TECH BRIEFS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Materials

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INTRODUCTION

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TECH BRIEFS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Semiautonomous Avionics-and-Sensors System for a UAV

**Sensors and associated circuitry are packaged compactly on a circuit board.**

Langley Research Center, Hampton, Virginia

Unmanned Aerial Vehicles (UAVs) — autonomous or remotely controlled pilotless aircraft — have been recently thrust into the spotlight for military applications, for homeland security, and as test beds for research. In addition to these functions, there are many space applications in which lightweight, inexpensive, small UAVS can be used — e.g., to determine the chemical composition and other qualities of the atmospheres of remote planets. Moreover, on Earth, such UAVs can be used to obtain information about weather in various regions; in particular, they can be used to analyze wide-band acoustic signals to aid in determining the complex dynamics of movement of hurricanes.

The Advanced Sensors and Electronics group at Langley Research Center has developed an inexpensive, small, integrated avionics-and-sensors system to be installed in a UAV that serves two purposes. The first purpose is to provide flight data to an AI (Artificial Intelligence) controller as part of an autonomous flight-control system. The second purpose is to store data from a subsystem of distributed MEMS (microelectromechanical systems) sensors.

Examples of these MEMS sensors include humidity, temperature, and acoustic sensors, plus chemical sensors for detecting various vapors and other gases in the environment. The critical sensors used for flight control are a differential-pressure sensor that is part of an apparatus for determining airspeed, an absolute-pressure sensor for determining altitude, three orthogonal accelerometers for determining tilt and acceleration, and three orthogonal angular-rate detectors (gyroscopes). By using these eight sensors, it is possible to determine the orientation, height, speed, and rates of roll, pitch, and yaw of the UAV. This avionics-and-sensors system is shown in the figure.

During the last few years, there has been rapid growth and advancement in the technological disciplines of MEMS, of onboard artificial-intelligence systems, and of smaller, faster, and smarter wireless telemetry systems. The major attraction of
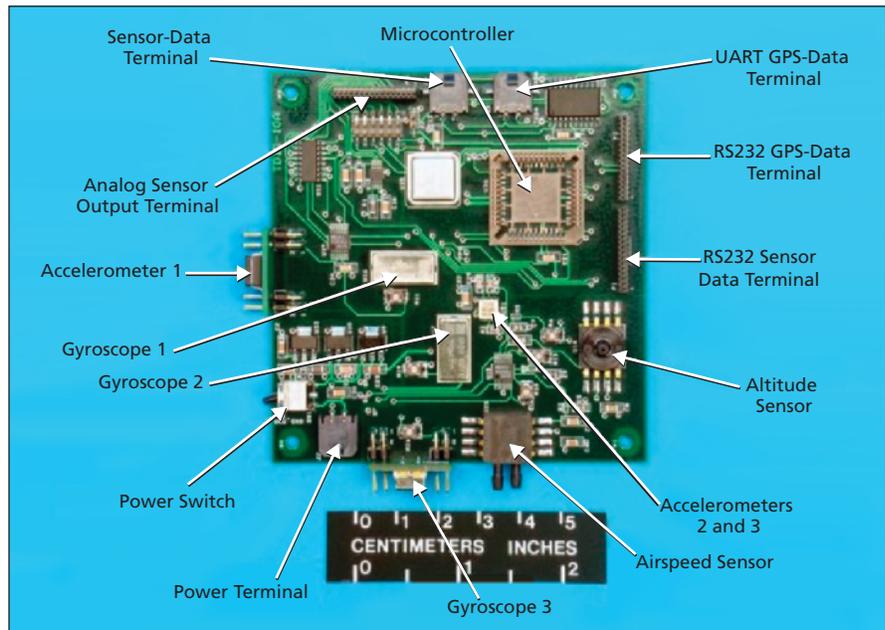
This **Photograph of the Avionics-and-Sensors System** shows the critical sensors used for flight control.

MEMS lies in orders-of-magnitude reductions of power requirements relative to traditional electronic components that perform equivalent functions. In addition, the compactness of MEMS, relative to functionally equivalent traditional electronics systems, makes MEMS attractive for UAV applications. Recent advances in MEMS have made it possible to produce pressure, acceleration, humidity, and temperature sensors having masses in subgram range and possessing sensitivities and accuracies comparable to those of larger devices.

Some flight-control sensors, including pressure sensors, incorporate supporting circuitry that enables adjustment of their ranges (to values different from those set at the factory) in order to satisfy mission needs. Hence, the pressure sensors can be set to measure pressures in certain ranges (in effect, an absolute-pressure sensor can be set to be sensitive to a specific altitude and/or a differential-pressure sensor can be set to be sensitive to specific airspeed). If the altitude and airspeed requirements of the UAV are changed, the sensor ranges can be adjusted accordingly. The accelerometers incorporate circuitry that

adjusts their offset output voltages so that an onboard analog-to-digital converter (16-bit ADC) can center on their stable voltages. The data from the various sensors are multiplexed via the ADC, and the data are then gathered by an onboard microcontroller. The microcontroller determines the sample rate for each sensor and processes the digitized sensor data into a serial stream at a user-programmable rate.

An interface between this avionics-and-sensors system and an external system can be established at any of several points in the circuitry — which point depending on the type and level of control needed by the external system. For example, the serial data stream is sent to an onboard UART (Universal Asynchronous Receiver/Transmitter), the 0-to-5-volt output of which can be utilized directly by an external controller or processor. In addition, the data stream is also sent to an onboard RS-232 level converter chip, enabling a direct serial-port connection to an external computer when this avionics-and-sensors system is operated in a laboratory. The onboard microcontroller can be utilized in two ways: enabling an external microcontroller or computer to simply re-

ceive and respond to the sensor data, or controlling the flow of the sensor data.

