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TECH BRIEFS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

INTRODUCTION

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TECH BRIEFS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technology Focus: Mechanical Components

Mars Science Laboratory Drill

This device also has applications for drilling in mines and other dangerous areas.

NASA's Jet Propulsion Laboratory, Pasadena, California

This drill (see Figure 1) is the primary sample acquisition element of the Mars Science Laboratory (MSL) that collects powdered samples from various types of rock (from clays to massive basalts) at depths up to 50 mm below the surface. A rotary-percussive sample acquisition device was developed with an emphasis on toughness and robustness to handle the harsh environment on Mars. It is the first rover-based sample acquisition device to be flight-qualified (see Figure 2). This drill features an autonomous tool change-out on a mobile robot, and novel voice-coil-based percussion.

The drill comprises seven subelements. Starting at the end of the drill, there is a bit assembly that cuts the rock and collects the sample. Supporting the bit is a subassembly comprising a chuck mechanism to engage and release the new and worn bits, respectively, and a spindle mechanism to rotate the bit. Just aft of that is a percussion mechanism, which generates hammer blows to break the rock and create the dynamic environment used to flow the powdered sample. These components are mounted to a translation mechanism, which provides linear motion and senses weight-on-bit with a force sensor. There is a passive-contact sensor/stabilizer mechanism that secures the drill's position on the rock surface, and flex harness management hardware to provide the power and signals to the translating components. The drill housing serves as the primary structure of the turret, to which the additional tools and instruments are attached.

The drill bit assembly (DBA) is a passive device that is rotated and hammered in order to cut rock (i.e. science targets) and collect the cuttings (powder) in a sample chamber until ready for transfer to the CHIMRA (Collection and Handling for Interior Martian Rock Analysis). The DBA consists of a 5/8-in. (≈1.6-cm) commercial hammer drill bit whose shank has been turned down and machined with deep flutes designed for aggressive cutting removal. Surrounding the shank of the bit is a thick-walled maraging steel collection tube allowing the powdered sample to be augured up the hole into the sample chamber. For robustness, the wall thickness of the DBA was maximized while still ensuring effective sample collection. There are four recesses in the bit tube that are used to retain the fresh bits in their bit box.

The rotating bit is supported by a back-to-back duplex bearing pair within a housing that is connected to the outer DBA housing by two titanium diaphragms. The only bearings on the drill in the sample flow are protected by a spring-energized seal, and an integrated shield that diverts the ingested powdered sample from the moving interface. The DBA diaphragms provide radial constraint of the rotating bit and form the sample chambers. Between the diaphragms there is a sample exit tube from which the sample is transferred to the CHIMRA. To ensure that the entire collected sample is retained, no matter the orientation of the drill with respect to gravity during sampling, the pass-through from the forward to the aft chamber resides opposite to the exit tube.

The drill spindle mechanism (DSM), nested within the chuck/spindle subassembly, provides the torque to rotate the bit for drilling and unlocking the fresh bit assemblies from the bit box. The mechanism is actuated by an electrically commutated gear motor that drives the spindle shaft via a spur gear train. The maximum mean contact stress in the bearings is kept low to prevent lube degradation. Mounted to the shaft is a dirt-tolerant torque coupling that transmits torque to the bit. The coupling accommodates axial, radial, and angular motion between the bit and spindle

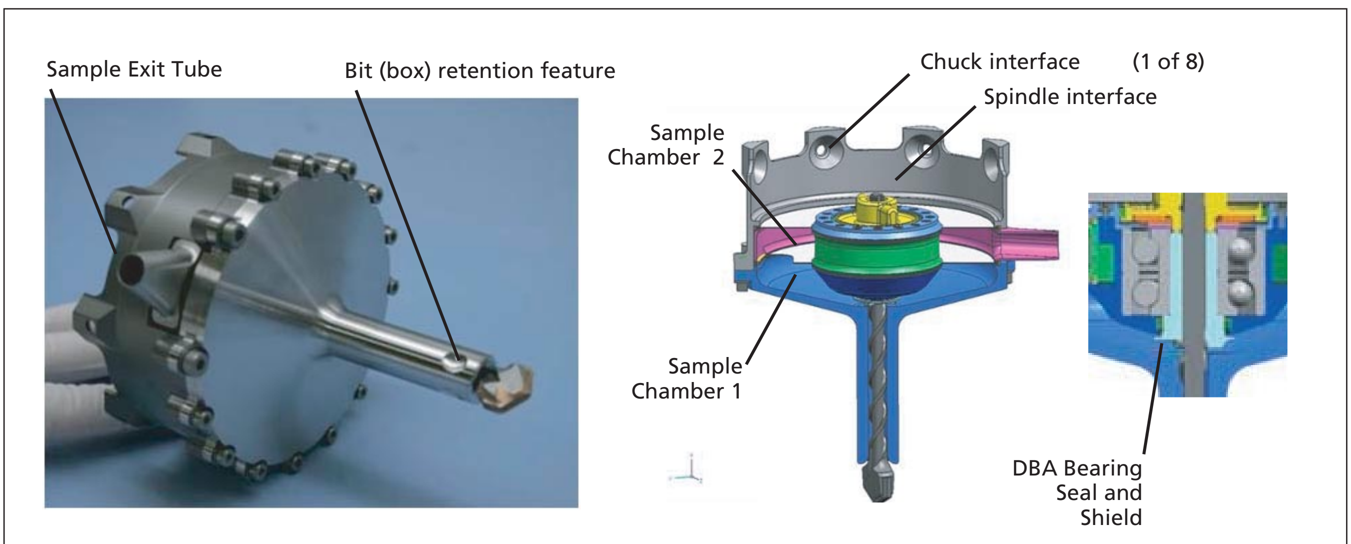

Figure 1. The **Drill Bit Assembly** (left) and **Sample Paths and Interfaces** (right) for the DBA.

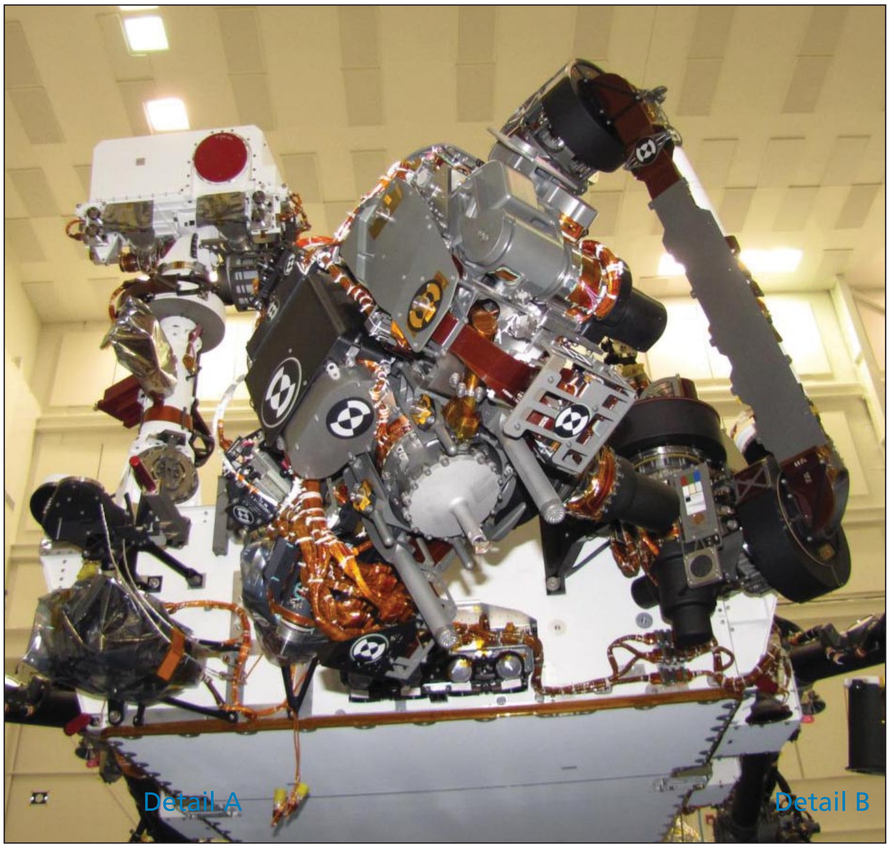

Figure 2. The flight **MSL Drill** undergoing system-level testing after it has been integrated at the end of the robotic arm on the MSL Rover.

shaft to permit the following functions: the transmission of the hammer blow directly onto the bit, the mating of a fresh bit, and release of the bit both in free space and under load.

The drill chuck mechanism (DCM), also residing within the chuck/spindle subassembly, enables the drill to release worn bits and take hold of fresh ones stored on the rover front panel. The design driver was not just to survive a worst-case load scenario — the complete slip of the rover on a Martian slope — but to release the bit while subjected to it.

The drill percussion mechanism (DPM) generates the impact needed to break the rock and the dynamic (vibration) environment required to move powdered sample through the DBA. The mechanism operates at 1,800 blows-per-minute and has variable impact energy levels that range from 0.05 to 0.8 Joules. The DPM is a functionally simple device consisting primarily of a hammer assembly, energy storage spring, and housing/linear bearing assembly. The DPM is actuated by a long-stroke voice coil that is operated using an open loop voltage drive method. Within the DPM is an array of reed switch sensors that provides coarse hammer position telemetry.

The drill translation mechanism (DTM) provides the linear motion of the bit, spindle, chuck, and percussion drill subassemblies for the following functions: maintaining 120 N weight-on-bit (WOB) during sample acquisition, generating the retraction force to extract the bit from the hole, and mating to a fresh bit in the bit box.

