



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

Indrani Graczyk
(818) 354-2241
indrani.graczyk@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



TECH BRIEFS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION



5 Technology Focus: Sensors

- 5 Single-Photon-Sensitive HgCdTe Avalanche Photodiode Detector
- 5 Surface-Enhanced Raman Scattering Using Silica Whispering-Gallery Mode Resonators
- 6 3D Hail Size Distribution Interpolation/Extrapolation Algorithm
- 6 Color-Changing Sensors for Detecting the Presence of Hypergolic Fuels
- 7 Artificial Intelligence Software for Assessing Postural Stability



9 Materials & Coatings

- 9 Transformers: Shape-Changing Space Systems Built With Robotic Textiles
- 9 Fibrillar Adhesive for Climbing Robots
- 10 Using Pre-Melted Phase Change Material to Keep Payloads in Space Warm for Hours Without Power



11 Manufacturing & Prototyping

- 11 Development of a Centrifugal Technique for the Microbial Bioburden Analysis of Freon (CFC-11)
- 11 Microwave Sinterator Freeform Additive Construction System (MS-FACS)



13 Electronics/Computers

- 13 DSP/FPGA Design for a High-Speed Programmable S-Band Space Transceiver
- 13 On-Chip Power-Combining for High-Power Schottky Diode-Based Frequency Multipliers
- 14 FPGA Vision Data Architecture
- 15 Memory Circuit Fault Simulator



17 Mechanics/Machinery

- 17 Ultra-Compact Transputer-Based Controller for High-Level, Multi-Axis Coordination
- 17 Regolith Advanced Surface Systems Operations Robot Excavator
- 18 Magnetically Actuated Seal
- 18 Hybrid Electrostatic/Flextensional Mirror for Lightweight, Large-Aperture, and Cryogenic Space Telescopes



21 Software

- 21 System for Contributing and Discovering Derived Mission and Science Data
- 21 Remote Viewer for Maritime Robotics Software Stackfile Database
- 21 Reachability Maps for *In Situ* Operations
- 22 JPL Space Telecommunications Radio System Operating Environment

- 22 RFI-SIM: RFI Simulation Package
- 22 ION Configuration Editor
- 22 Dtest Testing Software
- 23 IMPaCT — Integration of Missions, Programs, and Core Technologies
- 23 Integrated Systems Health Management (ISHM) Toolkit



25 Physical Sciences

- 25 Wind-Driven Wireless Networked System of Mobile Sensors for Mars Exploration
- 26 *In Situ* Solid Particle Generator
- 27 Analysis of the Effects of Streamwise Lift Distribution on Sonic Boom Signature
- 27 Rad-Tolerant, Thermally Stable, High-Speed Fiber-Optic Network for Harsh Environments
- 28 Towed Subsurface Optical Communications Buoy
- 28 High-Collection-Efficiency Fluorescence Detection Cell
- 29 Ultra-Compact, Superconducting Spectrometer-on-a-Chip at Submillimeter Wavelengths
- 29 UV Resonant Raman Spectrometer With Multi-Line Laser Excitation



31 Bio-Medical

- 31 Medicine Delivery Device With Integrated Sterilization and Detection



33 Information Technology

- 33 Ionospheric Simulation System for Satellite Observations and Global Assimilative Model Experiments — ISOGAME
- 33 Airborne Tomographic Swath Ice Sounding Processing System
- 34 flexplan: Mission Planning System for the Lunar Reconnaissance Orbiter
- 35 Estimating Torque Imparted on Spacecraft Using Telemetry
- 35 PowderSim: Lagrangian Discrete and Mesh-Free Continuum Simulation Code for Cohesive Soils
- 36 Multiple-Frame Detection of Subpixel Targets in Thermal Image Sequences
- 36 Metric Learning to Enhance Hyperspectral Image Segmentation
- 37 Basic Operational Robotics Instructional System



39 Books & Reports

- 39 Sheet Membrane Spacesuit Water Membrane Evaporator
- 39 Advanced Materials and Manufacturing for Low-Cost, High-Performance Liquid Rocket Combustion Chambers
- 39 Motor Qualification for Long-Duration Mars Missions

This document was prepared under the sponsorship of the National Aeronautics and Space Administration. Neither the United States Government nor any person acting on behalf of the United States Government assumes any liability resulting from the use of the information contained in this document, or warrants that such use will be free from privately owned rights.



Single-Photon-Sensitive HgCdTe Avalanche Photodiode Detector Detector provides extra dimension to lidar scene data for multi-photon returns.

Goddard Space Flight Center, Greenbelt, Maryland

The purpose of this program was to develop single-photon-sensitive short-wavelength infrared (SWIR) and mid-wavelength infrared (MWIR) avalanche photodiode (APD) receivers based on linear-mode HgCdTe APDs, for application by NASA in light detection and ranging (lidar) sensors. Linear-mode photon-counting APDs are desired for lidar because they have a shorter pixel dead time than Geiger APDs, and can detect sequential pulse returns from multiple objects that are closely spaced in range. Linear-mode APDs can also measure photon number, which Geiger APDs cannot, adding an extra dimension to lidar scene data for multi-photon returns. High-gain APDs with low multiplication noise are required for efficient linear-mode detection of single photons because of APD gain statistics — a low-excess-noise APD will generate detectable current pulses from single photon input at a much higher rate of occurrence than will a noisy APD operated at the same average gain. MWIR and LWIR electron-avalanche HgCdTe APDs have been shown to operate in linear mode at high average

avalanche gain ($M > 1000$) without excess multiplication noise ($F = 1$), and are therefore very good candidates for linear-mode photon counting. However, detectors fashioned from these narrow-bandgap alloys require aggressive cooling to control thermal dark current. Wider-bandgap SWIR HgCdTe APDs were investigated in this program as a strategy to reduce detector cooling requirements.

The first objective was to build SWIR HgCdTe APDs, and to assess their suitability for photon counting in linear mode. The second objective was to implement manufacturing improvements to mitigate surface dark current, improve reliability, and eliminate peaking in the spectral response.

Voxtel manufactured and characterized 2.7- μm -cutoff HgCdTe APDs, publishing excess noise data taken at the highest avalanche gain levels yet demonstrated for SWIR HgCdTe APDs ($M = 80$). Quantum efficiency was limited to approximately 73% at 1,550 nm by partial reflection from the non-coated optical entrance surface; quantum efficiency near 94% is expected for these devices if

an anti-reflection coating is used. Excellent yield of operable APD pixels and uniformity of APD response were both obtained, but the maximum avalanche gain that could be achieved with SWIR-cutoff material was deemed too low to enable single-photon detection. Comparison of Voxtel's maximum gain measurements suggests that this is an inherent material limitation of the SWIR alloy. Room-temperature responsivity of about 5 kV/W and noise-equivalent power (NEP) of 33.3 nW were measured at 1550 nm when the APD operated at a gain of $M=6.6$.

Completion of development of CdTe surface passivation for MWIR HgCdTe APDs presents the best opportunity to further improve receiver sensitivity, as it will enable operation at much higher avalanche gain with reduced dark current. This innovation can find use with quantum information (encryption and basic science), semiconductor inspection, and molecular spectroscopy.

This work was done by Andrew Huntington of Voxtel, Inc. for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16140-1

Surface-Enhanced Raman Scattering Using Silica Whispering-Gallery Mode Resonators

Silica sphere optical resonators are used to provide surface-enhanced spectroscopic signal.

NASA's Jet Propulsion Laboratory, Pasadena, California

The motivation of this work was to have robust spectroscopic sensors for sensitive detection and chemical analysis of organic and molecular compounds. The solution is to use silica sphere optical resonators to provide surface-enhanced spectroscopic signal.

Whispering-gallery mode (WGM) resonators made from silica microspheres were used for surface-enhanced Raman scattering (SERS) without coupling to a plasmonic mechanism. Large Raman signal enhancement is observed by exclusively using 5.08-micron silica spheres with

785-nm laser excitation. The advantage of this non-plasmonic approach is that the active substrate is chemically inert silica, thermally stable, and relatively simple to fabricate. The Raman signal enhancement is broadly applicable to a wide range of molecular functional groups including aliphatic hydrocarbons, siloxanes, and esters. Applications include trace organic analysis, particularly for in situ planetary instruments that require robust sensors with consistent response.

WGM SERS using microspheres or quartz surface structures provide a chem-

ically robust surface for sensor applications that could be cleaned by resistively heating the sensor element. This is particularly useful for spacecraft instruments used for the detection of organics in planetary soils. The conventional silver-based SERS substrates are limited by reactivity of silver. In the case of gold SERS substrates, high temperatures (<200 °C) will cause diffusion in the gold that degrades the nanostructure. The use of WGM SERS may also be used for surface analysis in a manner similar to attenuated total reflectance used in infrared spec-

troscopy. The surface localized field enhancement could be used to probe the upper layers of a sample surface.

WGM resonances (1, 2, X =also termed morphology-dependent resonances) take place when an incident light becomes trapped near the inner surface of a particle resulting from total internal reflection. This results in enhancement of the evanescent electromagnetic field at certain nodes near the surface of the particle. WGM resonance structures have been proposed as chem-

ical sensors and when coupled with conventional Plasmon-based SERS, for single-molecule spectroscopy.

Very large enhancements are feasible by using 5-micron silica microspheres. Enhancement factors comparable to those seen from noble metal spheroids are possible enhancements when the Raman-scattered radiation also overlaps with a WGM resonance. For microspheres with radius of 5 microns, the enhancement factor can exceed an order of magnitude. This is a signifi-

cant result that indicates that it would be possible to observe SERS with non-resonant scatterers.

This work was done by Mark S. Anderson of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.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, NASA Management Office-JPL. Refer to NPO-47604.t

3D Hail Size Distribution Interpolation/Extrapolation Algorithm

Multiple sensors are not required.

John F. Kennedy Space Center, Florida

Radar data can usually detect hail; however, it is difficult for present day radar to accurately discriminate between hail and rain. Local ground-based hail sensors are much better at detecting hail against a rain background, and when incorporated with radar data, provide a much better local picture of a severe rain or hail event.

The previous disdrometer interpolation/extrapolation algorithm described a method to interpolate horizontally between multiple ground sensors (a minimum of three) and extrapolate vertically. This work is a modification to that approach that generates a purely extrapolated 3D spatial distribution when using a single sensor.

A 3D high-resolution mapping of hail, as well as rain, is desirable in many instances. For example, hail mapping in the vicinity of a launch vehicle on the launch pad would help determine

whether or not damage has occurred following a hail event. In addition to quantifying the size and quantity of hail, it is desirable to know where on the vehicle hail impacts may have occurred. A method that was previously developed, and that required multiple ground sensors, has been modified to accommodate a single sensor. The 3D extrapolation from a single (or multiple) ground sensor can then be compared to the 3D radar-generated spatial map.

The 3D hydrometeor size interpolation scheme described in previous work assumes that a minimum of three hydrometeor disdrometers (rain or hail) are required for successful interpolation/extrapolation of the hydrometeor distribution in time and space. By simply bypassing the "gravity interpolation algorithm" for multiple sensors, it is shown that good agreement between single sites vs. multiple sites vs. radar is obtained.

The software modification allows any number of sensors, from 1 to N , to be used in the 3D-DSD algorithm. As would be expected, the more sensors that are available, the better, but the requirement for a minimum of three sensors has now been eliminated. This disclosure demonstrates that multiple sensors are not required for successful implementation of the 3D interpolation/extrapolation algorithm. This is a great benefit, since it is seldom that multiple sensors in the required spatial arrangement are available for this type of analysis. This can be used in conjunction with a single sensor or an array of hail monitors, or single or multiple rainfall disdrometers.

This work was done by John Lane of ASRC Aerospace Corporation for Kennedy Space Center. Further information is contained in a TSP (see page 1). KSC-13244

Color-Changing Sensors for Detecting the Presence of Hypergolic Fuels

Chemochromic pigment indicates the presence of hypergols, improving workers' safety.

John F. Kennedy Space Center, Florida

Hypergolic fuel sensors were designed to incorporate novel chemochromic pigments into substrates for use in various methods of leak detection. There are several embodiments to this invention that would provide specific visual indication of hypergols used during and after transfer. The ability to incorporate these pig-

ments into various polymer matrices provides a unique opportunity to manufacture nearly any type of sensor shape that is required. The vibrant color change from yellow to black instantaneously shows the worker the presence of hypergols in the area, providing the worker the ability to immediately evacuate the area.

The chemochromic pigments are prepared in powder or liquid form for addition into many different materials in different articles. With the ability to incorporate the pigment into a wide range of materials, the sensor can take any embodiment allowed by various manufacturing methods. For example,

the sensor can be manufactured in the form of polymer tape that can have several unique structures designed for different applications, from several layers to protect the tape from environmental conditions, to re-useable adhesive to allow for repositioning of the sensor. The sensor can be extruded into various size tapes or sheets, injection molded into uniquely shaped parts, or incorporated into fibers with fiber-spinning

methods to make fabrics or personal protective equipment. Additionally, the sensor can be incorporated into a badge holder to be used as a point leak detector. This can be done by creating a clear, or nearly clear, polymer cap for connection points, and placing the sensing material at the end of the cap where it can be seen by a technician.

These sensors provide the capability for numerous areas to be constantly visu-

ally monitored for leaks. These sensors are easy to replace and have a very low implementation cost.