The UAV control system provides (1) external connections to flight sensors, (2) the computational resources neces-sary to make flight decisions, and (3) a simple interface through which control can be exerted over the servomotors that actuate the flight-control mecha-nisms of the UAV.

# Biomimetic/Optical Sensors for Detecting Bacterial Species

Bacteria in liquid samples could be detected in real time.

NASA's Jet Propulsion Laboratory, Pasadena, California

Biomimetic/optical sensors have been proposed as means of real-time detection of bacteria in liquid samples through real-time detection of compounds se-creted by the bacteria. Bacterial species of interest would be identified through detection of signaling compounds unique to those species. The best-charac-terized examples of quorum-signaling compounds are acyl-homoserine lac-tones and peptides. Each compound, se-creted by each bacterium of an affected species, serves as a signal to other bacte-ria of the same species to engage in a col-lective behavior when the population density of that species reaches a thresh-old level analogous to a quorum.

A sensor according to the proposal would include a specially formulated biomimetic film, made of a molecularly imprinted polymer (MIP), that would respond optically to the signaling com-pound of interest. The MIP film would be integrated directly onto an optical-waveguide-based ring resonator for op-tical readout. Optically, the sensor would resemble the one described in "Chemical Sensors Based on Optical Ring Resonators" (NPO-40601), *NASA Tech Briefs*, Vol. 29, No. 10 (October 2005), page 32.

MIPs have been used before as mo-lecular-recognition compounds, though not in the manner of the pres-ent proposal. Molecular imprinting is an approach to making molecularly se-lective cavities in a polymer matrix. These cavities function much as en-zyme receptor sites: the chemical func-tionality and shape of a cavity in the polymer matrix cause the cavity to bind to specific molecules. An MIP matrix is made by polymerizing monomers in the presence of the compound of inter-est (template molecule). The polymer forms around the template. After the polymer solidifies, the template mole-cules are removed from the polymer matrix by decomplexing them from their binding sites and then dissolving
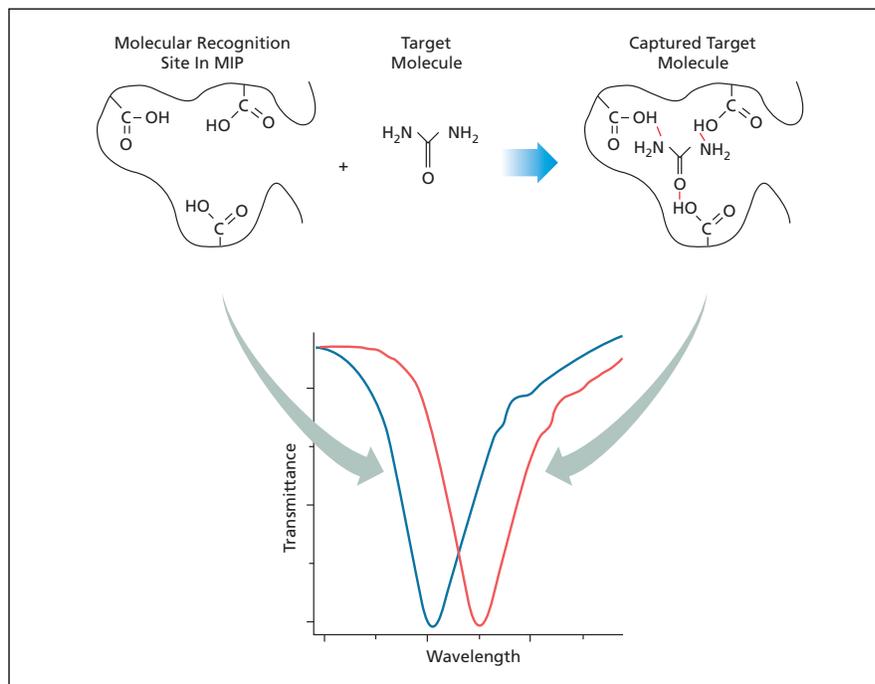
Capture of Target Molecules at molecular recognition sites in an MIP film would cause a change in the wavelength of an optical resonance. The change would be proportional to the concentration of bac-teria that secreted the target molecules.

them, leaving cavities that are matched to the template molecules in size, shape, and chemical functionality. The cavities thus become molecular-recog-nition sites that bind only to molecules matched to the sites; other molecules are excluded.

In a sensor according to the pro-posal, the MIP would feature molecular recognition sites that would bind the specific signaling molecules selectively according to their size, shape, and chemical functionality (see figure). As the film took up the signaling mole-cules in the molecular recognition sites, the index of refraction and thick-ness of the film would change, causing a wavelength shift of the peak of the resonance spectrum. It has been esti-mated that by measuring this wave-length shift, it should be possible to de-tect as little as 10 picomoles of a peptide signaling compound.

System Would Detect Foreign-Object Damage in Turbofan Engine

Vibration-sensor and gas-path-analysis data would be fused.

John H. Glenn Research Center, Cleveland, Ohio

A proposed data-fusion system, to be implemented mostly in software, would further process the digitized and pre-processed outputs of sensors in a turbofan engine to detect foreign-object damage (FOD) [more precisely, damage caused by impingement of such foreign objects as birds, pieces of ice, and runway debris]. The proposed system could help a flight crew to decide what, if any, response is necessary to complete a flight safely, and could aid mechanics in deciding what post-flight maintenance action might be needed.