The dual-bridge force sensor is required to sense the low WOB because the nominal axial load is too low to be observed in the actuator current telemetry. The inner diameter of the force sensor is axially clamped to the ball nut. The force sensor outer diameter is axially constrained between two preloaded wave springs. The force sensor and wave springs are housed in a gimbal assembly, which couples the translation mechanism to the translation tube. The gimbal isolates the ball screw and force sensor from radial and bending loads.

This work was done by Avi B. Okon, Kyle M. Brown, Paul L. McGrath, Kerry J. Klein, Ian W. Cady, Justin Y. Lin, and Frank E. Ramirez of Caltech, and Matt Haberland of MIT for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47523

Ultra-Compact Motor Controller

Applications include industrial robotic arms, industrial machinery, and automobiles.

Lyndon B. Johnson Space Center, Houston, Texas

This invention is an electronically commutated brushless motor controller that incorporates Hall-array sensing in a small, 42-gram package that provides 4096 absolute counts per motor revolution position sensing. The unit is the size of a miniature hockey puck, and is a 44-pin male connector that provides many I/O channels, including CANbus, RS-232 communications, general-purpose analog and digital I/O (GPIO), analog and digital Hall inputs, DC power input (18–90 VDC, 0–l0 A), three-phase motor outputs, and a strain gauge amplifier.

This controller replaces air cooling with conduction cooling via a high-thermal-conductivity epoxy casting. A secondary advantage of the relatively good heat conductivity that comes with ultra-small size is that temperature differences within the controller become smaller, so that it is easier to measure the hottest temperature in the controller with fewer temperature sensors, or even one temperature sensor.

Another size-sensitive design feature is in the approach to electrical noise immunity. At a very small size, where conduction paths are much shorter than in conventional designs, the ground becomes essentially isopotential, and so certain (space-consuming) electrical noise control components become unnecessary, which helps make small size possible. One winding-current sensor, applied to all of the windings in fast sequence, is smaller and wastes less power than the two or more sensors conventionally used to sense and control winding currents. An unexpected benefit of using only one current sensor is that it actually improves the precision of current control by using the "same" sensors to read each of the three phases. Folding the encoder directly into the controller electronics eliminates a great deal of redundant electronics, packaging, connectors, and hook-up wiring. The reduction of wires and connectors subtracts substantial bulk and eliminates their role in behaving as EMI (electro-magnetic interference) antennas.

A shared knowledge by each motor controller of the state of all the motors in the system at 500 Hz also allows parallel processing of higher-level kinematic matrix calculations.

This work was done by William T. Townsend, Adam Crowell, and Traveler Hauptman of Barrett Technology, Inc., and Gill Andrews Pratt of Olin College for Johnson Space Center. For further information, contact the JSC Innovation Partnerships Office at (281) 483-3809.

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:

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Refer to MSC-23930-1, volume and number of this NASA Tech Briefs *issue, and the page number.*

A Reversible Thermally Driven Pump for Use in a Sub-Kelvin Magnetic Refrigerator

Goddard Space Flight Center, Greenbelt, Maryland

A document describes a continuous magnetic refrigerator that is suited for cooling astrophysics detectors. This refrigerator has the potential to provide efficient, continuous cooling to temperatures below 50 mK for detectors, and has the benefits over existing magnetic coolers of reduced mass because of faster cycle times, the ability to pump the cooled fluid to remote cooling locations away from the magnetic field created by the superconducting magnet, elimination of the added complexity and mass of heat switches, and elimination of the need for a thermal bus and single crystal paramagnetic materials due to the good thermal contact between the fluid and the paramagnetic material.

A reliable, thermodynamically efficient pump that will work at 1.8 K was needed to enable development of the new magnetic refrigerator. The pump consists of two canisters packed with pieces of gadolinium gallium garnet (GGG). The canisters are connected by a superleak (a porous piece of VYCOR® glass). A superconducting magnetic coil surrounds each of the canisters. The configuration enables driving of cyclic thermodynamic cycles (such as the sub-Kelvin Active Magnetic Regenerative Refrigerator) without using pistons or moving parts.

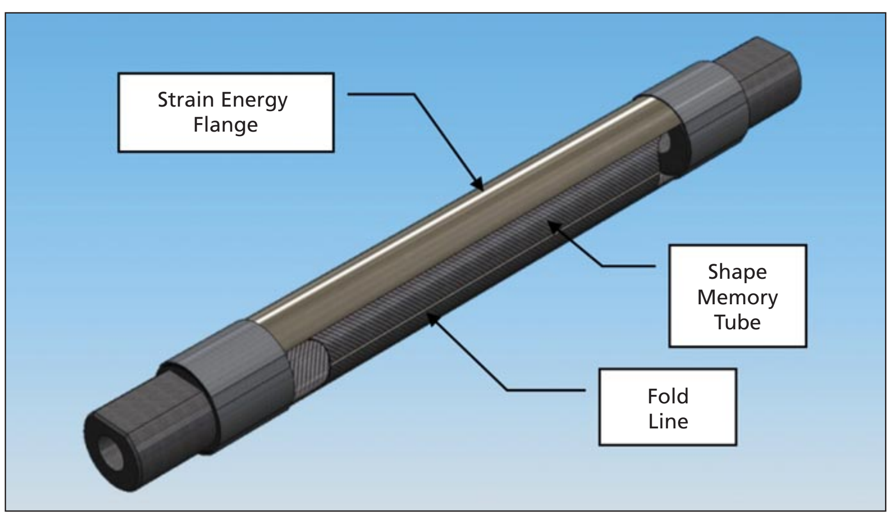
This work was done by Franklin K. Miller of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15573-1

Shape Memory Composite Hybrid Hinge

The hinge can be used for in-space deployment of antennas, reflectors, cameras, solar panels, and sunshields, as well as in any structure requiring hinges.

NASA's Jet Propulsion Laboratory, Pasadena, California

There are two conventional types of hinges for in-space deployment applications. The first type is mechanically deploying hinges. A typical mechanically deploying hinge is usually composed of several tens of components. It is complicated, heavy, and bulky. More components imply higher deployment failure probability. Due to the existence of relatively moving components among a mechanically deploying hinge, it unavoidably has microdynamic problems. The second type of conventional hinge relies on strain energy for deployment. A tape-spring hinge is a typical strain energy hinge. A fundamental problem of a strain energy hinge is that its deployment dynamic is uncontrollable. Usually, its deployment is associated with a large impact, which is unacceptable for many



The **Shape Memory Composite Hybrid Hinge** is composed of two strain energy flanges and one shape memory composite tube.

space applications. Some damping technologies have been experimented with to reduce the impact, but they increased the risks of an unsuccessful deployment.

Coalescing strain energy components with shape memory composite (SMC) components to form a hybrid hinge is the solution. SMCs are well suited for deployable structures. A SMC is created from a high-performance fiber and a shape memory polymer resin. When the resin is heated to above its glass transition temperature, the composite becomes flexible and can be folded or packed. Once cooled to below the glass transition temperature, the composite remains in the packed state. When the structure is ready to be deployed, the SMC component is reheated to above the glass transition temperature, and it returns to its as-fabricated shape.

A hybrid hinge is composed of two strain energy flanges (also called tape-springs) and one SMC tube. Two folding lines are placed on the SMC tube to avoid excessive strain on the SMC during folding. Two adapters are used to connect the hybrid hinge to its adjacent structural components. While the SMC tube is heated to above its glass transition temperature, a hybrid hinge can be folded and stays at folded status after the temperature is reduced to below its glass transition temperature. After the deployable structure is launched in space, the SMC tube is reheated and the hinge is unfolded to deploy the structure. Based on test results, the hybrid hinge can achieve higher than 99.999% shape recovery.

The hybrid hinge inherits all of the good characteristics of a tape-spring hinge such as simplicity, light weight, high deployment reliability, and high deployment precision. Conversely, it eliminates the deployment impact that has significantly limited the applications of a tape-spring hinge. The deployment dynamics of a hybrid hinge are in a slow and controllable fashion. The SMC tube of a hybrid hinge is a multifunctional component. It serves as a deployment mechanism during the deployment process, and also serves as a structural component after the hinge is fully deployed, which makes a hybrid hinge much stronger and stiffer than a tape-spring hinge. Unlike a mechanically deploying hinge that uses relatively moving components, a hybrid hinge depends on material deformation for its packing and deployment. It naturally eliminates the microdynamic phenomenon.

This work was performed by Houfei Fang and Eastwood Im of Caltech, and John Lin and Stephen Scarborough of ILC Dover LP for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48370

Binding Causes of Printed Wiring Assemblies With Card-Loks

Goddard Space Flight Center, Greenbelt, Maryland

A document discusses a study that presents the first documented extraction loads, both nominal and worst-case, and presents the first comprehensive evaluation of extraction techniques, methodologies, and tool requirements relating to extracting printed wiring assemblies (PWAs) with Card-Loks during EVA (extra vehicular activity). This task was performed for the first time during HST (Hubble Space Telescope) Servicing Mission 4.

With impending missions to Mars and to the Moon relying on an astronaut's abilities to perform repair and servicing tasks during EVAs, this study provides some insight into what challenges may be encountered during a repair/replacement of a PWA with Card-Loks. Extraction techniques presented in this study could be applicable to other PWA geometries with similar locking devices. Ground-based extractions also benefit from the techniques and extraction tool requirements presented in the study. The findings highlight techniques that work reliably, efficiently, and provide design requirements for tools necessary for extracting PWAs with Card-Loks on ground.

This work was done by Hans Raven of ATK and Kevin Eisenhower of Alliant Techsystems for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16160-1

Coring Sample Acquisition Tool

NASA's Jet Propulsion Laboratory, Pasadena, California

A sample acquisition tool (SAT) has been developed that can be used autonomously to sample drill and capture rock cores. The tool is designed to accommodate core transfer using a sample tube to the IMSAH (integrated Mars sample acquisition and handling) SHEC (sample handling, encapsulation, and containerization) without ever touching the pristine core sample in the transfer process.

