10-13 October 2013

Tech Briefs

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

INTRODUCTION

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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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10-13 October 2013

TECH BRIEFS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

A Short-Range Distance Sensor with Exceptional Linearity

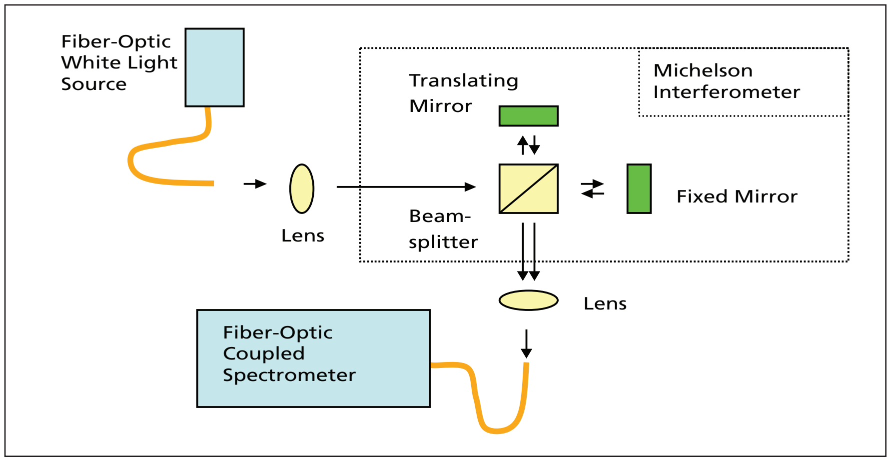
Potential uses exist in the areas of micromachining and nanotechnology.

John F. Kennedy Space Center, Florida

A sensor has been demonstrated that can measure distance over a total range of about 300 microns to an accuracy of about 0.1 nm (resolution of about 0.01 nm). This represents an exceptionally large dynamic range of operation — over 1,000,000. The sensor is optical in nature, and requires the attachment of a mirror to the object whose distance is being measured.

This work resulted from actively developing a white light interferometric system to be used to measure the depths of defects in the Space Shuttle Orbiter windows. The concept was then applied to measuring distance. The concept later expanded to include spectrometer calibration.

In summary, broadband (i.e., white) light is launched into a Michelson interferometer, one mirror of which is fixed and one of which is attached to the object whose distance is to be measured. The light emerging from the interferometer has traveled one of two distances: either the distance to the fixed mirror and back, or the distance to the moving mirror and back. These two light beams mix and produce an interference pattern where some wavelengths interfere constructively and some destructively. Sending this light into a spectrometer allows this interference pattern to be analyzed, yielding the net distance difference between the two paths.



The **Distance Sensor** is based on the wavelength variations of the light transfer through a Michelson interferometer. Collimated white light is launched into an interferometer composed of a fixed mirror and a translating mirror aligned with a beamsplitter. Light reflected from each mirror makes its way to a small spectrometer where the optical intensity can be measured as a function of wavelength.

The unique feature of this distance sensor is its ability to measure accurately distance over a dynamic range of more than one million, the ratio of its range (about 300 microns) to its accuracy (about 0.1 nanometer). Such a large linear operating range is rare and arises here because both amplitude and phase-matching algorithms contribute to the performance. The sensor is limited by the need to attach a mirror of some kind to the object being tracked, and by the fairly small total range, but the exceptional dynamic range should make it of interest.

This work was done by Stephen Simmons and Robert Youngquist of Kennedy Space Center. For more information, contact the Kennedy Space Center Technology Transfer Office at (321) 867-7171. KSC-13382

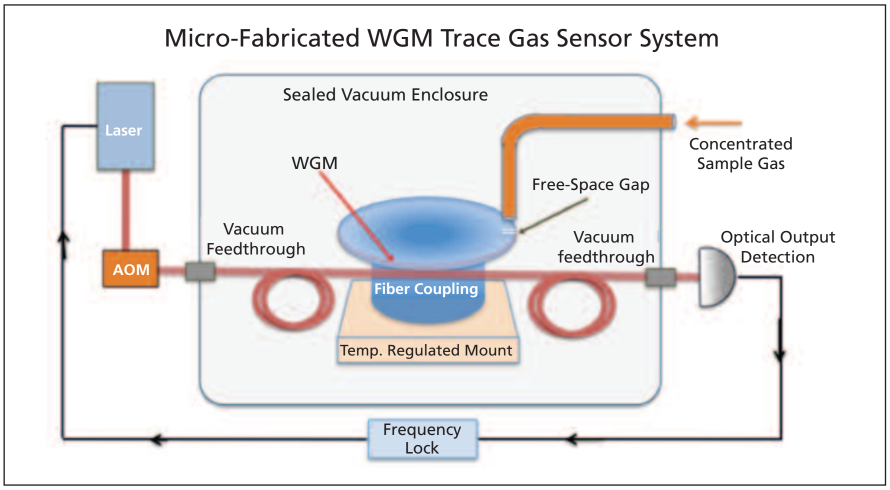
Miniature Trace Gas Detector Based on Microfabricated Optical Resonators

Ultra-sensitive detection of molecules is available with a modified whispering gallery mode resonator.

NASA's Jet Propulsion Laboratory, Pasadena, California

While a variety of techniques exist to monitor trace gases, methods relying on absorption of laser light are the most commonly used in terrestrial applications. Cavity-enhanced absorption techniques typically use high-reflectivity mirrors to form a resonant cavity, inside of which a sample gas can be analyzed. The effective absorption length is augmented by the cavity's high quality factor, or *Q*, because the light reflects many times between the mirrors. The sensitivity of such mirror-based sensors scales with size, generally making them somewhat bulky in volume. Also, specialized coatings for the high-reflectivity mirrors have limited bandwidth (typically just a few nanometers), and the delicate mirror surfaces can easily be degraded by dust or chemical films.

As a highly sensitive and compact alternative, JPL is developing a novel trace gas sensor based on a monolithic optical resonator structure that has been modified such that a gas sample can be directly injected into the cavity. This device concept combines ultra-high *Q*



The **Trace Gas Detection System** features a concentrated sample gas flowing to the free-space gap in the microfabricated disc, packaged inside a compact sealed enclosure with external laser and detection electronics. Also shown is a SEM image of a high-*Q* calcium fluoride disc that has been augmented with a notch using FIB.

optical whispering gallery mode resonators (WGMR) with microfabrication technology used in the semiconductor industry. For direct access to the optical mode inside a resonator, material can be precisely milled from its perimeter, creating an open gap within the WGMR. Within this open notch, the full optical mode of the resonator can be accessed. While this modification may limit the obtainable *Q*, calculations show that the reduction is not significant enough to outweigh its utility for trace gas detection. The notch can be milled from the high-*Q* crystalline WGMR with a focused ion beam (FIB) instrument with resolution much finer than an optical wavelength, thereby minimizing scattering losses and preserving the optical quality. Initial experimental demonstrations have shown that these opened cavities still support high-*Q* whispering gallery modes.

This technology could provide ultra-sensitive detection of a variety of molecular species in an extremely compact and robust package. With this type of modified WGMR, one can inject a gas sample into the open gap, allowing highly sensitive trace molecule detection within a roughly 1-cm volume. Other critical components of the instrument, such as the detector and a semiconductor laser, could be directly packaged with the resonator so as to not significantly increase the size of the device.

Besides its low mass, volume, and power consumption, the monolithic design makes these resonators intrinsically robust devices, capable of handling significant temperature excursions, without moving parts to wear out or delicate coatings that can be easily damaged. A sensor could integrate with microfluidics technology for a chip-scale device. It could be mounted to the end of a deployable arm, or inserted into a borehole. Also, a network of individual sensors could be dispersed to monitor conditions over a wide region.

This work was done by David C. Aveline, Nan Yu, Robert J. Thompson, and Dmitry V. Strekalov of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). *NPO-47173*

Commercial Non-Dispersive Infrared Spectroscopy Sensors for Sub-Ambient Carbon Dioxide Detection

Lyndon B. Johnson Space Center, Houston, Texas

Carbon dioxide produced through respiration can accumulate rapidly within closed spaces. If not managed, a crew's respiratory rate increases, headaches and hyperventilation occur, vision and hearing are affected, and cognitive abilities decrease. Consequently, development continues on a number of CO_2 removal technologies for human spacecraft and spacesuits. Terrestrially, technology development requires precise performance characterization to qualify promising air revitalization equipment. On-orbit, instrumentation is required to identify and eliminate unsafe conditions. This necessitates accurate *in situ* CO_2 detection.

Recursive compensation algorithms were developed for sub-ambient detection of CO_2 with commercial off-the-shelf (COTS) non-dispersive infrared (NDIR) sensors. In addition, the source of the exponential loss in accuracy is developed theoretically. The basis of the loss can be explained through thermal, Doppler, and Lorentz broadening effects that arise as a result of the temperature, pressure, and composition of the gas mixture under analysis.

The objective was to develop a mathematical routine to compensate COTS CO_2 sensors relying on NDIR over pressures, temperatures, and compositions far from calibration conditions. The routine relies on a power-law relationship for the pressure dependency of the sensors along with an equivalent pressure to account for the composition dependency. A Newton-Raphson iterative technique solves for actual carbon dioxide concentration based on the reported concentration. Moreover, first principles routines were established to predict mixed-gas spectra based on sensor specifications (e.g., optical path length). The first principles model can be used to parametrically optimize sensors or sensor arrays across a wide variety of pressures/temperatures/compositions.

In this work, heuristic scaling arguments were utilized to develop reasonable compensation techniques. Experimental results confirmed this approach and provided evidence that composition broadening significantly alters spectra when pressure is reduced. Consequently, a recursive compensation technique was developed with the Newton-Raphson method, which was subsequently verified through experimentation.

This work was done by Michael J. Swickrath and Molly S. Anderson of Johnson Space Center, Summer McMillin of Jacobs Technology, and Craig Broerman of Hamilton Sundstrand. Further information is contained in a TSP (see page 1). *MSC-25343-1*

Fast, Large-Area, Wide-Bandgap UV Photodetector for Cherenkov Light Detection

This detector can be used for monitoring fires, microbial sterilization/disinfection processing, and spectrophotometry analysis.