This work was done by Luke Roberson, Janine Captain, Edgardo Santiago-Maldonado, and Stanley Starr of Kennedy Space Center; and Robert DeVor of ASRC Aerospace Corporation. For more information, contact the Kennedy Space Center Innovative Partnerships Office at 321-867-5033. KSC-13351/636

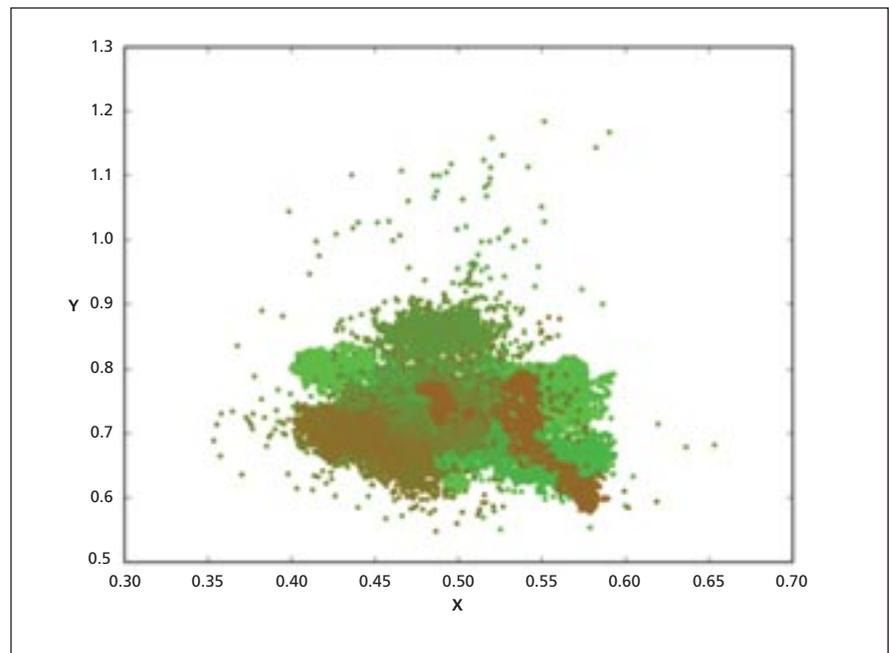
Artificial Intelligence Software for Assessing Postural Stability

Lyndon B. Johnson Space Center, Houston, Texas

A software package reads and analyzes pressure distributions from sensors mounted under a person's feet. Pressure data from sensors mounted in shoes, or in a platform, can be used to provide a description of postural stability (assessing competence to deficiency) and enables the determination of the person's present activity (running, walking, squatting, falling). This package has three parts: a preprocessing algorithm for reading input from pressure sensors; a Hidden Markov Model (HMM), which is used to determine the person's present activity and level of sensing-motor competence; and a suite of graphical algorithms, which allows visual representation of the person's activity and vestibular function over time.

In this innovation, the Hidden Markov Model algorithm assesses center-of-force time series data. Using the Viterbi algorithm acting on center-of-force velocity, these trajectories can be classified into local equilibria separated by dynamic regions. These dynamic regions represent control failures and, ordinarily, lead into a new equilibrium. However, the local equilibria wander inside a broad "safe zone" of which the size and shape are able to be quantified (see figure). By quantifying the dwell time, size, and shape of the equilibria, the dynamic trajectories and the safe zone as a whole, sensing-motor performance can be assessed. For instance, equilibria for subjects with their eyes closed are shorter and more diffuse than those for subjects with eyes open.

This same algorithm can easily distinguish quiescent standing from squatting or



The "Safe Zone": Eighteen subjects stood for two intervals of two minutes each on an EquiTest platform. Weight distribution from left foot (0) to right foot (1) is shown on the x-axis. Center-of-force in the anterior (1)/posterior (0) direction is plotted on the y-axis, normalized by foot length. Color corresponds to individual. The safe zone is elliptical in shape, but is far larger than the region encompassed by a single equilibrium or any 2-minute standing interval.

a hand raise and may be useful in checking how well an astronaut is adjusting to changes in gravitational field strength, in the context of Earth re-entry following space travel, or a Moon or Mars mission. Also, this innovation can be used to help a physical therapist gauge the progress of a stroke patient relearning skills like standing, walking, and running. The algorithm can be used as a training tool for athletes by quantifying their daily behavior (time spent running, etc) during training.

This work was a joint effort done by Erez

Lieberman, MIT and Harvard; Katharine Forth, USRA; and William Paloski, NASA Johnson Space Center. Inquiries concerning rights for its commercial use should be addressed to:

*Massachusetts Institute of Technology
Director of Technology Licensing Office
Room NE 25-230*

*Five Cambridge Center, Kendall Square
Cambridge, MA 02142*

Refer to MSC-24387-1, volume and number of this NASA Tech Briefs issue, and the page number.



Transformers: Shape-Changing Space Systems Built With Robotic Textiles

These easy-to-fabricate textiles can be used in robotics and smart habitats/shelters.

NASA's Jet Propulsion Laboratory, Pasadena, California

Prior approaches to transformer-like robots had only very limited success. They suffer from lack of reliability, ability to integrate large surfaces, and very modest change in overall shape. Robots can now be built from two-dimensional (2D) layers of robotic fabric. This expands on ideas of electronic fabrics for electronic textiles, and incorporates sensors, actuators, power, and communications. The 2D solution is easier/cheaper to fabricate, packs more compactly, and ensures a wider range of shape change than 3D modules.

These transformers, a new kind of robotic space system, are dramatically different from current systems in at least two ways. First, the entire transformer is built from a single, thin sheet; a flexible layer of a robotic fabric (ro-fabric); or robotic textile (ro-textile). The ro-textile would be produced as a gossamer-thin ($\approx 100 \mu\text{m}$) and light flexible layer, survivable to extreme environments. Along its large surface, the ro-fabric would be partitioned into modular cells. Each cell would include, distributed within this skin-like thin layer, all the structures for spacecraft/robotic subsystems, including propulsion and power (solar), avionics and controls, sensing, actuation (e.g., shape-memory alloys), and communication (circuits and antennas).

Second, the ro-textile layer is foldable to small volume and self-unfolding to adapt shape and function to mission phases. Tightly folded at launch, it would self-unfold to take the shape/function needed by the mission target, and then again transform its shape as needed. For dramatic changes, one can speculate it could morph between a large solar sail for interplanetary interstellar travel, its component patches could separate in swarms of winged flyers in atmosphere, or it could take shape as a limbed robot capable of surface mobility and sample manipulation.

Some 3D payloads may still be needed, e.g., some special instruments that cannot be integrated as 2D structures; these would be carried as payloads in kernels around which the 2D layer would fold. Proper partitioning of the ro-fabric sheet would allow shaping of practically any 3D shape, as insured by various mathematical proofs. Flexible layers would provide further freedom for modification of shape at sub-cell resolution.

The surface of ro-fabrics is composed of connected (zipped) multi-cell patches that can separate to operate in formations; these may be all the same or specialized (e.g., one with more sensing circuitry). Each cell would normally embed

the circuits of all subsystems (electronics/computing, propulsion, and power photo-elements/imaging cells, actuators, conductors for antennas, etc.).

A cell-based architecture fits well with modular, reconfigurable electronics, based on field programmable (FP) arrays, or in general on distributed computing/electronics. From computational perspective, each (cm-size) cell of the ro-textile could be a basic computational element — a single FPGA (field programmable gate array)/FPAA (FP gate/analog array) mixed cell, a cluster of cells, or a large-density array of FP cells (the low density may be suitable for non-silicon materials that may be preferable for reasons other than high integration). The ro-textile would be built with materials that survive to extreme environments without insulation or thermal control.

In summary, this concept may be a solution to faster, cheaper, and lighter space systems, reducing the launch cost and the redesign cost for new missions; thus, one can launch more of them and at shorter intervals, and send them to more places after launch.

This work was done by Adrian Stoica of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48349

Fibrillar Adhesive for Climbing Robots

This material can be used to hang items on walls without the need for drilling holes, as surgical sutures, or to attach and maneuver components during assembly.

NASA's Jet Propulsion Laboratory, Pasadena, California

A climbing robot needs to use its adhesive patches over and over again as it scales a slope. Replacing the adhesive at each step is generally impractical. If the adhesive or attachment mechanism cannot be used repeatedly, then the robot must carry an extra load of this adhesive to apply a fresh layer with each move.

Common failure modes include tearing, contamination by dirt, plastic deformation of fibers, and damage from loading/unloading. A gecko-like fibrillar adhesive has been developed that has been shown useful for climbing robots, and may later prove useful for grasping, anchoring, and medical applications.

The material consists of a hierarchical fibrillar structure that currently contains two levels, but may be extended to three or four levels in continuing work. The contacting level has tens of thousands of microscopic fibers made from a rubber-like material that bend over and create intimate contact with a surface to

achieve maximum van der Waals forces. By maximizing the real area of contact that these fibers make and minimizing the bending energy necessary to achieve that contact, the net amount of adhesion has been improved dramatically.

The suspension structure consists of millimeter-scale fibers that are bonded to the contacting level through a wet assembly step. These millimeter-sized fibers serve as a discretized way of both conforming to roughness on the surface and distributing the overall climbing loads down to the individual contacts. These structures have been tested on an experimental testbed meant to determine the contact forces very exactly, and have also been demonstrated by hanging weights off of a patch adhering to a variety of walls (glass, metal, wood, plastic, drywall, etc).

This material is fabricated via a molding process. A new process has been de-

veloped at JPL to make this process simpler, more reliable, and to allow new geometries not previously possible. These new geometries will make the adhesive and the reliability significantly better, and will drive down cost and development time.

The process involves using optical lithography to make a master pattern, and from this master pattern, making a reusable master mold that is used to cast the adhesive strips. To create the master photoresist pattern that will be used to make the master mold, a self-aligned double exposure technique was used. Two different angled UV exposures are performed using a single opaque pattern on a transparent wafer. This simplifies fabrication considerably.

A second advantage of this technique is the ability to achieve right-angle wedge-shaped structures with both sides

of the wedge leaning to the same side, i.e., an actual overhang of the fibers, which is more like the arrangement of a gecko foot's fibers. A third critical difference is the use of a standard positive Novalac photoresist, which has a wide process latitude.

The new microfabrication process has allowed the shape of the wedge-like fibers to be controlled. Prior to these process improvements, only right-angle wedges had been fabricated. Now, the process not only allows for increased control over the angle of these fibers, but is also much more reliable, manufacturable, and cost-effective.

This work was done by Aaron Parness and Victor E. White of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48156

Using Pre-Melted Phase Change Material to Keep Payloads in Space Warm for Hours Without Power

Goddard Space Flight Center, Greenbelt, Maryland

Adding phase change material (PCM) to a mission payload can maintain its temperature above the cold survival limit, without power, for several hours in space. For the International Space Station, PCM is melted by heaters just prior to the payload translation to the worksite when power is available. When power is cut off during the six-hour translation, the PCM releases its latent heat to make up the heat loss

from the radiator(s) to space. For the interplanetary Probe, PCM is melted by heaters just prior to separation from the orbiter when power is available from the orbiter power system. After the Probe separates from the orbiter, the PCM releases its latent heat to make up the heat loss from the Probe exterior to space.

Paraffin wax is a good PCM candidate. It has a high solid-to-liquid enthalpy,

which is about 225 kJ/kg, and a range of melting points. For example, C₁₈H₃₈ has a melting point of 28 °C, which is well within the payload temperature limits. At the time of this reporting, paraffin wax PCM had a TRL (technology readiness level) of 7.

This work was done by Michael Choi of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16539-1



Development of a Centrifugal Technique for the Microbial Bioburden Analysis of Freon (CFC-11)

Commercial applications include pharmaceutical development and quality assurance, and chemical manufacturing.

NASA's Jet Propulsion Laboratory, Pasadena, California

NASA Procedural Requirement 8020.12C entitled "Planetary Protection Provisions for Robotic Extraterrestrial Missions" states that the source-specific encapsulated microbial density for encapsulated organisms (div(0)) in non-metallic materials ranges from 1-30 spores/cm³. The standard laboratory procedure, NASA Standard Procedures for the Microbial Examination of Space Hardware, NHB 5340.1B, does not provide any direction into the methodologies to understand the bioburden within such a fluid as CFC-11 (Freon). This general specification value for the Freon would be applicable to the Freon charged within the Mars Science Laboratory's (MSL's) Heat Rejection System. Due to the large volume required to fill this system, MSL could not afford to conservatively allocate 55.8% of the total spore budget of the entire laboratory system (rover, descent stage, cruise stage, and aeroshell) of 5.00×10^5 spores at launch.

A novel filtration approach was developed to analyze the Freon employing a 50 kDa molecular weight cutoff (MCO) filter, followed by 0.22- μ m pore-size filter to establish a calculated microbial bioburden.

Filtration of microorganisms from liquid matrices is a standard laboratory approach. Due to the volatility of Freon, a standard vacuum filtration unit would not suffice because of the lack of a cold trap on the vacuum unit. A more economical approach had to be devised. The two-pronged concentration approach is advantageous due to the fact that it initially concentrates the Freon from liters to milliliters where it can then be feasibility filtered and microbes extracted from the filter. This is a technology improvement over prior art as it defines the specific parameters to concentrate microbial organisms from a low-boiling-point fluid such as Freon.

This work relates to the current MSL mission but also has implications for future NASA missions that will utilize the same or similar heat rejection fluids. If the same lot of material is utilized on a future mission, then the experimentally derived value can be directly used based on this study (MSL-heritage). If a new lot or similar material composition is used in a future mission, then this technology can be employed or modified accordingly to accommodate such a fluid. This technology development will allow for a heritage-based starting point for fluids on other missions in which a calculated microbial bioburden is necessary.

This work was done by James N. Benardini, Robert C. Koukol, Gayane A. Kazarians, and Fabian Morales of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48303

Microwave Sinterator Freeform Additive Construction System (MS-FACS)

This system can create hard surfaces for walkways, roadways, or landing pads.

NASA's Jet Propulsion Laboratory, Pasadena, California

The harmful properties of lunar dust, such as small size, glass composition, abnormal surface area, and coatings of imbedded nanophase iron, lead to a unique coupling of the dust with microwave radiation. This coupling can be exploited for rapid sintering of lunar soil for use as a construction material that can be formed to take on an infinite number of shapes and sizes.

This work describes a system concept for building structures on the lunar surface using lunar regolith (soil). This system uses the ATHLETE (All-Terrain Hex-Limbed Extra-Terrestrial Explorer)

mobility system as a positioning system with a microwave print head (similar to that of a smaller-scale 3D printer). A processing system delivers the lunar regolith to the microwave print head, where the microwave print head/chamber lays down a layer of melted regolith. An arm on the ATHLETE system positions the layer depending on the desired structure.

