaller subset of mission-generated notifications via email. A common complaint of users was that the system-generated e-mails often "get lost" with other e-mail that comes in. This software allows for an expanded set (including user-generated) of notifications displayed in-line of the program. By separating notifications, this can improve a user's workflow.

# SIM_EXPLORE: Software for Directed Exploration of Complex Systems

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Physics-based numerical simulation codes are widely used in science and engineering to model complex systems that would be infeasible to study otherwise. While such codes may provide the highest-fidelity representation of system behavior, they are often so slow to run that insight into the system is limited. Trying to understand the effects of inputs on outputs by conducting an exhaustive grid-based sweep over the input parameter space is simply too time-consuming. An alternative approach called "directed exploration" (see figure) has been developed to harvest information from numerical simulators more efficiently. The basic idea is to employ active learning and supervised machine learning to choose cleverly at each step which simulation trials to run next based on the results of previous trials.

SIM_EXPLORE is a new computer program that uses directed exploration to explore efficiently complex systems
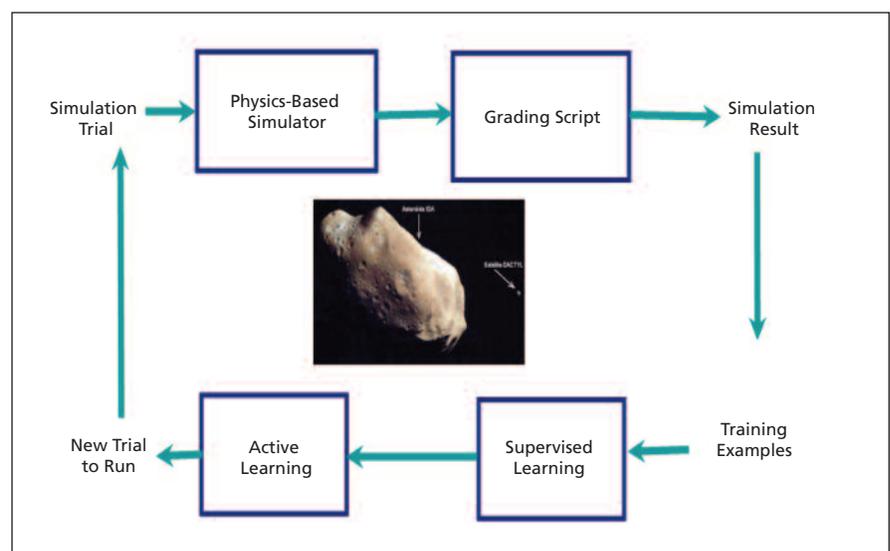


Illustration of the **Directed Exploration** approach in an asteroid collision application. The central image shows the Ida-Dactyl asteroid pair observed serendipitously by the Galileo spacecraft. Planetary scientists are interested in understanding how such systems form and more generally in how asteroid families form. Physics-based numerical simulations offer a means to gain insight into such systems; however, the simulations are so slow to run that a *directed exploration* strategy is required.

represented by numerical simulations. The software sequentially identifies and runs simulation trials that it believes will be most informative given the results of previous trials. The results of new trials are incorporated into the software's model of the system behavior. The updated model is then used to pick the next round of new trials. This process, implemented as a closed-loop system wrapped around existing simulation code, provides a means to improve the speed and efficiency with which a set of simulations can yield scientifically useful results.

The software focuses on the case in which the feedback from the simulation trials is binary-valued, i.e., the learner is only informed of the success or failure of the simulation trial to produce a desired output. The software offers a number of choices for the supervised learning algorithm (the method used to model the system behavior given the results so far) and a number of choices for the active learning strategy (the method used to choose which new simulation trials to run given the current behavior model). The software also makes use of the LEGION distributed computing

framework to leverage the power of a set of compute nodes. The approach has been demonstrated on a planetary science application in which numerical simulations are used to study the formation of asteroid families.

*This work was done by Michael Burl and Esther Wang of Caltech, and Brian Enke and William J. Merline of SWRI for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-47919.*

# Mobile Timekeeping Application Built on Reverse-Engineered JPL Infrastructure

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Every year, non-exempt employees cumulatively waste over one man-year tracking their time and using the timekeeping Web page to save those times. This app eliminates this waste.