The sensory information to be utilized by the proposed system would consist of (1) the output of an accelerometer in an engine-vibration-monitoring subsystem and (2) features extracted from a gas path analysis. ["Gas path analysis" (GPA) is a term of art that denotes comprehensive analysis of engine performance derived from readings of fuel-flow meters, shaft-speed sensors, temperature sen-

sors, and the like.]

- The acceleration signal would first be processed by a wavelet-transform-based algorithm, using a wavelet created for the specific purpose of finding abrupt FOD-induced changes in noisy accelerometer signals. Two additional features extracted would be the amplitude of vibration (determined via a single-frequency Fourier transform calculated at the rotational speed of the engine), and the rate of change in amplitude due to an FOD-induced rotor imbalance.
- This system would utilize two GPA features: the fan efficiency and the rate of change of fan efficiency with time.

The selected GPA and vibrational features would be assessed by two fuzzy-logic inference engines, denoted the "Gas Path Expert" and the "Vibration Expert," respectively (see Figure 1). Each of these inference engines would generate a "possibility" distribution for occurrence of an FOD event: Each inference engine would assign, to

its input information, degrees of membership, which would subsequently be transformed into basic probability assignments for the gas-path and vibration components. The outputs of the inference engines would be fused by use of Dempster's combination algorithm (more precisely, an algorithm, based on the Dempster-Shafer-Yager theory of evidence, for fusing uncertain or imprecise information) to provide a reduced body of information to a human or computer decision maker. Figure 2 depicts some outputs generated in response to simulated accelerometer and GPA signals.

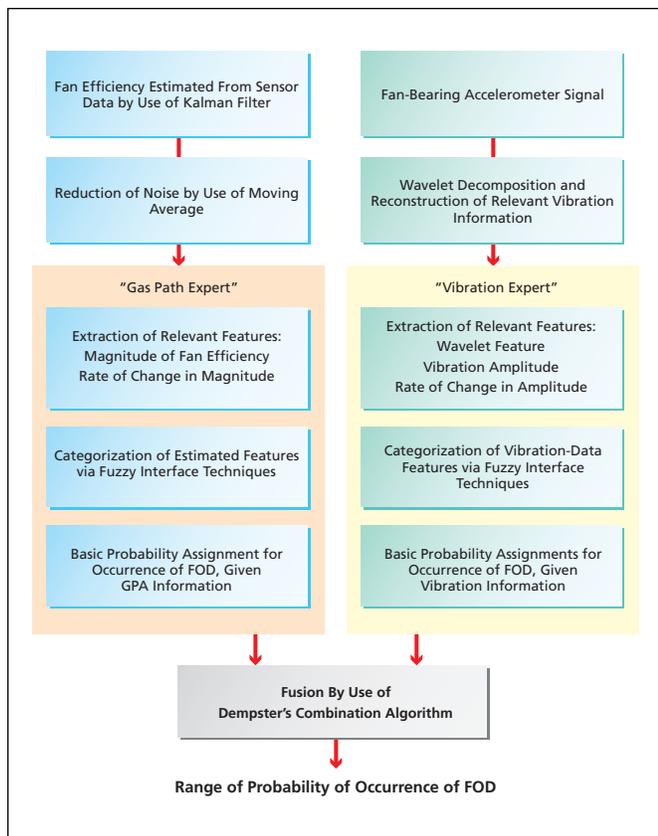Figure 1. **Outputs of Two "Experts"** (fuzzy-logic inference engines) would be fused at the feature level by means of Dempster's combination algorithm.
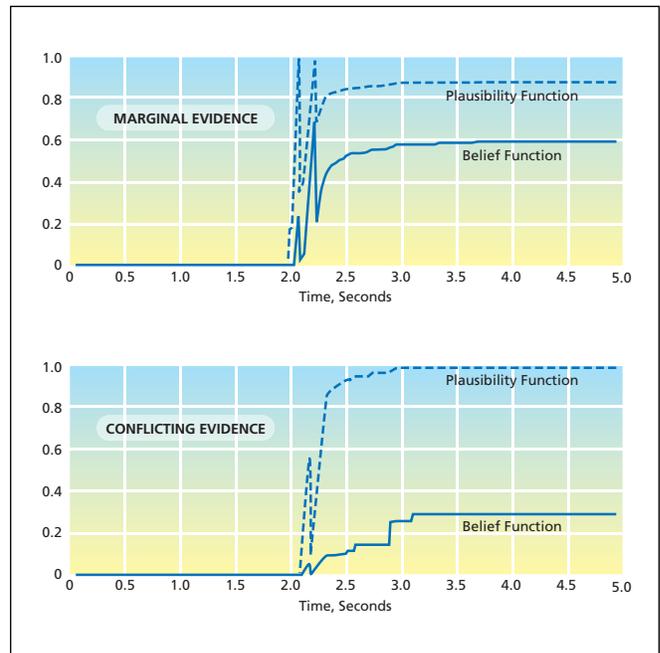

Figure 2. These **Example Outputs** of the proposed system were generated in response to simulated vibrational and GPA inputs characteristic of marginal and conflicting evidence, respectively, of occurrence of an FOD event near the 2-second time mark.

Detection of Water Hazards for Autonomous Robotic Vehicles

**Four methods of optoelectronic detection complement each other.**

NASA's Jet Propulsion Laboratory, Pasadena, California

Four methods of detection of bodies of water are under development as means to enable autonomous robotic ground vehicles to avoid water hazards when traversing off-road terrain. The methods involve processing of digitized outputs of optoelectronic sensors aboard the vehicles. It is planned to implement these methods in hardware and software that would operate in conjunction with the hardware and software for navigation and for avoidance of solid terrain obstacles and hazards.

