11-13

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TECH BRIEFS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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**.

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11-13 November 2013

Tech Briefs

National Aeronautics and Space Administration

Technology Focus: Data Acquisition

Cryogenic Liquid Sample Acquisition System for Remote Space Applications

Goddard Space Flight Center, Greenbelt, Maryland

There is a need to acquire autonomously cryogenic hydrocarbon liquid sample from remote planetary locations such as the lakes of Titan for instruments such as mass spectrometers. There are several problems that had to be solved relative to collecting the right amount of cryogenic liquid sample into a warmer spacecraft, such as not allowing the sample to boil off or fractionate too early; controlling the intermediate and final pressures within carefully designed volumes; designing for various particulates and viscosities; designing to thermal, mass, and power-limited spacecraft interfaces; and reducing risk. Prior art inlets for similar instruments in spaceflight were designed primarily for atmospheric gas sampling and are not useful for this front-end application.

These cryogenic liquid sample acquisition system designs for remote space applications allow for remote, autonomous, controlled sample collections of a range of challenging cryogenic sample types. The design can control the size of the sample, prevent fractionation, control pressures at various stages, and allow for various liquid sample levels. It is capable of collecting repeated samples autonomously in difficult low-temperature conditions often found in planetary missions. It is capable of collecting samples for use by instruments from difficult sample types such as cryogenic hydrocarbon (methane, ethane, and propane) mixtures with solid particulates such as found on Titan. The design with a warm actuated valve is compatible with various spacecraft thermal and structural interfaces.

The design uses controlled volumes, heaters, inlet and vent tubes, a cryogenic valve seat, inlet screens, temperature and cryogenic liquid sensors, seals, and vents to accomplish its task.

This work was done by Paul Mahaffy, Melissa Trainer, Don Wegel, Douglas Hawk, Tony Melek, Christopher Johnson, Michael Amato, and John Galloway of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16510-1

Spatial Statistical Data Fusion (SSDF)

The approach models the spatial covariance function of the underlying geophysical field using linear combinations of multi-resolution spatial basis functions of low dimensionality.

NASA's Jet Propulsion Laboratory, Pasadena, California

As remote sensing for scientific purposes has transitioned from an experimental technology to an operational one, the selection of instruments has become more coordinated, so that the scientific community can exploit complementary measurements. However, technological and scientific heterogeneity across devices means that the statistical characteristics of the data they collect are different. The challenge addressed here is how to combine heterogeneous remote sensing data sets in a way that yields optimal statistical estimates of the underlying geophysical field, and provides rigorous uncertainty measures for those estimates. Different remote sensing data sets may have different spatial resolutions, different measurement error biases and variances, and other disparate characteristics.

A state-of-the-art spatial statistical model was used to relate the true, but not directly observed, geophysical field to noisy, spatial aggregates observed by remote sensing instruments. The spatial covariances of the true field and the covariances of the true field with the observations were modeled. The observations are spatial averages of the true field values, over pixels, with different measurement noise superimposed. A kriging framework is used to infer optimal (minimum mean squared error and unbiased) estimates of the true field at point locations from pixel-level, noisy observations.

A key feature of the spatial statistical model is the spatial mixed effects model that underlies it. The approach models the spatial covariance function of the underlying field using linear combinations of basis functions of fixed size. Approaches based on kriging require the inversion of very large spatial covariance matrices, and this is usually done by making simplifying assumptions about spatial covariance structure that simply do not hold for geophysical variables. In contrast, this method does not require these assumptions, and is also computationally much faster. This method is fundamentally different than other approaches to data fusion for remote sensing data because it is inferential rather than merely descriptive. All approaches combine data in a way that minimizes some specified loss function. Most of these are more or less ad hoc criteria based on what looks good to the eye, or some criteria that relate only to the data at hand.

This work was done by Amy J. Braverman and Hai M. Nguyen of Caltech, and Noel Cressie of the Ohio State University for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

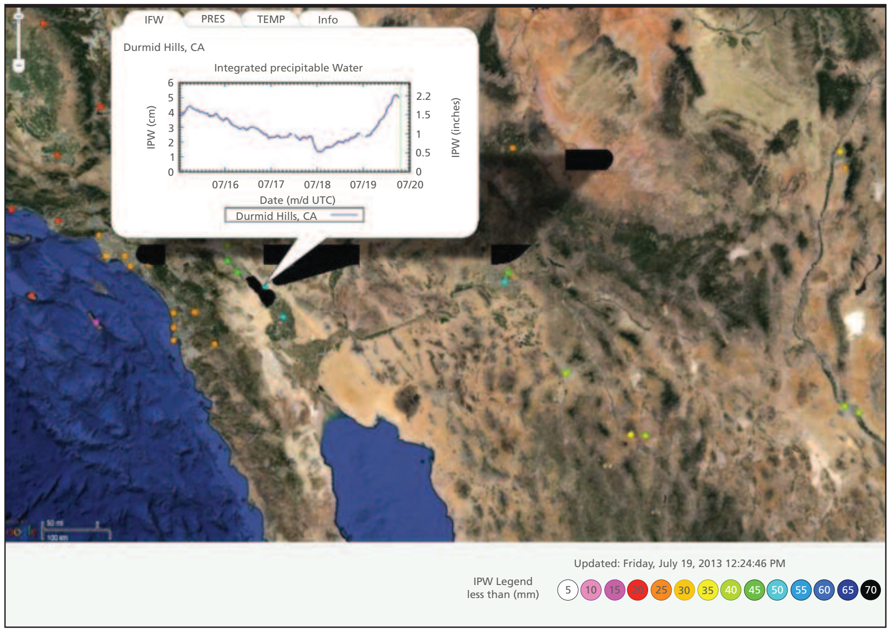
This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48131.

GPS Estimates of Integrated Precipitable Water Aid Weather Forecasters

This technique improves weather-forecasting operations.

NASA's Jet Propulsion Laboratory, Pasadena, California

Global Positioning System (GPS) meteorology provides enhanced density, low-latency (30-min resolution), integrated precipitable water (IPW) estimates to NOAA NWS (National Oceanic and Atmospheric Administration National Weather Service) Weather Forecast Offices (WFOs) to provide improved model and satellite data verification capability and more accurate forecasts of extreme weather such as flooding. An early activity of this project was to increase the number of stations contributing to the NOAA Earth System Research Laboratory (ESRL) GPS meteorology observing network in Southern California by about 27 stations. Following this, the Los Angeles/Oxnard and San Diego WFOs began using the enhanced GPS-based IPW measurements provided by ESRL in the 2012 and 2013 monsoon seasons. Forecasters found GPS IPW to be an effective tool in evaluating model performance, and in monitoring monsoon development between weather model runs for improved flood forecasting.



A screenshot from http://gpsmet.noaa.gov of ground GPS-based **Integrated Water Vapor Information** utilized by NOAA NWS San Diego Weather Forecasting Office during the 2013 monsoon season. The upward IWV trend supported satellite data and contributed to the issuance of a flood watch.