The innovation is a native iPhone app. Libraries were built around a reverse-engineered JPL API. It represents a punch-in/punch-out paradigm for timekeeping. It is accessible

natively via iPhones, and features ease of access.

Any non-exempt employee can natively punch in and out, as well as save and view their JPL timecard. This app is built on custom libraries created by reverse-engineering the standard timekeeping application. Communication is through custom libraries that re-route traffic through BrowserRAS (remote access service).

This has value at any center where employees track their time.

*This work was done by Robert J. Witoff of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.*

*This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48449.*

# Advanced Query and Data Mining Capabilities for MaROS

*NASA's Jet Propulsion Laboratory, Pasadena, California*

The Mars Relay Operational Service (MaROS) comprises a number of tools to coordinate, plan, and visualize various aspects of the Mars Relay network. These levels include a Web-based user interface, a back-end "ReSTlet" built in Java, and databases that store the data as it is received from the network. As part of MaROS, the innovators have developed and implemented a feature set that operates on several levels of the software architecture.

This new feature is an advanced querying capability through either the Web-based user interface, or through a back-end REST interface to access all of the data gathered from the network. This software is not meant to replace the REST interface, but to augment and expand the range of available data. The current REST interface provides specific data that is

used by the MaROS Web application to display and visualize the information; however, the returned information from the REST interface has typically been pre-processed to return only a subset of the entire information within the repository, particularly only the information that is of interest to the GUI (graphical user interface). The new, advanced query and data mining capabilities allow users to retrieve the raw data and/or to perform their own data processing. The query language used to access the repository is a restricted subset of the structured query language (SQL) that can be built safely from the Web user interface, or entered as freeform SQL by a user. The results are returned in a CSV (Comma Separated Values) format for easy exporting to third-party tools and applications that can

be used for data mining or user-defined visualization and interpretation. This is the first time that a service is capable of providing access to all cross-project relay data from a single Web resource.

Because MaROS contains the data for a variety of missions from the Mars network, which span both NASA and ESA, the software also establishes an access control list (ACL) on each data record in the database repository to enforce user access permissions through a multi-layered approach.

*This work was done by Paul Wang, Michael N. Wallick, Daniel A. Allard, Roy E. Gladden, and Franklin H. Hy of Caltech for NASA's Jet Propulsion Laboratory.*

*This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. NPO-48575*

# Jettison Engineering Trajectory Tool

*Lyndon B. Johnson Space Center, Houston, Texas*

The Jettison Engineering Trajectory Tool (JETT) performs the jettison analysis function for any orbiting asset. It provides a method to compute the relative trajectories between an orbiting asset and any jettisoned item (intentional or unintentional) or sublimating particles generated by fluid dumps to assess whether an object is safe to jettison, or if there is a risk with an item that was inadvertently lost overboard. The main concern is the interaction and possible recontact of the jettisoned object with an asset. This supports the analysis that jettisoned items will safely clear the vehicle, ensuring no collisions.

The software will reduce the jettison analysis task from one that could take days to complete to one that can be completed in hours, with an analysis that is more comprehensive than the previous method. It provides the ability to define the jettison operation relative to International Space Station (ISS) structure, and provides 2D and 3D plotting capability to allow an analyst to perform a subjective clearance assessment with ISS structures.

The developers followed the SMP to create the code and all supporting documentation. The code makes extensive use of the object-oriented format of Java and, in addition, the Model-View-Controller architecture was used in the organization of the code, allowing each piece to be independent of updates to the other pieces. The model category is for maintaining data entered by the user and generated by the analysis. The view category provides capabilities for data entry and displaying all or a portion of the analysis data in tabular, 2D, and 3D representation. The controller category allows for handling events that affect the model or view(s). The JETT utilizes orbital mechanics with complex algorithms. Since JETT is written in JAVA, it is essentially platform-independent.

*This work was done by Mariusz Zaczek of Johnson Space Center; and Patrick Walter, Joseph Pascucci, Phyllis Armstrong, Patricia Hallbick, Randal Morgan, and James Cooney of the United Space Alliance. Further information is contained in a TSP (see page 1). MSC-25271-1*

# MPST Software: grl_suppdoc

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Due to the nature of the GRAIL mission, the GRAIL Mission Planning and Sequence Team (MPST) is required to generate ground and uplink products faster than ever done before. The existing correct_transmitter_min_dur tool that provides a similar function to grl_suppdoc lacks the ability to operate accurately or quickly enough to support the rapid turnaround required of the GRAIL MPST.