The first method, intended for use during the day, is based on the observation that, under most off-road conditions, reflections of sky from water are easily discriminated from the adjacent terrain by their color and brightness, regardless of the weather and of the state of surface waves on the water. Accordingly, this method involves collection of color imagery by a video camera and processing of the image data by an algorithm that classifies each pixel as soil, water, or vegetation according to its color and brightness values (see figure). Among the issues that arise is the fact that in the presence of reflections of objects on the opposite shore, it is difficult to distinguish water by color and brightness alone. Another issue is that once a body of water has been identified by means of color and brightness, its boundary must be mapped for use in navigation. Techniques for addressing these issues are under investigation.

The second method, which is not limited by time of day, is based on the observation that ladar returns from bodies of water are usually too weak to be detected. In this method, ladar scans of the terrain are analyzed for returns and the absence thereof. In appropriate regions, the presence of water can be inferred from the absence of returns. Under some conditions in which reflections from the bottom are detectable, ladar returns could, in principle, be used to determine depth.

The third method involves the recognition of bodies of water as dark areas
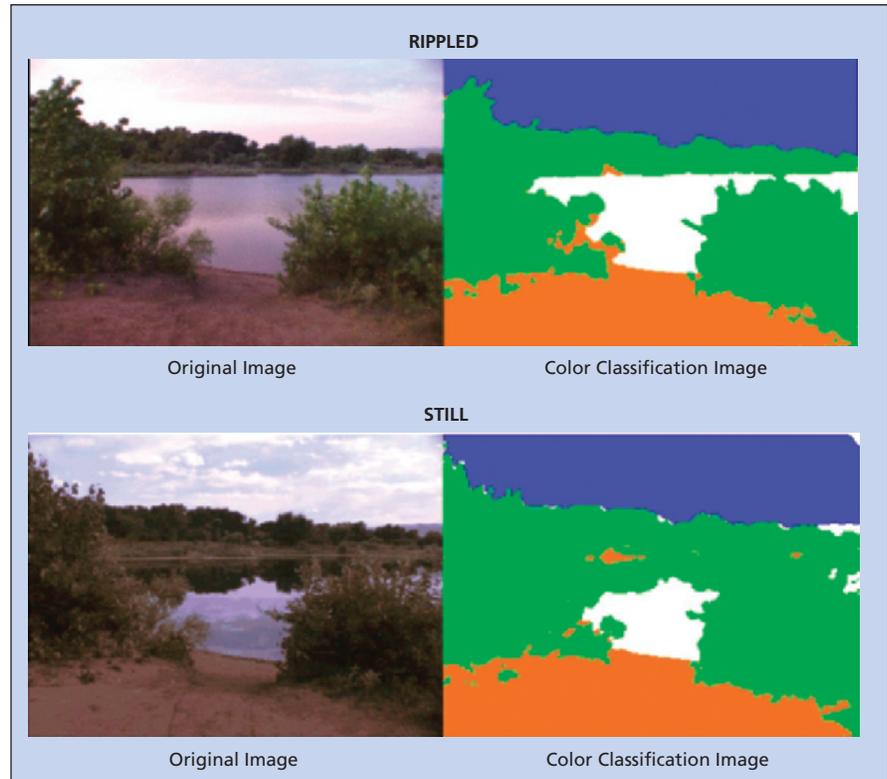
Images of the Chatfield Reservoir in Denver were acquired under rippled and still surface conditions, then pixels were classified by color. In the synthetic color classification images, white represents water, brown represents soil, green signifies vegetation, and blue signifies anything else. In the rippled case, all of the water is correctly labeled. In the still case, water reflecting the sky is correctly classified, but water reflecting trees is erroneously classified as vegetation.

in short-wavelength infrared (SWIR) images. This method is based on the fact, well known among experts in remote sensing, that water bodies of any appreciable depth appear very dark in near-infrared, overhead imagery. Even under a thick layer of marine fog, SWIR illumination is present. Hence, this method may work even in the presence of clouds, though it is unlikely to work at night. Snow and ice also exhibit very strong absorption at wavelengths greater than about 1.4 µm. Hence, the wavelength range of about 1.5 to 1.6 µm might be useable in this method for recognizing water, snow, and ice. One notable drawback of this method is that useful look-ahead distance could be limited by surface reflections.

The fourth method, intended for use at night, involves the contrast between water and terrain in thermal-infrared (medium-wavelength infrared) imagery. This method is based on the fact that at night, water is usually warmer than the adjacent terrain. Look-ahead distance could be limited in this method because, for reasons not yet fully understood, water appears to darken in the thermal infrared with increasing distance.

Electronics/Computers

Fuel Cells Utilizing Oxygen From Air at Low Pressures

Power-to-weight ratios would be higher than in prior fuel cells.

John H. Glenn Research Center, Cleveland, Ohio

A fuel cell stack has been developed to supply power for a high-altitude aircraft with a minimum of air handling. The fuel cell is capable of utilizing oxygen from ambient air at low pressure with no need for compression. For such an application, it is advantageous to take oxygen from the air (in contradistinction to carrying a supply of oxygen onboard), but it is a challenging problem to design a fuel-cell stack of reasonable weight that can generate sufficient power while operating at reduced pressures.

The present fuel-cell design is a response to this challenge. The design features a novel bipolar plate structure in combination with a gas-diffusion structure based on a conductive metal core and a carbon gas-diffusion matrix. This combination makes it possible for the flow fields in the stack to have a large open fraction (ratio between open volume and total volume) to permit large volumes of air to flow through with exceptionally low backpressure. Operations at reduced pressure require a corresponding increase in the volume of air that must be handled to deliver the same number of moles of oxygen to the anodes. Moreover, the increase in the open fraction, relative to that of a comparable prior fuel-cell design, reduces the mass of the stack.