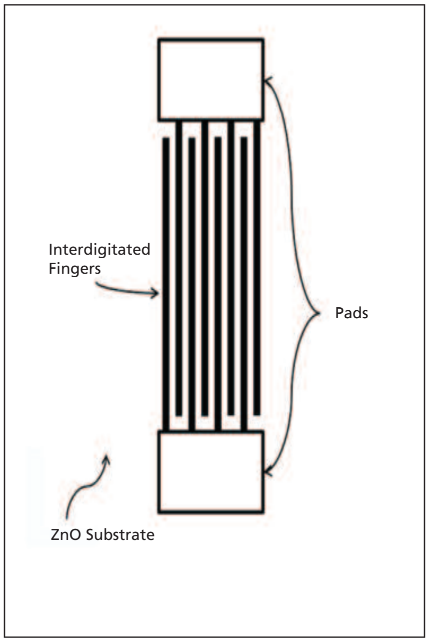
John H. Glenn Research Center, Cleveland, Ohio

Due to limited resources available for power and space for payloads, miniaturizing and integrating instrumentation is a high priority for addressing the challenges of manned and unmanned deep space missions to high Earth orbit (HEO), near Earth objects (NEOs), Lunar and Martian orbits and surfaces, and outer planetary systems, as well as improvements to high-altitude aircraft safety. New, robust, and compact detectors allow future instrumentation packages more options in satisfying specific mission goals.

A solid-state ultraviolet (UV) detector was developed with a theoretical fast response time and large detection area intended for application to Cherenkov detectors. The detector is based on the wide-bandgap semiconductor zinc oxide (ZnO), which in a bridge circuit can detect small, fast pulses of UV light like those required for Cherenkov detectors. The goal is to replace the role of photomultiplier tubes in Cherenkov detectors with these solid-state devices, saving on size, weight, and required power.

For improving detection geometry, a spherical detector to measure high atomic number and energy (HZE) ions from any direction has been patented as part of a larger space radiation detector system. The detector will require the development of solid-state UV photodetectors fast enough (2 ns response time or better) to detect the shockwave of Cherenkov light emitted as the ions pass through a quartz, sapphire, or acrylic ball. The detector must be small enough to fit in the detector system structure, but have an active area large enough to capture enough Cherenkov light from the sphere.

The detector is fabricated on bulk single-crystal undoped ZnO. Interdigitated finger electrodes and contact pads are patterned via photolithography, and formed by sputtered metal of silver, platinum, or other high-conductivity metal.



Schematic of the **UV Photodetector**.

The detector is operated as a resistive sensor, such as an RTD (resistance temperature detector) or strain gauge with a supplied voltage/current, and monitoring resulting current/voltage. A common embodiment is as part of a bridge circuit where a supplied voltage is divided between the detector and a dummy resistor, in parallel with two other resistors of similar values of the detector and dummy resistor. Directly observing the difference of the voltage drop of the detector and its parallel resistor, a UV light measurement can be made. The preferred embodiment is in half-bridge configuration where the dummy resistor is another interdigitated finger electrode pattern on the same ZnO substrate, but coated with a UV blocking material.

When exposed to UV light (or any light of sufficient energy), the electrons in valence bands of the semiconductor absorb sufficient energy to jump into the conductive band and freely move about the semiconductor. Unless defined by an electric field, the motions of these electrons are random, and will lose enough energy to fall back into a valence band. An applied electric field thus directs the drift of the conductive electrons, and the addition of conductive electrons by the absorption of UV light reduces the resistance of the semiconductor.

The main feature of the detector is the simplicity of design with the large area and the fast response time necessary for detecting Cherenkov light in radiation detectors. The sensor can be fabricated using standard microfabrication processes without doping, allowing extended use in space without loss of sensitivity. The response time is dependent on electrode spacing, but the wavelength is not, allowing the detector to be fabricated to tolerances specific to mission requirements.

This work was done by John D. Wrbanek and Susan Y. Wrbanek 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-19040-1.

Software

Mission Data System Java Edition Version 7

The Mission Data System framework defines closed-loop control system abstractions from State Analysis including interfaces for state variables, goals, estimators, and controllers that can be adapted to implement a goal-oriented control system. The framework further provides an execution environment that includes a goal scheduler, execution engine, and fault monitor that support the expression of goal network activity plans. Using these frameworks, adapters can build a goal-oriented control system where activity coordination is verified before execution begins (plan time), and continually during execution. Plan failures including violations of safety constraints expressed in the plan can be handled through automatic re-planning.

This version optimizes a number of key interfaces and features to minimize dependencies, performance overhead, and improve reliability. Fault diagnosis and real-time projection capabilities are incorporated. This version enhances earlier versions primarily through optimizations and quality improvements that raise the technology readiness level.

Goals explicitly constrain system states over explicit time intervals to eliminate ambiguity about intent, as compared to command-oriented control that only implies persistent intent until another command is sent. A goal network scheduling and verification process ensures that all goals in the plan are achievable before starting execution. Goal failures at runtime can be detected (including predicted failures) and handled by adapted response logic. Responses can include plan repairs (try an alternate tactic to achieve the same goal), goal shedding, ignoring the fault, cancelling the plan, or safing the system.

This work was done by William K. Reinholtz and David A. Wagner 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-47804.

Adaptive Distributed Environment for Procedure Training (ADEPT)

ADEPT (Adaptive Distributed Environment for Procedure Training) is designed to provide more effective, flexible, and portable training for NASA systems controllers. When creating a training scenario, an exercise author can specify a representative rationale structure using the graphical user interface, annotating the results with instructional texts where needed. The author's structure may distinguish between essential and optional parts of the rationale, and may also include "red herrings" — hypotheses that are essential to consider, until evidence and reasoning allow them to be ruled out.

The system is built from pre-existing components, including Stottler Henke's SimVentive™ instructional simulation authoring tool and runtime. To that, a capability was added to author and exploit explicit control decision rationale representations. ADEPT uses SimVentive's Scalable Vector Graphics (SVG)-based interactive graphic display capability as the basis of the tool for quickly noting aspects of decision rationale in graph form.

The ADEPT prototype is built in Java, and will run on any computer using Windows, MacOS, or Linux. No special peripheral equipment is required.

The software enables a style of student/tutor interaction focused on the reasoning behind systems control behavior that better mimics proven Socratic human tutoring behaviors for highly cognitive skills. It supports fast, easy, and convenient authoring of such tutoring behaviors, allowing specification of detailed scenario-specific, but content-sensitive, high-quality tutor hints and feedback. The system places relatively light data-entry demands on the student to enable its rationale-centered discussions, and provides a support mechanism for fostering coherence in the student/tutor dialog by including focusing, sequencing, and utterance tuning mechanisms intended to better fit tutor hints and feedback into the ongoing context.

This work was done by Eric Domeshek, James Ong, and John Mohammed of Stottler Henke Associates, Inc. for Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-24493-1

LEGEND, a LEO-to-GEO Environment Debris Model

LEGEND (LEO-to-GEO Environment Debris model) is a three-dimensional orbital debris evolutionary model that is capable of simulating the historical and future debris populations in the near-Earth environment. The historical component in LEGEND adopts a deterministic approach to mimic the known historical populations. Launched rocket bodies, spacecraft, and mission-related debris (rings, bolts, etc.) are added to the simulated environment. Known historical breakup events are reproduced, and fragments down to 1 mm in size are created.

The LEGEND future projection component adopts a Monte Carlo approach and uses an innovative pair-wise collision probability evaluation algorithm to simulate the future breakups and the growth of the debris populations. This algorithm is based on a new "random sampling in time" approach that preserves characteristics of the traditional approach and captures the rapidly changing nature of the orbital debris environment.

LEGEND is a Fortran 90-based numerical simulation program. It operates in a UNIX/Linux environment.

This work was done by Jer Chyi Liou and Doyle T. Hall of Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-24805-1

Electronics/Computers

Millimeter-Wave Localizers for Aircraft-to-Aircraft Approach Navigation

Beyond aircraft refueling, this system can be used in automotive navigation and unmanned aerial vehicle refueling.

NASA's Jet Propulsion Laboratory, Pasadena, California

Aerial refueling technology for both manned and unmanned aircraft is critical for operations where extended aircraft flight time is required. Existing refueling assets are typically manned aircraft, which couple to a second aircraft through the use of a refueling boom. Alignment and mating of the two aircraft continues to rely on human control with use of high-resolution cameras. With the recent advances in unmanned aircraft, it would be highly advantageous to remove/reduce human control from the refueling process, simplifying the amount of remote mission management and enabling new operational scenarios.

Existing aerial refueling uses a camera, making it non-autonomous and prone to human error. Existing commercial localizer technology has proven robust and reliable, but not suited for aircraft-to-aircraft approaches like in aerial refueling scenarios since the resolution is too coarse (approximately one meter). A localizer approach system for aircraft-to-aircraft docking can be constructed using the same modulation with a millimeter-wave carrier to provide high resolution.

One technology used to remotely align commercial aircraft on approach to a runway are ILS (instrument landing systems). ILS have been in service within the U.S. for almost 50 years. In a commercial ILS, two partially overlapping beams of UHF (109 to 126 MHz) are broadcast from an antenna array so that their overlapping region defines the centerline of the runway. This is called a localizer system and is responsible for horizontal alignment of the approach. One beam is modulated with a 150-Hz tone, while the other with a 90-Hz tone. Through comparison of the modulation depths of both tones, an autopilot system aligns the approaching aircraft with the runway centerline. A similar system called a glide-slope (GS) exists in the 320-to-330MHz band for vertical alignment of the approach. While this technology has been proven reliable for millions of commercial flights annually, its UHF nature limits its ability to operate beyond the 1-to-2-meter precisions associated with commercial runway width.

A prototype ILS-type system operates at millimeter-wave frequencies to provide automatic and robust approach control for aerial refueling. The system allows for the coupling process to remain completely autonomous, as a boom operator is no longer required. Operating beyond 100 GHz provides enough resolution and a narrow enough beamwidth that an approach corridor of centimeter scales can be maintained.

Two modules were used to accomplish this task. The first module is a localizer/glide-slope module that can be fitted on a refueling aircraft. This module provides the navigation beams for aligning the approaching aircraft. The second module is navigational receiver fitted onto the approaching aircraft to be refueled that can detect the approach beams. Since unmanned aircraft have a limited payload size and limited electrical power, the receiver portion was implemented in CMOS (complementary metal oxide semiconductor) technology based on a super-regenerative receiver (SRR) architecture. The SRR achieves mW-level power consumption and chip sizes less than 1 mm^2. While super-regenerative techniques have small bandwidths that limit use in communication systems, their advantages of high sensitivity, low complexity, and low power make them ideal in this situation where modulating tones of less than 1 kHz are used.