The SAT can be divided into four subelements termed the spindle/percussion assembly (SPA), magnetic chuck assembly (MCA), core bit assembly (CBA), and the core break-off assembly (CBO). The SPA is used to impart the necessary rotational degree of freedom to the CBA to clear cuttings and impart the required impact energy to facilitate rock fracture. The percussive nature of the tool is imparted through the use of an eccentric CAM/lever mechanism. The MCA is designed to actively release the CBA to the SHEC and in air (no load), and passively under large enough side loads, and in air (no load). The magnetic chuck uses two diametrically polarized rings (permanent magnet) stacked one on top of the other. A low-torque actuator is then used to engage or disengage the chuck by aligning or de-aligning the polarized ring poles. The CBA accepts the rotational degree of freedom from the SPA and is used to clear the rock cuttings using a two-lead flute-coring bit. The CBA also transfers the impacts of a striker inside the SPA to the rock being drilled. Furthermore, the coring bit shapes and defines the geometric constraints of the core sample.

Lastly, the CBO is housed inside the CBA and is used to create break-off and capture the core sample. It is actuated through the use of a torque nut that axially retracts an outer tube using an

Acme thread. The outer tube has a series of ramps that drives a set of teeth into the shaped core, fracturing the base of the core and effectively capturing the core within a sample tube. The tool is designed to allow the captured core to be transferred out of the aft portion of the CBA and CBO without ever having to handle the core after capture.

This work was done by Nicolas E. Haddad, Saben D. Murray, Phillip E. Walkemeyer, Mircea Badescu, Stewart Sherrit, Xiaoqi Bao, Kristopher L. Kriechbaum, Megan Richardson, and Kerry J. Klein of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47564

Joining and Assembly of Bulk Metallic Glass Composites Through Capacitive Discharge

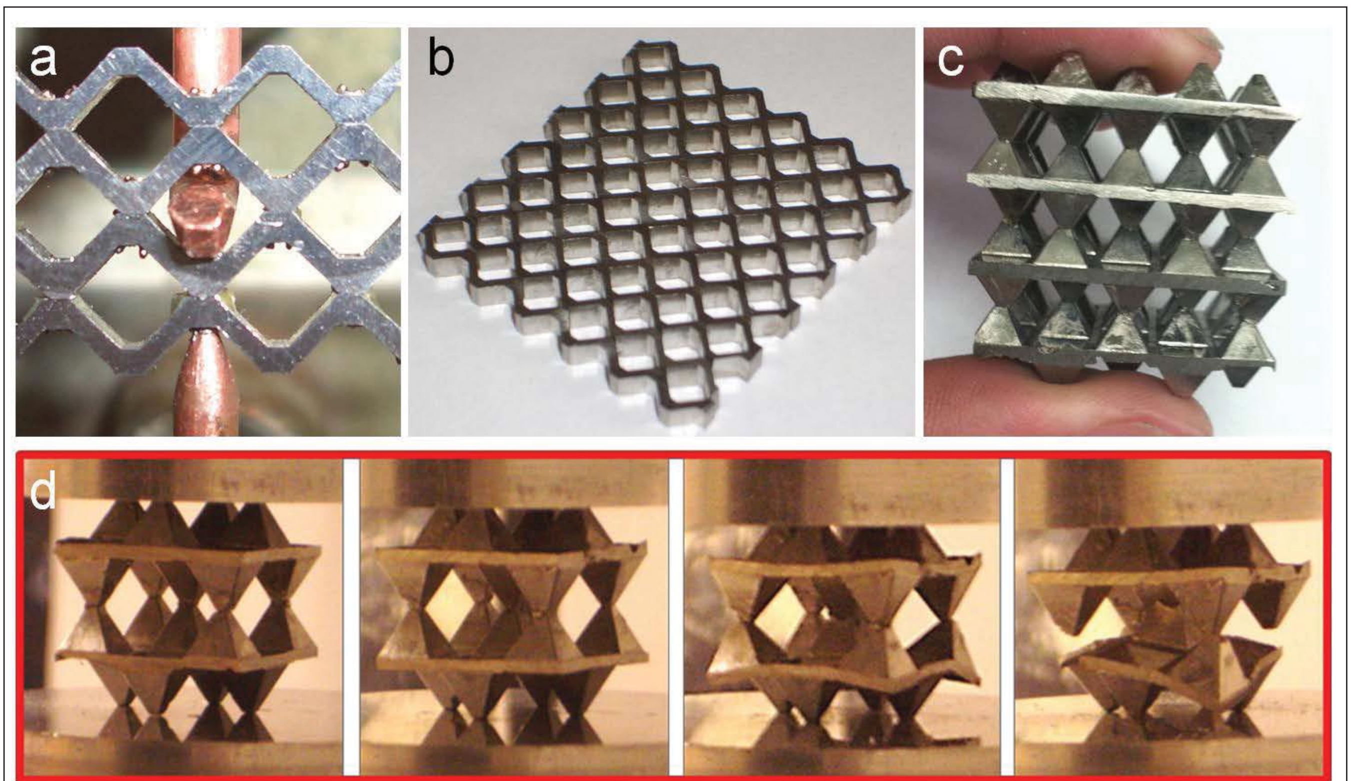
Commercial uses include spacecraft debris shielding, energy-absorbing panels on military vehicles, and sporting goods.

NASA's Jet Propulsion Laboratory, Pasadena, California

Bulk metallic glasses (BMGs), a class of amorphous metals defined as having a thickness greater than 1 mm, are being broadly investigated by NASA for use in spacecraft hardware. Their unique properties, attained from their non-crystalline structure, motivate several game-changing aerospace applications. BMGs have low melting temperatures so they can be cheaply and repeatedly cast into complex net shapes, such as mirrors or electronic casings. They are extremely strong and wear-resistant, which motivates their use in gears and bearings. Amorphous metal coatings are hard, corrosion-resistant, and have high reflectivity. BMG composites, reinforced with soft second phases, can be fabricated into energy-absorbing cellular panels for orbital debris shielding.

One limitation of BMG materials is their inability to be welded, bonded, brazed, or fastened in a convenient method to form larger structures. Cellular structures (which can be classified as trusses, foams, honeycombs, egg boxes, etc.) are useful for many NASA, commercial, and military aerospace applications, including low-density paneling and shields. Although conventional cellular structures exhibit high specific strength, their porous structures make them challenging to fabricate. In particular, metal cellular structures are extremely difficult to fabricate due to their high processing temperatures. Aluminum honeycomb sandwich panels, for example, are used widely as spacecraft shields due to their low density and ease of fabrication, but suffer from low strength.

A desirable metal cellular structure is one with high strength, combined with low density and simple fabrication. The thermoplastic joining process described here allows for the fabrication of monolithic BMG truss-like structures that are 90% porous and have no heat-affected zone, weld, bond, or braze. This is accomplished by welding the nodes of stacked BMG composite panels using a localized capacitor discharge, forming a single monolithic structure. This removes many complicated and costly fabrication steps. Moreover, the cellular structures detailed in this work are among the highest-strength and most energy-absorbent



BMG Features: (a) Enlarged view of capacitive discharging technique used to fuse BMG cellular structures. (b) A BMG composite honeycomb sandwich panel joined using the new technique. (c) A four-layer BMG composite foam fabricated by joining each node of adjacent panels into a single monolithic structure. (d) A compression test in a two-layer welded structure showing buckling and eventual fracture of the welded joints.

materials known. This implies that a fabricated structure made from these materials would have unequaled mechanical properties compared to other metal foams or trusses.

The process works by taking advantage of the electrical properties of the matrix material in the metal-matrix composite, which in this case is a metallic glass. Due to the random nanoscale arrangement of atoms (without any grain boundaries), the matrix glass exhibits a near-constant electrical resistivity as a function of temperature. By placing the composite panels between two copper electrode plates and discharging a capacitor, the entire matrix of the panel can be heated to approximately 700 °C in 10 milliseconds, which is above the alloy's solidus but below the liquidus. By designing the geometry of the panels into the shape of an egg box, the electrical discharge localizes only in the tips of each pyramidal cell. By applying a forging load during discharge, the nodes of the panels can be fused together into a single piece, which then dissipates heat through radiation back into a glassy state. This means that two panels can be metallurgically fused into one panel with no heat-affected zone, creating a seamless connection between panels. During the process, the soft metal particles (dendrites) that are uniformly distributed in the glassy matrix to increase the toughness are completely unaffected by the thermoplastic joining. The novelty is that a truss (or foam-like) structure can be formed with excellent energy-absorbing capabilities without the need for machining. The technique allows for large-scale fabrication of panels, well-suited for spacecraft shields or military vehicle door panels.

Crystalline metal cellular structures cannot be fabricated using the thermoplastic joining technique described here. If metal panels were to be assembled into a cellular structure, they would either have to be welded, brazed, bonded, or fastened together, creating a weak spot in the structure at each connection. Welded parts require a welding material to be added to the joint and exhibit a soft and weak heat-affected zone. Brazing and bonding do not form a metallurgical joint and thus exhibit low strengths, especially when the panels are pulled apart and fasteners require high-stress-concentration holes to be drilled. No equivalent rapid heating method exists for assembling metal panels together into cellular structures, and thus, those parts must be foamed, machined, or investment cast if they are to form a monolithic structure. If the crystalline panels were to be joined using capacitive discharge, as with a spot welder, their bond would be very weak, and the panels would have to be extremely thin. In contrast, the strength of joined BMG parts has been demonstrated to have strength comparable to the parent material. This technique opens up the possibility of using large-scale BMG hardware in spacecraft, military, or commercial applications.