GPS stations are multi-purpose, and routine processing for position solutions also yields estimates of tropospheric zenith delays, which can be converted into mm-accuracy PWV (precipitable water vapor) using in situ pressure and temperature measurements, the basis for GPS meteorology. NOAA ESRL has implemented this concept with a nationwide distribution of more than 300 "GPS-Met" stations providing IPW estimates at sub-hourly resolution currently used in operational weather models in the U.S.

This work was done by Angelyn W. Moore of Caltech; Seth I. Gutman and Kirk Holub of NOAA Earth System Research Laboratory; Yehuda Bock of UC San Diego's Scripps Institution of Oceanography; and David Danielson, Jayme Laber, and Ivory Small of NOAA National Weather Service. Further information is contained in a TSP (see page 1). NPO-48881

Integrating a Microwave Radiometer into Radar Hardware for Simultaneous Data Collection Between the Instruments

Electronics are shared between the instruments.

Goddard Space Flight Center, Greenbelt, Maryland

The conventional method for integrating a radiometer into radar hardware is to share the RF front end between the instruments, and to have separate IF receivers that take data at separate times. Alternatively, the radar and radiometer could share the antenna through the use of a diplexer, but have completely independent receivers. This novel method shares the radar's RF electronics and digital receiver with the radiometer, while allowing for simultaneous operation of the radar and radiometer.

Radars and radiometers, while often having near-identical RF receivers, generally have substantially different IF and baseband receivers. Operation of the two instruments simultaneously is difficult, since airborne radars will pulse at a rate of hundreds of microseconds. Radiometer integration time is typically 10s or 100s of milliseconds. The bandwidth of radar may be 1 to 25 MHz, while a radiometer will have an RF bandwidth of up to a GHz. As such, the conventional method of integrating radar and radiometer hardware is to share the high-frequency RF receiver, but to have separate IF subsystems and digitizers. To avoid corruption of the radiometer data, the radar is turned off during the radiometer dwell time.

This method utilizes a modern radar digital receiver to allow simultaneous operation of a radiometer and radar with a shared RF front end and digital receiver. The radiometer signal is coupled out after the first down-conversion stage. From there, the radar transmit frequencies are heavily filtered, and the bands outside the transmit filter are amplified and passed to a detector diode. This diode produces a DC output proportional to the input power. For a conventional radiometer, this level would be digitized. By taking this DC output and mixing it with a system oscillator at 10 MHz, the signal can instead be digitized by a second channel on the radar digital receiver (which typically do not accept DC inputs), and can be down-converted to a DC level again digitally. This unintuitive step allows the digital receiver to sample both the radiometer and radar data at a rapid, synchronized data rate (greater than 1 MHz bandwidth).

Once both signals are sampled by the same digital receiver, high-speed quality control can be performed on the radiometer data to allow it to take data simultaneously with the radar. The radiometer data can be blanked during radar transmit, or when the radar return is of a power level high enough to corrupt the radiometer data. Additionally, the receiver protection switches in the RF front end can double as radiometer calibration sources, the short (four-microsecond level) switching periods integrated over many seconds to estimate the radiometer offset.

The major benefit of this innovation is that there is minimal impact on the radar performance due to the integration of the radiometer, and the radiometer performance is similarly minimally affected by the radar. As the radar and radiometer are able to operate simultaneously, there is no extended period of integration time loss for the radiometer (maximizing sensitivity), and the radar is able to maintain its full number of pulses (increasing sensitivity and decreasing measurement uncertainty).

This work was done by Matthew McLinden and Jeffrey Piepmeier of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16490-1

Rapid Detection of Herpes Viruses for Clinical Applications

Lyndon B. Johnson Space Center, Houston, Texas

There are eight herpes viruses that infect humans, causing a wide range of diseases resulting in considerable morbidity and associated costs. Varicella zoster virus (VZV) is a human herpes virus that causes chickenpox in children and shingles in adults. Approximately 1,000,000 new cases of shingles occur each year; post-herpetic neuralgia (PHN) follows shingles in 100,000 to 200,000 people annually. PHN is characterized by debilitating, nearly unbearable pain for weeks, months, and even years. The onset of shingles is characterized by pain, followed by the zoster rash, leading to blisters and severe pain. The problem is that in the early stages, shingles can be difficult to diagnose; chickenpox in adults can be equally difficult to diagnose. As a result, both diseases can be misdiagnosed (false positive/negative).

A molecular assay has been adapted for use in diagnosing VZV diseases. The polymerase chain reaction (PCR) assay is a non-invasive, rapid, sensitive, and highly specific method for VZV DNA detection. It provides unequivocal results and can effectively end misdiagnoses. This is an approximately two-hour assay that allows unequivocal diagnosis and rapid antiviral drug intervention. It has been demonstrated that rapid intervention can prevent full development of the disease, resulting in reduced likelihood of PHN. The technology was extended to shingles patients and demonstrated that VZV is shed in saliva and blood of all shingles patients. The amount of VZV in saliva parallels the medical outcome.

This work was done by Duane Pierson of Johnson Space Center, and Satish Mehta of Enterprise Advisory Services, Inc. For further information, contact the JSC Innovation Partnerships Office at (281) 483-3809. MSC-25009-1

High-Speed Data Recorder for Space, Geodesy, and Other High-Speed Recording Applications

Goddard Space Flight Center, Greenbelt, Maryland

A high-speed data recorder and replay equipment has been developed for reliable high-data-rate recording to disk media. It solves problems with slow or faulty disks, multiple disk insertions, high-altitude operation, reliable performance using COTS hardware, and long-term maintenance and upgrade path challenges.

The current generation data recorders used within the VLBI community are aging, special-purpose machines that are both slow (do not meet today's requirements) and are very expensive to maintain and operate. Furthermore, they are not easily upgraded to take advantage of commercial technology development, and are not scalable to multiple 10s of Gbit/s data rates required by new applications.

The innovation provides a software-defined, high-speed data recorder that is scalable with technology advances in the commercial space. It maximally utilizes current technologies without being locked to a particular hardware platform. The innovation also provides a cost-effective way of streaming large amounts of data from sensors to disk, enabling many applications to store raw sensor data and perform post and signal processing offline.

This recording system will be applicable to many applications needing real-world, high-speed data collection, including electronic warfare, software-defined radar, signal history storage of multispectral sensors, development of autonomous vehicles, and more.

Datacasting V3.0

NASA's Jet Propulsion Laboratory, Pasadena, California

Datacasting V3.0 provides an RSS-based feed mechanism for publishing the availability of Earth science data records in real time. It also provides a utility for subscribing to these feeds and sifting through all the items in an automatic manner to identify and download the data records that are required for a specific application.

Datacasting is a method by which multiple data providers can publish the availability of new Earth science data and users download those files that meet a predefined need; for example, to only download data files related to a specific earthquake or region on the globe.