In support of long-duration human missions to the lunar surface, a variety of *in situ* derived structures have been proposed that would enhance the utility of a permanent outpost, provide safety for the outpost elements, and mitigate the gen-

eration of dust. Using regolith in a variety of ways, it has been proposed that berms, paving, walls, roads, and other structures could be constructed to serve as permanent outpost. However, the means of creating the *in situ* structures with hardened surfaces remains a challenge.

A lunar regolith processing system mounted on the underside of ATHLETE will deliver correctly sized regolith particles to a microwave print head via a material handling system. The microwave print head with tunable microwave chamber then lays down a layer of melted regolith as the ATHLETE arm traces a pre-defined

path forming a layer of printed structure in any desired shape. The process is repeated for subsequent layers, allowing the system to construct hard walls, vaults, domes, paving, and other *in situ* structures. Since any solid structure can be printed in this way, the construction mechanism is named Freeform Additive Construction System (FACS), using a Microwave Sinterator (MS) as a print head. Structures can be modeled in advance using CAD systems, and then sent to the lunar system to “make a FACS (FAX)” of the structure on the lunar surface.

The key to the microwave heating of lunar soil is the coupling of certain microwave frequencies to specific materials. This will improve the efficiency of the device and expedite heating of the soil. Since lunar soil is composed of a variety of materials, a broadband microwave emitter must be used such as a magnetron or a traveling wave tube amplifier. The microwave energy must be aimed into a resonant chamber containing the regolith. The frequency, the chamber, or both will need to be autonomously tuned to excite frequencies that couple the microwave energy with the regolith. This will create a more efficient heating of the regolith.

The novelty of the FACS concept lies in the unique capability of the ATHLETE system as a positioning system, coupled with an efficient material handling system and the ability of the adjustable microwave chamber MS print head to produce hard structures in the



The **Microwave Sinterator Freeform Additive Construction System (MS-FACS)** uses the ATHLETE mobility system as a positioning system.

vacuum environment of space, and result in a digitally printed *in situ* structure using *in situ* raw materials.

The simplest application of this technology is a microwave road-paver. This device will be able to create hard surfaces in the immediate area of astronauts for walkways, roadways, or landing pads. These hard surfaces will mitigate the effects of dust by limiting the expo-

sure in the immediate area of habitats and minimizing the amount of dust kicked up by the descent engines of landing spacecraft.

This work was done by Alan S. Howe, Brian H. Wilcox, Martin B. Barmatz, Michael B. Mercury, Michael A. Seibert, and Richard R. Rieber of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48291



DSP/FPGA Design for a High-Speed Programmable S-Band Space Transceiver

Goddard Space Flight Center, Greenbelt, Maryland

Traditional command uplink receivers are very limited in performance capability, take a long time to acquire, cannot operate on both uplink bands (NASA & AFSCN), and only support low-rate communications. As a result, transceivers end up on many programs' critical paths, even though they should be a standard purchased spacecraft subsystem. Also, many missions are impacted by the low effective uplink throughput. In order to tackle these challenges, a transceiver was developed that will provide on-site frequency agility, support of high uplink rates, and operation on both NASA and AFSCN frequency bands.

The device is a low-power, high-reliability, and high-performance digital signal processing (DSP) demodulator for an on-orbit programmable com-

mand receiver. There are several drivers available for the modulation technique. Those drivers include receiver complexity, power consumption, spectral efficiency, and CCSDS (Consultative Committee for Space Data Systems) framework recommendations. Previous research suggests that GMSK (Gaussian Minimum Shift Keying) and BPSK (Binary Phase Shift Keying) are good choices for the uplink modulation format. This approach is supported by CCSDS and helps reduce receiver complexity.

Analysis and derived simulations were performed for power, bandwidth, clock generator, bit synchronizer, and carrier loop. At the time of this reporting, the code was not yet written, and will evolve from the existing analysis and simulation.

The demodulator operates on the two selected modes, BPSK and GMSK. The bit rate covers multiple octaves and includes a bit synchronizer function. The modulator is unique in that it operates with high Doppler, over a large bit rate range, and in a space environment. In addition, this demodulator attempts to maximize low power, small size, and ease of modification to new applications.

Novel features of the innovation include DSP logic for multiple modulation types in a low-power and rad-tolerant platform. Advantages include on-the-fly programmable low-power receive communications for spacecraft.

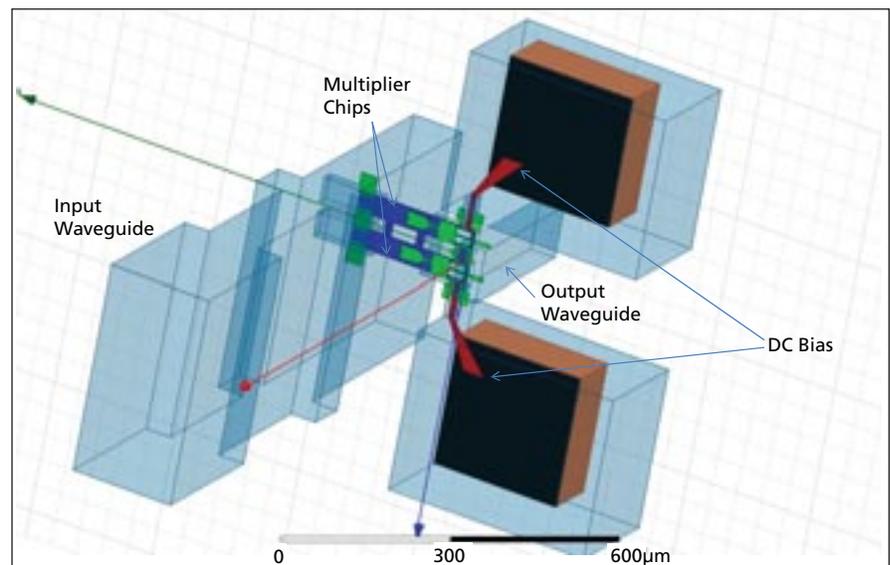
This work was done by Jeffrey Janicik and Assi Friedman of Innoflight, Inc. for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16030-1

On-Chip Power-Combining for High-Power Schottky Diode-Based Frequency Multipliers

High-power solid-state sources operate at terahertz frequencies.

NASA's Jet Propulsion Laboratory, Pasadena, California

A 1.6-THz power-combined Schottky frequency tripler was designed to handle approximately 30 mW input power. The design of Schottky-based triplers at this frequency range is mainly constrained by the shrinkage of the waveguide dimensions with frequency and the minimum diode mesa sizes, which limits the maximum number of diodes that can be placed on the chip to no more than two. Hence, multiple-chip power-combined schemes become necessary to increase the power-handling capabilities of high-frequency multipliers. However, the traditional power-combining topologies that are used below 1 THz present some inconvenience beyond 1 THz. The use of Y-junctions or hybrid couplers to divide/combine the input/output power at these frequency bands increases unnecessarily the electrical path of the sig-



1.9 THz On-Chip Power-Combining (2 chips).

nal in the range of frequencies where waveguide losses are considerable. Also, guaranteeing a perfect alignment of the very small chips during assembly, in order to preserve the balanced nature of the multiplier, is practically impossible with the subsequent impact on the multiplier performance.

The design presented here overcomes these difficulties by performing the power-combining directly on-chip. Four E-probes are located at a single input waveguide in order to equally pump four multiplying structures (featuring two diodes each). The produced output power is then recombined at the output using the same concept. The four multiplying structures are physically connected on one chip, so that the align-

ment and symmetry of the circuits can be very well preserved. Contrary to traditional frequency triplers, in this design the input and output waveguides are perpendicular to the waveguide channels where the diodes are located. Therefore, the multiplier block is easier to fabricate with silicon micromachining technology instead of regular machining. The expected conversion efficiency of the tripler is ≈ 2 to 3% over a $\approx 20\%$ bandwidth, which is similar to that which is simulated for an equivalent single-chip tripler driven with one fourth the input power.

This work was done by Goutam Chattopadhyay, Imran Mehdi, Erich T. Schlecht, and Choonsup Lee of NASA's Jet Propulsion Laboratory and Caltech; Jose V. Siles – Fulbright

Fellow at NASA's Jet Propulsion Laboratory; Alain E. Maestrini of the University of Paris; Bertrand Thomas of Radiometer Physics; and Cecile D. Jung of ORU for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

*Innovative Technology Assets Management
JPL*

Mail Stop 202-233

4800 Oak Grove Drive

Pasadena, CA 91109-8099

E-mail: iaoffice@jpl.nasa.gov

Refer to NPO-48155, volume and number of this NASA Tech Briefs issue, and the page number.

FPGA Vision Data Architecture

This is an aid to any FPGA vision processing, and can be used by the automotive industry to detect collisions before they occur, and for robotic autonomous navigation for disaster relief.

NASA's Jet Propulsion Laboratory, Pasadena, California

JPL has produced a series of FPGA (field programmable gate array) vision algorithms that were written with custom interfaces to get data in and out of each vision module. Each module has unique requirements on the data interface, and further vision modules are continually being developed, each with their own custom interfaces.

Each memory module had also been designed for direct access to memory or to another memory module. On the development board originally used (an Alpha Data XRC4), there were six independent SSRAM (synchronous static RAM) banks that allowed each module sole access. For a flight mission, there likely would be between one and three memory banks, and arbitration of those banks would need to be supported, interleaving access to individual memory banks between multiple modules.

An FPGA data architecture was required to allow arbitration to onboard DDR (double data rate) and/or SSRAM memory, and to allow up to 10 to 30 independent agents access to that memory. It also required a method of exchanging data directly between modules without reducing the throughput of memory access. This architecture also had to support both low-latency reads and writes, and offer high throughput.

Each FPGA vision module had slightly different input and output re-

quirements. Some required serial access to data, and some were random access. There were 8-bit, 16-bit, and 32-bit input/output widths. Three modules could connect directly together in a series or go directly to memory, depending on runtime configuration options. One of the larger difficulties was posed by the random read access. For industry-standard buses such as AMBA, PLB, or OPB, a single random-read request can take 5 to 10 clock cycles, locking out all other users on the bus until the request was complete. This is far too slow for the vision modules and would effectively reduce performance by 2 to 5 times.

An architecture was created that met the same data throughput as the prior custom interface that had no arbitration. The new architecture also allowed for multiple memory types (DDR, DDRII, SSRAM, NAND memory) without any modification of the FPGA vision modules themselves.

The current Rover Navigation FPGA Vision system contains five vision modules: Rectification, Filtering, Disparity, Feature Detector (via a Harris detector), and Visual Odometry score computation (via a sum of absolute differences operator). Further modules to handle path planning are likely.

Each vision module has an “agent” — an interface to memory for both reads

and writes of different sizes. R32 means a read agent of width 32 bits, and W8 means a write agent of width 8 bits. Each memory bank has a single arbiter that handles all memory requests to its bank. Each agent maps to a single arbiter, but because this mapping will be dependent upon the memory devices used and the number of memory devices available (i.e. two DDR banks vs. six SSRAM banks), there is a large multiplexer called the “vision agent to bank mapping,” which assigns agents to appropriate arbiters and memory banks.

Each agent can queue multiple memory requests and queue multiple responses from memory. This allows bursting of data for high throughput, and decouples the action of requesting memory from the action of receiving data. Many of the vision modules have one part dedicated to computing the location of the next request, and a separate part dedicated to handling the data at that location.

This work was done by Arin C. Morfopoulos and Thang D. Pham of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

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, NASA Management Office-JPL. Refer to NPO-47869.

Memory Circuit Fault Simulator

A wide variety of decision structures and formalisms is represented in the matrix evaluations.

NASA's Jet Propulsion Laboratory, Pasadena, California

Spacecraft are known to experience significant memory part-related failures and problems, both pre- and post-launch. These memory parts include both static and dynamic memories (SRAM and DRAM). These failures manifest themselves in a variety of ways, such as pattern-sensitive failures, timing-sensitive failures, etc. Because of the mission critical nature memory devices play in spacecraft architecture and operation, understanding their failure modes is vital to successful mission operation.

To support this need, a generic simulation tool that can model different data patterns in conjunction with variable write and read conditions was developed. This tool is a mathematical and graphical way to embed pattern, electrical, and physical information to perform what-if analysis as part of a root cause failure analysis effort.

The memory device is modeled as an $n \times m$ matrix structure that is mathemati-

cally transformed by a series of matrix defined mathematical and logical operators that represent the read and write operations. The mathematical transformation process is a multi-step process that encompasses both logical and physical information of the memory array. The flexibility of MATLAB allows elements of each operator to be a wide variety of complex structures that includes integer, floating point, or character-based conditions and decision points. The application of operators can also include additional time elements to provide for time-based degradation of memory cells. The size of matrices can be scaled to represent large statistical concerns, or truncated and reduced to focus on regions of interest.

Pattern-sensitive testing schemes can be modeled to reflect real-world testing sequences. Moving inversion, walking, and disturb-based sequences are examples of standard algorithmic patterns

that can be applied. Degradations and faults can be modeled at both the logical and physical levels with this formalism. Logical to physical transformations are often at the core of modern sophisticated memory faults.

System designers often assume uniform bit/byte performance while the physical reality is represented by voltage-dependent writes and cells with varying capacitance and drive capability. The fault simulator formalism presented here allows for what-if analysis to help characterize this logical to physical transformation.

This work was done by Douglas J. Sheldon of Caltech and Tucker McClure of MathWorks for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

The software used in this innovation is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-48591.



⚙️ Ultra-Compact Transputer-Based Controller for High-Level, Multi-Axis Coordination

Features include reduction in flex wear, streamlining of robotic structures, survivability, and uniformity in handling various types of servos.

Lyndon B. Johnson Space Center, Houston, Texas

The design of machines that rely on arrays of servomotors such as robotic arms, orbital platforms, and combinations of both, imposes a heavy computational burden to coordinate their actions to perform coherent tasks. For example, the robotic equivalent of a person tracing a straight line in space requires enormously complex kinematics calculations, and complexity increases with the number of servo nodes. The conventional method of executing these calculations is with a PC-style set of electronics including a powerful CPU (central processing unit) microprocessor, operating system, power supply, a number of peripherals, connectors to support each servo node, and a web of star-topology wiring across the machine (including flexing joints), generally exceeding 100 conductors. In industry, the most common implementation is one or more dedicated PC cards mounted on an ISA (Industry Standard Architecture), PCI (Peripheral Component Interconnect), or VME bus. These cards provide the I/O connectors and supplement the CPU to execute the massive kinematic calculations in real time.