This work was done by Douglas C. Hofmann, Scott Roberts, Henry Kozachkov, Marios D. Demetriou, Joseph P. Schramm, and William L. Johnson 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 rightsfor its commercial use should be addressed to:

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Refer to NPO-48047, volume and number of this NASA Tech Briefs *issue, and the page number.*

670-GHz Schottky Diode-Based Subharmonic Mixer With CPW Circuits and 70-GHz IF

This technology can be used in terahertz imaging applications.

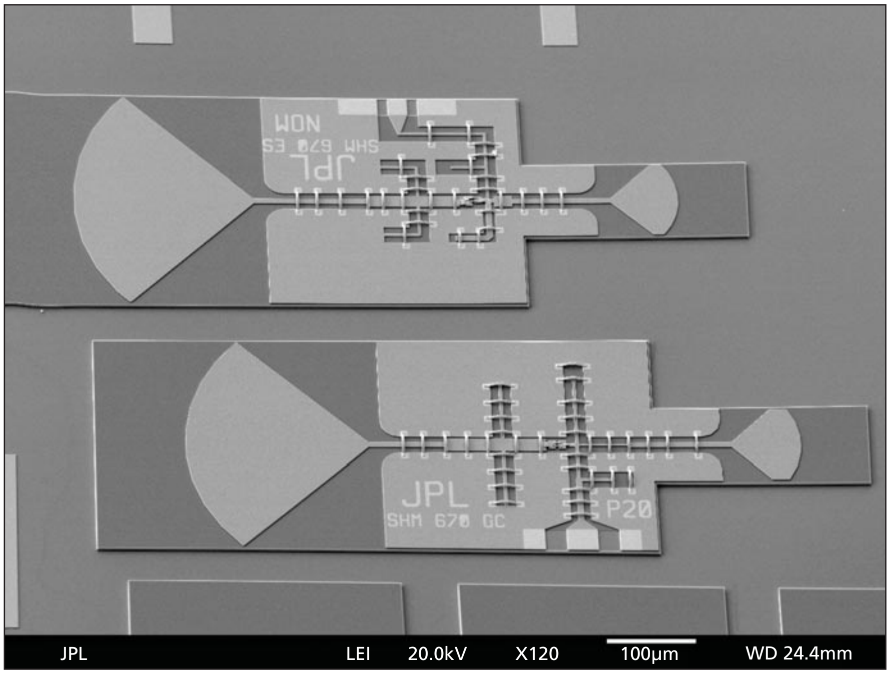
NASA's Jet Propulsion Laboratory, Pasadena, California

GaAs-based, sub-harmonically pumped Schottky diode mixers offer a number of advantages for array implementation in a heterodyne receiver system. Since the radio frequency (RF) and local oscillator (LO) signals are far apart, system design becomes much simpler.

A proprietary planar GaAs Schottky diode process was developed that results in very low parasitic anodes that have cutoff frequencies in the tens of terahertz. This technology enables robust implementation of monolithic mixer and frequency multiplier circuits well into the terahertz frequency range. Using optical and e-beam lithography, and conventional epitaxial layer design with innovative usage of GaAs membranes and metal beam leads, high-performance terahertz circuits can be designed with high fidelity.

All of these mixers use metal waveguide structures for housing. Metal machined structures for RF and LO coupling hamper these mixers to be integrated in multi-pixel heterodyne array receivers for spectroscopic and imaging applications. Moreover, the recent developments of terahertz transistors on InP substrate provide an opportunity, for the first time, to have integrated amplifiers followed by Schottky diode mixers in a heterodyne receiver at these frequencies. Since the amplifiers are developed on a planar architecture to facilitate multi-pixel array implementation, it is quite important to find alternative architecture to waveguide-based mixers.

Transmission lines such as microstrips and striplines are very lossy at terahertz frequencies, and therefore have a detrimental effect on the performance of Schottky diode mixers, and they have higher conversion loss and noise temperatures. These mixers were designed using CPW coupling structures, which have lower loss and are more amenable to planar architecture and higher level of integration. CPW lines were used to couple the RF and LO signal to a pair of anti-parallel diodes. The LO is injected from one end where there is a CPW impedance-matching network and a quarter-wavelength short-circuited stub (at the LO frequency), which shorts the RF at the LO end of the circuit. On the RF end, there is a CPW impedance-matching network and an open-circuited, quarter-wavelength stub (at the LO frequency), which acts as a short at the LO frequency at the RF end of the circuit. The IF is taken out through a CPW filter from the RF end of the diodes.



A photograph of the fabricated **Subharmonic Mixer** devices.

In an integrated receiver system, the CPW lines — both for the RF and LO — can directly connect to low-noise amplifiers for the RF and frequency multiplier output for the LO.

Most of the reported results for subharmonic mixers at 670 GHz use low-loss waveguide coupling structures and metal housing. At the time of this reporting, this is the first time a planar CPW topology has been used to design and develop a subharmonic mixer at these frequencies. This design architecture easily leads to seamless integration with planar CPW amplifiers and can be used for multi-pixel heterodyne arrays.

This work was done by Goutam Chattopadhyay, Erich T. Schlecht, Choonsup Lee, Robert H. Lin, John J. Gill, Imran Mehdi, and Seth Sin of Caltech; and William Deal, Kwok K. Loi, Peta Nam, and Bryan Rodriguez of Northrop Grumman 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:

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Refer to NPO-48021, volume and number of this NASA Tech Briefs *issue, and the page number.*

Self-Nulling Lock-in Detection Electronics for Capacitance Probe Electrometer

NASA's Jet Propulsion Laboratory, Pasadena, California

A multi-channel electrometer voltmeter that employs self-nulling lock-in detection electronics in conjunction with a mechanical resonator with noncontact voltage sensing electrodes has been developed for space-based measurement of an Internal Electrostatic Discharge Monitor (IESDM). The IESDM is new sensor technology targeted for integration into a Space Environmental Monitor (SEM) subsystem used for the characterization and monitoring of deep dielectric charging on spacecraft.

Use of an AC-coupled lock-in amplifier with closed-loop sense-signal nulling via generation of an active guard-driving feedback voltage provides the resolution, accuracy, linearity and stability needed for long-term space-based measurement of the IESDM. This implementation relies on adjusting the feedback voltage to drive the sense current received from the resonator's variable-capacitance-probe voltage transducer to approximately zero, as limited by the signal-to-noise performance of the loop electronics. The magnitude of the sense current is proportional to the difference between the input voltage being measured and the feedback voltage, which matches the input voltage when the sense current is zero. High signal-to-noise-ratio (SNR) is achieved by synchronous detection of the sense signal using the correlated reference signal derived from the oscillator circuit that drives the mechanical resonator. The magnitude of the feedback voltage, while the loop is in a settled state with essentially zero sense current, is an accurate estimate of the input voltage being measured. This technique has many beneficial attributes including immunity to drift, high linearity, high SNR from synchronous detection of a single-frequency carrier selected to avoid potentially noisy 1/f low-frequency spectrum of the signal-chain electronics, and high accuracy provided through the benefits of a driven shield encasing the capacitance-probe transducer and guarded input triaxial lead-in.

Measurements obtained from a 2-channel prototype electrometer have demonstrated good accuracy ($|\text{error}| < 0.2$ V) and high stability. Twenty-four-hour tests have been performed with virtually no drift. Additionally, 5,500 repeated one-second measurements of 100 V input were shown to be approximately normally distributed with a standard deviation of 140 mV.

This work was done by Brent R. Blaes and Rembrandt T. Schaefer of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47339

Discontinuous Mode Power Supply

Goddard Space Flight Center, Greenbelt, Maryland

A document discusses the changes made to a standard push-pull inverter circuit to avoid saturation effects in the main inverter power supply. Typically, in a standard push-pull arrangement, the unsymmetrical primary excitation causes variations in the volt second integral of each half of the excitation cycle that could lead to the establishment of DC flux density in the magnetic core, which could eventually cause saturation of the main inverter transformer.

The relocation of the filter reactor normally placed across the output of the power supply solves this problem. The filter reactor was placed in series with the primary circuit of the main inverter transformer, and is presented as impedance against the sudden changes on the input current. The reactor averaged the input current in the primary circuit, avoiding saturation of the main inverter transformer. Since the implementation of the described change, the above problem has not reoccurred, and failures in the main power transistors have been avoided.

This work was done by John Lagadinos and Ethel Poulos of Pulse Systems, Inc. for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16281-1

Optimal Dynamic Sub-Threshold Technique for Extreme Low Power Consumption for VLSI

This technique approaches increased chip density with lower power consumption.

NASA's Jet Propulsion Laboratory, Pasadena, California

For miniaturization of electronics systems, power consumption plays a key role in the realm of constraints. Considering the very large scale integration (VLSI) design aspect, as transistor feature size is decreased to 50 nm and below, there is sizable increase in the number of transistors as more functional building blocks are embedded in the same chip. However, the consequent increase in power consumption (dynamic and leakage) will serve as a key constraint to inhibit the advantages of transistor feature size reduction.

Power consumption can be reduced by minimizing the voltage supply (for dynamic power consumption) and/or increasing threshold voltage (V_{th}, for reducing leakage power). When the feature size of the transistor is reduced, supply voltage (V_{dd}) and threshold voltage (V_{th}) are also reduced accordingly; then, the leakage current becomes a bigger factor of the total power consumption. To maintain low power consumption, operation of electronics at sub-threshold levels can be a potentially strong contender; however, there are two obstacles to be faced: more leakage current per transistor will cause more leakage power consumption, and slow response time when the transistor is operated in weak inversion region.

To enable low power consumption and yet obtain high performance, the CMOS (complementary metal oxide semiconductor) transistor as a basic element is viewed and controlled as a four-terminal device: source, drain, gate, and body, as differentiated from the traditional approach with three terminals: i.e., source and body, drain, and gate.