The fuel cell has been demonstrated to operate at a power density as high as 105 W/cm^2 at an air pressure as low as 2 psia (absolute pressure ≈14 kPa), which is the atmospheric pressure at an altitude of about 50,000 ft (≈15.2 km). The improvements in the design of this fuel cell could be incorporated into designs of other fuel cells to make them lighter in weight and effective at altitudes higher than those of prior designs. Potential commercial applications for these improvements include most applications now under consideration for fuel cells.

This work was done by Alan Cisar, Chris Boyer, and Charles Greenwald of Lynntech, Inc., for **Glenn Research Center**.

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17284-1.

Hybrid Ion-Detector/Data-Acquisition System for a TOF-MS

John F. Kennedy Space Center, Florida

A modified ion-detector/data-acquisition system has been devised to increase the dynamic range of a time-of-flight mass spectrometer (TOF-MS) that, previously, included a microchannel-plate detector and a data-acquisition system based on counting pulses and time-tagging them by use of a time-to-digital converter (TDC). The dynamic range of the TOF-MS was limited by saturation of the microchannel-plate detector, which can handle no more than a few million counts per second. The modified system includes (1) a combined microchannel plate/discrete ion multiplier and (2) a hybrid data-acquisition system that simultaneously performs analog current or voltage measurements and multianode single-ion-pulse-counting time-of-flight measurements to extend the dynamic range of a TDC into the regime in which a mass peak comprises multiple ions arriving simultaneously at the detector. The multianode data are used to determine, in real time, whether the detector is saturated. When saturation is detected, the data-acquisition system selectively enables circuitry that simultaneously determines the ion-peak intensity by measuring the time profile of the analog current or voltage detector-output signal.

This work was done by William D. Burton, Jr.; J. Albert Schultz; Valentine Vaughn; Michael McCully; Steven Ulrich; and Thomas F. Egan of Ionwerks, Inc., for **Kennedy Space Center**.

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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Spontaneous-Desorption Ionizer for a TOF-MS

John F. Kennedy Space Center, Florida

A time-of-flight mass spectrometer (TOF-MS) like the one mentioned in the immediately preceding article has been retrofitted with an ionizer based on a surface spontaneous-desorption process. This ionizer includes an electron multiplier in the form of a microchannel plate (MCP). Relative to an ionizer based on a hot-filament electron source, this ionizer offers advantages of less power consumption and greater mechanical ruggedness. The current density and stability characteristics of the electron emission of this ionizer are similar to those of a

filament-based ionizer. In tests of various versions of this ionizer in the TOF-MS, electron currents up to 100 nA were registered. Currents of microamperes or more — great enough to satisfy requirements in most TOF-MS applications — could be obtained by use of MCPs different from those used in the tests, albeit at the cost of greater bulk. One drawback of this ionizer is that the gain of the MCP decreases as a function of the charge extracted thus far; the total charge that can be extracted over the operational lifetime is about 1 coulomb. An MCP in the ion-detector portion of the TOF-MS is subject to the same limitation.

This work was done by J. Albert Schultz of Ionwerks Inc. for **Kennedy Space Center**.

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 KSC-12607, volume and number of this NASA Tech Briefs *issue, and the page number.*

Equipment for On-Wafer Testing From 220 to 325 GHz
On-wafer vector network analysis of semiconductors is extended to higher frequencies.

NASA's Jet Propulsion Laboratory, Pasadena, California

A system of electronic instrumentation, constituting the equivalent of a two-port vector network analyzer, has been developed for use in on-wafer measurement of key electrical characteristics of semiconductor devices at frequencies from 220 to 325 GHz. A prior system designed according to similar principles was reported in "Equipment for On-Wafer Testing at Frequencies Up to 220 GHz" (NPO-20760), *NASA Tech Briefs*, Vol. 25, No. 11 (November 2001), page 42. As one would expect, a major source of difficulty in progressing to the present higher-frequency-range system was the need for greater mechanical precision as wavelengths shorten into the millimeter range, approaching the scale of mechanical tolerances of prior systems.

The system (see figure) includes both commercial off-the-shelf and custom equipment. As in the system of the cited prior article, the equipment includes test sets that are extended versions of commercial network analyzers that function in a lower frequency range. The extension to the higher frequency range is accomplished by use of custom frequency-extension modules that contain frequency multipliers and harmonic mixers. On-wafer measurement is made possible by waveguide wafer probes that were custom designed and built for this wavelength range,
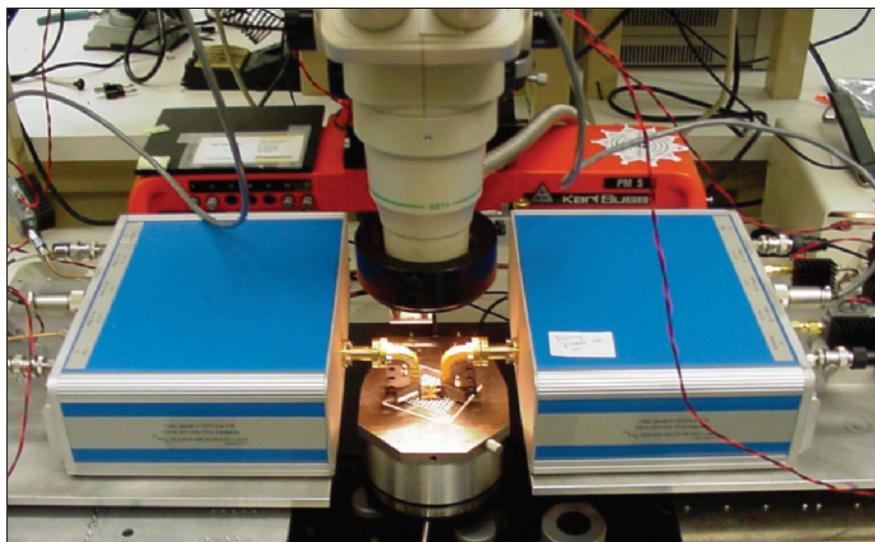
A **Probe Station and Test Sets** assembled from commercial-off-the-shelf and custom components enable on-wafer measurement of electrical characteristics of devices in the previously inaccessible frequency range of 220 to 325 GHz.