A new high-level architecture for coordinated servo-machine control enables a practical, distributed transputer alternative to conventional central processor electronics. The solution is inherently scalable, dramatically reduces bulkiness and number of conductor runs throughout the machine, requires only a fraction of the power, and is designed for cooling in a vacuum.

The benefit of this innovation is total elimination of the central controller and reducing the heavy web of star-topology wiring across the machine to four wires along a shared serial bus. This scalable innovation results in decreased power consumption, decreased bulk, and vacuum compatibility.

This controller places a digital signal processor (DSP), instead of a microprocessor, at each motor axis, each with its own power supply, conduction cooling, etc. The DSPs communicate via CANbus over RS-485 hardware, forming the heart of the transputer.

Features of the device include reduction in flex wear in serial-articulating joints, streamlining of robotic structures (with reduced wire-harness bulk), surviv-

ability in the case of a single-processor failure, and uniformity in handling various types of servos (brushless, brushed, etc.) and sizes up to 300 W. Brushless compatibility supports elimination of brush-life limits and particulate generation. Power in the 2-wire bus flows directly between regenerative power nodes and motive power nodes, rather than traversing the round-trip star topology.

This work was done by Brian Zenowich, Adam Crowell, and William T. Townsend of Barrett Technology Inc. for Johnson Space Center. Further information is contained in a TSP (see page 1).

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

Barrett Technology Inc.

625 Mount Auburn Street

Cambridge, MA 02138-4555 USA

Phone: (617)252-9000

Fax: (617) 252-9021

E-mail: robot@barrett.com

Refer to MSC-24295-1, volume and number of this NASA Tech Briefs issue, and the page number.

⚙️ Regolith Advanced Surface Systems Operations Robot Excavator

This design enables new ways of excavating for resources on planetary bodies.

John F. Kennedy Space Center, Florida

The Regolith Advanced Surface Systems Operations Robot (RASSOR) excavator robot is a teleoperated mobility platform with a space regolith excavation capability. This more compact, lightweight design (<50 kg) has counter-rotating bucket drums, which results in a net-zero reaction horizontal force due to the self-cancellation of the symmetrical, equal but opposing, digging forces.

This robot can operate in extremely low-gravity conditions, such as on the Moon, Mars, an asteroid, or a comet. In addition, the RASSOR system is designed to be easily transported to a space destination on a robotic precursor landing mission. The robot is capable of traversing over steep slopes and difficult regolith terrain, such as an impact crater on the Moon, and has a reversible oper-

ation mode so that it can tolerate an over-turning incident with a graceful recovery, allowing regolith excavation operations to continue.

The RASSOR excavator consists of a mobility platform with tread belts on the port and starboard sides that are each driven by electrical motors, but it could also operate with a wheel system to further reduce mass. Two batteries are

mounted in a “saddlebag” configuration on either side. Two counter-rotating bucket drum digging implements are held by a rotating cantilever mechanism at the fore and aft ends of the mobility platform. The cantilever arms are raised and lowered to engage the bucket drum into the soil or regolith. A variable cutting depth is possible by controlling the angles of the cantilever arms.

The unit has three modes of operation: load, haul, and dump. During loading, the bucket drums will excavate soil/regolith by using a rotational motion whereby scoops mounted on the drum’s exteriors sequentially take multiple cuts of soil/regolith while rotating at approximately 20 revolutions per min-

ute. During hauling, the bucket drums are raised by rotating the arms to provide a clearance with the surface being excavated. The mobility platform can then proceed to move while the soil/regolith remains in the raised bucket drums. Finally, when the excavator reaches the end-user or dump location, the bucket drums are commanded to reverse their direction of rotation to the opposite spin from digging, causing the gathered materials to be expelled out of each successive scoop. It can also stand up in a vertical mode to deliver regolith over the edge of a hopper container.

The RASSOR can operate with either side up in a reversible mode and it can flip itself over. This means the unit can

drive directly off of the deck of a lander to deploy in low gravity, eliminating a deployment mechanism, which saves mass and increases reliability due to decreased complexity. The RASSOR system is scalable and may be mounted on mobility platforms of various sizes, and has control equipment — wireless signal router, computer, joystick, E-stop, and associated software.

This work was done by Robert P. Mueller, Jonathan D. Smith, Tom Ebert, Rachel Cox, Laila Rahmatian, and James Wood of Kennedy Space Center; Jason Schuler of EASI; and Andrew Nick of Sierra Lobo. For more information, contact the Kennedy Space Center Innovative Partnerships Office at 321-867-5033. Refer to KSC-13664.

Magnetically Actuated Seal

Design replaces existing pressure-actuated lift-off seals in turbopumps and eliminates low pressure drains, thereby increasing overall efficiency.

Marshall Space Flight Center, Alabama

This invention is a magnetically actuated seal in which either a single electromagnet, or multiple electromagnets, are used to control the seal’s position. This system can either be an open/close type of system or an actively controlled system.

A lift-off seal (LOS) is a type of shaft seal used in a turbopump that does not allow propellants to enter the turbine during pre-start operations, such as when a cryogenic turbopump is being chilled-in or when the pump is being primed prior to start. Typically, lift-off seals are pressure activated and a low constant pressure in the seal’s secondary seal cavity is needed to provide the delta-P necessary for the seal to open. This is typically accomplished with an

overboard drain cavity. The LOS must remain closed during pre-start operations. This prevents cryogenic liquid from chilling-in the turbine, which would result in excessive thermal shock, and subsequent turbine blade cracking. During the start-transient, the LOS must open to prevent propellant gasification and sometimes to provide coolant to the turbine disk. If it opens too soon, however, the turbine pressure can be higher than the pump pressure, and result in hot gas ingestion into the pump or bearings. If it opens too late, the seal surface speed becomes excessive, and results in excessive wear and premature failure of the seal.

The magnetically actuated LOS is more reliable and requires no low-pres-

sure secondary seal cavity or overboard drain (thereby improving efficiency). An electromagnet is used to open and close the seal at an exact prescribed instant during the transient. Additionally, with the magnetically actuated seal, the particular instant can be different between the start transient and shut-down transient. This allows for more desirable and predictable transient performance of the turbopump as well as more certain wear performance of the seal.

This work was done by Alex Pinera of Florida Turbine Technologies, Inc. for Marshall Space Flight Center. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32979-1.

Hybrid Electrostatic/Flextensional Mirror for Lightweight, Large-Aperture, and Cryogenic Space Telescopes

A much lighter-weight structure with higher correction range uses polymer-based membrane mirror technology.

Marshall Space Flight Center, Alabama

A lightweight, cryogenically capable, scalable, deformable mirror has been developed for space telescopes. This innovation makes use of polymer-based membrane mirror technology to enable

large-aperture mirrors that can be easily launched and deployed. The key component of this innovation is a lightweight, large-stroke, cryogenic actuator array that combines the high degree of

mirror figure control needed with a large actuator influence function. The latter aspect of the innovation allows membrane mirror figure correction with a relatively low actuator density,

preserving the lightweight attributes of the system.

The principal components of this technology are lightweight, low-profile, high-stroke, cryogenic-capable piezoelectric actuators based on PMN-PT (piezoelectric lead magnesium niobate-lead titanate) single-crystal configured in a flextensional actuator format; high-quality, low-thermal-expansion polymer membrane mirror materials developed by NeXolve; and electrostatic coupling between the membrane mirror and the piezoelectric actuator assembly to minimize problems such as actuator print-through. PMN-PT single-crystal material provides a piezoelectric driver that delivers appreciable strain from above room temperature to less than 20 K. The combination of a polymer membrane mate-

rial for the mirror and the flextensional actuator design results in a very lightweight structure with a large range of aberration correction.

The membrane mirror is a low-stiffness component that requires relatively low actuator force. The flextensional actuator design is a low-force, high-displacement (>400 microns), lightweight piezoelectric positioning technology. The combination of the two results in a much lighter-weight structure with higher correction range than can be achieved with conventional piston-style actuators and glass face sheets. To combat actuator print-through and to lessen actuator density, a hybrid piezoelectric-electrostatic actuation approach was developed. The actuators push on an electrode plate held at a high voltage. The

plate is coupled to the mirror through the electrostatic field established by the applied voltage, but does not make direct mechanical contact with the mirror. As the actuators move the electrode plate, the mirror is stretched or relaxed as needed. This allows a high degree of figure control with a relatively small actuator density. Control can be further enhanced by including multiple actuators for each electrode plate, allowing both piston and tip/tilt motion.

This work was done by Brian Patrick and James Moore of ManTech NeXolve Corp., and Wesley Hackenberger and Xiaoning Jiang of TRS Technologies, Inc. for Marshall Space Flight Center. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32878-1.



System for Contributing and Discovering Derived Mission and Science Data

A system was developed to provide a new mechanism for members of the mission community to create and contribute new science data to the rest of the community. Mission tools have allowed members of the mission community to share first order data (data that is created by the mission's process in command and control of the spacecraft or the data that is captured by the craft itself, like images, science results, etc.). However, second and higher order data (data that is created after the fact by scientists and other members of the mission) was previously not widely disseminated, nor did it make its way into the mission planning process.

This software allows members of the mission community to create and contribute second and higher order data into the set of mission data for use in planning and operations of a mission. This kind of data is indexed and treated in the same way as first order data. The data is discoverable by other users and can be part of the planning process. The system improves the ability to share results, make discoveries, and aid in the operations of a mission. At the time of this reporting, this capability was not available in other software.

This work was done by Michael N. Wallick, Mark W. Powell, Khawaja S. Shams, Megan C. Mickelson, Darrick M. Ohata, James A. Kwień, and Lucy Abramyan 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 Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-48217.

Remote Viewer for Maritime Robotics Software

This software is a viewer program for maritime robotics software that provides a 3D visualization of the boat pose, its position history, ENC (Electrical Nautical Chart) information, camera images, map overlay, and detected tracks.

It is usually very difficult to understand the internal states of onboard robotics software. One common approach is text-based printouts on a terminal, but

it is very difficult to interpret large amounts of data printed out on the screen. Another challenge is that the network connection to the robot might not be reliable, where constantly monitoring the data at high bandwidth is impossible.

This software provides a Qt-based viewer that is intended to be used with onboard robotics software to visualize its internal states and the situational awareness of the robot. OpenGL is used to render vehicle/objects/ENC data, etc. in 3D. It uses UDP (User Datagram Protocol) communication to talk to the onboard software, so each side of the robot and the viewer program can be stopped and started at any time, and the performance degrades gracefully over lossy wireless communications links. It can also save a log of the viewer messages and replay at various speeds, so that it can reconstruct and analyze what happens in the field trials. Other features include QuickTime-based movie creation, overlay of maps, and display of ENC objects.

This software is easily adopted by other robotics projects. It serves as an engineering display for software debugging/monitoring, and also a tool to explain to sponsors/customers what the onboard navigation/perception/control algorithms are doing.

This work was done by Yoshiaki Kuwata, Michael Wolf, Terrance L. Huntsberger, and Andrew B. Howard of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48126

Stackfile Database

This software provides storage retrieval and analysis functionality for managing satellite altimetry data. It improves the efficiency and analysis capabilities of existing database software with improved flexibility and documentation. It offers flexibility in the type of data that can be stored. There is efficient retrieval either across the spatial domain or the time domain. Built-in analysis tools are provided for frequently performed altimetry tasks.

This software package is used for storing and manipulating satellite measurement data. It was developed with a focus on handling the requirements of repeat-track altimetry missions such as Topex

and Jason. It was, however, designed to work with a wide variety of satellite measurement data [e.g., Gravity Recovery And Climate Experiment — GRACE). The software consists of several command-line tools for importing, retrieving, and analyzing satellite measurement data.

This work was done by Robert deCarvalho, Shailen D. Desai, Bruce J. Haines, Gerhard L. Kruizinga, and Christopher Gilmer 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 Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-48210.

Reachability Maps for In Situ Operations

This work covers two programs that accomplish the same goal: creation of a “reachability map” from stereo imagery that tells where operators of a robotic arm can reach or touch the surface, and with which instruments. The programs are “marsreach” (for MER) and “phxreach.” These programs make use of the planetary image geometry (PIG) library. However, unlike the other programs, they are not multi-mission. Because of the complexity of arm kinematics, the programs are specific to each mission.

In each case, the input consists of XYZ and surface normal data. The output is a multiband image, co-registered to the input image. Each band represents a predefined combination of arm instrument and arm configuration (e.g., elbow up, elbow down), and the value indicates whether or not the instrument can observe (see or touch) the surface at the corresponding pixel.

This software models the arm precisely, using the same algorithms as the flight software. It is thus uniquely suited to determining reachability and safety of robot arm operations. The MER RAT instrument provides additional information beyond just a flag — it supplies a “preload” value, which indicates how much force the arm can apply at that spot. The MER reachability program considers collisions of the arm with terrain in determining reachability; the PHX program does not.

These programs provide this reachability information in an easy-to-use format by combining the surface position and orientation, arm kinematics, instrument mounting, and instrument approach angles. This software is also integrated into the ground data system and the automated processing pipelines. It understands the EDR and RDR file formats and metadata, and products tailored for in situ surface operations.

This work was done by Robert G. Deen, Patrick C. Leger, Matthew L. Robinson, and Robert G. Bonitz 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 Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47731.

JPL Space Telecommunications Radio System Operating Environment

A flight-qualified implementation of a Software Defined Radio (SDR) Operating Environment for the JPL-SDR built for the CoNNeCT Project has been developed. It is compliant with the NASA Space Telecommunications Radio System (STRS) Architecture Standard, and provides the software infrastructure for STRS compliant waveform applications. This software provides a standards-compliant abstracted view of the JPL-SDR hardware platform. It uses industry standard POSIX interfaces for most functions, as well as exposing the STRS API (Application Programming Interface) required by the standard. This software includes a standardized interface for IP components instantiated within a Xilinx FPGA (Field Programmable Gate Array).