This technique features multiple voltage sources to supply the dynamic control, and uses dynamic control to enable low-threshold voltage when the channel (N or P) is active, for speed response enhancement and high threshold voltage, and when the transistor channel (N or P) is inactive, to reduce the leakage current for low-leakage power consumption.

This work was done by Tuan A. Duong of Caltech 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:

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Refer to NPO-47337, volume and number of this NASA Tech Briefs *issue, and the page number.*

Hardware for Accelerating N-Modular Redundant Systems for High-Reliability Computing

Goddard Space Flight Center, Greenbelt, Maryland

A hardware unit has been designed that reduces the cost, in terms of performance and power consumption, for implementing N-modular redundancy (NMR) in a multiprocessor device. The innovation monitors transactions to memory, and calculates a form of sumcheck on-the-fly, thereby relieving the processors of calculating the sumcheck in software.

This sumcheck could be calculated using addition operations, or CRC-type (cyclic redundancy check) operations — whichever is most economical in terms of die area and power consumption. In each of the NMR systems, the sumcheck logic is initialized at the start of a task (a well-defined unit of work that will be performed by each of the NMR systems), then captured and transmitted to the vote-taker at the end of the task. The vote-taker compares the sumchecks, determines if errors have occurred, and what action, if any, should be taken to correct the errors.

The advantage over existing techniques is that minimal logic is required to implement the sumcheck unit, minimal power is consumed by the sumcheck unit when active, and the unit can have a reduced power sleep mode when inactive. Calculating a sumcheck for a task using the sumcheck unit requires no additional cycles, and so has lower latency than calculating it as a post-task in the processing unit.

This work was done by Keith Bindloss and Carl Dobbs, Sr. of Coherent Logix for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16324-1

Materials & Coatings

Blocking Filters With Enhanced Throughput for X-Ray Microcalorimetry

Polyimide replaces the standard metal mesh.

Goddard Space Flight Center, Greenbelt, Maryland

New and improved blocking filters (see figure) have been developed for microcalorimeters on several mission payloads, made of high-transmission polyimide support mesh, that can replace the nickel mesh used in previous blocking filter flight designs. To realize the resolution and signal sensitivity of today's x-ray microcalorimeters, significant improvements in the blocking filter stack are needed.

Using high-transmission polyimide support mesh, it is possible to improve overall throughput on a typical microcalorimeter such as Suzaku's X-ray Spectrometer by 11%, compared to previous flight designs. Using polyimide to replace standard metal mesh means the mesh will be transparent to energies 3 keV and higher. Incorporating polyimide's advantageous strength-to-weight ratio, thermal stability, and transmission characteristics permits thinner filter materials, significantly enhancing throughput. A prototype contamination blocking filter for ASTRO-H has passed QT-level acoustic testing. Resistive traces can also be incorporated to provide decontamination capability to actively restore filter performance in orbit.

SUVI (Solar Ultraviolet Imager) Entrance Filter Prototype —150 nm Al on 70 lpi polyimide mesh and an ASTRO-H DMS filter prototype — 80 nm Al on 100 nm polyimide with 70 lpi polyimide mesh.

This work was done by David Grove, Jacob Betcher, and Mark Hagen of Luxel Corp. for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16292-1

High-Thermal-Conductivity Fabrics

Applications include cooling garments for firefighters, hazmat personnel, soldiers, and in cooling vests for multiple sclerosis patients.

Lyndon B. Johnson Space Center, Houston, Texas

Heat management with common textiles such as nylon and spandex is hindered by the poor thermal conductivity from the skin surface to cooling surfaces. This innovation showed marked improvement in thermal conductivity of the individual fibers and tubing, as well as components assembled from them.

The problem is centered on improving the heat removal of the liquid-cooled ventilation garments (LCVGs) used by astronauts. The current design uses an extensive network of water-cooling tubes that introduces bulkiness and discomfort, and increases fatigue. Range of motion and ease of movement are affected as well. The current technology is the same as developed during the Apollo program of the 1960s. Tubing material is hand-threaded through a spandex/nylon mesh layer, in a series of loops throughout the torso and limbs such that there is close, form-fitting contact with the user. Usually, there is a nylon liner layer to improve comfort. Circulating water is chilled by an external heat exchanger (sublimator).

The purpose of this innovation is to produce new LCVG components with improved thermal conductivity. This was addressed using nanocomposite engineering incorporating high-thermal-conductivity nanoscale fillers in the fabric and tubing components. Specifically, carbon nanotubes were added using normal processing methods such as thermoplastic melt mixing (compounding twin screw extruder) and downstream processing (fiber spinning, tubing extrusion). Fibers were produced as yarns and woven into fabric cloths. The application of isotropic nanofillers can be modeled using a modified Nielsen Model for conductive fillers in a matrix based on Einstein's viscosity model.

This is a drop-in technology with no additional equipment needed. The loading is limited by the ability to maintain adequate dispersion. Undispersed materials will plug filtering screens in processing equipment. Generally, the viscosity increases were acceptable, and allowed the filled polymers to still be processed.

The novel feature is that fabrics do not inherently possess good thermal conductivity. In fact, fabrics are used for thermal insulation, not heat removal. The technology represents the first material that is a wearable fabric, based on company textiles and materials that will significantly conduct heat.

This work was done by L. P. Felipe Chibante of NanoTex Corporation 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:

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Refer to MSC-24389-1, volume and number of this NASA Tech Briefs *issue, and the page number.*

Imidazolium-Based Polymeric Materials as Alkaline Anion-Exchange Fuel Cell Membranes

Polymer electrolyte membrane fuel cells can be used for portable power sources.

NASA's Jet Propulsion Laboratory, Pasadena, California

Polymer electrolyte membranes that conduct hydroxide ions have potential use in fuel cells. A variety of polystyrene-based quaternary ammonium hydroxides have been reported as anion exchange fuel cell membranes. However, the hydrolytic stability and conductivity of the commercially available membranes are not adequate to meet the requirements of fuel cell applications. When compared with commercially available membranes, polystyrene-imidazolium alkaline membrane electrolytes are more stable and more highly conducting. At the time of this reporting, this has been the first such usage for imidazolium-based polymeric materials for fuel cells.

Imidazolium salts are known to be electrochemically stable over wide potential ranges. By controlling the relative ratio of imidazolium groups in polystyrene-imidazolium salts, their physiochemical properties could be modulated.

Alkaline anion exchange membranes based on polystyrene-imidazolium hydroxide materials have been developed. The first step was to synthesize the poly(styrene-co-(1-((4-vinyl)methyl)-3-methylimidazolium) chloride through a free-radical polymerization. Casting of this material followed by *in situ* treatment of the membranes with sodium hydroxide solutions provided the corresponding hydroxide salts. Various ratios of the monomers 4-chloromoethylvinylbenzine (CMVB) and vinylbenzine (VB) provided various compositions of the polymer. The preferred material, due to the relative ease of casting the film, and its relatively low hygroscopic nature, was a 2:1 ratio of CMVB to VB.

Testing confirmed that at room temperature, the new membranes outperformed commercially available membranes by a large margin. With fuel cells now in use at NASA and in transportation, and with defense potential, any improvement to fuel cell efficiency is a significant development.

This work was done by Sri R. Narayan and Shiao-Ping S. Yen of Caltech, and Prakash V. Reddy and Nanditha Nair of Missouri University of Science and Technology for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-46457

Electrospun Nanofiber Coating of Fiber Materials: A Composite Toughening Approach

Companies could apply this technology in producing fabric products for use in composite manufacturing.

John H. Glenn Research Center, Cleveland, Ohio

Textile-based composites could significantly benefit from local toughening using nanofiber coatings. Nanofibers, thermoplastic or otherwise, can be applied to the surface of the fiber tow bundle, achieving toughening of the fiber tow contact surfaces, resulting in tougher and more damage-resistant/tolerant composite structures. The same technique could also be applied to other technologies such as tape laying, fiber placement, or filament winding operations. Other modifications to the composite properties such as thermal and electrical conductivity could be made through selection of appropriate nanofiber material.

Investigations of the failure and damage mechanisms of textile composites has led to the conclusion that toughening of the matrix material would result in increased material performance. Several approaches exist in which the bulk of the matrix is modified either through chemical formulation or the addition of fillers. These methods can detrimentally affect the processability of the resulting matrix material. Other methods exist that rely on modification of the fiber material (so-called "fuzzy fiber" approaches) that results in reduced fiber performance.

Control of the needle electric potential, precursor solution, ambient temperature, ambient humidity, airflow, etc., are used to vary the diameter and nanofiber coating morphology as needed. Post-coating heat treatments may also be used for the purpose of curing, drying, oxidation, annealing, etc. The array of electrospinning jets may be varied as needed to achieve uniform, quality coatings, and may involve the controlled use of gas flow to direct nanofiber deposition. An adhesive coating may also be applied (pre- or post-application) to the receiving material to enhance the mechanical stability of the nanofiber coating. Additionally, any number of different nanofiber materials can be simultaneously applied.

This method produces a product with a toughening agent applied to the fiber tow or other continuous composite precursor material where it is needed (at interfaces and boundaries) without interfering with other composite processing characteristics.

This work was done by Lee W. Kohlman and Gary D. Roberts of Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18844-1.