Datacasting is a server-client architecture. The server-side software is used by data providers to create and publish the metadata about recently available data according to the Datacasting RSS (Really Simple Syndication) specification. The client software subscribes to the Datacasting RSS and other RSS-based feeds. By configuring filters associated with feeds, data consumers can use the client to identify and automatically download files that meet a specific need.

On the client side, a Datacasting feed reader monitors the server for new feeds. The feed reader will be tuned by the user, via a graphical user interface (GUI), to examine the content of the feeds and initiate a data pull after some criteria are satisfied. The criteria might be, for example, to download sea surface temperature data for a particular region that has cloud cover less than 50% and during daylight hours. After the granule is downloaded to the client, the user will have the ability to visualize the data in the GUI.

Based on the popular concept of podcasting, which gives listeners the capability to download only those MP3 files that match their preference, Earth science Datacasting will give users a method to download only the Earth science data files that are required for a particular application.

This work was done by Andrew W. Bingham, Sean W. McCleese, Robert G. Deen, Nga T. Chung, and Timothy M. Stough of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48048.

Electronics/Computers

An All-Solid-State, Room-Temperature, Heterodyne Receiver for Atmospheric Spectroscopy at 1.2 THz

This receiver enables terahertz heterodyne spectroscopy of outer planet atmospheres without cryogenic cooling.

NASA's Jet Propulsion Laboratory, Pasadena, California

Heterodyne receivers at submillimeter wavelengths have played a major role in astrophysics as well as Earth and planetary remote sensing. All-solid-state heterodyne receivers using both MMIC (monolithic microwave integrated circuit) Schottky-diode-based LO (local oscillator) sources and mixers are uniquely suited for long-term planetary missions or Earth climate monitoring missions as they can operate for decades without the need for any active cryogenic cooling. However, the main concern in using Schottky-diode-based mixers at frequencies beyond 1 THz has been the lack of enough LO power to drive the devices because 1 to 3 mW are required to properly pump Schottky diode mixers. Recent progress in HEMT- (high-electron-mobility-transistor) based power amplifier technology, with output power levels in excess of 1 W recently demonstrated at W-band, as well as advances in MMIC Schottky diode circuit technology, have led to measured output powers up to 1.4 mW at 0.9 THz.

Here the first room-temperature tunable, all-planar, Schottky-diode-based receiver is reported that is operating at 1.2 THz over a wide (≈20%) bandwidth. The receiver front-end (see figure) consists of a Schottky-diode-based 540 to 640 GHz multiplied LO chain (featuring a cascade of W-band power amplifiers providing around 120 to 180 mW at W-band), a 200-GHz MMIC frequency doubler, and a 600-GHz MMIC frequency tripler, plus a biasable 1.2-THz MMIC sub-harmonic Schottky-diode mixer. The LO chain has been designed, fabricated, and tested at JPL and provides around 1 to 1.5 mW at 540 to 640 GHz. The sub-harmonic mixer consists of two Schottky diodes on a thin GaAs membrane in an anti-parallel configuration. An integrated metal insulator metal (MIM) capacitor has been included on-chip to allow dc bias for the Schottky diodes. A bias voltage of around 0.5 V/diode is necessary to reduce the LO power required down to the 1 to 1.5 mW available from the LO chain. The epilayer thickness and doping profiles have been specifically optimized to maximize the mixer performance beyond 1 THz.

The measured DSB noise temperatures and conversion losses of the receiver are 2,000 to 3,500 K and 12 to 14 dB, respectively, at 120 K, and 4,000 to 6,000 K and 13 to 15 dB, respectively, at 300 K. These results establish the state-

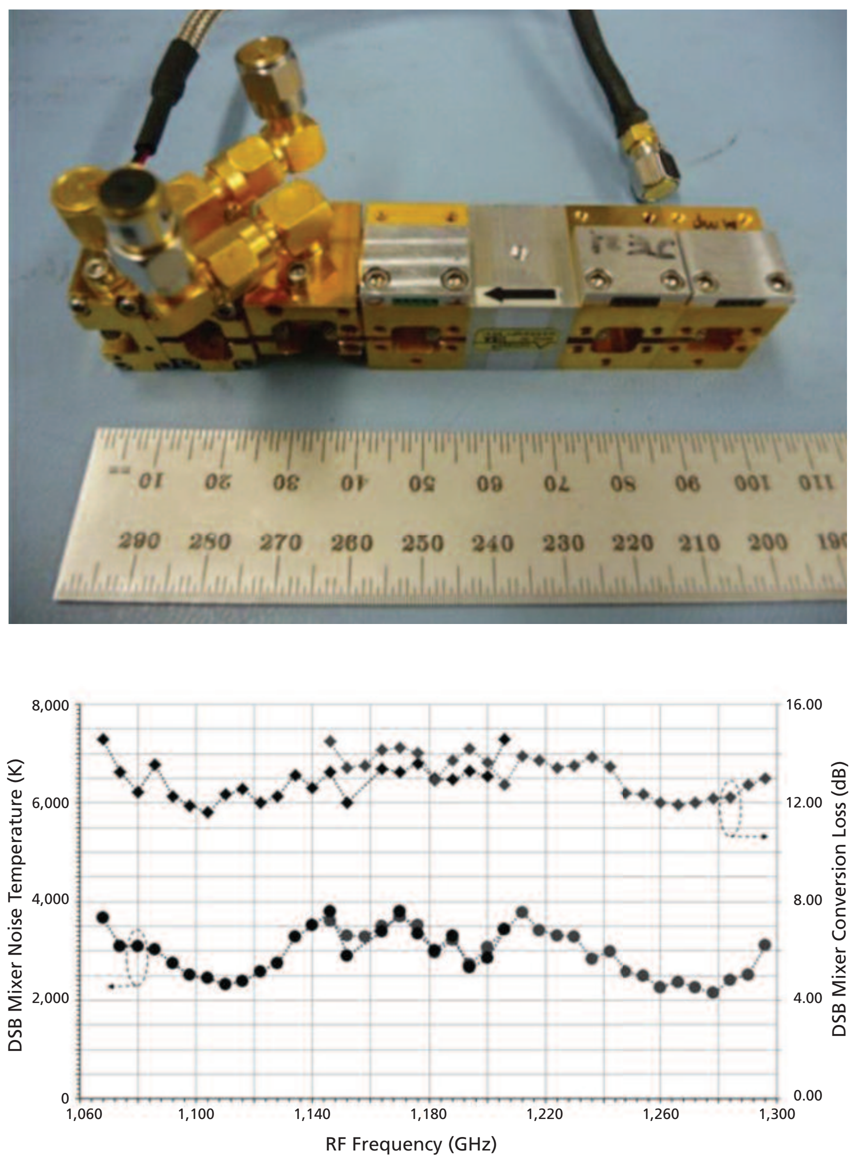


Photo and Performance of the Schottky-diode based 1.2-THz heterodyne receiver.

of-the-art for all-solid-state, all-planar heterodyne receivers at 1.2 THz operating at either room temperature or using passive cooling only. Since no cryogenic cooling is needed, the receiver is eminently suited to atmospheric heterodyne spectroscopy of the outer planets and their moons.