The software provides a standardized abstracted interface to platform resources such as data converters, file system, etc., which can be used by STRS standards conformant waveform applications. It provides a generic SDR operating environment with a much smaller resource footprint than similar products such as SCA (Software Communications Architecture) compliant implementations, or the DoD Joint Tactical Radio Systems (JTRS).

This work was done by James P. Lux, Minh Lang, Kenneth J. Peters, Gregory H. Taylor, Courtney B. Duncan, David S. Orozco, Ryan A. Stern, Earl R. Ahten, and Mike Girard 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 Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47766.

RFI-SIM: RFI Simulation Package

RFI-SIM simulates the RFI environment to estimate the interference from terrestrial emitters into spacecraft, or vice versa. A high-fidelity simulation of the RFI environment has been developed by employing all antenna-related and radar system-related parameters of multiple emitters, as well as that of the desired spacecraft.

In the simulation, the real-time analysis of the interference and its effects on error budgets of a desired radar system is taken into account. This provides a reliable tool for radar system design to deal with RFI issues and to evaluate the sensitivity of various parts of a radar system including antenna pattern, RF front-end and digital processing to RFI signals.

The simulator is capable of a high-fidelity, complex, and real-time simulation of RFI environment. It is flexible enough to be employed for various scenarios and for several NASA missions. RFI-SIM can perform the following in support of radar system design and performance analyses:

- Error budget analyses due to RFI on a space-borne radar system;
- Sensitivity analysis of the various radar parameters, as well as hardware specs, in the presence of RFI;
- Verification of the radar system design at several stages of RF and digital components in order to evaluate their robustness against RFI;
- Assistance in algorithm development for RFI detection and removal approach;
- Based on the available database, the RFI environment over North America at L-band has been reliably and successfully simulated and validated so it can be used for L-band space-borne radars in the RFI environment; and
- Estimation of the interference from space-borne radars into terrestrial FAA radars regarding FAA compatibility issues.

This work was done by Hiram Ghaemi and Curtis W. Chen 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 Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-48565.

ION Configuration Editor

The configuration of ION (Interplanetary Overlay Network) network nodes is a manual task that is complex, time-consuming, and error-prone. This program seeks to accelerate this job and produce reliable configurations.

The ION Configuration Editor is a model-based smart editor based on Eclipse Modeling Framework technology. An ION network designer uses this Eclipse-based GUI to construct a data model of the complete target network and then generate configurations. The data model is captured in an XML file. Intrinsic editor features aid in achieving model correctness, such as field fill-in, type-checking, lists of valid values, and suitable default values. Additionally, an explicit "validation" feature executes custom rules to catch more subtle model errors. A "survey" feature provides a set of reports providing an overview of the entire network, enabling a quick assessment of the model's completeness and correctness. The "configuration" feature produces the main final result, a complete set of ION configuration files (eight distinct file types) for each ION node in the network.

This work was done by Richard L. Borgen 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 Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-48209.

Dtest Testing Software

This software runs a suite of arbitrary software tests spanning various software languages and types of tests (unit level, system level, or file comparison tests). The dtest utility can be set to automate periodic testing of large suites of software, as well as running individual tests. It supports distributing multiple tests over multiple CPU cores, if available.

The dtest tool is a utility program (written in Python) that scans through a directory (and its subdirectories) and finds all directories that match a certain pattern (directory name starts with "test_" or "test-") and then executes any tests in that directory as described in simple configuration files. The tests are completely arbitrary and are not tied to any specific programming language. A variety of tests is available to support comparing test output files

with pre-validated versions. Dtest can be used in an automated testing environment or by an individual software developer to manually create or maintain individual tests. Dtest accumulates test results in data files that can be used for reporting test results by email or on a Web site.

At the time of creation, only unit-level testing utilities such as Junit, CppUnit, etc. existed that focused on tests for a specific language. The dtest utility generalizes these capabilities to arbitrary types of tests.

This work was done by Abhinandan Jain, Jonathan M. Cameron, and Steven Myint 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 Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-48199.

IMPaCT — Integration of Missions, Programs, and Core Technologies

IMPaCT enables comprehensive information on current NASA missions, prospective future missions, and the technologies that NASA is investing in, or considering investing in, to be accessed from a common Web-based interface. It allows dependencies to be established between missions and technology, and from this, the benefits of investing in individual technologies can be determined. The software also allows various scenarios for future missions to be explored against resource constraints, and the nominal cost and schedule of each mission to be modified in an effort to fit within a prescribed budget.

The objective is to establish linkages between future missions and technologies so that a more rational technology investment program can be carried out and the benefits of technologies to missions can be explored systematically. The software manages the primary data elements of Technology Sets, Technologies, Mission Sets, Missions, Time Lines, and Funding Profiles. The software reports and graphs the interrelationships (de-

pendencies) among these elements in an aggregating Portfolio.

A Portfolio in IMPaCT is a set of missions and/or mission concepts and their associated technologies that can be selected by the user for the purpose of analyzing and exploring mission scenario options. Portfolios are particularly useful for understanding how a set of missions and technologies can be accommodated in a constrained funding profile by changing launch dates and/or reducing mission costs.

IMPaCT can display this information interactively or it can also be downloaded using reporting routines to standard formats such as Adobe .pdf files, MS Excel, or MS Word. IMPaCT has been developed at JPL under NASA's Planetary Science Program Support task to aid NASA in planning and defining a viable portfolio of missions and technologies.

This work was done by Carlos P. Balacuit, James A. Cutts, Craig E. Peterson, Patricia M. Beauchamp, Susan K. Jones, Winnie N. Hang, and Shahin D. Dastur of Caltech for NASA's Jet Propulsion Laboratory. For more information, go to the IMPaCT web site: <https://impacts.jpl.nasa.gov>.

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-48197.

Integrated Systems Health Management (ISHM) Toolkit

A framework of software components has been implemented to facilitate the development of ISHM systems according to a methodology based on Reliability Centered Maintenance (RCM). This framework is collectively referred to as the Toolkit and was developed using General Atomics' HealthMAP™ technology.

The toolkit is intended to provide assistance to software developers of mission-critical system health monitoring applications in the specification, implementation, configuration, and deployment of such applications. In addition to software tools designed to facilitate these objectives, the toolkit also pro-

vides direction to software developers in accordance with an ISHM specification and development methodology. The development tools are based on an RCM approach for the development of ISHM systems. This approach focuses on defining, detecting, and predicting the likelihood of system functional failures and their undesirable consequences.

The toolkit provides users with an object-oriented environment in which to specify and program software application behavior that leverages model-based reasoning specifically targeted for ISHM applications. Furthermore, the application has been designed to follow a recommended RCM-based ISHM system design methodology, providing guidance to the developer in building the overall capability of the ISHM system. The advantages of the ISHMToolkit include: (1) guidance to ISHM system developers based on a proven methodology that strives to detect, diagnose, and predict those system failures that interfere with mission objectives; (2) access to reusable class libraries and behaviors; (3) the ability to leverage model-based reasoning; (4) the incorporation of graphical programming capabilities; (5) access to a central supervisory software layer that operates and correlates over aggregated information; and (6) a layered ISHM architecture that conforms to Open System Architecture standards.

The toolkit is a software environment designed for leveraging reusable libraries developed by General Atomics that provide generic class definition, generic class behavior, and generic failure models. The toolkit also provides capability for building or extending such class libraries.

This work was done by Meera Venkatesh, Ravi Kapadia, Mark Walker, and Kim Wilkins of General Atomics for Stennis Space Center. Inquiries concerning rights for its commercial use should be addressed to:

*General Atomics
3550 General Atomics Court
San Diego, CA 92121
Telephone No. (858) 676-7169*

Refer to SSC-00367, volume and number of this NASA Tech Briefs issue, and the page number.



Wind-Driven Wireless Networked System of Mobile Sensors for Mars Exploration

GOne with the Wind ON-Mars (GOWON-Mars): A mobile sensor network that could be used on any windy solar system body, such as Mars or Titan.

NASA's Jet Propulsion Laboratory, Pasadena, California

A revolutionary way is proposed of studying the surface of Mars using a wind-driven network of mobile sensors: GOWON. GOWON would be a scalable, self-powered and autonomous distributed system that could allow *in situ* mapping of a wide range of environmental phenomena in a much larger portion of

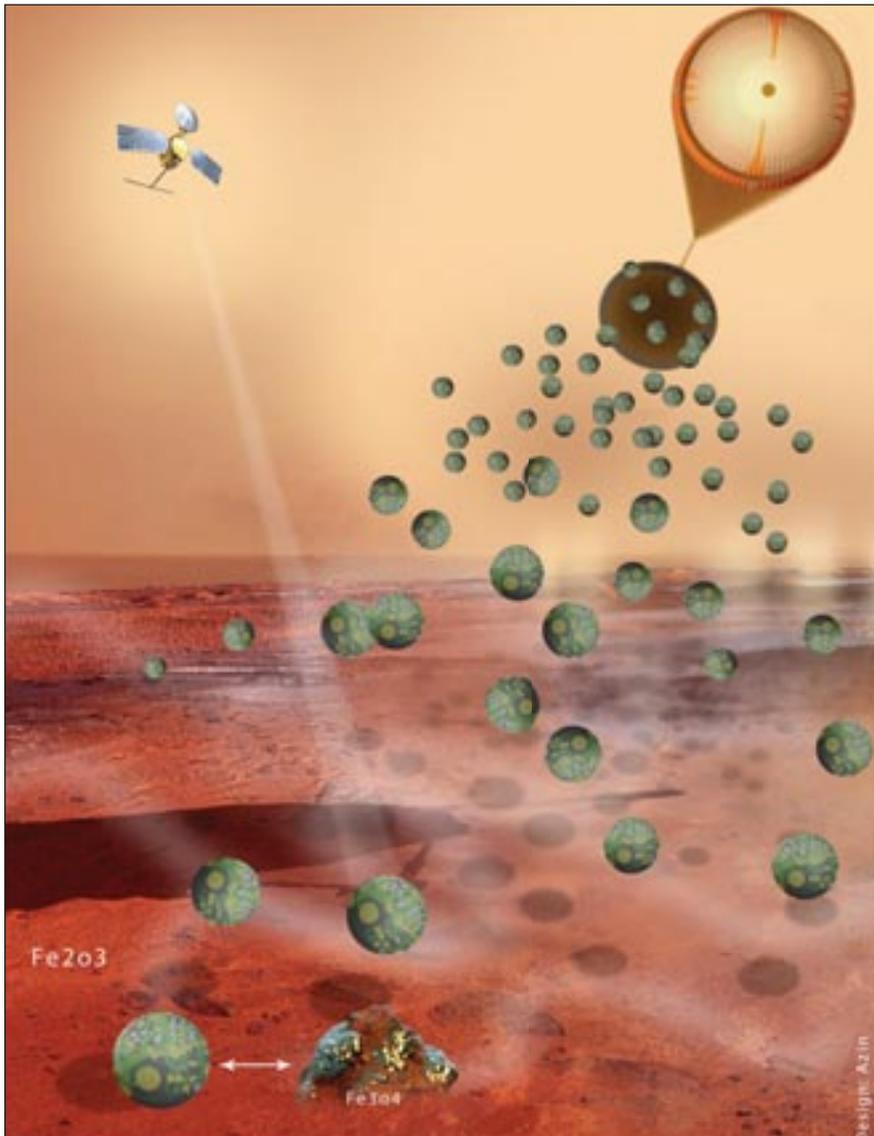
the surface of Mars compared to earlier missions. It could improve the possibility of finding rare phenomena such as "blueberries" or bio-signatures and mapping their occurrence, through random wind-driven search. It would explore difficult terrains that were beyond the reach of previous missions, such as regions with

very steep slopes and cluttered surfaces. GOWON has a potentially long life span, as individual elements can be added to the array periodically. It could potentially provide a cost-effective solution for mapping wide areas of Martian terrain, enabling leaving a long-lasting sensing and searching infrastructure on the surface of Mars.

Thanks to earlier exploration missions, there is a much better understanding of the natural characteristics of Mars; in particular, average wind speeds of 15 to 20 m/s and much higher maximum speeds have been characterized. There are communication satellite systems in place that orbit Mars and that can monitor its surface. Future Mars missions can leverage these characteristics and capabilities, and may do so by exploiting, for example, recent advances in power scavenging techniques, micro-devices using MEMS technologies, miniature instruments, low-power wireless devices, mesh networking technologies, low-power data management strategies, and novel system architectures. The system proposed here addresses this opportunity using such technology advances in a distributed system of wind-driven sensors, referred to as Moballs.

The Moballs could communicate with each other and Earth through a satellite system orbiting Mars. Moballs would also use peer-to-peer communication to create a network of sharing data, computing, and sensing tasks. The Moballs would negotiate with each other locally and share tasks intelligently in order to optimize the entire system's resources (energy, memory, and communication bandwidth).

Moballs would exploit local resources for locomotion and power: they would be wind-driven, and so do not need energy for locomotion. The energy required for sensing, data processing, and communication could be generated from sunlight. In addition, the Moballs could harvest energy from their motion



A depiction of **Moballs** being released on Mars.

and vibrations, thermoelectricity, and other energy scavenging techniques, when they are in shadow. Together this allows each Moball to have a low mass, enabling a large number of Moballs to be deployed by a single mission.

The effectiveness of sensor networks, as opposed to a single sophisticated sensor, is now well understood in a terrestrial setting. Mobile sensor networks are also gaining traction. There exist several proposals, for example, to exploit the accelerometers that exist in handheld cellphones to characterize earthquakes. Here it is the mobility of the cellphone users, the fact that they move about randomly and unpre-

dictably, and that they are in constant contact with base stations that allow this. One can think of GOWON as such a mobile sensor network, making a wide range of measurements distributed across the Martian terrain, and leveraging natural resources and facilities currently in place on Mars, such as existing satellite systems.

GOWON would be a system complementary to current Mars missions, making measurements over a much larger geographic expanse than current *in situ* experiments, providing ground-truth for orbiting experiments, and helping identify promising locations for future manned and unmanned missions.