Bio-Medical

Experimental Modeling of Sterilization Effects for Atmospheric Entry Heating on Microorganisms

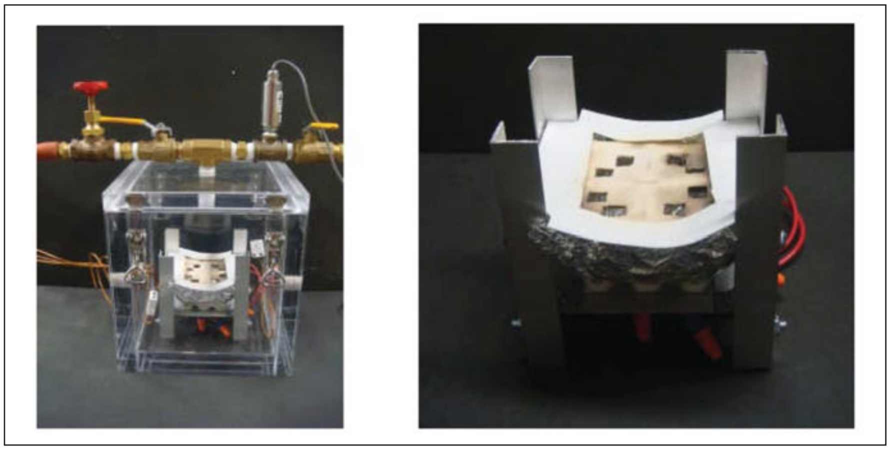
Silicon was chosen for sample coupons.

NASA's Jet Propulsion Laboratory, Pasadena, California

The objective of this research was to design, build, and test an experimental apparatus for studying the parameters of atmospheric entry heating, and the inactivation of temperature-resistant bacterial spores. The apparatus is capable of controlled, rapid heating of sample coupons to temperatures of 200 to 350 °C and above. The vacuum chamber permits operation under vacuum or special atmospheric gas mixtures.

A radiant heating system using tungsten-halogen lamps was chosen to heat the spores to the desired temperatures. This method of heating was preferred because there was no physical contact between the heater and the sample coupons, the radiant heat can be controlled more precisely than heating methods by conduction and convection, and halogen light bulbs are readily available. The design allowed for the bulbs to radiantly heat the backside of the sample coupons, avoiding possible sterilization of the spores by a method other than just heating, such as ultraviolet radiation.

The material chosen for the sample coupons was silicon, due to its favorable properties for this application. Silicon is chemically and biologically inert, and has very high thermal conductivity. Furthermore, silicon has high emissivity in the visible and near-infrared portion of the electromagnetic spectrum, and has a lower emissivity in the mid-infrared range. This means that the silicon coupons are able to absorb a significant portion of the radiation output by the halogen light bulbs, but not re-radiate much mid-infrared radiation at the sample temperatures. This unique property of silicon allows for the sample coupons to be heated very quickly and accurately using the radiant heat from the halogen light bulbs. Furthermore, due to the widespread use of silicon in the microelectronics industry, silicon was available in very thin wafers. The low thermal mass of the thin wafers helped them heat up very quickly.



The **Experimental Apparatus** consists of a vacuum chamber (left) and the stand for the silicon chips (right).

This work was done by Wayne W. Schubert and James A. Spry of Caltech; Paul D. Ronney and Nathan R. Pandian of the University of Southern California; and Eric Welder of Stanford University for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48091

Saliva Preservative for Diagnostic Purposes

This preservative can be used in remote areas without refrigeration for at least two months.

Lyndon B. Johnson Space Center, Houston, Texas

Saliva is an important body fluid for diagnostic purposes. Glycoproteins, glucose, steroids, DNA, and other molecules of diagnostic value are found in saliva. It is easier to collect as compared to blood or urine. Unfortunately, saliva also contains large numbers of bacteria that can release enzymes, which can degrade proteins and nucleic acids. These degradative enzymes destroy or reduce saliva's diagnostic value. This innovation describes the formulation of a chemical preservative that prevents microbial growth and inactivates the degradative enzymes. This extends the time that saliva can be stored or transported without losing its diagnostic value. Multiple samples of saliva can be collected if needed without causing discomfort to the subject and it does not require any special facilities to handle after it is collected.

The preservative contains sodium dodecyl sulfate (SDS), ethylenediaminetetraacetic acid (EDTA), and Tris buffer. This preservative was developed to preserve saliva from astronauts during spaceflight without refrigeration to determine if virus DNA was present. Saliva with added preservative can be stored at room temperature for up to 60 days without any measureable degradation. Viral DNA is routinely measured from saliva stored in this manner without refrigeration. Thus, this preservative can be used to preserve critical macromolecules (nucleic acids and proteins) without consuming power resources. This preservative has been used on flight experiments aboard both the Space Shuttle and the International Space Station.

Saliva contains hormones such as cortisol and DHEA, cytokines (immune markers), DNA and RNA viruses, antibodies, and many other substances of diagnostic value. Saliva also contains many bacteria that produce proteases that destroy proteins, nucleases that destroy DNA and RNA, and other degradative enzymes. Typically, saliva and other body fluids are refrigerated (or frozen) to prevent or slow the degradation process. Refrigeration and freezers are extremely limited resources in spacecraft, undeveloped countries, and during activities away from electricity. Although not tested, the preservative is expected to be effective for other body fluids such as urine and blood. In addition, the toxicity of the preservative is very low.

The preservative consists of 0.5% sodium dodecysulfate (a detergent), 1.0 mM EDTA (a metal chelator), and 1.0 mM Tris (a buffer to maintain correct pH). The preservative is stable at room temperature for at least six months. A small volume of the liquid preservative is added to saliva (or other body fluids), the mixture is mixed by inversion, and then is left undisturbed at room temperature until the analysis is conducted. No other preservative has been identified that stabilizes saliva and other body fluids at room temperature for subsequent analyses.

This work was done by Duane L. Pierson of Johnson Space Center and Satish K. Mehta of EASI. Further information is contained in a TSP (see page 1). MSC-25144-1

Hands-Free Transcranial Color Doppler Probe

These probes enable full use of TCD technology for neurological diagnostics.

Lyndon B. Johnson Space Center, Houston, TX

Current transcranial color Doppler (TCD) transducer probes are bulky and difficult to move in tiny increments to search and optimize TCD signals. This invention provides miniature motions of a TCD transducer probe to optimize TCD signals.

The mechanical probe uses spherical bearing in guiding and locating the tilting crystal face. The lateral motion of the crystal face as it tilts across the full range of motion was achieved by minimizing the distance between the pivot location and the crystal face. The smallest commonly available metal spherical bearing was used with an outer diameter of 12 mm, a 3-mm tall retaining ring, and 5-mm overall height. Small geared motors were used that would provide sufficient power in a very compact package. After confirming the validity of the basic positioning concept, optimization design loops were completed to yield the final design.

A parallel motor configuration was used to minimize the amount of space wasted inside the probe case while minimizing the overall case dimensions. The distance from the front edge of the crystal to the edge of the case was also minimized to allow positioning of the probe very close to the ear on the temporal lobe. The mechanical probe is able to achieve a ±20° tip and tilt with smooth repeatable action in a very compact package. The enclosed probe is about 7 cm long, 4 cm wide, and 1.8 cm tall.

The device is compact, hands-free, and can be adjusted via an innovative touchscreen. Positioning of the probe to the head is performed via conventional transducer gels and pillows. This device is amendable to having advanced software, which could intelligently focus and optimize the TCD signal.

The first effort will be development of monitoring systems for space use and field deployment. The need for long-lived, inexpensive clinical diagnostic instruments for military applications is substantial. Potential future uses of this system by NASA and other commercial end-users include monitoring cerebral blood flow of ambulatory patients, prognostic of potential for embolic stroke, ultrasonic blood clot treatment, monitoring open-heart and carotid endarterectomy surgery, and resolution of the controversy regarding transient ischemic attacks and emboli's role. Monitoring applications include those for embolism formation during diving ascents, changes in CBFV (cerebral blood flow velocity) in relation to cognitive function as associated with sick building syndrome or exposure to environmental and workplace toxins, changes of CBFV for testing and evaluating Gulf War Syndrome, and patients or subjects while moving or performing tasks.

This work was done by Robert Chin of GeneXpress Informatics, and Srihdar Madala and Graham Sattler of Indus Instruments 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:

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Refer to MSC-24702-1, volume and number of this NASA Tech Briefs *issue, and the page number.*

Software

Aerosol and Surface Parameter Retrievals for a Multi-Angle, Multiband Spectrometer

This software retrieves the surface and atmosphere parameters of multi-angle, multiband spectra. The synthetic spectra are generated by applying the modified Rahman-Pinty-Verstraete Bidirectional Reflectance Distribution Function (BRDF) model, and a single-scattering dominated atmosphere model to surface reflectance data from Multiangle Imaging SpectroRadiometer (MISR). The aerosol physical model uses a single scattering approximation using Rayleigh scattering molecules, and Henyey-Greenstein aerosols. The surface and atmosphere parameters of the models are retrieved using the Lavenberg-Marquardt algorithm.

The software can retrieve the surface and atmosphere parameters with two different scales. The surface parameters are retrieved pixel-by-pixel while the atmosphere parameters are retrieved for a group of pixels where the same atmosphere model parameters are applied. This two-scale approach allows one to select the natural scale of the atmosphere properties relative to surface properties. The software also takes advantage of an intelligent initial condition given by the solution of the neighbor pixels.

This work was done by Seungwon Lee, Rachel A. Hodos, and Paul A. Von Allmen 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-47510.

LogScope

LogScope is a software package for analyzing log files. The intended use is for offline post-processing of such logs, after the execution of the system under test. LogScope can, however, in principle, also be used to monitor systems online during their execution. Logs are checked against requirements formulated as monitors expressed in a rule-based specification language. This language has similarities to a state machine language, but is more expressive, for example, in its handling of data parameters. The specification language is user friendly, simple, and yet expressive enough for many practical scenarios.

The LogScope software was initially developed to specifically assist in testing JPL's Mars Science Laboratory (MSL) flight software, but it is very generic in nature and can be applied to any application that produces some form of logging information (which almost any software does).