This work was done by Jose V. Siles, Imran Mehdi, Erich T. Schlecht, Samuel Gulkis, Goutam Chattopadhyay, Robert H. Lin, Choonsup Lee, and John J. Gill of Caltech; Bertrand Thomas of Radiometer Physic; and Alain E. Maestrini of Observatoire de Paris for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48896

Stacked Transformer for Driver Gain and Receive Signal Splitting

Lyndon B. Johnson Space Center, Houston, Texas

In a high-speed signal transmission system that uses transformer coupling, there is a need to provide increased transmitted signal strength without adding active components. This invention uses additional transformers to achieve the needed gain. The prior art uses stronger drivers (which require an IC redesign and a higher power supply voltage), or the addition of another active component (which can decrease reliability, increase power consumption, reduce the beneficial effect of serializer/deserializer preemphasis or deemphasis, and/or interfere with fault containment mechanisms), or uses a different transformer winding ratio (which requires redesign of the transformer and may not be feasible with high-speed signals that require a 1:1 winding ratio).

This invention achieves the required gain by connecting the secondaries of multiple transformers in series. The primaries of these transformers are currently either connected in parallel or are connected to multiple drivers. There is also a need to split a receive signal to multiple destinations with minimal signal loss. Additional transformers can achieve the split. The prior art uses impedance-matching series resistors that cause a loss of signal. Instead of causing a loss, most instantiations of this invention would actually provide gain. Multiple transformers are used instead of multiple windings on a single transformer because multiple windings on the same transformer would require a redesign of the transformer, and may not be feasible with high-speed transformers that usually require a bifilar winding with a 1:1 ratio. This invention creates the split by connecting the primaries of multiple transformers in series. The secondary of each transformer is connected to one of the intended destinations without the use of impedance-matching series resistors.

This work was done by Kevin R. Driscoll of Honeywell for Johnson Space Center. For further information, contact the JSC Innovation Partnerships Office at (281) 483-3809.

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act {42 U.S.C. 2457(f)}, to Honeywell. Inquiries concerning licenses for its commercial development should be addressed to:

Honeywell
P.O. Box 52199
Phoenix, AZ 85072-2199

Refer to MSC-24854-1/6-1, volume and number of this NASA Tech Briefs *issue, and the page number.*

Wireless Integrated Microelectronic Vacuum Sensor System

This system is applicable to facility monitoring applications, as well as cryogenic fluid manufacture and transport.

Stennis Space Center, Mississippi

NASA Stennis Space Center's (SSC's) large rocket engine test facility requires the use of liquid propellants, including the use of cryogenic fluids like liquid hydrogen as fuel, and liquid oxygen as an oxidizer (gases which have been liquefied at very low temperatures). These fluids require special handling, storage, and transfer technology. The biggest problem associated with transferring cryogenic liquids is product loss due to heat transfer. Vacuum jacketed piping is specifically designed to maintain high thermal efficiency so that cryogenic liquids can be transferred with minimal heat transfer.

A vacuum jacketed pipe is essentially two pipes in one. There is an inner carrier pipe, in which the cryogenic liquid is actually transferred, and an outer jacket pipe that supports and seals the vacuum insulation, forming the "vacuum jacket." The integrity of the vacuum jacketed transmission lines that transfer the cryogenic fluid from delivery barges to the test stand must be maintained prior to and during engine testing. To monitor the vacuum in these vacuum jacketed transmission lines, vacuum gauge readings are used. At SSC, vacuum gauge measurements are done on a manual rotation basis with two technicians, each using a handheld instrument. Manual collection of vacuum data is labor intensive and uses valuable personnel time. Additionally, there are times when personnel cannot collect the data in a timely fashion (i.e., when a leak is detected, measurements must be taken more often). Additionally, distribution of this data to all interested parties can be cumbersome.

To simplify the vacuum-gauge data collection process, automate the data collection, and decrease the labor costs associated with acquiring these measurements, an automated system that monitors the existing gauges was developed by Invocon, Inc. For this project, Invocon developed a Wireless Integrated Microelectronic Vacuum Sensor System (WIMVSS) that provides the ability to gather vacuum-gauge measurements automatically and wirelessly, in near-real time — using a low-maintenance, low-power sensor mesh network. The WIMVSS operates by using a self-configuring mesh network of wireless sensor units. Mesh networking is a type of networking where each sensor or node can capture and disseminate its own data, but also serve as a relay to receive and transmit data from other sensors. Each sensor node can synchronize with adjacent sensors, and propagate data from one sensor to the next, until the destination is reached. In this case, the destination is a Network Interface Unit (NIU). The WIMVSS sensors are mounted on the existing vacuum gauges. Information gathered by the sensors is sent to the NIU. Because of the mesh networking, if a sensor cannot directly send the data to the NIU, it can be propagated through the network of sensors. The NIU requires antenna access to the sensor units, AC power, and an Ethernet connection. The NIU bridges the sensor network to a WIMVSS server via an Ethernet connection. The server is configured with a database, a Web server, and proprietary interface software that makes it possible for the vacuum measurements from vacuum jacketed fluid lines to be saved, retrieved, and then displayed from any Web-enabled PC that has access to the Internet. Authorized users can then simply access the data from any PC with Internet connection. Commands can also be sent directly from the Web interface for control and maintenance of the sensor network.

The technology enabled by the WIMVSS decreases labor required for gathering vacuum measurements, increases access to vacuum data by making it available on any computer with access to the Internet, increases the frequency with which data points can be acquired for evaluating the system, and decreases the recurring cost of the sensors by using off-the-shelf components and integrating these with heritage vacuum gauges.

This work was done by Eric Krug, Brian Philpot, Aaron Trott, and Shaun Lawrence of Invocon, Inc., for Stennis Space Center. For more information, please contact Invocon, Inc. at (281) 292-9903. Refer to SSC-00342.

Manufacturing & Prototyping

Fabrication Method for LOBSTER-Eye Optics in <110> Silicon

The major advantages are the potential for higher x-ray throughout and lower cost over the slumped micropore glass plates.

Goddard Space Flight Center, Greenbelt, Maryland

Soft x-ray optics can use narrow slots to direct x-rays into a desirable pattern on a focal plane. While square-pack, square-pore, slumped optics exist for this purpose, they are costly. Silicon (Si) is being examined as a possible low-cost replacement. A fabrication method was developed for narrow slots in <110> Si demonstrating the feasibility of stacked slot optics to replace micropores.