This work was done by Adrian J. Tang of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-48868

Impedance Discontinuity Reduction Between High-Speed Differential Connectors and PCB Interfaces

Lyndon B. Johnson Space Center, Houston, Texas

High-speed serial communication (i.e., Gigabit Ethernet) requires differential transmission and controlled impedances. Impedance control is essential throughout cabling, connector, and circuit board construction.

An impedance discontinuity arises at the interface of a high-speed quadrax and twinax connectors and the attached printed circuit board (PCB). This discontinuity usually is lower impedance since the relative dielectric constant of the board is higher (i.e., polyimide ≈4) than the connector (Teflon ≈2.25). The discontinuity can be observed in transmit or receive eye diagrams, and can reduce the effective link margin of serial data networks.

High-speed serial data network transmission improvements can be made at the connector-to-board interfaces as well as improving differential via hole impedances. The impedance discontinuity was improved by 10 percent by drilling a 20-mil (≈0.5-mm) hole in between the pin of a differential connector spaced 55 mils (≈1.4 mm) apart as it is attached to the PCB.

The effective dielectric constant of the board can be lowered by drilling holes into the board material between the differential lines in a quadrax or twinax connector attachment points. The differential impedance is inversely proportional to the square root of the relative dielectric constant. This increases the differential impedance and thus reduces the above described impedance discontinuity. The differential via hole impedance can also be increased in the same manner. This technique can be extended to multiple smaller drilled holes as well as tapered holes (i.e., big in the middle followed by smaller ones diagonally).

This work was done by Sal Navidi, Rodell Agdinaoay, and Keith Walter of Honeywell Aerospace 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 Aerospace. Inquiries concerning licenses for its commercial development should be addressed to:

Honeywell Aerospace
P.O. Box 52199
Phoenix, AZ 85072

Refer to MSC-24855-l, volume and number of this NASA Tech Briefs *issue, and the page number.*

SpaceCube Version 1.5

This processing system is suited for any sub-orbital application that requires a compact solution with high-data-rate storage capability and high-performance processing.

Goddard Space Flight Center, Greenbelt, Maryland

SpaceCube 1.5 is a high-performance and low-power system in a compact form factor. It is a hybrid processing system consisting of CPU (central processing unit), FPGA (field-programmable gate array), and DSP (digital signal processor) processing elements. The primary processing engine is the Virtex-5 FX100T FPGA, which has two embedded processors. The SpaceCube 1.5 System was a bridge to the SpaceCube 2.0 and SpaceCube 2.0 Mini processing systems. The SpaceCube 1.5 system was the primary avionics in the successful SMART (Small Rocket/Spacecraft Technology) Sounding Rocket mission that was launched in the summer of 2011.

For SMART and similar missions, an avionics processor is required that is reconfigurable, has high processing capability, has multi-gigabit interfaces, is low power, and comes in a rugged/compact form factor. The original SpaceCube 1.0 met a number of the criteria, but did not possess the multi-gigabit interfaces that were required and is a higher-cost system. The SpaceCube 1.5 was designed with those mission requirements in mind.

The SpaceCube 1.5 features one Xilinx Virtex-5 FX100T FPGA and has excellent size, weight, and power characteristics [4×4×3 in. (≈10×10×8 cm), 3 lb (≈1.4 kg), and 5 to 15 W depending on the application]. The estimated computing power of the two PowerPC 440s in the Virtex-5 FPGA is 1100 DMIPS each. The SpaceCube 1.5 includes two Gigabit Ethernet (1 Gbps) interfaces as well as two SATA-I/II interfaces (1.5 to 3.0 Gbps) for recording to data drives. The SpaceCube 1.5 also features DDR2 SDRAM (double data rate synchronous dynamic random access memory); 4-Gbit Flash for storing application code for the CPU, FPGA, and DSP processing elements; and a Xilinx Platform Flash XL to store FPGA configuration files or application code.

The system also incorporates a 12 bit analog to digital converter with the ability to read 32 discrete analog sensor inputs. The SpaceCube 1.5 design also has a built-in accelerometer. In addition, the system has 12 receive and transmit RS-422 interfaces for legacy support. The SpaceCube 1.5 processor card represents the first NASA Goddard design in a compact form factor featuring the Xilinx Virtex-5. The SpaceCube 1.5 incorporates backward compatibility with the SpaceCube 1.0 form factor and stackable architecture. It also makes use of low-cost commercial parts, but is designed for operation in harsh environments.

This work was done by Alessandro Geist, Michael Lin, Tom Flatley, and David Petrick of Goddard Space Flight Center. Further information is contained in a TSP (see page 1).
GSC-15936-1

Manufacturing & Prototyping

High-Pressure Lightweight Thrusters

Carbon/carbon composite structures are braided over iridium-lined mandrels and densified by chemical vapor infiltration.

Marshall Space Flight Center, Alabama

Returning samples of Martian soil and rock to Earth is of great interest to scientists. There were numerous studies to evaluate Mars Sample Return (MSR) mission architectures, technology needs, development plans, and requirements. The largest propulsion risk element of the MSR mission is the Mars Ascent Vehicle (MAV). Along with the baseline solid-propellant vehicle, liquid propellants have been considered. Similar requirements apply to other lander ascent engines and reaction control systems.

The performance of current state-of-the-art liquid propellant engines can be significantly improved by increasing both combustion temperature and pressure. Pump-fed propulsion is suggested for a single-stage bipropellant MAV. Achieving a 90-percent stage propellant fraction is thought to be possible on a 100-kg scale, including sufficient thrust for lifting off Mars.

To increase the performance of storable bipropellant rocket engines, a high-pressure, lightweight combustion chamber was designed. Iridium liner electrodeposition was investigated on complex-shaped thrust chamber mandrels. Dense, uniform iridium liners were produced on chamber and cylindrical mandrels. Carbon/carbon composite (C/C) structures were braided over iridium-lined mandrels and densified by chemical vapor infiltration. Niobium deposition was evaluated for forming a metallic attachment flange on the carbon/carbon structure. The new thrust chamber was designed to exceed state-of-the-art performance, and was manufactured with an 83-percent weight savings.

High-performance C/Cs possess a unique set of properties that make them desirable materials for high-temperature structures used in rocket propulsion components, hypersonic vehicles, and aircraft brakes. In particular, more attention is focused on 3D braided C/Cs due to their mesh-work structure. Research on the properties of C/Cs has shown that the strength of composites is strongly affected by the fiber-matrix interfacial bonding, and that weakening interface realizes pseudo-plastic behavior with significant increase in the tensile strength. The investigation of high-temperature strength of C/Cs under high-rate heating (critical for thrust chambers) shows that tensile and compression strength increases from 70 MPa at room temperature to 110 MPa at 1,773 K, and up to 125 MPa at 2,473 K.

Despite these unique properties, the use of C/Cs is limited by its high oxidation rate at elevated temperatures. Lining carbon/carbon chambers with a thin layer of iridium or iridium and rhenium is an innovative way to use proven refractory metals and provide the oxidation barrier necessary to enable the use of carbon/carbon composites. Due to the lower density of C/Cs as compared to SiC/SiC composites, an iridium liner can be added to the C/C structure and still be below the overall thruster weight. Weight calculations show that C/C, C/C with 50 microns of Ir, and C/C with 100 microns of Ir are of less weight than alternative materials for the same construction.

This work was done by Richard Holmes of Marshall Space Flight Center and Timothy McKechnie, Anatoliy Shchetkovskiy, and Alexander Smirnov of Plasma Processes, Inc. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32883-1.

Non-Magnetic, Tough, Corrosion- and Wear-Resistant Knives From Bulk Metallic Glasses and Composites

High-performance knives are used in hunting, fishing, sailing, diving, industrial, and military applications.

NASA's Jet Propulsion Laboratory, Pasadena, California

Quality knives are typically fabricated from high-strength steel alloys. Depending on the application, there are different requirements for mechanical and physical properties that cause problems for steel alloys. For example, diver's knives are generally used in salt water, which causes rust in steel knives. Titanium diver's knives are a popular alternative due to their salt water corrosion resistance, but are too soft to maintain a sharp cutting edge. Steel knives are also magnetic, which is undesirable for military applications where the knives are used as a tactical tool for diffusing magnetic mines. Steel is also significantly denser than titanium (8 g/cm^3 vs. 4.5 g/cm^3), which results in heavier knives for the same size. Steel is hard and wear-resistant, compared with titanium, and can keep a sharp edge during service. A major drawback of both steel and titanium knives is that they must be ground or machined into the final knife shape from a billet. Since most knives have a mirrored surface and a complex shape, manufacturing them is complex. It would be more desirable if the knife could be cast into a net or near-net shape in a single step.

The solution to the deficiencies of titanium, steel, and ceramic knives is to fabricate them using bulk metallic glasses (or composites). These alloys can be cast

A full tang **Bulk Metallic Glass Tactical Knife** with multi-faceted blade surface and carbon fiber grip with titanium pins, fabricated by Benjamin Potter of Altadena, CA. The knife was fabricated by water-grinding from a larger plate as an illustration. In a commercial setup, the knife would be cast to a net-shape using an auto-feed and eject system, similar to what is done in plastics.

into net or near-net shaped knives with a combination of properties that exceed both titanium and steel. A commercially viable BMG (bulk metallic glass) or composite knife is one that exhibits one or all of the following properties: It is based on titanium, has a self-sharpening edge, can retain an edge during service, is hard, is non-magnetic, is corrosion-resistant against a variety of corrosive environments, is tough (to allow for prying), can be cast into a net-shape with a mirror finish and a complex shape, has excellent wear resistance, and is low-density. These properties can be achieved in BMG and composites through alloy chemistry and processing. For each desired property for knife fabrication and performance, there is an alloy development strategy that optimizes behavior. Although BMG knives have been demonstrated as far back as 1995, they never found commercial success because they had to be ground (which presented problems because the alloys contained beryllium), they weren't low cost (because they weren't cast to a net-shape), they were brittle (because they were made with a low-quality commercial material), and they had extremely poor corrosion resistance (because corrosion was not well-understood in these materials). Ultimately, these shortcomings prevented the widespread commercialization.