plus an on-wafer calibration substrate designed for use with these probes. In this case, the calibration substrate was specially fabricated by laser milling. The system was used to make the first on-wafer measurements of a semiconductor device in the frequency range from 220 to 320 GHz. Some of the measurement results showed that the device had gain.

Software

Computing Isentropic Flow Properties of Air/R-134a Mixtures

MACHRK is a computer program that calculates isentropic flow properties of mixtures of air and refrigerant R-134a (tetrafluoroethane), which are used in transonic aerodynamic testing in a wind tunnel at Langley Research Center. Given the total temperature, total pressure, static pressure, and mole fraction of R-134a in a mixture, MACHRK calculates the Mach number and the following associated flow properties: dynamic pressure, velocity, density, static temperature, speed of sound, viscosity, ratio of specific heats, Reynolds number, and Prandtl number. Real-gas effects are taken into account by treating the gases comprising the mixture as both thermally and calorically imperfect. The Redlich-Kwong equation of state for mixtures and the constant-pressure ideal heat-capacity equation for the mixture are used in combination with the departure-function approach of thermodynamics to obtain the equations for computing the flow properties. In addition to the aforementioned calculations for air/R-134a mixtures, a research version of MACHRK can perform the corresponding calculations for mixtures of air and R-12 (dichlorodifluoromethane) and for air/SF_6 mixtures. [R-12 was replaced by R-134a because of environmental concerns. SF_6 has been considered for use in increasing the Reynolds-number range.]

This program was written by Ray Kvaternik of **Langley Research Center**. *Further information is contained in a TSP (see page 1).*
LAR-17095-1

Java Mission Evaluation Workstation System

The Java Mission Evaluation Workstation System (JMEWS) is a collection of applications designed to retrieve, display, and analyze both real-time and recorded telemetry data. This software is currently being used by both the Space Shuttle Program (SSP) and the International Space Station (ISS) program. JMEWS was written in the Java programming language to satisfy the requirement of platform independence.

An object-oriented design was used to satisfy additional requirements and to make the software easily extendable. By virtue of its platform independence, JMEWS can be used on the UNIX workstations in the Mission Control Center (MCC) and on office computers. JMEWS includes an interactive editor that allows users to easily develop displays that meet their specific needs. The displays can be developed and modified while viewing data. By simply selecting a data source, the user can view real-time, recorded, or test data.

This program was written by Ross Pettinger, Tim Watlington, Richard Ryley, and Jeff Harbour of Lockheed Martin Corp. for **Johnson Space Center**. *For further information, contact the Johnson Innovative Partnerships Office at (281) 483-3809.*
MSC-23665

Using a Quadtree Algorithm To Assess Line of Sight

A matched pair of computer algorithms determines whether line of sight (LOS) is obstructed by terrain. These algorithms were originally designed for use in conjunction with combat-simulation software in military training exercises, but could also be used for such commercial purposes as evaluating lines of sight for antennas or determining what can be seen from a "room with a view." The quadtree preparation algorithm operates on an array of digital elevation data and only needs to be run once for a terrain region, which can be quite large. Relatively little computation time is needed, as each elevation value is considered only one and one-third times. The LOS assessment algorithm uses that quadtree to answer LOS queries. To determine whether LOS is obstructed, a piecewise-planar (or higher-order) terrain skin is computationally draped over the digital elevation data. Adjustments are made to compensate for curvature of the Earth and for refraction of the LOS by the atmosphere. Average computing time appears to be proportional to the number of queries times the logarithm of the number of elevation data points. Accuracy is as high as is possible for the available elevation data, and symmetric results are assured. In the simulation, the LOS query program runs as a separate process, thereby making more random-access memory available for other computations.

These programs were written by Joseph Gonzalez, Robert Chamberlain, Eric Tailor, and Gary Gutt 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 Karina Edmonds of the California Institute of Technology at (818) 393-2827. Refer to NPO-40596.

Software for Automated Generation of Cartesian Meshes

Cart3D is a collection of computer programs for generating Cartesian meshes [for computational fluid dynamics (CFD) and other applications] in volumes bounded by solid objects. Aspects of Cart3D at earlier stages of development were reported in "Robust and Efficient Generation of Cartesian Meshes for CFD" (ARC-14275), *NASA Tech Briefs,* Vol. 23, No. 8 (August 1999), page 30. The geometric input to Cart3D comprises surface triangulations like those commonly generated by computer-aided-design programs. Complexly shaped objects can be represented as assemblies of simpler ones. Cart3D deletes all portions of such an assembled object that are not on the exterior surface. Intersections between components are preserved in the resulting triangulation. A tie-breaking routine unambiguously resolves geometric degeneracies. Then taking the intersected surface triangulation as input, the volume mesh is generated through division of cells of an initially coarse hexahedral grid. Cells are subdivided to refine the grid in regions of increased surface curvature and/or increased flow gradients. Cells that become split into multiple unconnected regions by thin pieces of surface are identified.