Current micropore optics exist that have 20-micron-square pores on 26-micron pitch in glass with a depth of 1 mm and an extent of several square centimeters. Among several proposals to emulate the square pore optics are stacked slot chips with etched vertical slots. When the slots in the stack are positioned orthogonally to each other, the component will approach the soft x-ray focusing observed in the micropore optics. A specific improvement Si provides is that it can have narrower sidewalls between slots to permit greater throughput of x-rays through the optics. In general, Si can have more variation in slot geometry (width, length). Further, the sidewalls can be coated with high-Z materials to enhance reflection and potentially reduce the surface roughness of the reflecting surface.

Narrow, close-packed deep slots in <110> Si have been produced using potassium hydroxide (KOH) etching and a patterned silicon nitride (SiN) mask. The achieved slot geometries have sufficient wall smoothness, as observed through scanning electron microscope (SEM) imaging, to enable evaluation of these slot plates as an optical element for soft x-rays. Etches of different angles to the crystal plane of Si were evaluated to identify a specific range of etch angles that will enable low undercut slots in the Si <110> material. These slots with the narrow sidewalls are demonstrated to several hundred microns in depth, and a technical path to 500-micron deep slots in a precision geometry of narrow, close-packed slots is feasible. Although intrinsic stress in ultrathin wall Si is observed, slots with walls approaching 1.5 microns can be achieved (a significant improvement over the 6-micron walls in micropore optics).

The major advantages of this technique are the potential for higher x-ray throughout (due to narrow slot walls) and lower cost over the existing slumped micropore glass plates. KOH etching of smooth sidewalls has been demonstrated for many applications, suggesting its feasibility for implementation in x-ray optics. Si cannot be slumped like the micropore optics, so the focusing will be achieved with millimeter-scale slot plates that populate a spherical dome. The possibility for large-scale production exists for Si parts that is more difficult to achieve in micropore parts.

This work was done by James Chervenak and Michael Collier of Goddard Space Flight Center, and Jennette Mateo of SB Microsystems. Further information is contained in a TSP (see page 1). GSC-16717-1

Compact Focal Plane Assembly for Planetary Science

New fabrication methods were incorporated to produce an ultra-lightweight and compact radiometer.

Goddard Space Flight Center, Greenbelt, Maryland

A compact radiometric focal plane assembly (FPA) has been designed in which the filters are individually co-registered over compact thermopile pixels. This allows for construction of an ultra-lightweight and compact radiometric instrument. The FPA also incorporates micromachined baffles in order to mitigate crosstalk and low-pass filter windows in order to eliminate high-frequency radiation.

Compact metal mesh bandpass filters were fabricated for the far infrared (FIR) spectral range (17 to 100 microns), a game-changing technology for future planetary FIR instruments. This fabrication approach allows the dimensions of individual metal mesh filters to be tailored with better than 10-micron precision. In contrast, conventional compact filters employed in recent missions and in near-term instruments consist of large filter sheets manually cut into much smaller pieces, which is a much less precise and much more labor-intensive, expensive, and difficult process.

Filter performance was validated by integrating them with thermopile arrays. Demonstration of the FPA will require the integration of two technologies. The first technology is compact, lightweight, robust against cryogenic thermal cycling, and radiation-hard micromachined bandpass filters. They consist of a copper mesh supported on a deep reactive ion-etched silicon frame. This design architecture is advantageous when constructing a lightweight and compact instrument because (1) the frame acts like a jig and facilitates filter integration with the FPA, (2) the frame can be designed so as to maximize the FPA field of view, (3) the frame can be simultaneously used as a baffle for mitigating crosstalk, and (4) micron-scale alignment features can be patterned so as to permit high-precision filter stacking and, consequently, increase the filter bandwidth and sharpen the out-of-band rolloff.

The second technology consists of leveraging, from another project, compact and lightweight $Bi_{0.87}Sb_{0.13}/Sb$ arrayed thermopiles. These detectors consist of 30-layer thermopiles deposited in series upon a silicon nitride membrane. At 300 K, the thermopile arrays are highly linear over many orders of magnitude of incident IR power, and have a reported specific detectivity that exceeds the requirements imposed on future mission concepts.

The bandpass filter array board is integrated with a thermopile array board by mounting both boards on a machined aluminum jig.

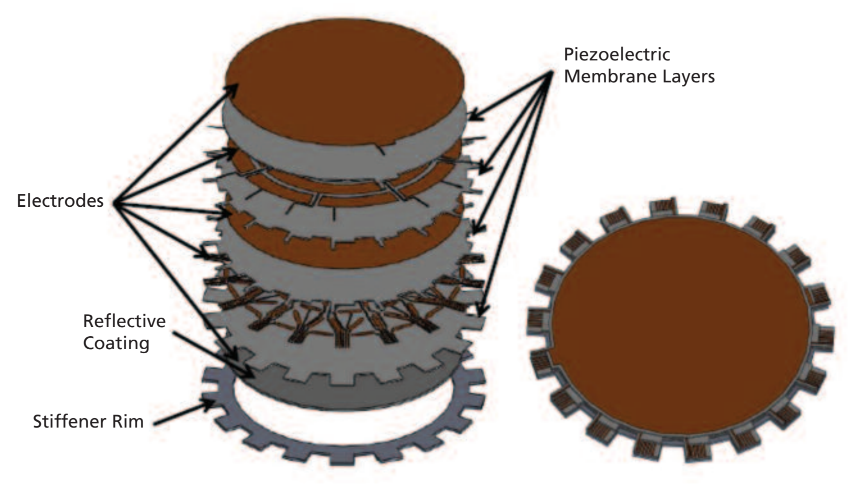
This work was done by Ari Brown, Shahid Aslam, Wei-Chung Huang, and Rosalind Steptoe-Jackson of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16704-1

Fabrication Methods for Adaptive Deformable Mirrors

Two methods are presented.

NASA's Jet Propulsion Laboratory, Pasadena, California

Previously, it was difficult to fabricate deformable mirrors made by piezoelectric actuators. This is because numerous actuators need to be precisely assembled to control the surface shape of the mirror. Two approaches have been developed. Both approaches begin by depositing a stack of piezoelectric films and electrodes over a silicon wafer substrate. In the first approach, the silicon wafer is removed initially by plasma-based reactive ion etching (RIE), and non-plasma dry etching with xenon difluoride (XeF_2). In the second approach, the actuator film stack is immersed in a liquid such as deionized water. The adhesion between the actuator film stack and the substrate is relatively weak. Simply by seeping liquid between the film and the substrate, the actuator film stack is gently released from the substrate.



The **Deformable Mirror** concept includes electrodes, a reflective coating, stiffener rim, and piezoelectric membrane layers.

The deformable mirror contains multiple piezoelectric membrane layers as well as multiple electrode layers (some are patterned and some are unpatterned). At the piezolectric layer, polyvinylidene fluoride (PVDF), or its co-polymer, poly(vinylidene fluoride trifluoroethylene P(VDF-TrFE) is used. The surface of the mirror is coated with a reflective coating. The actuator film stack is fabricated on silicon, or silicon on insulator (SOI) substrate, by repeatedly spin-coating the PVDF or P(VDF-TrFE) solution and patterned metal (electrode) deposition.