In the current work, the inventors have applied more than a decade of research on BMGs from Caltech and JPL to develop a better understanding of how to make BMG knives that exhibit an optimal combination of properties, processing and cost. Alloys have been developed based in titanium (and other metals), that exhibit high toughness, high hardness, excellent corrosion resistance, no ferromagnetism, edge-retaining self-sharpening, and the ability to be cast like a plastic using commercially available casting techniques (currently used by commercial companies such as Liquidmetal Technologies and Visser Precision Casting). The inventors argue that depending on the application (diving, military, tactical, utility, etc.) there is an optimal combination of design and alloy composition. Moreover, with new casting technologies not available at the inception of these materials, net-shaped knives can be cast into complex shapes that require no aftermarket forming, except for sharpening using water-cooled polishing wheel. These combinations of discoveries seek to make low-cost BMG knives commercially viable products that have no equal among metal or ceramic knives. Current work at JPL focuses on net-shape casting of these alloys and testing their mechanical properties versus commercially available knives to demonstrate their benefits.

This work was done by Douglas C. Hofmann of Caltech and Benjamin Potter for NASA's Jet Propulsion Laboratory. For more information, contact the inventors at dch@jpl.nasa.gov. NPO-48850

Materials & Coatings

Ambient Dried Aerogels

NASA's Jet Propulsion Laboratory, Pasadena, California

A method has been developed for creating aerogel using normal pressure and ambient temperatures. All spacecraft, satellites, and landers require the use of thermal insulation due to the extreme environments encountered in space and on extraterrestrial bodies. Ambient dried aerogels introduce the possibility of using aerogel as thermal insulation in a wide variety of instances where supercritically dried aerogels cannot be used. More specifically, thermoelectric devices can use ambient dried aerogel, where the advantages are in situ production using the cast-in ability of an aerogel.

Previously, aerogels required supercritical conditions (high temperature and high pressure) to be dried. Ambient dried aerogels can be dried at room temperature and pressure. This allows many materials, such as plastics and certain metal alloys that cannot survive supercritical conditions, to be directly immersed in liquid aerogel precursor and then encapsulated in the final, dried aerogel. Additionally, the metalized Mylar films that could not survive the previous methods of making aerogels can survive the ambient drying technique, thus making multilayer insulation (MLI) materials possible. This results in lighter insulation material as well.

Because this innovation does not require high-temperature or high-pressure drying, ambient dried aerogels are much less expensive to produce. The equipment needed to conduct supercritical drying costs many tens of thousands of dollars, and has associated running expenses for power, pressurized gasses, and maintenance. The ambient drying process also expands the size of the pieces of aerogel that can be made because a high-temperature, high-pressure system typically has internal dimensions of up to 30 cm in diameter and 60 cm in height. In the case of this innovation, the only limitation on the size of the aerogels produced would be in the ability of the solvent in the wet gel to escape from the gel network.

This work was done by Steven M. Jones and Jong-Ah Paik of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-49008

Applications for Gradient Metal Alloys Fabricated Using Additive Manufacturing

A new roadmap for gradient metals that could be used in cars, optics, aircraft, and sporting goods.

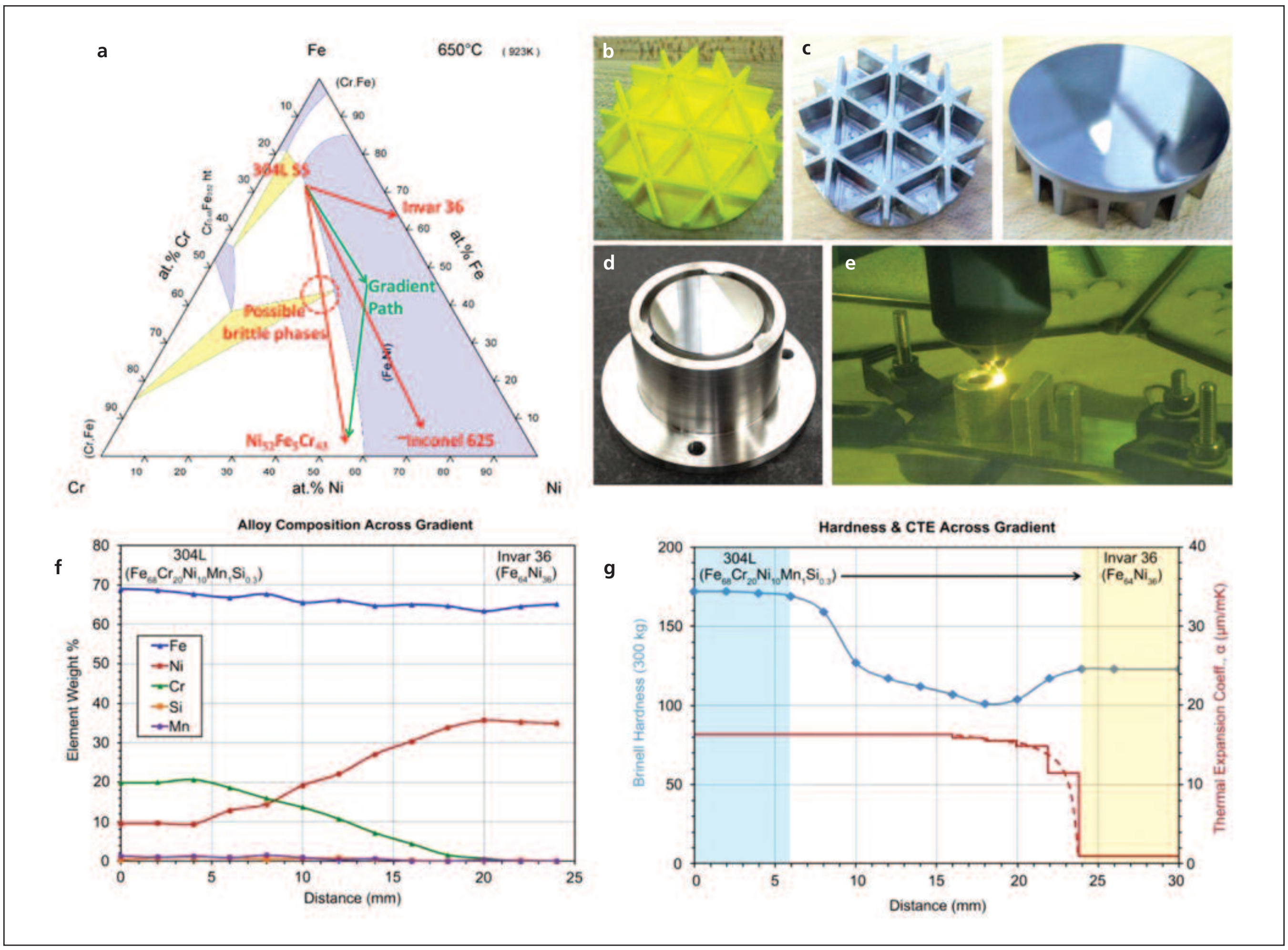
NASA's Jet Propulsion Laboratory, Pasadena, California

Recently, additive manufacturing (AM) techniques have been developed that may shift the paradigm of traditional metal production by allowing complex net-shaped hardware to be built up layer-by-layer, rather than being machined from a billet. The AM process is ubiquitous with polymers due to their low melting temperatures, fast curing, and controllable viscosity, and 3D printers are widely available as commercial or consumer products. 3D printing with metals is inherently more complicated than with polymers due to their higher melting temperatures and reactivity with air, particularly when heated or molten. The process generally requires a high-power laser or other focused heat source, like an electron beam, for precise melting and deposition. Several promising metal AM techniques have been developed, including laser deposition (also called laser engineered net shaping or LENS® and laser deposition technology (LDT)), direct metal laser sintering (DMLS), and electron beam free-form (EBF). These machines typically use powders or wire feedstock that are melted and deposited using a laser or electron beam. Complex net-shape parts have been widely demonstrated using these (and other) AM techniques and the process appears to be a promising alternative to machining in some cases.

Rather than simply competing with traditional machining for cost and time savings, the true advantage of AM involves the fabrication of hardware that cannot be produced using other techniques. This could include parts with "blind" features (like foams or trusses), parts that are difficult to machine conventionally, or parts made from materials that do not exist in bulk forms. In this work, the inventors identify that several AM techniques can be used to develop metal parts that change composition from one location in the part to another, allowing for complete control over the mechanical or physical properties. This changes the paradigm for conventional metal fabrication, which relies on an assortment of "post-processing" methods to locally alter properties (such as coating, heat treating, work hardening, shot peening, etching, anodizing, among others). Building the final part in an additive process allows for the development of an entirely new class of metals, so-called "functionally graded metals" or "gradient alloys." By carefully blending feedstock materials with different properties in an AM process, hardware can be developed with properties that cannot be obtained using other techniques but with the added benefit of the net-shaped fabrication that AM allows.

Functionally graded metal alloys have been demonstrated previously using the LENS® process but the technique has not been used to develop functional hardware because the fabrication of robust gradient compositions is not trivial. In most cases, one cannot simply add a feedstock metal to another and expect to develop a new metal alloy free of cracks and unwanted phases. Developing gradient metal alloys requires a significant amount of knowledge in phase transformations to avoid compositions where brittle intermetallic compounds form (which may crack and, thus, destroy the hardware). To address this, the inventors have developed a technique where potential gradient compositions can be simplified and transposed onto a three-component (ternary) phase diagram (or a 3-dimensional hybrid phase diagram, in some cases) and the desired gradient composition can be "mapped" to avoid unwanted phases (see figure). This process is part of a broader roadmap for gradient alloys that the inventors have developed to go from a desired combination of properties to a final part. This process proceeds by (1) identifying a combination of desired properties and modeling a component, (2) selecting metal alloys that satisfy the desired mechanical or physical properties, (3) developing a composition map to transition from one alloy to the other without forming unwanted phases, (4) selecting the desired AM building process, and (5) fabricating the part. Although at the time of this reporting it has not yet been demonstrated in the literature, the authors have identified a number of AM techniques that can be used to fabricate gradient metals, including laser deposition, laser sintering, wire free-form, thermal spray coating, metal dipping, among others. In any additive process involving metal feedstock, gradient alloys are possible.