This work was done by Faranak Davoodi and Neil Murphy of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

*Innovative Technology Assets Management
JPL*

Mail Stop 202-233

4800 Oak Grove Drive

Pasadena, CA 91109-8099

E-mail: iaoffice@jpl.nasa.gov

Refer to NPO-48601, volume and number of this NASA Tech Briefs issue, and the page number.

In Situ Solid Particle Generator

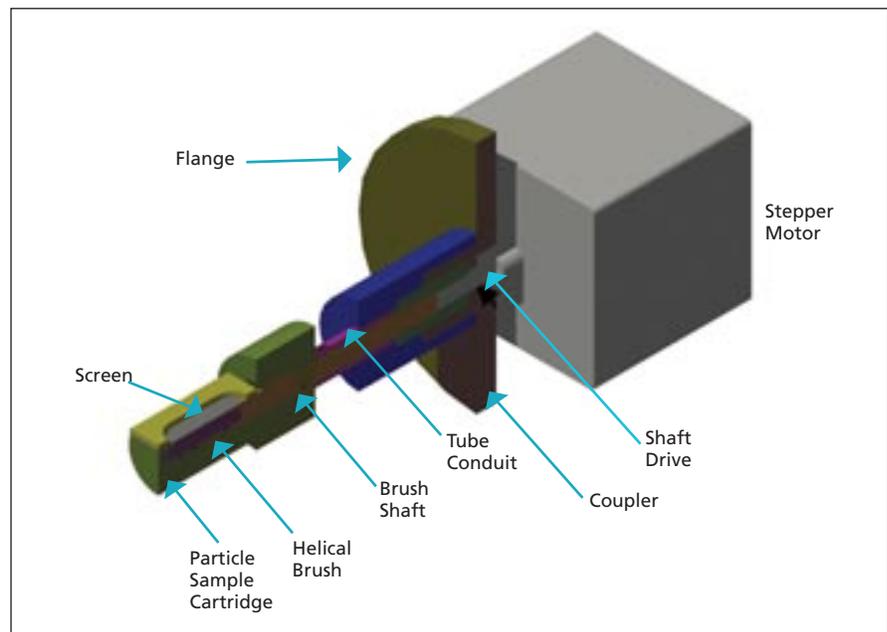
This system enables filter testing, and fluid and gas dynamic research, in closed-system, non-standard, or extreme environments.

John H. Glenn Research Center, Cleveland, Ohio

Particle seeding is a key diagnostic component of filter testing and flow imaging techniques. Typical particle generators rely on pressurized air or gas sources to propel the particles into the flow field. Other techniques involve liquid droplet atomizers. These conventional techniques have drawbacks that include challenging access to the flow field, flow and pressure disturbances to the investigated flow, and they are prohibitive in high-temperature, non-standard, extreme, and closed-system flow conditions and environments.

In this concept, the particles are supplied directly within a flow environment. A particle sample cartridge containing the particles is positioned somewhere inside the flow field. The particles are ejected into the flow by mechanical brush/wiper feeding and sieving that takes place within the cartridge chamber. Some aspects of this concept are based on established material handling techniques, but they have not been used previously in the current configuration, in combination with flow seeding concepts, and in the current operational mode. Unlike other particle generation methods, this concept has control over the particle size range ejected, breaks up agglomerates, and is gravity-independent. This makes this device useful for testing in microgravity environments.

Before any particles can be generated in the flow, the cartridge chamber is



The *In Situ Solid Particle Generator* supplies particles directly within a flow environment.

filled with the solid particles of choice. A programmable mechanical motor providing a range of rotational motion is used to drive a helical brush (or wiper) inside the chamber. Due to the action of the brush, the particles are dragged across the length of the internal chamber, particularly along the surface of the fine mesh screen, causing the particles to pass through the screen. The flow around the cylindrical body of the cartridge then entrains the ejected particles

into the flow stream. System components consist of: a motor, flange supports for mounting and sealing the internal chamber volume, a drive shaft and tube conduit, a particle sample cartridge, a helical wire brush or wiper, a fine mesh screen, and screws (see figure). An optional aerodynamic leading edge can be used to streamline or stabilize the flow around the cartridge body, and to decrease flow effects as the particles are entrained in the flow. Alternately, a turbulence gener-

ating element can be used to accelerate the spreading angle of the particle flow, as a result of turbulent mixing, for more complete particle coverage throughout the flow stream.

The concept provides the additional advantages of unlimited choice of solid particles, including somewhat sharp and abrasive particles; no need for an outside pressurized gas feed source; com-

plete containment and enclosure of the flow environment; and the ability to be used in non-standard (temperature and pressure) environments and closed systems. Additionally, the rate of particle flux and the upper cut size of particles delivered to the flow can be controlled. The particles can also be released and distributed over a broad cross-section of the flow duct/pipe.

This work was done by Juan H. Agui of Glenn Research Center, and R. Vijayakumar of Aerfil. 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-18837-1.

Analysis of the Effects of Streamwise Lift Distribution on Sonic Boom Signature

The objective is to find ways to reduce sonic booms.

Dryden Flight Research Center, Edwards, California

Investigation of sonic boom has been one of the major areas of study in aeronautics due to the benefits a low-boom aircraft has in both civilian and military applications. Current Federal Aviation Administration regulations prohibit supersonic flight over land due to potential effects the sonic boom may have on structures and humans.

This work conducts a numerical analysis of the effects of streamwise lift distribution on the shock coalescence characteristics. A simple wing-canard-stabilator body model is used in the numerical simulation. The streamwise lift distribution is varied by fixing the canard at a deflection angle while trimming the aircraft with the wing and the stabilator at the desired lift coefficient. The lift and the pitching moment coefficients are computed using the Missile DATCOM v. 707. The flow field around the wing-canard-stabilator body model is resolved using the OVERFLOW-2 flow solver. Over-set/chimera grid topology is used to simplify the grid generation of various config-

urations representing different streamwise lift distributions. The numerical simulations are performed without viscosity unless it is required for numerical stability. All configurations are simulated at Mach 1.4, angle-of-attack of 1.50, lift coefficient of 0.05, and pitching moment coefficient of approximately 0. Four streamwise lift distribution configurations were tested.

The pressure signatures are measured at 1.6 body lengths below the aircraft on the symmetry plane of the aircraft. The results to note are the relative location and the strength of the shocks for different configurations. Correlating between the amount of positive lift generated by a lifting surface and the shock location, it is clear to see that shock of the lifting surface that generates more positive lift "arrives" at the measurement point in front of the shocks of lifting surface that generate less positive lift. This observation is valid for all three lifting surfaces. This is clearly evident when comparing the shocks of the wing and canard for

different configurations. The observation is not as clear in the stabilator; however, it is still valid when examining a magnified view of the plot. This shows that lift can directly influence the local Mach angle of shocks. In addition, an observation can be made that the shock of the wing that generates more positive lift is stronger compared to shocks generated from wing with less positive lift.

From the above observation of relationships among the lift, shock strength, local Mach angle, and shock location, it can be reasoned that the shock coalescence can be mitigated if all shocks generated on the aircraft are of equal strength. The shocks of such configuration would propagate at a same angle, which would prevent shock coalescence. Therefore, instead of producing two strong sonic booms, it would produce multiple, weaker sonic booms.

This work was done by Paul Yoo of Dryden Flight Research Center. Further information is contained in a TSP (see page 1), DRC-009-025

Rad-Tolerant, Thermally Stable, High-Speed Fiber-Optic Network for Harsh Environments

Goddard Space Flight Center, Greenbelt, Maryland

Future NASA destinations will be challenging to get to, have extreme environmental conditions, and may present difficulty in retrieving a spacecraft or its data. Space Photonics is developing a radiation-tolerant (rad-tolerant), high-speed, multi-channel fiber-optic transceiver, associated reconfigurable intelligent node communications architecture, and sup-

porting hardware for intravehicular and ground-based optical networking applications. Data rates approaching 3.2 Gbps per channel will be achieved.

The high-speed 3.2-Gbps components, coupled with their Intelligent Node architecture, or universally with other architectures, will allow for orders of magnitude increases in the levels of

automated onboard science data processing. Pure hardware processing capabilities have been achieved with the flexibility of reprogrammability utilizing FPGA control chips in the Intelligent Node architecture. Rad-tolerant versions of the current FPGA being evaluated are available through Xilinx. Due to the high-speed designs and partnerships

with custom laser diode and photodiode manufacturers, total power requirements of the complete four-channel, 2.0-Gbps FireRing products are less than 1.5 Watts. Similar results are anticipated from the proposed 3.2-Gbps development effort. Additional packaging innovations as alternatives to costly hermetic sealing, passive integration, and heat dissipation will also compliment this aspect of the proposed effort.

The ultimate goal of this project will

be the successful design, fabrication, and demonstration of a rad-hard, single-channel, 3.2-Gbps serial fiber-optic transceiver that is universally compatible with virtually all protocols and architectures that interest NASA and the DoD. Key functional attributes and/or improvements beyond the current state of the art in harsh-environment fiber-optic networking components are improved thermal stability, reduced power dissipation, reduced size and mass, special-pur-

pose data processing, reconfigurable computing, protocol-transparent/multi-protocol-compatible, subsystem data transfer, intra-system data transfer, data system support, and proven materials, fabrication, and packaging processes.

This work was done by Matt Leftwich, Tony Hull, Michael Leary, and Marcus Leftwich of Space Photonics, Inc. for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16414-1

Towed Subsurface Optical Communications Buoy

NASA's Jet Propulsion Laboratory, Pasadena, California

The innovation allows critical, high-bandwidth submarine communications at speed and depth. This reported innovation is a subsurface optical communications buoy, with active neutral buoyancy and streamlined flow surface veins for depth control. This novel sub-

surface positioning for the towed communications buoy enables substantial reduction in water-absorption and increased optical transmission by eliminating the intervening water absorption and dispersion, as well as by reducing or eliminating the beam

spread and the pulse spreading that is associated with submarine-launched optical beams.

This work was done by Robert C. Stirbl and William H. Farr of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47737

High-Collection-Efficiency Fluorescence Detection Cell

A relatively compact and economical unit is used for the detection of formaldehyde.

Goddard Space Flight Center, Greenbelt, Maryland

A new fluorescence cell has been developed for the laser induced fluorescence (LIF) detection of formaldehyde. The cell is used to sample a flow of air that contains trace concentrations of formaldehyde. The cell provides a hermetically sealed volume in which a flow of air containing formaldehyde can be illuminated by a laser. The cell includes the optics for transmitting the laser beam that is used to excite the formaldehyde and for collecting the resulting fluorescence. The novelty of the cell is its small size and simple design that provides a more robust and cheaper alternative to the state of the art. Despite its simplicity, the cell provides the same sensitivity to detection as larger, more complicated cells.

Laser induced fluorescence detection uses a laser to excite the atomic or molecular species of interest to a higher energy state. As the excited species relaxes, it fluoresces, i.e., it releases a photon. A photon-counting photomultiplier tube (PMT) is used to detect the emitted photon. The design parameters that determine the sensitivity of LIF detection are

the excitation rate, the fluorescence collection efficiency, and the background from stray laser light. The design used for LIF detection is based on a multipass cell design, such as a White or Herriott cell. In these implementations, two or three mirrors are used to obtain multiple reflections of the laser (30+ passes) within the cell, resulting in increased laser fluence in the detection region and thus, higher detection sensitivity.

A smaller, simpler, and more robust LIF detection cell was designed for a new instrument prototype. The primary consideration in the detection cell is the sensitivity it provides to detecting a species with LIF. The new design forgoes the multipass approach that increases laser fluence. Instead, the focus is on the increased fluorescence collection efficiency and decreased stray light factors. The new fluorescence detection cell uses a single laser pass that is carefully baffled to reduce stray light. The key features in the reduction of stray light are the placement of precision, laser-machined apertures; the use of high-grade black absorptive paint; and

wedged or angled anti-reflection-coated laser windows.

The small detection volume illuminated by the single laser pass allows higher numerical aperture optics to collect the fluorescence. An aspheric lens with NA = 0.66 is used to image the fluorescence on a large-area PMT. The use of the high NA aspheric lens and the placement of the PMT close to the illuminated volume are the key features for the high collection efficiency.

The overall performance of the cell is comparable to the performance of a White-type multipass cell that has 32 passes. The size of the new cell is half the size of a White cell with comparable sensitivity. All components are either off-the-shelf or standard products. No custom optics were used in this design. Most importantly, the cell is extremely simple to adjust or align, and once aligned, it is insensitive to thermal and mechanical distortions.

This work was done by Thomas Hanisco and Maria Cazorla of Goddard Space Flight Center, and Andrew Swanson of the University of Maryland, Baltimore County. Further information is contained in a TSP (see page 1). GSC-16433-1

Ultra-Compact, Superconducting Spectrometer-on-a-Chip at Submillimeter Wavelengths

These spectrometer modules can be used for future astrophysics missions that require compact cryogenic spectrometers.

NASA's Jet Propulsion Laboratory, Pasadena, California

Small size, wide spectral bandwidth, and highly multiplexed detector readout are required to develop powerful multi-beam spectrometers for high-redshift observations. Currently available spectrometers at these frequencies are large and bulky. The grating sizes for these spectrometers are prohibitive. This fundamental size issue is a key limitation for space-based spectrometers for astrophysics applications.

A novel, moderate-resolving-power (R-700), ultra-compact spectrograph-on-a-chip for millimeter and submillimeter wavelengths is the solution. Its very small size, wide spectral bandwidth, and highly multiplexed detector readout will enable construction of powerful multi-beam spectrometers for high-redshift observations. The octave-bandwidth, background-limited performance of this spectrometer is comparable to that of a diffraction grating,

but in a photolithographically developed thin-film package. This novel photolithographic on-chip spectrometer camera is compact, delivering 200 to 500 km/s spectral resolution over an octave bandwidth for hundreds of pixels in the telescope's field of view.