The GRAIL MPST was required to build this new tool to facilitate the ground and uplink generation processes to meet a tight sequence development timeline.

The grl_suppdoc tool enables the GRAIL MPST to generate automatically Deep Space Network (DSN) transmitter suppressions based on short uplinks that are found in the ground/modeled Predicted Events File (PEF).

The grl_suppdoc script automatically generates applicable DSN uplink suppressions in the form of a Spacecraft Activity Sequence File (SASF) to protect the GRAIL project from short DSN uplink windows, which can be cause for operator error at the DSN antennas. Currently, no software exists that provides this functionality at the efficiency required for GRAIL sequence team operations. Compared to a manual process, this script reduces human error and saves considerable man-hours by automating and streamlining the mission planning and sequencing task for the GRAIL mission.

*This work was done by Jared A. Call and John H. Kwok of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.*

*This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48659.*

# PredGuid+A: Orion Entry Guidance Modified for Aerocapture

*Lyndon B. Johnson Space Center, Houston, Texas*

PredGuid+A software was developed to enable a unique numerical predictor-corrector aerocapture guidance capability that builds on heritage Orion entry guidance algorithms. The software can be used for both planetary entry and aerocapture applications. Furthermore, PredGuid+A implements a new Delta-V minimization guidance option that can take the place of traditional targeting guidance and can result in substantial propellant savings.

PredGuid+A allows the user to set a mode flag and input a target orbit's apoapsis and periapsis. Using bank angle control, the guidance will then guide the vehicle to the appropriate post-aerocapture orbit using one of two algorithms: Apoapsis Targeting or Delta-V Minimization (as chosen by the user).

Recently, the PredGuid guidance algorithm was adapted for use in skip-entry scenarios for NASA's Orion multi-purpose crew vehicle (MPCV). To leverage flight heritage, most of Orion's entry guidance routines are adapted from the Apollo program.

*This work was done by Jarret Lafleur of Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-25199-1*

## Planning Coverage Campaigns for Mission Design and Analysis: CLASP for DESDynl

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Mission design and analysis presents challenges in that almost all variables are in constant flux, yet the goal is to achieve an acceptable level of performance against a concept of operations, which might also be in flux. To increase responsiveness, automated planning tools are used that allow for the continual modification of spacecraft, ground system, staffing, and concept of operations, while returning metrics that are important to mission evaluation, such as area covered, peak memory usage, and peak data throughput. This approach was applied to the DESDynl mission design using the CLASP planning system, but since this adaptation, many techniques have changed under the hood for CLASP, and the DESDynl mission concept has undergone drastic changes.

The software produces mission evaluation products, such as memory high-water marks, coverage percentages, given a mission design in the form of coverage targets, concept of operations, spacecraft parameters, and orbital parameters. It tries to overcome the lack of fidelity and timeliness of mission requirements coverage analysis during mission design.

Previous techniques primarily use Excel in ad hoc fashion to approximate key factors in mission performance, often falling victim to overgeneralizations necessary in such an adaptation. The new program allows designers to faithfully represent their mission designs quickly, and get more accurate results just as quickly.

*This work was done by Russell L. Knight, David A. McLaren, and Steven Hu of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.*

*This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48598.*

## Space Place Prime

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Space Place Prime is public engagement and education software for use on iPad. It targets a multi-generational audience with news, images, videos, and educational articles from the Space Place Web site and other NASA sources.

New content is downloaded daily (or whenever the user accesses the app) via the wireless connection. In addition to the Space Place Web site, several NASA RSS feeds are tapped to provide new content. Content is retained for the previous several days, or some number of editions of each feed. All content is controlled on the server side, so features about the latest news, or changes to any content, can be made without updating the app in the Apple Store. It gathers many popular NASA features into one app.

The interface is a boundless, slidable-in-any-direction grid of images, unique for each feature, and iconized as image, video, or article. A tap opens the feature. An alternate list mode presents menus of images, videos, and articles separately. Favorites can be tagged for permanent archive. Facebook, Twitter, and e-mail connections make any feature shareable.

*This work was done by Austin J. Fitzpatrick, Alexander Novati, Diane K. Fisher, and Nancy J. Leon of Caltech, and Ruth Netting of NASA HQ for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.*

*This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48754.*

National Aeronautics and
Space Administration