In the current program, funded by NASA's Jet Propulsion Laboratory, the inventors use the gradient alloy roadmap to explore several desirable spacecraft applications. The LENS® technique was selected to develop gradient compositions free of brittle phases and those alloys were fabricated into prototype hardware. In one application, a gradient alloy mirror mount was developed that transitions between stainless steel at the base and Invar (an FeNi alloy) at the top. In space optics applications, glass mirrors are often bonded with epoxy to metal mirror mounts,



Various Aspects of the Innovation: (a) An isothermal slice of the Fe-Ni-Cr ternary phase diagram showing how different gradient compositions can be mapped. The lines represent composition gradients between 304L stainless steel and Invar 36, a simplified Inconel 625 alloy and a NiFeCr alloy. In some gradients, the path intersects brittle intermetallic phases, which can be avoided by changing the path to go through more desirable phases (the segmented green line). (b) An isogrid mirror fabricated using a 3D plastic printer and (c) the same part fabricated using LENS after some finish machining. The mirror surface is made of Invar 36 and the isogrid backing is a gradient alloy that transitions from Invar 36 to stainless steel. (d) A gradient alloy mirror assembly with a metal-coated glass mirror attached to the Invar side of the assembly using epoxy. The mirror assembly transitions into stainless steel at the base. (e) Test samples of a Ti-V gradient alloy being fabricated by LENS. (f) The compositions (as measured through electron dispersive XRD) of the gradient mirror assembly in (d) showing the transition between Invar and stainless steel. (g) A plot of hardness and thermal expansion across the gradient mirror assembly. The intermediate phases of the gradient have been designed to be soft austenite (as demonstrated by the decreased hardness). The controllable thermal expansion makes this part alluring for optics applications. One side of the gradient has a near-zero thermal expansion while the other side matches steel.

which are then bonded or fastened to an optical bench. When the part is exposed to extreme cold, the epoxy holding the mirror can crack and the fasteners holding the mirror mount can shrink, shifting the position of the mirror. In the gradient alloy, the glass mirror can be bonded to Invar, which has a near-zero thermal expansion coefficient that matches glass. However, the whole part does not need to be made from Invar, but rather it can be graded to stainless steel and then welded to the optical bench, eliminating thermal expansion mismatch from dissimilar metals. The gradient technique has also been used in an optics application to fabricate an Invar mirror with a high-stiffness isogrid backing. Isogrids are extremely costly and complicated to fabricate, but the AM technique allows gradient compositions to be built up right on the backside of the mirror. Other gradients have been developed, including a stainless steel to Inconel (a high-temperature Ni alloy) gradient to be fabricated into a valve stem for automotive applications. Invar-containing metal inserts have been developed to eliminate low-temperature pull-out in carbon fiber panels and low-density titanium alloys have been graded to refractory metals (e.g. Nb and V) for high-temperature applications (such as rocket nozzles and engine components). Ongoing work has focused on developing new types of gradient armor for defense applications as well as a wide assortment of commercial applications.

This work was done by Douglas C. Hofmann, John Paul C. Borgonia, Robert P. Dillon, Eric J. Suh, Jerry L. Mulder, and Paul B. Gardner 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-48419, volume and number of this NASA Tech Briefs *issue, and the page number.*

Passivation of Flexible YBCO Superconducting Current Lead With Amorphous SiO_2 Layer

The aim of this project is to design and construct leads from YBCO composite conductors to reduce the heat load to adiabatic demagnetization refrigerators.

Goddard Space Flight Center, Greenbelt, Maryland

Adiabatic demagnetization refrigerators (ADR) are operated in space to cool detectors of cosmic radiation to a few 10s of mK. A key element of the ADR is a superconducting magnet operating at about 0.3 K that is continually energized and de-energized in synchronism with a thermal switch, such that a piece of paramagnetic salt is alternately warm in a high magnetic field and cold in zero magnetic field. This causes the salt pill or refrigerant to cool, and it is able to suck heat from an object, e.g., the sensor, to be cooled. Current has to be fed into and out of the magnets from a dissipative power supply at the ambient temperature of the spacecraft. The current leads that link the magnets to the power supply inevitably conduct a significant amount of heat into the colder regions of the supporting cryostat, resulting in the need for larger, heavier, and more powerful supporting refrigerators. The aim of this project was to design and construct high-temperature superconductor (HTS) leads from YBCO (yttrium barium copper oxide) composite conductors to reduce the heat load significantly in the temperature regime below the critical temperature of YBCO.

The magnet lead does not have to support current in the event that the YBCO ceases to be superconducting. Customarily, a normal metal conductor in parallel with the YBCO is a necessary part of the lead structure to allow for this upset condition; however, for this application, the normal metal can be dispensed with.

Amorphous silicon dioxide is deposited directly onto the surface of YBCO, which resides on a flexible substrate. The silicon dioxide protects the YBCO from chemically reacting with atmospheric water and carbon dioxide, thus preserving the superconducting properties of the YBCO. The customary protective coating for flexible YBCO conductors is silver or a silver/gold alloy, which conducts heat many orders of magnitude better than SiO_2 and so limits the use of such a composite conductor for passing current across a thermal gradient with as little flow of heat as possible to make an efficient current lead. By protecting YBCO on a flexible substrate of low thermal conductivity with SiO_2, a thermally efficient and flexible current lead can be fabricated. The technology is also applicable to current leads for 4 K superconducting electronics current biasing.

A commercially available thin-film YBCO composite tape conductor is first stripped of its protective silver coating. It is then mounted on a jig that holds the sample flat and acts as a heat sink. Silicon dioxide is then deposited onto the YBCO to a thickness of about 1 micron using PECVD (plasma-enhanced chemical vapor deposition), without heating the YBCO to the point where degradation occurs.

Since SiO_2 can have good high-frequency electrical properties, it can be used to coat YBCO cable structures used to feed RF signals across temperature gradients. The prime embodiment concerns the conduction of DC current across the cryogenic temperature gradient. The coating is hard and electrically insulating, but flexible.

This work was done by Daniel Johannes and Robert Webber of Hypes for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16732-1

Mechanics/Machinery

Propellant-Flow-Actuated Rocket Engine Igniter

A pneumatically driven hammer initiates ignition.

Lyndon B. Johnson Space Center, Houston, Texas

A rocket engine igniter has been created that uses a pneumatically driven hammer that, by specialized geometry, is induced into an oscillatory state that can be used to either repeatedly impact a piezoelectric crystal with sufficient force to generate a spark capable of initiating combustion, or can be used with any other system capable of generating a spark from direct oscillatory motion.

This innovation uses the energy of flowing gaseous propellant, which by means of pressure differentials and kinetic motion, causes a hammer object to oscillate. The concept works by mass flows being induced through orifices on both sides of a cylindrical tube with one or more vent paths. As the mass flow enters the chamber, the pressure differential is caused because the hammer object is supplied with flow on one side and the other side is opened with access to the vent path. The object then crosses the vent opening and begins to slow because the pressure differential across the ball reverses due to the geometry in the tube.

Eventually, the object stops because of the increasing pressure differential on the object until all of the kinetic energy has been transferred to the gas via compression. This is the point where the object reverses direction because of the pressure differential. This behavior excites a piezoelectric crystal via direct impact from the hammer object. The hammer strikes a piezoelectric crystal, then reverses direction, and the resultant high voltage created from the crystal is transferred via an electrode to a spark gap in the ignition zone, thereby providing a spark to ignite the engine. Magnets, or other retention methods, might be employed to favorably position the hammer object prior to start, but are not necessary to maintain the oscillatory behavior. Various manifestations of the igniter have been developed and tested to improve device efficiency, and some improved designs are capable of operation at gas flow rates of a fraction of a gram per second (0.001 lb/s) and pressure drops on the order of 30 to 50 kilopascal (a few psi).

An analytical model has been created and tested in conjunction with a precisely calibrated reference model. The analytical model accurately captures the overall behavior of this innovation. The model is a simple "volume-orifice" concept, with each chamber considered a single temperature and pressure "node" connected to adjacent nodes, or to vent paths through flow control orifices. Mass and energy balances are applied to each node, with gas flow predicted using simple compressible flow equations.

This work was done by Mark Wollen of Innovative Engineering Solutions, Inc. for Johnson Space Center. Further information is contained in a TSP (see page 1).

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

Innovative Engineering Solutions, Inc
26200 Adams Avenue
Murrieta, CA 92562-7060

Refer to MSC-25078-1, volume and number of this NASA Tech Briefs *issue, and the page number.*

Lightweight Liquid Helium Dewar for High-Altitude Balloon Payloads

A factor-of-five or better reduction in mass is achieved.

Goddard Space Flight Center, Greenbelt, Maryland

Astrophysical observations at millimeter wavelengths require large (2-to-5-meter diameter) telescopes carried to altitudes above 35 km by scientific research balloons. The scientific performance is greatly enhanced if the telescope is cooled to temperatures below 10 K with no emissive windows between the telescope and the sky. Standard liquid helium bucket dewars can contain a suitable telescope for telescope diameter less than two meters. However, the mass of a dewar large enough to hold a 3-to-5-meter diameter telescope would exceed the balloon lift capacity.

The solution is to separate the functions of cryogen storage and in-flight thermal isolation, utilizing the unique physical conditions at balloon altitudes. Conventional dewars are launched cold: the vacuum walls necessary for thermal isolation must also withstand the pressure gradient at sea level and are correspondingly thick and heavy. The pressure at 40 km is less than 0.3% of sea level: a dewar designed for use only at 40 km can use ultra thin walls to achieve significant reductions in mass.

This innovation concerns new construction and operational techniques to produce a lightweight liquid helium bucket dewar. The dewar is intended for use on high-altitude balloon payloads. The mass is low enough to allow a large (3-to-5-meter) diameter dewar to fly at altitudes above 35 km on conventional scientific research balloons without exceeding the lift capability of the balloon.

The lightweight dewar has thin (250-micron) stainless steel walls. The walls are too thin to support the pressure gradient at sea level: the dewar launches warm with the vacuum space vented continuously during ascent to eliminate any pressure gradient across the walls. A commercial 500-liter storage dewar maintains a reservoir of liquid helium within a minimal (hence low mass) volume. Once a 40-km altitude is reached, the valve venting the vacuum space of the bucket dewar is closed to seal the vacuum space. A vacuum pump then evacuates the dewar vacuum space to provide the necessary thermal isolation. Liquid helium may then be transferred from the storage dewar into the bucket dewar to cool the telescope inside the bucket dewar.

By splitting the functions of helium storage and in-flight thermal isolation, the parasitic mass associated with the dewar pressure vessel is eliminated to achieve factor-of-five or better reduction in mass. The lower mass allows flight on conventional scientific research balloons, even for telescopes 3 to 5 meters in diameter.