In the first approach, the actuator film stack is prepared on SOI substrate. Then, the thick silicon (typically 500-micron thick and called handle silicon) of the SOI wafer is etched by a deep reactive ion etching process tool (SF6-based plasma etching). This deep RIE stops at the middle SiO_2 layer. The middle SiO_2 layer is etched by either HF-based wet etching or dry plasma etch. The thin silicon layer (generally called a device layer) of SOI is removed by XeF_2 dry etch. This XeF_2 etch is very gentle and extremely selective, so the released mirror membrane is not damaged. It is possible to replace SOI with silicon substrate, but this will require tighter DRIE process control as well as generally longer and less efficient XeF_2 etch.

In the second approach, the actuator film stack is first constructed on a silicon wafer. It helps to use a polyimide intermediate layer such as Kapton because the adhesion between the polyimide and silicon is generally weak. A mirror mount ring is attached by using adhesive. Then, the assembly is partially submerged in liquid water. The water tends to seep between the actuator film stack and silicon substrate. As a result, the actuator membrane can be gently released from the silicon substrate. The actuator membrane is very flat because it is fixed to the mirror mount prior to the release.

Deformable mirrors require extremely good surface optical quality. In the technology described here, the deformable mirror is fabricated on pristine substrates such as prime-grade silicon wafers. The deformable mirror is released by selectively removing the substrate. Therefore, the released deformable mirror surface replicates the optical quality of the underlying pristine substrate.

This work was done by Risaku Toda, Victor E. White, Harish Manohara, Keith D. Patterson, Namiko Yamamoto, Eleftherios Gdoutos, John B. Steeves, Chiara Daraio, and Sergio Pellegrino 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-48665, volume and number of this NASA Tech Briefs *issue, and the page number.*

Software

Visiting Vehicle Ground Trajectory Tool

The International Space Station (ISS) Visiting Vehicle Group needed a targeting tool for vehicles that rendezvous with the ISS. The Visiting Vehicle Ground Trajectory targeting tool provides the ability to perform both real-time and planning operations for the Visiting Vehicle Group. This tool provides a highly reconfigurable base, which allows the Visiting Vehicle Group to perform their work. The application is composed of a telemetry processing function, a relative motion function, a targeting function, a vector view, and 2D/3D world map type graphics.

The software tool provides the ability to plan a rendezvous trajectory for vehicles that visit the ISS. It models these relative trajectories using planned and real-time data from the vehicle. The tool monitors ongoing rendezvous trajectory relative motion, and ensures visiting vehicles stay within agreed corridors.

The software provides the ability to update or re-plan a rendezvous to support contingency operations. Adding new parameters and incorporating them into the system was previously not available on-the-fly. If an unanticipated capability wasn't discovered until the vehicle was flying, there was no way to update things.

This work was done by Dustin Hamm of Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-24763-1

Workflow-Based Software Development Environment

The Software Developer's Assistant (SDA) helps software teams more efficiently and accurately conduct or execute software processes associated with NASA mission-critical software. SDA is a process enactment platform that guides software teams through project-specific standards, processes, and procedures. Software projects are decomposed into all of their required process steps or tasks, and each task is assigned to project personnel. SDA orchestrates the performance of work required to complete all process tasks in the correct sequence. The software then notifies team members when they may begin work on their assigned tasks and provides the tools, instructions, reference materials, and supportive artifacts that allow users to compliantly perform the work.

A combination of technology components captures and enacts any software process use to support the software lifecycle. It creates an adaptive workflow environment that can be modified as needed. SDA achieves software process automation through a Business Process Management (BPM) approach to managing the software lifecycle for mission-critical projects. It contains five main parts: TieFlow (workflow engine), Business Rules (rules to alter process flow), Common Repository (storage for project artifacts, versions, history, schedules, etc.), SOA (interface to allow internal, GFE, or COTS tools integration), and the Web Portal Interface (collaborative web environment).

The advantages of automating the software process using SDA are:

- Software systems are delivered faster, less expensively, with fewer defects, and requiring fewer highly skilled personnel.
- Portal-based collaboration allows large geographically dispersed teams to work in concert via a simple and consistent Web interface.
- A portal allows individuals to customize their views of the software project/process based on their project role.
- Electronic task handoffs improve overall team efficiency.
- Tedious and clerical work are automated.
- Highly skilled personnel spend more time on their areas of expertise instead of in processing paperwork.
- Greater project management visibility through real-time status, dashboard views, alerts, and reports gives users more time to avert problems or react to new events.
- Complete audit trail for all events involving the project, process, and associated people.
- Process is treated as an IT asset, making it possible to modify and optimize the process.
- Faster ROI than manual implementation.

This work was done by Michel E. Izygon of Tietronix Software, Inc. for Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-24424-1

Mobile Thread Task Manager

The Mobile Thread Task Manager (MTTM) is being applied to parallelizing existing flight software to understand the benefits and to develop new techniques and architectural concepts for adapting software to multicore architectures. It allocates and load-balances tasks for a group of threads that migrate across processors to improve cache performance.

In order to balance-load across threads, the MTTM augments a basic map-reduce strategy to draw jobs from a global queue. In a multicore processor, memory may be "homed" to the cache of a specific processor and must be accessed from that processor. The MTTB architecture wraps access to data with thread management to move threads to the home processor for that data so that the computation follows the data in an attempt to avoid L2 cache misses. Cache homing is also handled by a memory manager that translates identifiers to processor IDs where the data will be homed (according to rules defined by the user). The user can also specify the number of threads and processors separately, which is important for tuning performance for different patterns of computation and memory access.

MTTM efficiently processes tasks in parallel on a multiprocessor computer. It also provides an interface to make it easier to adapt existing software to a multiprocessor environment.

This work was done by Bradley J. Clement, Tara A. Estlin, and Benjamin J. Bornstein of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This software is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48425.

Mechanics/Machinery

A Kinematic Calibration Process for Flight Robotic Arms

NASA's Jet Propulsion Laboratory, Pasadena, California

The Mars Science Laboratory (MSL) robotic arm is ten times more massive than any Mars robotic arm before it, yet with similar accuracy and repeatability positioning requirements. In order to assess and validate these requirements, a higher-fidelity model and calibration processes were needed.

Kinematic calibration of robotic arms is a common and necessary process to ensure good positioning performance. Most methodologies assume a rigid arm, high-accuracy data collection, and some kind of optimization of kinematic parameters. A new detailed kinematic and deflection model of the MSL robotic arm was formulated in the design phase and used to update the initial positioning and orientation accuracy and repeatability requirements. This model included a higher-fidelity link stiffness matrix representation, as well as a link level thermal expansion model. In addition, it included an actuator backlash model.

Analytical results highlighted the sensitivity of the arm accuracy to its joint initialization methodology. Because of this, a new technique for initializing the arm joint encoders through hardstop calibration was developed. This involved selecting arm configurations to use in Earth-based hardstop calibration that had corresponding configurations on Mars with the same joint torque to ensure repeatability in the different gravity environment.