The spectrometer employs a filter bank consisting of planar, lithographed, superconducting transmission line resonators. Each millimeter-wave resonator is weakly coupled to both the feedline and to the inductive portion of a lumped-element microwave kinetic inductance detector (MKID). Incoming millimeter-wave radiation breaks Cooper pairs in the MKID, modifying its kinetic inductance and resonant frequency, allowing for frequency-multiplexed readout. This is realized using thin-film lithographic structures on a silicon wafer, with titanium nitride MKID resonators.

The ultra-compact superconducting spectrometer approach offers the potential for hundreds of individual spectrometers integrated into a 2D focal plane for future ground- and space-based astrophysics instruments.

This work was done by Goutam Chattopadhyay, Jonas Zmuidzinas, Charles M. Bradford, Henry G. Leduc, Peter K. Day, Loren Swenson, Steven Hailey-Dunsheath, Roger C. O'Brient, Stephen Padin, Erik D. Shirokoff, and Christopher McKenney of Caltech; Theodore Reck of ORAU; Jose V. Siles of Fulbright/JPL; Peter Barry, Simon Doyle, and Philip Maukopf of Cardiff University; Nuria Llombart of Universidad Complutense de Madrid; Attila Kovacs of the University of Minnesota; and Dan P. Marrone of the University of Arizona for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48592

UV Resonant Raman Spectrometer With Multi-Line Laser Excitation

NASA's Jet Propulsion Laboratory, Pasadena, California

A Raman spectrometer employs two or more UV (ultraviolet) laser wavelengths to generate UV resonant Raman (UVRR) spectra in organic samples. Resonant Raman scattering results when the laser excitation is near an electronic transition of a molecule, and the enhancement of Raman signals can be several orders of magnitude. In addition, the Raman cross-section is inversely proportional to the fourth power of the wavelength, so the UV Raman emission is increased by another factor of 16, or greater, over visible Raman emissions. The Raman-scattered light is collected using a high-resolution broadband spectrograph. Further suppression of the

Rayleigh-scattered laser light is provided by custom UV notch filters.

The complete Raman instrument is compact and robust, and suitable for *in-situ* chemical analysis. By employing multiple UV lasers at a suitable wavelength spacing, a matrix of resonant Raman bands can be generated for organic compounds in the UV that are distinct and easily resolvable from the fluorescence emission in the visible-wavelength region. The multiple excitation laser wavelengths produce a repeated series of Raman bands, each with the same frequency shifts from the corresponding excitation laser. UV laser excitation, in addition, allows a resonant enhancement of the Raman

scattering in organic compounds such as aromatic hydrocarbons, nucleic acids, and proteins. The multiple excitation wavelengths can be generated from a single UV laser by using stimulated Raman scattering in a hydrogen gas cell. This coherent, multi-wavelength light source has the ideal frequency spacing to maximize spectral coverage and to avoid overlap of adjacent Raman spectra.

This work was done by James L. Lambert, James M. Kohel, James P. Kirby, John Michael Morookian, and Michael J. Pelletier of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47423



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, CA

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 pro-

duce 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 TiO₂, 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 ger-

micidal deposited conformally with ALD. The coating can also be illuminated with ultraviolet light for the purpose of sterilization 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 molecule 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

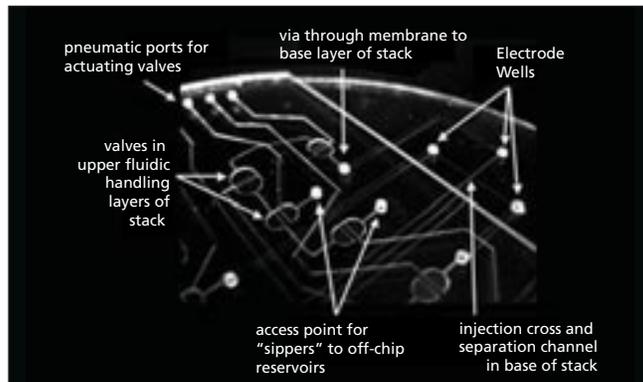


Fig 1 – JPL's Microfluidic Chip for sample preparation, delivery, and analysis.

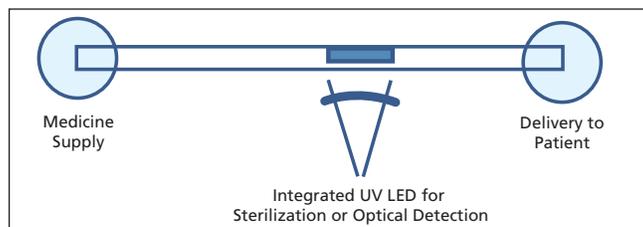


Fig 2 – Schematic of a Microchannel in the medicine delivery device with integrated sterilization or analysis on an extremely high-surface-area template.



Ionospheric Simulation System for Satellite Observations and Global Assimilative Model Experiments — ISOGAME

Modeling helps develop improved systems to study the ionosphere.

NASA's Jet Propulsion Laboratory, Pasadena, California

Modeling and imaging the Earth's ionosphere as well as understanding its structures, inhomogeneities, and disturbances is a key part of NASA's Heliophysics Directorate science roadmap. This invention provides a design tool for scientific missions focused on the ionosphere. It is a scientifically important and technologically challenging task to assess the impact of a new observation system quantitatively on our capability of imaging and modeling the ionosphere. This question is often raised whenever a new satellite system is proposed, a new type of data is emerging, or a new modeling technique is developed. An example is the proposed COSMIC-Follow-On mission (COSMIC stands for Constellation Observing System for Meteorology, Ionosphere, and Climate). The proposed constellation would be part of a new observation system with more low-Earth orbiters tracking more radio occultation signals broadcast by Global Navigation Satellite System (GNSS) than those offered by the current GPS and COSMIC observation system.

A simulation system was developed to fulfill this task. The system is composed of a suite of software that combines the Global Assimilative Ionospheric Model (GAIM) including first-principles and empirical ionospheric models, a multiple-dipole geomagnetic field model, data assimilation modules, observation simulator, visualization software, and orbit design, simulation, and optimization software.

The software system can assess the improvements to GAIM that assimilate data collected using a concerned observing system. The GNSS observation system, for instance, consists of the GNSS constellations that transmit L-band radio signals, low-Earth orbiting GNSS receiver constellations, and ground-based GNSS receiver networks. The satellites and ground networks can be designed with an existing, or any, distribution to meet user requirements, such as achieving global coverage with uniformly distributed observations. Under this system, an empirical ionospheric model or the GAIM physics model simulates a nominal or disturbed ionosphere for a

specific experiment. The observation simulator uses the designed observing scenario (LEO constellations and ground-based receiver networks) to simulate total electron content (TEC) observations along receiver-transmitter radio links. An Observation System Simulation Experiment (OSSE) can then be conducted by assimilating the synthetic observations into GAIM to quantitatively assess the degree of improvement of modeled ionospheric specifications under the observing scenario. The model that is used for data assimilation assessment can differ substantially from the model that is used to simulate the observations. Visualization software is used to examine and analyze the assimilating model's performance.

This work was done by Xiaoping Pi, Anthony J. Mannucci, Olga Verkhoglyadova, Philip Stephens, and Byron A. Iijima 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 Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47626.

Airborne Tomographic Swath Ice Sounding Processing System

This program enables 2D ice thickness measurement.

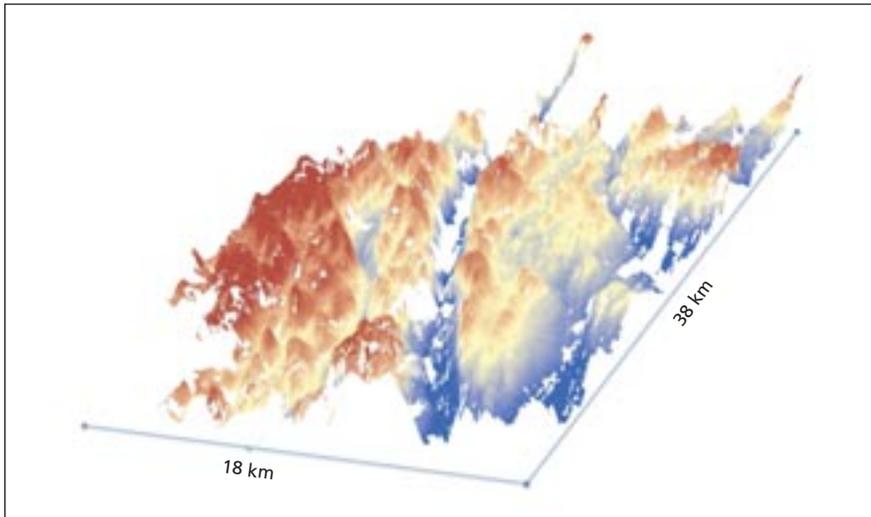
NASA's Jet Propulsion Laboratory, Pasadena, California

Glaciers and ice sheets modulate global sea level by storing water deposited as snow on the surface, and discharging water back into the ocean through melting. Their physical state can be characterized in terms of their mass balance and dynamics. To estimate the current ice mass balance, and to predict future changes in the motion of the Greenland and Antarctic ice sheets, it is necessary to know the ice sheet thickness and the physical conditions of the ice sheet surface and bed. This information is required at fine res-

olution and over extensive portions of the ice sheets.

The ice sheet has two major interfaces: the upper surface interface, between the air and the snow or ice; and the basal interface, between the ice and bedrock or subglacial water. In between, there are internal layers that originate from slight density changes or ancient volcanic deposits. Due to the broad antenna pattern of the sounding radar system, each image resolution cell will contain signals from the left and from the right of the antenna array, and originating from the

surface and from the bed. To resolve these signals and to achieve swath sounding capability, an array of receiving antennas in the cross track direction is used. A tomographic algorithm has been developed to take raw data collected by a multiple-channel synthetic aperture sounding radar system over a polar ice sheet and convert those data into two-dimensional (2D) ice thickness measurements. Prior to this work, conventional processing techniques only provided one-dimensional ice thickness measurements along profiles.



A 3D perspective of the Russell Glacier bed in Greenland produced from the 2011 Ice Bridge mission data using the **Tomographic Processor**.

In this innovative development supported in part by NASA ESTO, airborne tomographic ice sounding technology was used to successfully image the reflectivity and topography of the surface as

well as the reflectivity of the ice sheet base and ice sheet thickness. From the surface topography and ice thickness measurements, the 3D basal topography can be computed. For the first time, one is able

to “see” through kilometers-thick ice sheets and measure the 3D bottom topography and its scattering properties, across a several-kilometers-wide swath. Validation with independent measurements indicates that this technique provides accurate topographic measurement of ice sheet surface and bed, and can be used for local ice sheet bed mapping.

The tomographic sounding processing system is composed of several major modules: a sub-aperture, back-projection azimuth compression with ray-bending correction; a MUSIC/ML arrival angle estimation to estimate surface/bed return arrival angles; and post-processing modules including data regrid and DEM (digital elevation model) mosaic. It produces the ice thickness map and the bedmap as the final product.

This work was done by Xiaqing Wu, Ernesto Rodriguez, and Anthony Freeman of Caltech; and Ken Jezek of Ohio State University for NASA’s Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48638

flexplan: Mission Planning System for the Lunar Reconnaissance Orbiter

The tool can be configured for any mission without the need to modify or re-compile code.

Goddard Space Flight Center, Greenbelt, Maryland

flexplan is a mission planning and scheduling (MPS) tool that uses soft algorithms to define mission scheduling rules and constraints. This allows the operator to configure the tool for any mission without the need to modify or re-compile code. In addition, flexplan uses an ID system to track every output on the schedule to the input from which it was generated. This allows flexplan to receive feedback as the schedules are executed, and update the status of all activities in a Web-based client. flexplan outputs include various planning reports, stored command loads for the Lunar Reconnaissance Orbiter (LRO), ephemeris loads, and pass scripts for automation.

flexplan covers the end-to-end loop of MPS and allows users to adapt the system to their requirements quickly and easily. At the core of flexplan’s scheduling process is a soft algorithm generation engine that requires no recompiling of the tool whenever flight rules change. This engine is largely responsible for the ease of adaptability of flexplan to the different

mission phases, requirements, and styles of planning and scheduling operations. flexplan’s modular architecture allows its components to interact with each other via the database. This allows different components to be run at different times or concurrently by different operators. This architecture also allows flexplan to be easily extended with additional modules to support specific mission requirements or needs. The LRO MPS uses flexplan’s core modules plus additional modules developed using existing flexplan capabilities to support LRO’s flight software memory loads generation and modeling, a slew maneuver planning tool, and Web-based mission status reporting.

The flexplan components are divided into two categories: core components that are modules responsible for the generation of conflict-free schedules, and supporting components that are modules supporting additional requirements for the LRO and for the status awareness of planned activities.

flexplan offers three advantages over existing systems:

1. Use of soft algorithms to define mission scheduling rules and constraints. This allows the operators to define how planning and scheduling is accomplished, without the need for manufacturer modification to the software. All scheduling rules and constraints can be placed under configuration management, allowing the operation team to easily create and use rules for different phases of the mission.
2. Tracking ID. All inputs and outputs into and from flexplan are assigned a unique ID. This allows the operations team to identify the source of scheduled activities. It also allows flexplan to receive execution feedback for all schedule activities and update the activities status on a Web-based client for improved mission awareness.
3. Open XML format for all scheduling inputs. A single XML structure is used to ingest all scheduling inputs, regard-

less of the nature or source of the input. This allows new scheduling inputs to be processed without the need to configure the external interface to a specific input format.

flexplan is also used in the scheduling operations of the LDCM (Landsat Data

Continuity Mission) spacecraft, also at GSFC, which is currently undergoing final mission and ground readiness testing to prepare for upcoming launch in January of 2013, and undergoing customization for operational use in the TDRS (Tracking and Data Relay Satel-

ites) Space Network upgrade project, SGSS, a joint venture between NASA GSFC and WSC.

This work was done by Assaf Barnoy and Theresa Beech of GMV USA for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15558-1

➤ Estimating Torque Imparted on Spacecraft Using Telemetry

Methodology is straightforward and does not involve the use of any complex supporting ground software.