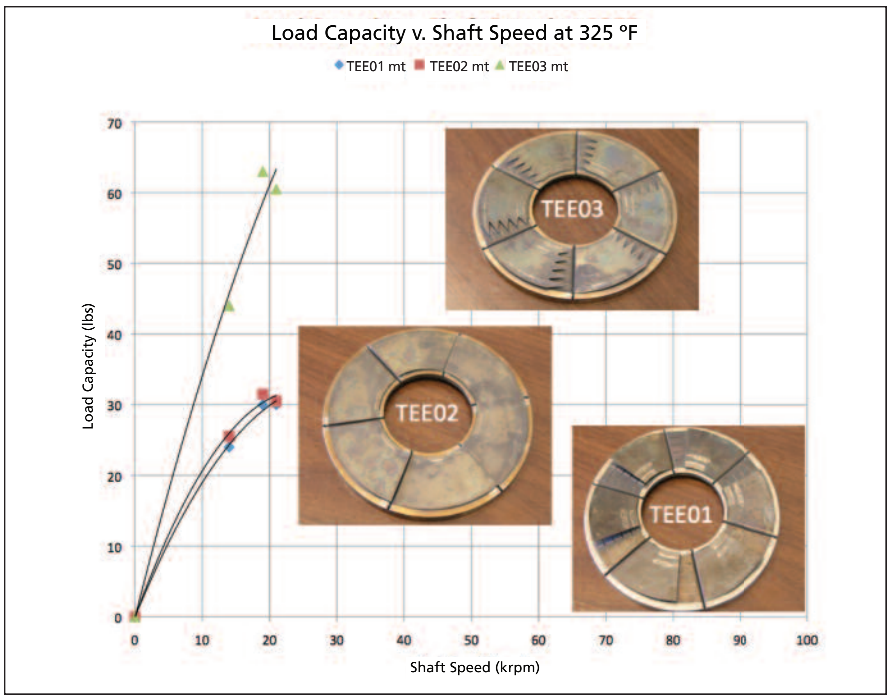
This work was done by Alan Kogut, Bryan James, and Dale Fixsen of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16687-1

Method to Increase Performance of Foil Bearings Through Passive Thermal Management

Bearing load capacity is improved by multiples and reliability is enhanced.

John H. Glenn Research Center, Cleveland, Ohio

This invention is a new approach to designing foil bearings to increase their load capacity and improve their reliability through passive thermal management. In the present case, the bearing is designed in such a way as to prevent the carryover of lubricant from the exit of one sector to the inlet of the ensuing sector of the foil bearing. When such passive thermal management techniques are used, bearing load capacity is improved by multiples, and reliability is enhanced when compared to current foil bearings. This concept has recently been tested and validated, and shows that load capacity performance of foil bearings can be improved by a factor of two at relatively low speeds with potentially greater relative improvements at higher speeds. Such improvements in performance with respect to speed are typical of foil bearings. Additionally, operation of these newly conceived bearings shows much more reliability and repeatable performance. This trait can be exploited in machine design to enhance safety, reliability, and overall performance. Finally, lower frictional torque has been demonstrated when operating at lower (non-load capacity) loads, thus providing another improvement above the current state of the art.



Low-speed data showing the increased load capacity of the **Foil Bearing Technology**.

The objective of the invention is to incorporate features into a foil bearing that both enhance passive thermal management and temperature control, while at the same time improve the hydrodynamic (load capacity) performance of the foil bearing. Foil bearings are unique antifriction devices that can utilize the working fluid of a machine as a lubricant (typically air for turbines and motors, liquids for pumps), and as a coolant to remove excess energy due to frictional heating. The current state of the art of foil bearings utilizes forced cooling of the bearing and shaft, which represents poor efficiency and poor reliability.

This invention embodies features that utilize the bearing geometry in such a manner as to both support load and provide an inherent and passive cooling mechanism. This cooling mechanism functions in such a way as to prevent used (higher temperature) lubricant from being carried over from the exit of one sector into the entry of the next sector of the foil bearing.

The disclosed innovation is an improved foil bearing design that reduces or eliminates the need for force cooling of the bearing, while at the same time improving the load capacity of the bearing by at least a factor of two. These improvements are due to the elimination of lubricant carryover from the trailing edge of one sector into the leading edge of the next, and the mixing of used lubricant with the surrounding ambient fluid.

This work was done by Robert Bruckner 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-18789-1

Unibody Composite Pressurized Structure

John H. Glenn Research Center, Cleveland, Ohio

An integrated, generic unibody composite pressurized structure (UCPS) combined with a positive expulsion device (PED), consisting of an elastomeric bladder for monopropellant hydrazine, has been quasi-standardized for spacecraft use. The combination functions as an all-composite, non-metallic, propellant tank with bladder. The integrated UCPS combines several previous innovations — specifically, the linerless, all-composite cryogenic tank technology; all-composite boss; resin formulation; and integrated stringer system. The innovation combines the UCPS with an integrated propellant management device (PMD), the PED or bladder, to create an entirely unique system for in-space use.

The UCPS is a pressure vessel that incorporates skirts, stringers, and other structures so that it is both an in-space hydrazine tank, and also a structural support system for a spacecraft in a single, all-composite unit. This innovation builds on the progress in the development of a previous SBIR (Small Business Innovation Research) Phase I with Glenn Research Center and an SBIR III with Johnson Space Center that included the fabrication of two 42-in. (≈107-cm) diameter all-composite cryogenic (LOX and liquid methane) UCPS test tanks for a lunar lander. This Phase II provides hydrazine compatibility testing of the elastomeric bladder, a see-through PED to validate the expulsion process and model, and a complete UCPS-based PED with stringers and skirts that will be used to conduct initial qualification and expulsion tests. This extends the UCPS technology to include hydrazine-based, in-space propulsion applications and can also be used for electric propulsion.

This innovation creates a system that, in comparison to the traditional approach, is lower in weight, cost, volume, and production time; is stronger; and is capable of much higher pressures. It also has fewer failure modes, and is applicable to both chemical and electric propulsion systems.

This work was done by Markus Rufer, Robert Conger, Thomas Bauer, and John Newman of Microcosm, Inc. for Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-19042-1.

Physical Sciences

JWST Integrated Science Instrument Module Alignment Optimization Tool

Goddard Space Flight Center, Greenbelt, Maryland

During cryogenic vacuum testing of the James Webb Space Telescope (JWST) Integrated Science Instrument Module (ISIM), the global alignment of the ISIM with respect to the designed interface of the JWST optical telescope element (OTE) will be measured through a series of optical characterization tests. These tests will determine the locations and orientations of the JWST science instrument projected focal surfaces and entrance pupils with respect to their corresponding OTE optical interfaces. If any optical performance non-compliances are identified, the ISIM will be adjusted to improve its performance. In order to understand how to manipulate the ISIM's degrees of freedom properly and to prepare for the ISIM flight model testing, a series of optical-mechanical analyses have been completed to develop and identify the best approaches for bringing a non-compliant ISIM element into compliance.

In order for JWST to meet its observatory-level optical requirements and ambitious science goals, the ISIM element has to meet approximately 150 separate optical requirements. Successfully achieving many of those optical requirements depends on the proper alignment of the ISIM element with respect to the OTE. To verify that the ISIM element will meet its optical requirements, a series of cryogenic vacuum tests will be conducted with an OTE Simulator (OSIM).

An optical Ray Trace and Geometry Model tool was developed to help solve the multi-dimensional alignment problem. The tool allows the user to determine how best to adjust the alignment of the JWST ISIM with respect to the ideal telescope interfaces so that the approximately 150 ISIM optical performance requirements can be satisfied. This capability has not existed previously.

This work was done by Brent Bos of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16698-1

Radar Range Sidelobe Reduction Using Adaptive Pulse Compression Technique

There is significant improvement on sidelobe performance.

Goddard Space Flight Center, Greenbelt, Maryland

Pulse compression has been widely used in radars so that low-power, long RF pulses can be transmitted, rather than a high-power short pulse. Pulse compression radars offer a number of advantages over high-power short pulsed radars, such as no need of high-power RF circuitry, no need of high-voltage electronics, compact size and light weight, better range resolution, and better reliability. However, range sidelobe associated with pulse compression has prevented the use of this technique on spaceborne radars since surface returns detected by range sidelobes may mask the returns from a nearby weak cloud or precipitation particles. Research on adaptive pulse compression was carried out utilizing a field-programmable gate array (FPGA) waveform generation board and a radar transceiver simulator. The results have shown significant improvements in pulse compression sidelobe performance.

Microwave and millimeter-wave radars present many technological challenges for Earth and planetary science applications. The traditional tube-based radars use high-voltage power supply/modulators and high-power RF transmitters; therefore, these radars usually have large size, heavy weight, and reliability issues for space and airborne platforms. Pulse compression technology has provided a path toward meeting many of these radar challenges. Recent advances in digital waveform generation, digital receivers, and solid-state power amplifiers have opened a new era for applying pulse compression to the development of compact and high-performance airborne and spaceborne remote sensing radars.

The primary objective of this innovative effort is to develop and test a new pulse compression technique to achieve ultra-range sidelobes so that this technique can be applied to spaceborne, airborne, and ground-based remote sensing radars to meet future science requirements. By using digital waveform generation, digital receiver, and solid-state power amplifier technologies, this improved pulse compression technique could bring significant impact on future radar development.

The novel feature of this innovation is the non-linear FM (NLFM) waveform design. The traditional linear FM has the limit (–20 log BT –3 dB) for achieving ultra-low-range sidelobe in pulse compression. For this study, a different combination of 20- or 40-microsecond chirp pulse width and 2- or 4-MHz chirp bandwidth was used. These are typical operational parameters for airborne or spaceborne weather radars. The NLFM waveform design was then implemented on a FPGA board to generate a real chirp signal, which was then sent to the radar transceiver simulator. The final results have shown significant improvement on sidelobe performance compared to that obtained using a traditional linear FM chirp.