These programs were written by Michael J. Aftosmis and John E. Melton of **Ames Research Center** *and Marsha J. Berger of the Courant Institute of Mathematics at New York University. Further information is contained in a TSP (see page 1).*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Technology Partnerships Division, Ames Research Center, (650) 604-2954. Refer to ARC-14275-1.

Optics Program Modified for Multithreaded Parallel Computing

A powerful high-performance computer program for simulating and analyzing adaptive and controlled optical systems has been developed by modifying the serial version of the Modeling and Analysis for Controlled Optical Systems (MACOS) program to impart capabilities for multithreaded parallel processing on computing systems ranging from supercomputers down to Symmetric Multiprocessing (SMP) personal computers. The modifications included the incorporation of OpenMP, a portable and widely supported application interface software, that can be used to explicitly add multithreaded parallelism to an application program under a shared-memory programming model. OpenMP was applied to parallelize ray-tracing calculations, one of the major computing components in MACOS. Multithreading is also used in the diffraction propagation of light in MACOS based on p-threads [POSIX Thread, (where "POSIX" signifies a portable operating system for UNIX)]. In tests of the parallelized version of MACOS, the speedup in ray-tracing calculations was found to be linear, or proportional to the number of processors, while the speedup in diffraction calculations ranged from 50 to 60 percent, depending on the type and number of processors. The parallelized version of MACOS is portable, and, to the user, its interface is basically the same as that of the original serial version of MACOS.

This program was written by John Lou, Dave Bedding, and Scott Basinger 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 Karina Edmonds of the California Institute of Technology at (818) 393-2827. Refer to NPO-40572.

Programs for Testing Processor-in-Memory Computing Systems

The Multithreaded Microbenchmarks for Processor-InMemory (PIM) Compilers, Simulators, and Hardware are computer programs arranged in a series for use in testing the performances of PIM computing systems, including compilers, simulators, and hardware. The programs at the beginning of the series test basic functionality; the programs at subsequent positions in the series test increasingly complex functionality. The programs are intended to be used while designing a PIM system, and can be used to verify that compilers, simulators, and hardware work correctly. The programs can also be used to enable designers of these system components to examine tradeoffs in implementation. Finally, these programs can be run on non-PIM hardware (either single-threaded or multithreaded) using the POSIX pthreads standard to verify that the benchmarks themselves operate correctly. [POSIX (Portable Operating System Interface for UNIX) is a set of standards that define how programs and operating systems interact with each other. pthreads is a library of pre-emptive thread routines that comply with one of the POSIX standards.]

These programs were written by Daniel S. Katz 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 Karina Edmonds of the California Institute of Technology at (818) 393-2827. Refer to NPO-41206.

PVM Enhancement for Beowulf Multiple-Processor Nodes

A recent version of the Parallel Virtual Machine (PVM) computer program has been enhanced to enable use of multiple processors in a single node of a Beowulf system (a cluster of personal computers that runs the Linux operating system). A previous version of PVM had been enhanced by addition of a software port, denoted BEOLIN, that enables the incorporation of a Beowulf system into a larger parallel processing system administered by PVM, as though the Beowulf system were a single computer in the larger system. BEOLIN spawns tasks on (that is, automatically assigns tasks to) individual nodes within the cluster. However, BEOLIN does not enable the use of multiple processors in a single node. The present enhancement adds support for a parameter in the PVM command line that enables the user to specify which Internet Protocol host address the code should use in communicating with other Beowulf nodes. This enhancement also provides for the case in which each node in a Beowulf system contains multiple processors. In this case, by making multiple references to a single node, the user can cause the software to spawn multiple tasks on the multiple processors in that node.

This work was done by Paul Springer of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

The software used in this innovation is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (818) 393-2827. Refer to NPO-41706.

# Ion-Exclusion Chromatography for Analyzing Organics in Water

Resolution of nonvolatile organic compounds is increased significantly.

Lyndon B. Johnson Space Center, Houston, Texas

A liquid-chromatography technique has been developed for use in the quantitative analysis of urea (and of other nonvolatile organic compounds typically found with urea) dissolved in water. The technique involves the use of a column that contains an ion-exclusion resin; heretofore, this column has been sold for use in analyzing monosaccharides and food softeners, but not for analyzing water supplies.

The prior technique commonly used to analyze water for urea content has been one of high-performance liquid chromatography (HPLC), with reliance on hydrophobic interactions between analytes in a water sample and long-chain alkyl groups bonded to an HPLC column. The prior technique has proven inadequate because of a strong tendency toward co-elution of urea with other compounds. Co-elution often causes the urea and other compounds to be crowded into a narrow region of the chromatogram (see left part of figure), thereby giving rise to low chromatographic resolution and misidentification of compounds. It is possible to quantitate urea or another analyte via ultraviolet- and visible-light absorbance measurements, but in order to perform such measurements, it is necessary to dilute the sample, causing a significant loss of sensitivity.