The process used to collect calibration data for the arm included the use of multiple weight stand-in turrets with enough metrology targets to reconstruct the full six-degree-of-freedom location of the rover and tool frames. The follow-on data processing of the metrology data utilized a standard differential formulation and linear parameter optimization technique.

This work was done by Curtis L. Collins and Matthew L. Robinson of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-49013

Magnetostrictive Alternator

John H. Glenn Research Center, Cleveland, Ohio

This innovation replaces the linear alternator presently used in Stirling engines with a continuous-gradient, impedance-matched, oscillating magnetostrictive transducer that eliminates all moving parts via compression, maintains high efficiency, costs less to manufacture, reduces mass, and eliminates the need for a bearing system.

The key components of this new technology are the use of stacked magnetostrictive materials, such as Terfenol-D, under a biased magnetic and stress-induced compression, continuous-gradient impedance-matching material, coils, force-focusing metallic structure, and supports. The acoustic energy from the engine travels through an impedance-matching layer that is physically connected to the magnetostrictive mass. Compression bolts keep the structure under compressive strain, allowing for the micron-scale compression of the magnetostrictive material and eliminating the need for bearings.

The relatively large millimeter displacement of the pressure side of the impedance-matching material is reduced to micron motion, and undergoes stress amplification at the magnetostrictive interface. The alternating compression and expansion of the magnetostrictive material creates an alternating magnetic field that then induces an electric current in a coil that is wound around the stack. This produces electrical power from the acoustic pressure wave and, if the resonant frequency is tuned to match the engine, can replace the linear alternator that is commonly used.

This work was done by Rodger Dyson and Geoffrey Bruder 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-18939-1.

Bulk Metallic Glasses and Composites for Optical and Compliant Mechanisms

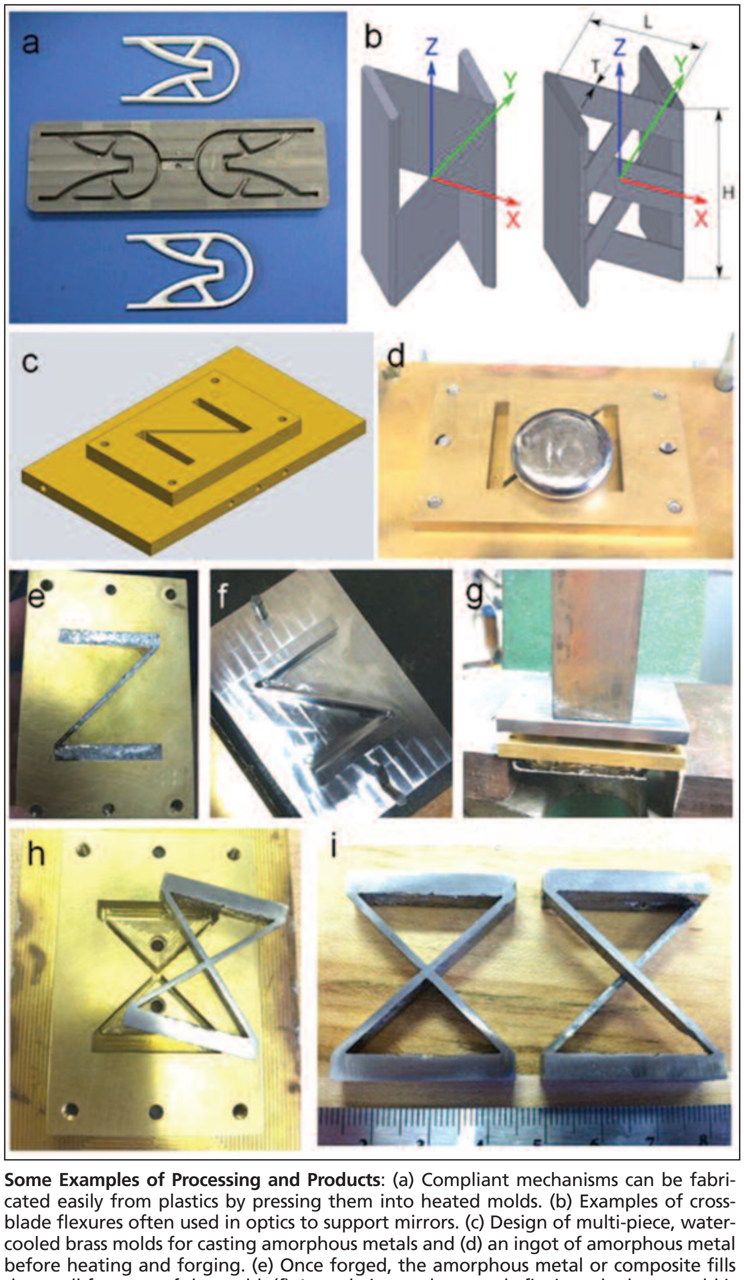
This innovation has uses in the aerospace, optics, bio-implants, spacecraft, and sporting equipment industries.

NASA's Jet Propulsion Laboratory, Pasadena, California

Mechanisms are used widely in engineering applications due to their ability to translate force and movement. They are found in kinematic pairs, gears, cams, linkages, and in flexure mechanisms (also known as compliant mechanisms). Mechanisms and flexures are used widely in spacecraft design, especially in the area of optics, where precise positioning of telescope mirrors requires elastic flexing of elements. A compliant mechanism is generally defined as a flexible mechanism that uses an elastic body deformation to cause a displacement (such as positing a mirror). The mechanisms are usually constructed as a single monolithic piece of material, and contain thin struts to allow for large elastic bending with low input force. This creates the largest problem with developing precise mechanisms; they must be fabricated from a single piece of metal, but are required to have strict accuracy on their dimensions. They are generally required to have high strength, elasticity, and low coefficient of thermal expansion.

The two biggest problems with conventional mechanisms are fabrication and materials selection. Plastic prototypes can be readily produced at low cost using 3D printing or molding, and utilize the large elasticity of polymers, but the mechanisms are unsuitable for structural applications due to their low strength and degradation, especially in spacecraft (polymers degrade in space due to the high UV exposure). A compliant mechanism used in a real engineering application must typically be made of metal, and must be fabricated either by machining or by an additive manufacturing process for metals. They are generally made from aluminum (low density and high machinability) or titanium (high strength and large elasticity). However, since the struts of the mechanism must be very thin (typically less than one mm thick), traditional machining is difficult to use because the struts bend during machining.

The use of amorphous metals (AMs) and their composites is ideal for both the mechanical properties and processing of compliant mechanisms and flexures. AMs have high strength, the elasticity of polymers, and the processability of plastics. They can be easily fabricated into monolithic mechanisms at significantly lower cost than machining, and exhibit performance better than tany crystalline material in the same application. Since they can be fabricated using reusable steel or brass molds, many parts can be fabricated using only the initial material cost and the initial mold cost. This allows for many mechanisms to be made cheaply.