This work was done by Lihua Li, Michael Coon, and Matthew McLinden of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16458-1

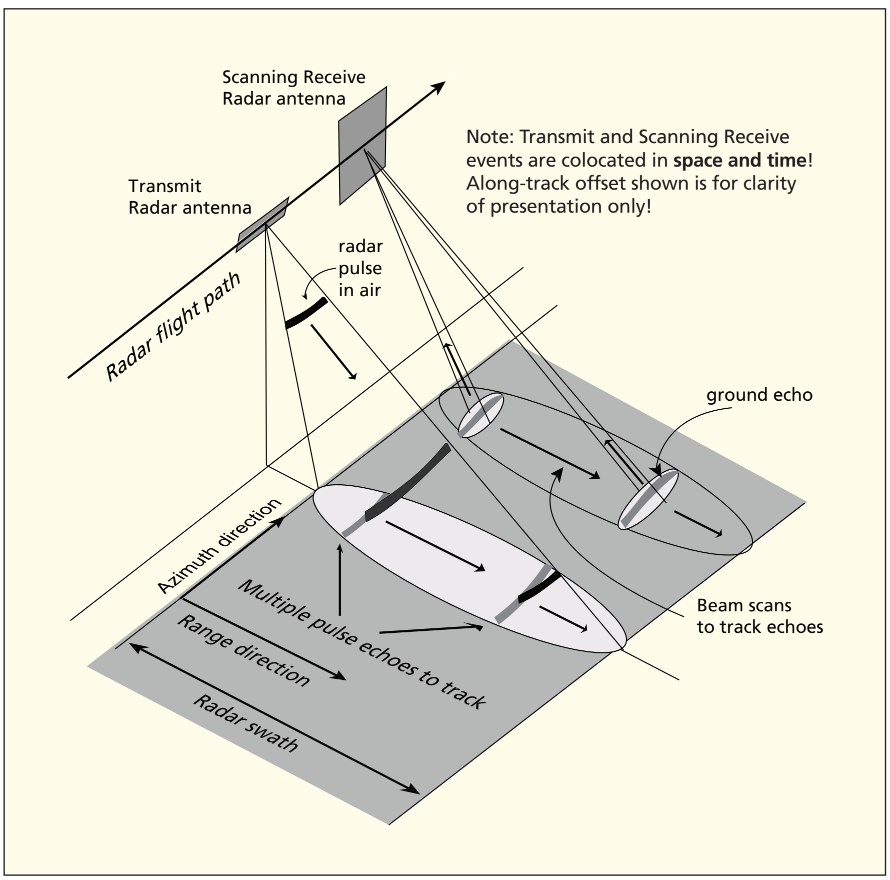
Digitally Calibrated TR Modules Enabling Real-Time Beamforming SweepSAR Architectures

Civilian and military remote sensing instruments could benefit from this work, as well as military intelligence applications.

NASA's Jet Propulsion Laboratory, Pasadena, California

SweepSAR, a novel radar architecture that depends on a DBF (digital beamforming) array, requires calibration accuracies that are order(s) of magnitude greater than is possible with traditional techniques, such as *a priori* characterization of TR (transmit/receive) modules in thermal vacuum chambers, or simple loop-back of the calibration signal. The advantages of a SweepSAR architecture are so great that it is worth applying significant resources to calibration efforts.

Due to the nature of the DBF, each channel contains a digitizer and very powerful digital processor. Each channel can independently digitize (with the digitizer) and analyze (with the processor) its channel's unique calibration signal, and extract the relevant calibration parameters, namely channel gain and channel phase delay commonly referred to as the gain (or amplitude) and phase of the channel. Using the processor, each channel's gain and phase can theoretically be estimated with arbitrary precision through averaging a sufficiently large number of samples. Systematic errors and the changing gain and phase of the channels, typically due to temperature drifts, limits how long the averaging can occur, which limits the precision of the calibration estimate. However, results indicate that calibration knowledge of both the transmit and receive chains of each TR module can be improved by one or two orders of magnitude. Due to the digital nature of the receiver data, the channel's gain and phase may be corrected by a similar amount, while the transmit chain can only be corrected in a traditional manner. To implement SweepSAR, the order of magnitude improvement in the knowledge of the channel's gain and phase is needed, and the control of the receiver to a similar level is required.



The **SweepSAR Transmit and Receive** swaths. Transmit requires illumination of a large swath (small aperture), while Receive requires multiple small swaths (large apertures).

Inherent to the DBF array is the individual digitization of each of the array's receiver channels. Current systems typically combine all of the analog signals in the array into one or two analog channels, which are then digitized and processed. All signal conditioning performed prior to digitization is done using analog hardware (which is less precise than digital signal conditioning and dependent on temperature). The DBF digitizes every signal prior to combining, and can therefore analyze and correct received signals, as well as analyze signals that are being transmitted through analog hardware (by sampling a copy and digitizing). Each channel of a DBF also has a powerful processor. With this combination, one is able to digitize, analyze, and correct each channel prior to its being combined.

A unique factor is the ability to digitize and analyze (in real time) each of the array's channels independently, allowing one to achieve unprecedented knowledge of each channel's performance (gain and phase), and since the combining is done digitally, each receive channel can be corrected prior to combining. This enables an unprecedented level of accuracy and control through onboard processing.

SweepSAR promises significant increases in instrument capability for solid earth and biomass remote sensing, while reducing mission mass and cost. This new instrument concept requires new methods for calibrating the multiple channels, which must be combined onboard, in real time. New methods are being developed for digitally calibrating digital beam-forming arrays to reduce development time, risk, and cost of precision calibrated TR modules for array architectures by accurately tracking modules' characteristics through closed-loop digital calibration, thus tracking systematic changes regardless of temperature.

This work was done by James P. Hoffman, Louise A. Veilleux, Eva Peral, Chung-Lun Chuang, and Scott J. Shaffer of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48310

Electro-Optic Time-to-Space Converter for Optical Detector Jitter Mitigation

The ability to more precisely measure the arrival time of an optical pulse is valuable in free space optical communications, lidar, and quantum key distribution.

NASA's Jet Propulsion Laboratory, Pasadena, California

A common problem in optical detection is determining the arrival time of a weak optical pulse that may comprise only one to a few photons. Currently, this problem is solved by using a photodetector to convert the optical signal to an electronic signal. The timing of the electrical signal is used to infer the timing of the optical pulse, but error is introduced by random delay between the absorption of the optical pulse and the creation of the electrical one. To eliminate this error, a time-to-space converter separates a sequence of optical pulses and sends them to different photodetectors, depending on their arrival time.

The random delay, called jitter, is at least 20 picoseconds for the best detectors capable of detecting the weakest optical pulses, a single photon, and can be as great as 500 picoseconds. This limits the resolution with which the timing of the optical pulse can be measured.

The time-to-space converter overcomes this limitation. Generally, the time-to-space converter imparts a time-dependent momentum shift to the incoming optical pulses, followed by an optical system that separates photons of different momenta. As an example, an electro-optic phase modulator can be used to apply longitudinal momentum changes (frequency changes) that vary in time, followed by an optical spectrometer (such as a diffraction grating), which separates photons with different momenta into different paths and directs them to impinge upon an array of photodetectors. The pulse arrival time is then inferred by measuring which photodetector receives the pulse.

The use of a time-to-space converter mitigates detector jitter and improves the resolution with which the timing of an optical pulse is determined. Also, the application of the converter enables the demodulation of a pulse position modulated signal (PPM) at higher bandwidths than using previous photodetector technology. This allows the creation of a receiver for a communication system with high bandwidth and high bits/photon efficiency.

This work was done by Kevin Birnbaum and William Farr of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-45799

Partially Transparent Petaled Mask/Occulter for Visible-Range Spectrum

The intensity along the optical axis can be suppressed up to ten orders of magnitude.

Goddard Space Flight Center, Greenbelt, Maryland

The presence of the Poisson Spot, also known as the spot of Arago, has been known since the 18th century. This spot is the consequence of constructive interference of light diffracted by the edge of the obstacle where the central position can be determined by symmetry of the object. More recently, many NASA missions require the suppression of this spot in the visible range. For instance, the exoplanetary missions involving space telescopes require telescopes to image the planetary bodies orbiting central stars. For this purpose, the starlight needs to be suppressed by several orders of magnitude in order to image the reflected light from the orbiting planet. For the Earth-like planets, this suppression needs to be at least ten orders of magnitude. One of the common methods of suppression involves sharp binary petaled occulters envisioned to be placed many thousands of miles away from the telescope blocking the starlight.

The suppression of the Poisson Spot by binary sharp petal tips can be problematic when the thickness of the tips becomes smaller than the wavelength of the incident beam. First they are difficult to manufacture and also it invalidates the laws of physical optics. The proposed partially transparent petaled masks/occulters compensate for this sharpness with transparency along the surface of the petals. Depending on the geometry of the problem, this transparency can be customized such that only a small region of the petal is transparent and the remaining of the surface is opaque. This feature allows easy fabrication of this type of occultation device either as a mask or occulter.

A partially transparent petaled mask/occulter has been designed for the visible spectrum range. The mask/occulter can suppress the intensity along the optical axis up to ten orders of magnitude. The design process can tailor the mask shape, number of petals, and transparency level to the near-field and far-field diffraction region. The mask/occulter can be used in space astronomy, ground-based telescope, and high-energy laser systems, and optical lithography to eliminate the Poisson Spot.

This work was done by Ron Shahram Shiri of Goddard Space Flight Center, and Wasyl Wasylkiwskyj of The George Washington University. Further information is contained in a TSP (see page 1). GSC-16588-1

Information Technology

Educational NASA Computational and Scientific Studies (enCOMPASS)

This project bridges the gap between computational objectives and needs of NASA's scientific research, missions, and projects, and academia's latest advances in applied mathematics and computer science.

Goddard Space Flight Center, Greenbelt, Maryland

Educational NASA Computational and Scientific Studies (enCOMPASS) is an educational project of NASA Goddard Space Flight Center aimed at bridging the gap between computational objectives and needs of NASA's scientific research, missions, and projects, and academia's latest advances in applied mathematics and computer science. enCOMPASS achieves this goal via bidirectional collaboration and communication between NASA and academia. Using developed NASA Computational Case Studies in university computer science/engineering and applied mathematics classes is a way of addressing NASA's goals of contributing to the Science, Technology, Education, and Math (STEM) National Objective. The enCOMPASS Web site at http://encompass.gsfc.nasa.gov provides additional information.

There are currently nine enCOMPASS case studies developed in areas of earth sciences, planetary sciences, and astrophysics. Some of these case studies have been published in AIP and IEEE's Computing in Science and Engineering magazines. A few university professors have used enCOMPASS case studies in their computational classes and contributed their findings to NASA scientists. In these case studies, after introducing the science area, the specific problem, and related NASA missions, students are first asked to solve a known problem using NASA data and past approaches used and often published in a scientific/research paper. Then, after learning about the NASA application and related computational tools and approaches for solving the proposed problem, students are given a harder problem as a challenge for them to research and develop solutions for.

This project provides a model for NASA scientists and engineers on one side, and university students, faculty, and researchers in computer science and applied mathematics on the other side, to learn from each other's areas of work, computational needs and solutions, and the latest advances in research and development. This innovation takes NASA science and engineering applications to computer science and applied mathematics university classes, and makes NASA objectives part of the university curricula. There is great potential for growth and return on investment of this program to the point where every major university in the U.S. would use at least one of these case studies in one of their computational courses, and where every NASA scientist and engineer facing a computational challenge (without having resources or expertise to solve it) would use enCOMPASS to formulate the problem as a case study, provide it to a university, and get back their solutions and ideas.