This work was done by Klaus Havelund and Margaret H. Smith of Caltech; Howard Barringer of University of Manchester, UK; and Alex Groce of Oregon State University for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-48068.

TraceContract

TraceContract is an API (Application Programming Interface) for trace analysis. A trace is a sequence of events, and can, for example, be generated by a running program, instrumented appropriately to generate events. An event can be any data object. An example of a trace is a log file containing events that a programmer has found important to record during a program execution. TraceContract takes as input such a trace together with a specification formulated using the API and reports on any violations of the specification, potentially calling code (reactions) to be executed when violations are detected.

The software is developed as an internal DSL (Domain Specific Language) in the Scala programming language. Scala is a relatively new programming language that is specifically convenient for defining such internal DSLs due to a number of language characteristics. This includes Scala's elegant combination of object-oriented and functional programming, a succinct notation, and an advanced type system. The DSL offers a combination of data-parameterized state machines and temporal logic, which is novel. As an extension of Scala, it is a very expressive and convenient log file analysis framework.

This work was done by Klaus Havelund of Caltech and Howard Barringer of University of Manchester, UK, 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-48071.

AIRS Maps From Space Processing Software

This software package processes Atmospheric Infrared Sounder (AIRS) Level 2 swath standard product geophysical parameters, and generates global, colorized, annotated maps. It automatically generates daily and multi-day averaged colorized and annotated maps of various AIRS Level 2 swath geophysical parameters. It also generates AIRS input data sets for Eyes on Earth, Puffersphere, and Magic Planet.

This program is tailored to AIRS Level 2 data products. It re-projects data into 1/4-degree grids that can be combined and averaged for any number of days. The software scales and colorizes global grids utilizing AIRS-specific color tables, and annotates images with title and color bar.

This software can be tailored for use with other swath data products for the purposes of visualization.

This work was done by Charles K. Thompson and Stephen J. Licata 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-48130.

POSTMAN: Point of Sail Tacking for Maritime Autonomous Navigation

Waves apply significant forces to small boats, in particular when such vessels are moving at a high speed in severe sea conditions. In addition, small high-speed boats run the risk of diving with the bow into the next wave crest during operations in the wavelengths and wave speeds that are typical for shallow water. In order to mitigate the issues of autonomous navigation in rough water, a hybrid controller called

POSTMAN combines the concept of POS (point of sail) tack planning from the sailing domain with a standard PID (proportional-integral-derivative) controller that implements reliable target reaching for the motorized small boat control task.

This is an embedded, adaptive software controller that uses look-ahead sensing in a closed loop method to perform path planning for safer navigation in rough waters. State-of-the-art controllers for small boats are based on complex models of the vessel's kinematics and dynamics. They enable the vessel to follow preplanned paths accurately and can theoretically control all of the small boat's six degrees of freedom. However, the problems of bow diving and other undesirable incidents are not addressed, and it is questionable if a six-DOF controller with basically a single actuator is possible at all. POSTMAN builds an adaptive capability into the controller based on sensed wave characteristics.

This software will bring a much-needed capability to unmanned small boats moving at high speeds. Previously, this class of boat was limited to wave heights of less than one meter in the sea states in which it could operate. POSTMAN is a major advance in autonomous safety for small maritime craft.

This work was done by Terrance L. Huntsberger of Caltech and Felix Reinhart of the Research Institute for Cognition and Robotics 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:

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Refer to NPO-47986, volume and number of this NASA Tech Briefs *issue, and the page number. NPO-47986*

Information Technology

Space Operations Learning Center

Goddard Space Flight Center, Greenbelt, Maryland

The Space Operations Learning Center (SOLC) is a tool that provides an online learning environment where students can learn science, technology, engineering, and mathematics (STEM) through a series of training modules. SOLC is also an effective media for NASA to showcase its contributions to the general public. SOLC is a Web-based environment with a learning platform for students to understand STEM through interactive modules in various engineering topics.

SOLC is unique in its approach to develop learning materials to teach school-aged students the basic concepts of space operations. SOLC utilizes the latest Web and software technologies to present this educational content in a fun and engaging way for all grade levels. SOLC uses animations, streaming video, cartoon characters, audio narration, interactive games and more to deliver educational concepts. The Web portal organizes all of these training modules in an easily accessible way for visitors worldwide.

SOLC provides multiple training modules on various topics. At the time of this reporting, seven modules have been developed: Space Communication, Flight Dynamics, Information Processing, Mission Operations, Kids Zone 1, Kids Zone 2, and Save The Forest. For the first four modules, each contains three components: Flight Training, Flight License, and Fly It! Kids Zone 1 and 2 include a number of educational videos and games designed specifically for grades K-6. Save The Forest is a space operations mission with four simulations and activities to complete, optimized for new touch screen technology. The Kids Zone 1 module has recently been ported to Facebook to attract wider audience.

This work was done by Ben Lui, Barbara Milner, Dan Binebrink, and Heng Kuok of Goddard Space Flight Center. For more information, visit http://solc.gsfc.nasa.gov. GSC-16063-1

OVERSMART Reporting Tool for Flow Computations Over Large Grid Systems

Ames Research Center, Moffett Field, California

Structured grid solvers such as NASA's OVERFLOW compressible Navier-Stokes flow solver can generate large data files that contain convergence histories for flow equation residuals, turbulence model equation residuals, component forces and moments, and component relative motion dynamics variables. Most of today's large-scale problems can extend to hundreds of grids, and over 100 million grid points. However, due to the lack of efficient tools, only a small fraction of information contained in these files is analyzed.

OVERSMART (OVERFLOW Solution Monitoring And Reporting Tool) provides a comprehensive report of solution convergence of flow computations over large, complex grid systems. It produces a one-page executive summary of the behavior of flow equation residuals, turbulence model equation residuals, and component forces and moments. Under the automatic option, a matrix of commonly viewed plots such as residual histograms, composite residuals, sub-iteration bar graphs, and component forces and moments is automatically generated. Specific plots required by the user can also be prescribed via a command file or a graphical user interface. Output is directed to the user's computer screen and/or to an html file for archival purposes.

The current implementation has been targeted for the OVERFLOW flow solver, which is used to obtain a flow solution on structured overset grids. The OVERSMART framework allows easy extension to other flow solvers.

This work was done by David L. Kao and William M. Chan of Ames Research Center. OVERSMART is part of the Chimera Grid Tools software package (ARC-16025-1), which is available for U.S. general release. Please contact Martha Del Alto, Software Release Authority, at Martha.E.DelAlto@nasa.gov for further inquiries. Further information is contained in a TSP (see page 1). ARC-16025-1A

Large Eddy Simulation (LES) of Particle-Laden Temporal Mixing Layers

NASA's Jet Propulsion Laboratory, Pasadena, California

High-fidelity models of plume-regolith interaction are difficult to develop because of the widely disparate flow conditions that exist in this process. The gas in the core of a rocket plume can often be modeled as a time-dependent, high-temperature, turbulent, reacting continuum flow. However, due to the vacuum conditions on the lunar surface, the mean molecular path in the outer parts of the plume is too long for the continuum assumption to remain valid. Molecular methods are better suited to model this region of the flow. Finally, granular and multiphase flow models must be employed to describe the dust and debris that are displaced from the surface, as well as how a crater is formed in the regolith. At present, standard commercial CFD (computational fluid dynamics) software is not capable of coupling each of these flow regimes to provide an accurate representation of this flow process, necessitating the development of custom software.

This software solves the fluid-flow-governing equations in an Eulerian framework, coupled with the particle transport equations that are solved in a Lagrangian framework. It uses a fourth-order explicit Runge-Kutta scheme for temporal integration, an eighth-order central finite differencing scheme for spatial discretization. The non-linear terms in the governing equations are recast in cubic skew symmetric form to reduce aliasing error. The second derivative viscous terms are computed using eighth-order narrow stencils that provide better diffusion for the highest resolved wave numbers. A fourth-order Lagrange interpolation procedure is used to obtain gas-phase variable values at the particle locations.

This work was done by Josette Bellan and Senthilkumaran Radhakrishnan of Caltech 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-47694.

Projection of Stabilized Aerial Imagery Onto Digital Elevation Maps for Geo-Rectified and Jitter-Free Viewing

Projection code is faster, cleaner, and easier to integrate.

NASA's Jet Propulsion Laboratory, Pasadena, California

As imagery is collected from an airborne platform, an individual viewing the images wants to know from where on the Earth the images were collected. To do this, some information about the camera needs to be known, such as its position and orientation relative to the Earth. This can be provided by common inertial navigation systems (INS). Once the location of the camera is known, it is useful to project an image onto some representation of the Earth. Due to the non-smooth terrain of the Earth (mountains, valleys, etc.), this projection is highly non-linear. Thus, to ensure accurate projection, one needs to project onto a digital elevation map (DEM). This allows one to view the images overlaid onto a representation of the Earth.

A code has been developed that takes an image, a model of the camera used to acquire that image, the pose of the camera during acquisition (as provided by an INS), and a DEM, and outputs an image that has been geo-rectified. The world coordinate of the bounds of the image are provided for viewing purposes. The code finds a mapping from points on the ground (DEM) to pixels in the image. By performing this process for all points on the ground, one can "paint" the ground with the image, effectively performing a projection of the image onto the ground. In order to make this process efficient, a method was developed for finding a region of interest (ROI) on the ground to where the image will project.

This code is useful in any scenario involving an aerial imaging platform that moves and rotates over time. Many other applications are possible in processing aerial and satellite imagery.

This work was done by Adnan I. Ansar, Shane Brennan, Daniel S. Clouse, Yang Cheng, Curtis W. Padgett, and David C. Trotz of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

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-46920.