Some Examples of Processing and Products: (a) Compliant mechanisms can be fabricated easily from plastics by pressing them into heated molds. (b) Examples of cross-blade flexures often used in optics to support mirrors. (c) Design of multi-piece, water-cooled brass molds for casting amorphous metals and (d) an ingot of amorphous metal before heating and forging. (e) Once forged, the amorphous metal or composite fills the small features of the mold. (f) A steel ejector that snugly fits into the brass mold is used to push out the amorphous metal mechanism from the mold. (g) The amorphous metal flexure is pressed out of the mold with a press. (h) In another geometry, a cartwheel flexure can be fabricated from amorphous metal, seen here after trimming, and the undamaged mold from which it was cast. (i) Side-by-side amorphous metal flexures; cartwheel (left) and cross-blade (right).

AMCs (amorphous metal composites) are composite alloys that exhibit similar properties and processing ability to monolithic AMs, but also have the ability to be much tougher (to avoid brittle failure), have much higher fracture toughness and fatigue life, and also can be tuned to have low coefficient of thermal expansion (CTE) by utilizing low CTE inclusions. These combinations of properties (mechanical performance and processing ability) have not been utilized for compliant mechanisms until now.

AMs (which are also known as bulk metallic glasses or BMGs) and their composites can be fabricated into optomechanical, compliant, or flexure mechanisms easily and at low cost. To accomplish this, a selected composition of AM or AMC is fabricated into a feedstock material that is heated (using radio frequency heating or resistance heating) and forged into a final part with either net or near-net shape. Because AM alloys have low melting temperatures, they can be melted and forced into a very complex mold, just like a plastic, but form a glass under the high cooling rate obtained by cooling lines in the mold. The quenched part does not react with the mold and is mechanically robust enough to survive the ejection process. The final part has the same tolerances as the mold (since there is very little shrinkage when forming a glassy metal) and yet can be removed without damaging the mold. This offers the potential to develop mechanisms that outperform currently available metals (aluminum, titanium, and steel) but that also can be fabricated in a low-cost, repeatable process. The resulting mechanisms, demonstrated here for Ti-Zr-Be alloys, have 2% elastic limit, up to 2 GPa yield strength, hardness >50 R_c, fracture toughness >100 MPa $m^{1/2}$, and excellent fatigue limit. Prototypes have been developed into two common mechanisms, a crossblade, and a cartwheel flexure (see figure).

This work was done by Douglas C. Hofmann and Gregory S. Agnes 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:

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Refer to NPO-48768, volume and number of this NASA Tech Briefs *issue, and the page number.*

Bio-Medical

Detection of Only Viable Bacterial Spores Using a Live/Dead Indicator in Mixed Populations

This technology can be used by the food and pharmaceutical industries to validate sterility and quality.

NASA's Jet Propulsion Laboratory, Pasadena, California

This method uses a photoaffinity label that recognizes DNA and can be used to distinguish populations of bacterial cells from bacterial spores without the use of heat shocking during conventional culture, and live from dead bacterial spores using molecular-based methods.

Biological validation of commercial sterility using traditional and alternative technologies remains challenging. Recovery of viable spores is cumbersome, as the process requires substantial incubation time, and the extended time to results limits the ability to quickly evaluate the efficacy of existing technologies. Nucleic acid amplification approaches such as PCR (polymerase chain reaction) have shown promise for improving time to detection for a wide range of applications. Recent real-time PCR methods are particularly promising, as these methods can be made at least semi-quantitative by correspondence to a standard curve. Nonetheless, PCR-based methods are rarely used for process validation, largely because the DNA from dead bacterial cells is highly stable and hence, DNA-based amplification methods fail to discriminate between live and inactivated microorganisms.

Currently, no published method has been shown to effectively distinguish between live and dead bacterial spores. This technology uses a DNA binding photoaffinity label that can be used to distinguish between live and dead bacterial spores with detection limits ranging from 10^9 to 10^2 spores/mL.

An environmental sample suspected of containing a mixture of live and dead vegetative cells and bacterial endospores is treated with a photoaffinity label. This step will eliminate any vegetative cells (live or dead) and dead endospores present in the sample. To further determine the bacterial spore viability, DNA is extracted from the spores and total population is quantified by real-time PCR.

The current NASA standard assay takes 72 hours for results. Part of this procedure requires a heat shock step at 80 °C for 15 minutes before the sample can be plated. Using a photoaffinity label would remove this step from the current assay as the label readily penetrates both live and dead bacterial cells. Secondly, the photoaffinity label can only penetrate dead bacterial spores, leaving behind the viable spore population. This would allow for rapid bacterial spore detection in a matter of hours compared to the several days that it takes for the NASA standard assay.

This work was done by Alberto E. Behar of Caltech; Christina N. Stam of Oak Ridge Associated Universities; and Ronald Smiley of the U.S. Food and Drug Administration for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-48259

Intravenous Fluid Generation System

This system can be used in remote medical facilities where limitations such as lack of refrigeration may limit the type and volume of medical fluids being stored or transported.

John H. Glenn Research Center, Cleveland, Ohio

The ability to stabilize and treat patients on exploration missions will depend on access to needed consumables. Intravenous (IV) fluids have been identified as required consumables. A review of the Space Medicine Exploration Medical Condition List (SMEMCL) lists over 400 medical conditions that could present and require treatment during ISS missions.

The Intravenous Fluid Generation System (IVGEN) technology provides the scalable capability to generate IV fluids from indigenous water supplies. It meets USP (U.S. Pharmacopeia) standards. This capability was performed using potable water from the ISS; water from more extreme environments would need preconditioning. The key advantage is the ability to filter mass and volume, providing the equivalent amount of IV fluid: this is critical for remote operations or resource-poor environments. The IVGEN technology purifies drinking water, mixes it with salt, and transfers it to a suitable bag to deliver a sterile normal saline solution.

Operational constraints such as mass limitations and lack of refrigeration may limit the type and volume of such fluids that can be carried onboard the spacecraft. In addition, most medical fluids have a shelf life that is shorter than some mission durations. Consequently, the objective of the IVGEN experiment was to develop, design, and validate the necessary methodology to purify spacecraft potable water into a normal saline solution, thus reducing the amount of IV fluids that are included in the launch manifest.

As currently conceived, an IVGEN system for a space exploration mission would consist of an accumulator, a purifier, a mixing assembly, a salt bag, and a sterile bag. The accumulator is used to transfer a measured amount of drinking water from the spacecraft to the purifier. The purifier uses filters to separate any air bubbles that may have gotten trapped during the drinking water transfer from flowing through a high-quality deionizing cartridge that removes the impurities in the water before entering the salt bag and mixing with the salt to create a normal saline solution.

This work was done by John McQuillen and Terri McKay of Glenn Research Center, and Daniel Brown and John Zoldak of ZIN Technologies. Inc. 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-19044-1.

National Aeronautics and
Space Administration