NASA's Jet Propulsion Laboratory, Pasadena, California

There have been a number of missions with spacecraft flying by planetary moons with atmospheres; there will be future missions with similar flybys. When a spacecraft such as Cassini flies by a moon with an atmosphere, the spacecraft will experience an atmospheric torque. This torque could be used to determine the density of the atmosphere. This is because the relation between the atmospheric torque vector and the atmosphere density could be established analytically using the mass properties of the spacecraft, known drag coefficient of objects in free-molecular flow, and the spacecraft velocity relative to the moon. The density estimated in this way could be used to check results measured by science instruments. Since the proposed methodology could estimate disturbance torque as small as 0.02 N-m, it could also be used to estimate disturbance torque imparted on the spacecraft during high-altitude flybys.

When the expected value of torque imparted on the spacecraft is low and

within the control authority of the reaction wheel assemblies (RWAs), mission design engineers will use these RWAs to control the spacecraft attitude. Relative to thrusters, RWA can produce better pointing control and stability performance. To estimate the disturbance torque imparted on the Cassini spacecraft, the proposed methodology exploits the unique and known relation between the disturbance torque and the RWA-based attitude control error during an Enceladus or Titan flyby.

To estimate the disturbance torque imparted on the Cassini spacecraft, the unique and known relation between the disturbance torque and the attitude and attitude rate control errors during an Enceladus flyby (or a Titan flyby) on reaction wheels was used. The effectiveness of this methodology is illustrated using telemetry data obtained from the 50-km Enceladus-3 flyby. Results determined using this approach were compared with those determined using the "time rate of change of spacecraft angular momentum" approach. Results of

this flyby determined that using this new approach compared very well with that estimated using the angular momentum approach. In effect, density estimates made using these two independent engineering methodologies could cross check each other. Moreover, density estimates determined using these methods could also be used to cross check science-based density estimates.

This method could be used to estimate very small torque imparted on the spacecraft. The methodology is straightforward and does not involve the use of any complex supporting ground software. This methodology uses telemetry data that are available at high telemetry frequency, and the telemetry data involved (per-axis attitude control errors and per-axis attitude rate control errors) are floating-point data with high accuracy.

This work was done by Allan Y. Lee, Eric K. Wang, and Glenn A. Macala of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47545

➤ PowderSim: Lagrangian Discrete and Mesh-Free Continuum Simulation Code for Cohesive Soils

John H. Glenn Research Center, Cleveland, Ohio

PowderSim is a calculation tool that combines a discrete-element method (DEM) module, including calibrated interparticle-interaction relationships, with a mesh-free, continuum, SPH (smoothed-particle hydrodynamics) based module that utilizes enhanced, calibrated, constitutive models capable of mimicking both large deformations and the flow behavior of regolith simulants and lunar regolith under condi-

tions anticipated during in situ resource utilization (ISRU) operations.

The major innovation introduced in PowderSim is to use a mesh-free method (SPH-based) with a calibrated and slightly modified critical-state soil mechanics constitutive model to extend the ability of the simulation tool to also address full-scale engineering systems in the continuum sense. The PowderSim software maintains the ability to address

particle-scale problems, like size segregation, in selected regions with a traditional DEM module, which has improved contact physics and electrostatic interaction models.

PowderSim provides answers with comprehensive cohesive-contact models and a new charge-spot model for electrostatic forces arising from localized charge patches on the surfaces and in the interiors of individual particles. For

systems that are too large to be simulated with a discrete element approach, PowderSim incorporates a continuum-based SPH module, which when considering the addition of a calibrated, cohesive, constitutive model (Lunar Regolith Constitutive Model (LRCM)), is a novel use of mesh-free methods. Because of the discrete and continuum methods implemented in the same framework, the software can capture dynamic particulate material behavior at a variety of

spatial scales from the coarse-grain scale (DEM) to the bulk scale (SPH). The DEM capability also supports clustering, which allows it to capture a rich variety of shape detail. Advanced contact models and charge spots capture many effects of contact plasticity and hysteresis, roughness, adhesion, and electrostatic interaction of particles. The SPH capability for bulk material behavior uses the LRCM to capture the critical-state behavior of cohesive lunar regolith.

This work was done by Scott Johnson, Otis Walton, and Randolph Settigast of Grain-flow Dynamics for 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-18801-1.

Multiple-Frame Detection of Subpixel Targets in Thermal Image Sequences

This technique has applicability in fire detection, and tracking ships, ground vehicles, and aircraft.

NASA's Jet Propulsion Laboratory, Pasadena, California

The new technology in this approach combines the subpixel detection information from multiple frames of a sequence to achieve a more sensitive detection result, using only the information found in the images themselves. It is taken as a constraint that the method is automated, robust, and computationally feasible for field networks with constrained computation and data rates. This precludes simply downloading a video stream for pixel-wise co-registration on the ground. It is also important that this method not require precise knowledge of sensor position or direction, because such information is often not available. It is also assumed that the scene in question is approximately planar, which is appropriate for a high-altitude airborne or orbital view.

This approach tracks scene content to estimate camera motion and finds geometric relationships between the images. An initial stage identifies stable image features, or interest points, in

consecutive frames, and uses geometric relationships to estimate a “homography” — a transformation mapping between frames. Interest points generally correspond to regions of high information or contrast. Previous work provides a wide range of interest point detectors. In this innovation, SIFT (Scale Invariant Feature Transform) keypoints recovered by a difference of Gaussians (DoG) operator applied at multiple scales are used. A nearest-neighbor matching procedure identifies candidate matches between frames. The end result of this first step is a list of candidate interest points and descriptors in each frame.

An important benefit of SIFT detection is that the system permits absolute georeferencing based on image contents alone. The SIFT features alone provide sufficient information to geolocate a hot pixel. This suggests an initial characterization phase where the remote observer transmits high-contrast, SIFT descriptors along with images of the (fire-free) sur-

face. The ground system, with possible human assistance, would determine the SIFT features' geographic locations.

During regular operations, the system can query the database to find geographic locations of new observations. Any preferred single- or multiple-channel detection rule is applied independently in each frame with a very lenient threshold. Then, the algorithm matches consecutive detections across potentially large displacements, and associates them into tracks, i.e., unique physical events with a precise geographic location, that may appear in multiple frames. Finally, the system considers the entire sequence history of each track to make the final detection decision.

This work was done by David R. Thompson of Caltech and Robert Kremens of Rochester Institute of Technology for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48129

Metric Learning to Enhance Hyperspectral Image Segmentation

NASA's Jet Propulsion Laboratory, Pasadena, California

Unsupervised hyperspectral image segmentation can reveal spatial trends that show the physical structure of the scene to an analyst. They highlight borders and reveal areas of homogeneity and change. Segmentations are independently helpful for object recognition, and assist with automated production of symbolic maps. Additionally, a good segmentation can dramatically re-

duce the number of effective spectra in an image, enabling analyses that would otherwise be computationally prohibitive. Specifically, using an over-segmentation of the image instead of individual pixels can reduce noise and potentially improve the results of statistical post-analysis.

In this innovation, a metric learning approach is presented to improve the

performance of unsupervised hyperspectral image segmentation. The prototype demonstrations attempt a superpixel segmentation in which the image is conservatively over-segmented; that is, the single surface features may be split into multiple segments, but each individual segment, or superpixel, is ensured to have homogeneous mineralogy.

A segmentation strategy was tested based on the “Felzenszwalb” algorithm for its simplicity and computational efficiency. This approach represents the hyperspectral image as an 8-connected grid of pixels that can begin as independent segments. Edges between nodes represent the distance between neighboring spectra, and each is weighted according to a measure of distance between pixels. The algorithm iteratively joins neighboring pixels together into larger segments, and describes each segment by the minimum spanning tree of edges that joins all segments in the cluster.

Hyperspectral segmentation algorithms partition images into spectrally homogenous regions. However, the exact definition of homogeneity is dependent on the chosen similarity metric. The segmentation algorithm is augmented with a task-specific distance metric. Here, a Mahalanobis distance metric is used, learned from training data. By leveraging a (small) set of labeled pixels with known mineralogical interpretations, the metric suppresses uninformative spectral content. Multiclass linear discriminant analysis (LDA) is used to maximize the ratio of between-class vs. within-class separation, defined by the

Rayleigh quotient computed over labeled training data. Other distance metrics and segmentation strategies are possible, and can be substituted for these choices in modular fashion as different applications demand.

This work was done by David R. Thompson and Rebecca Castano of Caltech, Brian Bue of Rice University, and Martha S. Gilmore of Wesleyan University for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-48092.

Basic Operational Robotics Instructional System

Lyndon B. Johnson Space Center, Houston, Texas

The Basic Operational Robotics Instructional System (BORIS) is a six-degree-of-freedom rotational robotic manipulator system simulation used for training of fundamental robotics concepts, with in-line shoulder, offset elbow, and offset wrist. BORIS is used to provide generic robotics training to aerospace professionals including flight crews, flight controllers, and robotics instructors. It uses forward kinematic and inverse kinematic algorithms to simulate joint and end-effector motion,

combined with a multibody dynamics model, moving-object contact model, and X-Windows based graphical user interfaces, coordinated in the Trick Simulation modeling environment.

The motivation for development of BORIS was the need for a generic system for basic robotics training. Before BORIS, introductory robotics training was done with either the SRMS (Shuttle Remote Manipulator System) or SSRMS (Space Station Remote Manipulator System) simulations. The unique construc-

tion of each of these systems required some specialized training that distracted students from the ideas and goals of the basic robotics instruction.

This work was done by Brian Keith Todd of Johnson Space Center, James Fischer of Titan Systems Corp., and Jane Falgout and John Schweers of L-3 Communications. For further information, contact the JSC Innovation Partnerships Office at (281) 483-3809. MSC-24850-1



Sheet Membrane Spacesuit Water Membrane Evaporator

A document describes a sheet membrane spacesuit water membrane evaporator (SWME), which allows for the use of one common water tank that can supply cooling water to the astronaut and to the evaporator. Test data showed that heat rejection performance dropped only 6 percent after being subjected to highly contaminated water. It also exhibited robustness with respect to freezing and Martian atmospheric simulation testing. Water was allowed to freeze in the water channels during testing that simulated a water loop failure and vapor backpressure valve failure. Upon closing the backpressure valve and energizing the pump, the ice eventually thawed and water began to flow with no apparent damage to the sheet membrane.

The membrane evaporator also serves to de-gas the water loop from entrained gases, thereby eliminating the need for special degassing equipment such as is needed by the current spacesuit system.

As water flows through the three annular water channels, water evaporates with the vapor flowing across the hydrophobic, porous sheet membrane to the vacuum side of the membrane. The rate at which water evaporates, and therefore, the rate at which the flowing water is cooled, is a function of the difference between the water saturation pressure on the water side of the membrane, and the pressure on the vacuum side of the membrane. The primary theory is that the hydrophobic sheet membrane retains water, but permits vapor pass-through when the vapor side pressure is less than the water saturation pressure. This results in evaporative cooling of the remaining water.

This work was done by Grant Bue and Luis Trevino of Johnson Space Center; Felipe Zapata and Paul Dillion of ERC, Inc.; and Juan Castillo, Walter Vonau, Bob Wilkes, Matthew Vogel, and Curtis Frodge of Jacobs Technology. Further information is contained in a TSP (see page 1). MSC-24840-1

Advanced Materials and Manufacturing for Low-Cost, High-Performance Liquid Rocket Combustion Chambers

A document describes the low-cost manufacturing of C103 niobium alloy combustion chambers, and the use of a high-temperature, oxidation-resistant coating that is superior to the standard silicide coating. The manufacturing process involved low-temperature spray deposition of C103 on removable plastic mandrels produced by rapid prototyping. Thin, vapor-deposited platinum-indium coatings were shown to substantially improve oxidation resistance relative to the standard silicide coating.

Development of different low-cost plastic thrust chamber mandrel materials and prototyping processes (selective laser sintering and stereolithography) yielded mandrels with good dimensional accuracy (within a couple of mils) for this stage of development.

The feasibility of using the kinetic metallization cold-spray process for fabrication of free-standing C103 thrusters on removable plastic mandrels was also demonstrated. The ambient and elevated temperature mechanical properties of the material were shown to be reasonably good relative to conventionally processed C103, but the greatest potential benefit is that cold-sprayed chambers require minimal post-process machining, resulting in substantially lower machining and material costs.

The platinum-iridium coating was shown to provide greatly increased oxidation resistance over the silicide when evaluated through oxyacetylene torch testing to as high as 300 °F (≈ 150 °C). The iridium component minimizes reaction with the niobium alloy chamber at high temperatures, and provides the high-temperature oxidation resistance needed at the throat.

This work was done by Brian E. Williams and Victor M. Arrieta of Ultramet for Johnson

Space Center. Further information is contained in a TSP (see page 1). MSC-24495-1

Motor Qualification for Long-Duration Mars Missions

Qualification of motors for deep space under extreme thermal environments to be encountered during the Mars Science Laboratory (MSL) mission is required to verify the reliability and validate mission assurance requirements. The motor assembly must survive all ground operations, plus the nominal 670 Martian-day (or sol) mission that includes summer and winter seasons of the Mars environment. The motor assembly was tested and characterized under extreme temperature conditions with reference to hardware requirements. The motor assembly has been proved to be remarkably robust and displayed no sign of degradation due to the 3 \times (three times per JPL design principles) thermal environmental exposure to the punishing Mars surface operations cycles. The motor characteristics obtained before, during, and post-test comparisons for the surface operations cycles are within measurement error of one another.

The motors withstood/survived 2,010 extreme temperature cycles with a ΔT of 190 °C deep temperature cycles, representing three times the expected thermal cycling exposure during the MSL surface operations. The qualification test hardware elements (A200 motor assembly, encoders, and resolver) have not shown any signs of degradation due to the PQV (Package Qualification and Verification) testing. The test hardware has demonstrated sufficient life to survive the deep thermal cycles associated with MSL mission surface operations for three lives.

This work was done by Rajeshuni Ramesham, Michael R. Johnson, Darren T. Cooper, Warren S. Lau, Kobie T. Boykins, Jonathan D. Perret, and Richard A. Rainen of Caltech; and Andrea Greb of Orbital for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48760



National Aeronautics and
Space Administration