This work was done by Nargess Memarsadeghi of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16288-1

Coarse-Grain Bandwidth Estimation Scheme for Large-Scale Network

A new analytical approach, called the "leveling scheme," was developed to model the mechanism of the network data flow.

NASA's Jet Propulsion Laboratory, Pasadena, California

A large-scale network that supports a large number of users can have an aggregate data rate of hundreds of Mbps at any time. High-fidelity simulation of a large-scale network might be too complicated and memory-intensive for typical commercial-off-the-shelf (COTS) tools. Unlike a large commercial wide-area-network (WAN) that shares diverse network resources among diverse users and has a complex topology that requires routing mechanism and flow control, the ground communication links of a space network operate under the assumption of a guaranteed dedicated bandwidth allocation between specific sparse endpoints in a star-like topology. This work solved the network design problem of estimating the bandwidths of a ground network architecture option that offer different service classes to meet the latency requirements of different user data types.

In this work, a top-down analysis and simulation approach was created to size the bandwidths of a store-and-forward network for a given network topology, a mission traffic scenario, and a set of data types with different latency requirements. These techniques were used to estimate the WAN bandwidths of the ground links for different architecture options of the proposed Integrated Space Communication and Navigation (SCaN) Network.

A new analytical approach, called the "leveling scheme," was developed to model the store-and-forward mechanism of the network data flow. The term "leveling" refers to the spreading of data across a longer time horizon without violating the corresponding latency requirement of the data type. Two versions of the leveling scheme were developed:

1. A straightforward version that simply spreads the data of each data type across the time horizon and doesn't take into account the interactions among data types within a pass, or between data types across overlapping passes at a network node, and is inherently sub-optimal.
2. Two-state Markov leveling scheme that takes into account the second order behavior of the store-and-forward mechanism, and the interactions among data types within a pass.

The novelty of this approach lies in the modeling of the store-and-forward mechanism of each network node. The term store-and-forward refers to the data traffic regulation technique in which data is sent to an intermediate network node where they are temporarily stored and sent at a later time to the destination node or to another intermediate node. Store-and-forward can be applied to both space-based networks that have intermittent connectivity, and ground-based networks with deterministic connectivity. For ground-based networks, the store-and-forward mechanism is used to regulate the network data flow and link resource utilization such that the user data types can be delivered to their destination nodes without violating their respective latency requirements.

This work was done by Kar-Ming Cheung, Esther H. Jennings, and John S. Segui 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 Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48426.

Detection of Moving Targets Using Soliton Resonance Effect

NASA's Jet Propulsion Laboratory, Pasadena, California

The objective of this research was to develop a fundamentally new method for detecting hidden moving targets within noisy and cluttered data-streams using a novel "soliton resonance" effect in nonlinear dynamical systems.

The technique uses an inhomogeneous Korteweg de Vries (KdV) equation containing moving-target information. Solution of the KdV equation will describe a soliton propagating with the same kinematic characteristics as the target. The approach uses the time-dependent data stream obtained with a sensor in form of the "forcing function," which is incorporated in an inhomogeneous KdV equation. When a hidden moving target (which in many ways resembles a soliton) encounters the natural "probe" soliton solution of the KdV equation, a strong resonance phenomenon results that makes the location and motion of the target apparent.

Soliton resonance method will amplify the moving target signal, suppressing the noise. The method will be a very effective tool for locating and identifying diverse, highly dynamic targets with ill-defined characteristics in a noisy environment.

The soliton resonance method for the detection of moving targets was developed in one and two dimensions. Computer simulations proved that the method could be used for detection of singe point-like targets moving with constant velocities and accelerations in 1D and along straight lines or curved trajectories in 2D. The method also allows estimation of the kinematic characteristics of moving targets, and reconstruction of target trajectories in 2D. The method could be very effective for target detection in the presence of clutter and for the case of target obscurations.

This work was done by Igor K. Kulikov of Caltech and Michail Zak of Raytheon for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48785

Books & Reports

High-Efficiency Nested Hall Thrusters for Robotic Solar System Exploration

This work describes the scaling and design attributes of Nested Hall Thrusters (NHT) with extremely large operational envelopes, including a wide range of throttleability in power and specific impulse at high efficiency (>50%). NHTs have the potential to provide the game changing performance, power-processing capabilities, and cost effectiveness required to enable missions that cannot otherwise be accomplished. NHTs were first identified in the electric propulsion community as a path to 100-kW class thrusters for human missions. This study aimed to identify the performance capabilities NHTs can provide for NASA robotic and human missions, with an emphasis on 10-kW class thrusters well-suited for robotic exploration. A key outcome of this work has been the identification of NHTs as nearly constant-efficiency devices over large power throttling ratios, especially in direct-drive power systems. NHT systems sized for robotic solar system exploration are predicted to be capable of high-efficiency operation over nearly their entire power throttling range.

A traditional Annular Hall Thruster (AHT) consists of a single annular discharge chamber where the propellant is ionized and accelerated. In an NHT, multiple annular channels are concentrically stacked. The channels can be operated in unison or individually depending on the available power or required performance. When throttling an AHT, performance must be sacrificed since a single channel cannot satisfy the diverse design attributes needed to maintain high thrust efficiency. NHTs can satisfy these requirements by varying which channels are operated and thereby offer significant benefits in terms of thruster performance, especially under deep power throttling conditions where the efficiency of an AHT suffers since a single channel can only operate efficiently (>50%) over a narrow power throttling ratio (3:1).

Designs for 10-kW class NHTs were developed and compared with AHT systems. Power processing systems were considered using either traditional Power Processing Units (PPU) or Direct Drive Units (DDU). In a PPU-based system, power from the solar arrays is transformed from the low voltage of the arrays to the high voltage needed by the thruster. In a DDU-based system, power from the solar arrays is fed to the thruster without conversion. DDU-based systems are attractive for their simplicity since they eliminate the most complex and expensive part of the propulsion system.

The results point to the strong potential of NHTs operating with either PPUs or DDUs to benefit robotic and human missions through their unprecedented power and specific impulse throttling capabilities. NHTs coupled to traditional PPUs are predicted to offer high-efficiency (>50%) power throttling ratios 320% greater than present capabilities, while NHTs with direct-drive power systems (DDU) could exceed existing capabilities by 340%. Because the NHT-DDU approach is implicitly low-cost, NHT-DDU technology has the potential to radically reduce the cost of SEP-enabled NASA missions while simultaneously enabling unprecedented performance capability.

This work was done by Richard R. Hofer of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48400

High-Voltage Clock Driver for Photon-Counting CCD Characterization

A document discusses the CCD97 from e2v technologies as it is being evaluated at Goddard Space Flight Center's Detector Characterization Laboratory (DCL) for possible use in ultra-low background noise space astronomy applications, such as Terrestrial Planet Finder Coronagraph (TPF-C). The CCD97 includes a photon-counting mode where the equivalent output noise is less than one electron. Use of this mode requires a clock signal at a voltage level greater than the level achievable by the existing CCD (charge-coupled-device) electronics.

A high-voltage waveform generator has been developed in code 660/601 to support the CCD97 evaluation. The unit generates required clock waveforms at voltage levels from –20 to +50 V. It deals with standard and arbitrary waveforms and supports pixel rates from 50 to 500 kHz. The system is designed to interface with existing Leach CCD electronics.

This work was done by Robert Baker of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15059-1

Development of the Code RITRACKS

A document discusses the code RITRACKS (Relativistic Ion Tracks), which was developed to simulate heavy ion track structure at the microscopic and nanoscopic scales. It is a Monte-Carlo code that simulates the production of radiolytic species in water, event-by-event, and which may be used to simulate tracks and also to calculate dose in targets and voxels of different sizes. The dose deposited by the radiation can be calculated in nanovolumes (voxels).

RITRACKS allows simulation of radiation tracks without the need of extensive knowledge of computer programming or Monte-Carlo simulations. It is installed as a regular application on Windows systems. The main input parameters entered by the user are the type and energy of the ion, the length and size of the irradiated volume, the number of ions impacting the volume, and the number of histories. The simulation can be started after the input parameters are entered in the GUI. The number of each kind of interactions for each track is shown in the result details window. The tracks can be visualized in 3D after the simulation is complete. It is also possible to see the time evolution of the tracks and zoom on specific parts of the tracks.

The software RITRACKS can be very useful for radiation scientists to investigate various problems in the fields of radiation physics, radiation chemistry, and radiation biology. For example, it can be used to simulate electron ejection experiments (radiation physics).

This work was done by Ianik Plante and Francis A. Cucinotta of Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-25076-1

Enabling Microliquid Chromatography by Microbead Packing of Microchannels

Goddard Space Flight Center, Greenbelt, Maryland

The microbead packing is the critical element required in the success of on-chip microfabrication of critical microfluidic components for in-situ analysis and detection of chiral amino acids. In order for microliquid chromatography to occur, there must be a stationary phase medium within the microchannel that interacts with the analytes present within flowing fluid. The stationary phase media are the microbeads packed by the process discussed in this work. The purpose of the microliquid chromatography is to provide a lightweight, low-volume, and low-power element to separate amino acids and their chiral partners efficiently to understand better the origin of life.

In order to densely pack microbeads into the microchannels, a liquid slurry of microbeads was created. Microbeads were extracted from a commercially available high-performance liquid chromatography column. The silica beads extracted were 5 microns in diameter, and had surface coating of phenyl-hexyl. These microbeads were mixed with a 200-proof ethanol solution to create a microbead slurry with the right viscosity for packing. A microfilter is placed at the outlet via of the microchannel and the slurry is injected, then withdrawn across a filter using modified syringes. After each injection, the channel is flushed with ethanol to enhance packing. This cycle is repeated numerous times to allow for a tightly packed channel of microbeads.

Typical microbead packing occurs in the macroscale into tubes or channels by using highly pressurized systems. Moreover, these channels are typically long and straight without any turns or curves. On the other hand, this method of microbead packing is completed within a microchannel 75 micrometers in diameter. Moreover, the microbead packing is completed into a serpentine type microchannel, such that it maximizes microchannel length within a microchip. Doing so enhances the interactions of the analytes with the microbeads to separate efficiently amino acids and amino acid enantiomers.

This work was done by Manuel Balvin and Yun Zheng of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16514-1

National Aeronautics and
Space Administration