Iterative Transform Phase Diversity: An Image-Based Object and Wavefront Recovery

Goddard Space Flight Center, Greenbelt, Maryland

The Iterative Transform Phase Diversity algorithm is designed to solve the problem of recovering the wavefront in the exit pupil of an optical system and the object being imaged. This algorithm builds upon the robust convergence capability of Variable Sampling Mapping (VSM), in combination with the known success of various deconvolution algorithms. VSM is an alternative method for enforcing the amplitude constraints of a Misell-Gerchberg-Saxton (MGS) algorithm. When provided the object and additional optical parameters, VSM can accurately recover the exit pupil wavefront. By combining VSM and deconvolution, one is able to simultaneously recover the wavefront and the object.

To recover the exit pupil wavefront, and the unknown object, first one must collect image plane data of the optical system under test. To increase convergence robustness, diversity images are collected. Next, a guess of the wavefront is made. This can be based on a prior estimate, or a simpler random solution of small values. This guess of the exit pupil and the image data will provide a starting point for VSM phase retrieval.

After several iterations of VSM phase retrieval, the algorithm will estimate the point spread function (PSF) based on the current estimate of the exit pupil wavefront. This estimated PSF is then deconvolved from the image data to provide an estimate of the object. At this point, one has an estimate of the object, and the estimated wavefront. The process is then repeated with the object included in the model in VSM. The entire process is repeated until a convergence criterion is met.

This work was done by Jeffrey Smith for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15963-1

3D Drop Size Distribution Extrapolation Algorithm Using a Single Disdrometer

Multiple sensors are not required for successful implementation of the 3D interpolation/extrapolation algorithm.

John F. Kennedy Space Center, Florida

Determining the Z-R relationship (where Z is the radar reflectivity factor and R is rainfall rate) from disdrometer data has been and is a common goal of cloud physicists and radar meteorology researchers. The usefulness of this quantity has traditionally been limited since radar represents a volume measurement, while a disdrometer corresponds to a point measurement. To solve that problem, a 3D-DSD (drop-size distribution) method of determining an equivalent 3D Z-R was developed at the University of Central Florida and tested at the Kennedy Space Center, FL. Unfortunately, that method required a minimum of three disdrometers clustered together within a microscale network (≈1-km separation). Since most commercial disdrometers used by the radar meteorology/cloud physics community are high-cost instruments, three disdrometers located within a microscale area is generally not a practical strategy due to the limitations of these kinds of research budgets.

A relatively simple modification to the 3D-DSD algorithm provides an estimate of the 3D-DSD and therefore, a 3D Z-R measurement using a single disdrometer. The basis of the horizontal extrapolation is mass conservation of a drop size increment, employing the mass conservation equation. For vertical extrapolation, convolution of a drop size increment using raindrop terminal velocity is used. Together, these two independent extrapolation techniques provide a complete 3D-DSD estimate in a volume around and above a single disdrometer. The estimation error is lowest along a vertical plane intersecting the disdrometer position in the direction of wind advection.

This work 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.

The original software (developed at the University of Central Florida, 1998—2000) has also been modified to read standardized disdrometer data format (Joss-Waldvogel format). Other modifications to the software involve accounting for vertical ambient wind motion, as well as evaporation of the raindrop during its flight time.

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-13302

Social Networking Adapted for Distributed Scientific Collaboration

Sci-Share provides scientists with a set of tools for e-mail, file sharing, and information transfer.

Goddard Space Flight Center, Greenbelt, Maryland

Sci-Share is a social networking site with novel, specially designed feature sets to enable simultaneous remote collaboration and sharing of large data sets among scientists. The site will include not only the standard features found on popular consumer-oriented social networking sites such as Facebook and Myspace, but also a number of powerful tools to extend its functionality to a science collaboration site.

A Virtual Observatory is a promising technology for making data accessible from various missions and instruments through a Web browser. Sci-Share augments services provided by Virtual Observatories by enabling distributed collaboration and sharing of downloaded and/or processed data among scientists. This will, in turn, increase science returns from NASA missions. Sci-Share also enables better utilization of NASA's high-performance computing resources by providing an easy and central mechanism to access and share large files on users' space or those saved on mass storage.

The most common means of remote scientific collaboration today remains the trio of e-mail for electronic communication, FTP for file sharing, and personalized Web sites for dissemination of papers and research results. Each of these tools has well-known limitations. Sci-Share transforms the social networking paradigm into a scientific collaboration environment by offering powerful tools for cooperative discourse and digital content sharing. Sci-Share differentiates itself by serving as an online repository for users' digital content with the following unique features:

- Sharing of any file type, any size, from anywhere;
- Creation of projects and groups for controlled sharing;

- Module for sharing files on HPC (High Performance Computing) sites;
- Universal accessibility of staged files as embedded links on other sites (e.g. Facebook) and tools (e.g. e-mail);
- Drag-and-drop transfer of large files, replacing awkward e-mail attachments (and file size limitations);
- Enterprise-level data and messaging encryption; and
- Easy-to-use intuitive workflow.

This work was done by Homa Karimabadi of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15883-1

General Methodology for Designing Spacecraft Trajectories

Lyndon B. Johnson Space Center, Houston, Texas

A methodology for designing spacecraft trajectories in any gravitational environment within the solar system has been developed. The methodology facilitates modeling and optimization for problems ranging from that of a single spacecraft orbiting a single celestial body to that of a mission involving multiple spacecraft and multiple propulsion systems operating in gravitational fields of multiple celestial bodies. The methodology consolidates almost all spacecraft trajectory design and optimization problems into a single conceptual framework requiring solution of either a system of nonlinear equations or a parameter-optimization problem with equality and/or inequality constraints.

The use of multiple reference frames that generally translate, rotate, and pulsate between two arbitrary celestial bodies facilitates analysis of such complex trajectories as those that pass (possibly multiple times) through gravitational fields of multiple celestial bodies. A basic building block that can accommodate impulsive maneuvers, maneuver- and non-maneuver-based mass discontinuities, and finite burn or finite control acceleration maneuvers, is used to construct trajectories. The methodology is implemented in an interactive computer program, COPERNICUS, wherein numerical integration, multi-dimensional nonlinear root-finding, and/or sequential quadratic programming are used for solving trajectory design, targeting, or optimization problems constructed by the analyst.

This work was done by Gerald Condon of Johnson Space Center; Cesar Ocampo, Ravishankar Mathur, and Fady Morcos of the University of Texas; Juan Senent of Odyssey Space Research; Jacob Williams of ERC, Inc.; and Elizabeth C. Davis of Jacobs Technology. For further information, contact the JSC Innovation Partnerships Office at (281) 483-3809. MSC-23671-1/4209-1/4586-1

Books & Reports

Hemispherical Field-of-View Above-Water Surface Imager for Submarines

A document discusses solutions to the problem of submarines having to rise above water to detect airplanes in the general vicinity. Two solutions are provided, in which a sensor is located just under the water surface, and at a few to tens of meter depth under the water surface.

The first option is a Fish Eye Lens (FEL) digital-camera combination, situated just under the water surface that will have near-full-hemisphere (360° azimuth and 90° elevation) field of view for detecting objects on the water surface. This sensor can provide a three-dimensional picture of the airspace both in the marine and in the land environment.

The FEL is coupled to a camera and can continuously look at the entire sky above it. The camera can have an Active Pixel Sensor (APS) focal plane array that allows logic circuitry to be built directly in the sensor. The logic circuitry allows data processing to occur on the sensor head without the need for any other external electronics.

In the second option, a single-photon sensitive (photon counting) detector-array is used at depth, without the need for any optics in front of it, since at this location, optical signals are scattered and arrive at a wide (tens of degrees) range of angles.

Beam scattering through clouds and seawater effectively negates optical imaging at depths below a few meters under cloudy or turbulent conditions. Under those conditions, maximum collection efficiency can be achieved by using a non-imaging photon-counting detector behind narrowband filters.

In either case, signals from these sensors may be fused and correlated or decorrelated with other sensor data to get an accurate picture of the object(s) above the submarine. These devices can complement traditional submarine periscopes that have a limited field of view in the elevation direction. Also, these techniques circumvent the need for exposing the entire submarine or its periscopes to the outside environment.

This work was done by Hamid Hemmati, Joseph M. Kovalik, and William H. Farr of Caltech, and John D. Dannecker of QinetiQ NA Corp. for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47916

Quantum-Well Infrared Photodetector (QWIP) Focal Plane Assembly

A paper describes the Thermal Infrared Sensor (TIRS), a QWIP-based instrument intended to supplement the Operational Land Imager (OLI) for the Landsat Data Continuity Mission (LDCM). The TIRS instrument is a far-infrared imager operating in the push-broom mode with two IR channels: 10.8 and 12 μm. The focal plane will contain three 640×512 QWIP arrays mounted on a silicon substrate. The silicon substrate is a custom-fabricated carrier board with a single layer of aluminum interconnects. The general fabrication process starts with a 4-in. (≈10-cm) diameter silicon wafer. The wafer is oxidized, a single substrate contact is etched, and aluminum is deposited, patterned, and alloyed.

This technology development is aimed at incorporating three large-format infrared detecting arrays based on GaAs QWIP technology onto a common focal plane with precision alignment of all three arrays. This focal plane must survive the rigors of flight qualification and operate at a temperature of 43 K (–230 °C) for five years while orbiting the Earth. The challenges presented include ensuring thermal compatibility among all the components, designing and building a compact, somewhat modular system and ensuring alignment to very tight levels.

The multi-array focal plane integrated onto a single silicon substrate is a new application of both QWIP array development and silicon wafer scale integration. The Invar-based assembly has been tested to ensure thermal reliability.

This work was done by Murzy Jhabvala, Christine A. Jhabvala, Audrey J. Ewin, Larry A. Hess, Thomas M. Hartmann, and Anh T. La of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15849-1

National Aeronautics and
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