The ion-exclusion resin used in the improved technique is sulfonated polystyrene in the calcium form. Whereas the alkyl-chain column used in the prior technique separates compounds on the basis of polarity only, the ion-exclusion-resin column used in the improved technique separates compounds on the basis of both molecular size and electric
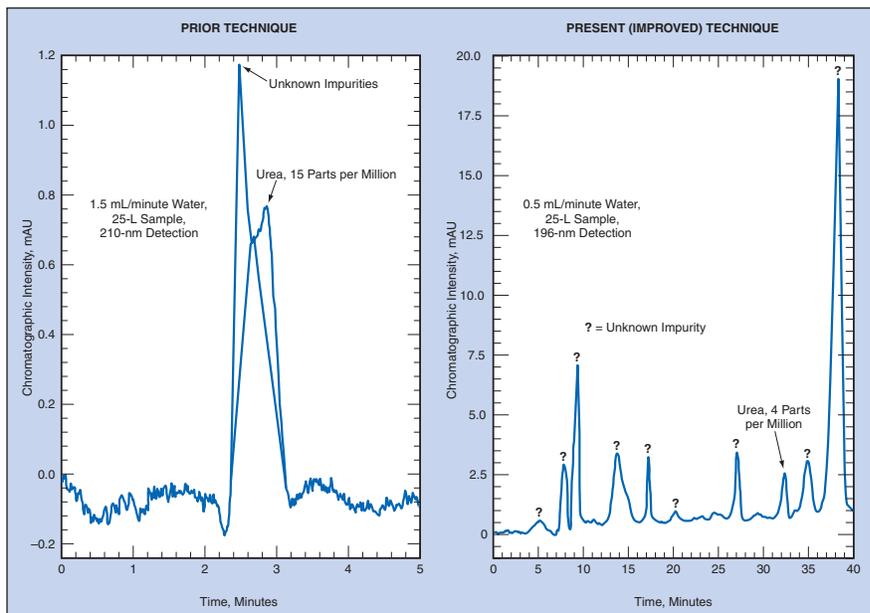
These **Chromatograms** were made from samples of space-shuttle humidity condensate, which contained dissolved urea and other impurities.

charge. As a result, the degree of separation is increased: instead of being crowded together into a single chromatographic peak only about 1 to 2 minutes wide as in the prior technique, the chromatographic peaks of different compounds are now separated from each other and spread out over a range about 33 minutes wide (see right part of figure), and the urea peak can readily be distinguished from the other peaks.

Although the analysis takes more time in the improved technique, this disadvantage is offset by two important advantages:

• Sensitivity is increased. The minimum concentration of urea that can be

measured is reduced (to between 1/5 and 1/3 of that of the prior technique) because it is not necessary to dilute the sample.

• The separation of peaks facilitates the identification and quantitation of the various compounds. The resolution of the compounds other than urea makes it possible to identify those compounds by use of mass spectrometry.

This work was done by Richard Sauer of **Johnson Space Center** *and Jeffrey A. Rutz and John R. Schultz of Wyle Laboratories. For further information, contact the Johnson Commercial Technology Office at (281) 483-3809.*
MSC-23000

Selective Plasma Deposition of Fluorocarbon Films on SAMs

The fluorocarbon films are useful as etch masks and perhaps as dielectric layers.

Goddard Space Flight Center, Greenbelt, Maryland

A dry plasma process has been demonstrated to be useful for the selective modification of self-assembled monolayers (SAMs) of alkanethiolates.

These SAMs are used, during the fabrication of semiconductor electronic devices, as etch masks on gold layers that are destined to be patterned and incor-

porated into the devices. The selective modification involves the formation of fluorocarbon films that render the SAMs more effective in protecting the masked

SAM Mask After Modification

Gold Remaining in Masked Areas
After Etching in KI Solution
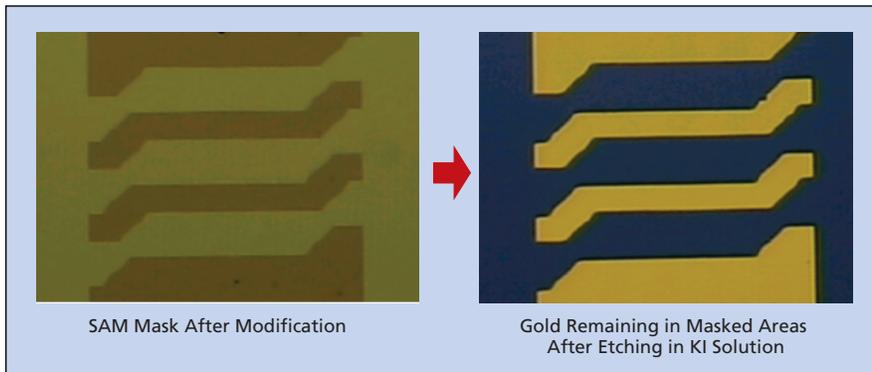
A **Gold Layer Was Patterned** by stamping it with a hexadecanethiol solution. The alkanethiolate SAM pattern thus formed was modified in a CF_4/H_2 plasma, forming an etch mask. Then gold was etched away from the areas not masked.

areas of the gold against etching by a potassium iodide (KI) solution. This modification can be utilized, not only in the fabrication of single electronic devices but also in the fabrication of integrated circuits, microelectromechanical systems, and circuit boards.

In the steps that precede the dry plasma process, a silicon mold in the desired pattern is fabricated by standard photolithographic techniques. A stamp is then made by casting polydimethylsiloxane (commonly known as silicone rubber) in the mold. The stamp is coated with an alkanethiol solution, then the stamp is pressed on the gold layer of a device to be fabricated in order to deposit the alkanethiol to form an alkanethiolate SAM in the desired pattern (see figure). Next, the workpiece is exposed to a radio-frequency plasma generated from a mixture of CF_4 and H_2 gases. After this plasma treatment, the SAM is found to be modified, while the exposed areas of gold remain unchanged.

This dry plasma process offers the potential for forming masks superior to those formed in a prior wet etching process. Among the advantages over the wet etching process are greater selectivity, fewer pin holes in the masks, and less nonuniformity of the masks. The fluorocarbon films formed in this way may also be useful as intermediate layers for subsequent fabrication steps and as dielectric layers to be incorporated into finished products.

This work was done by Mark M. Crain III, Kevin M. Walsh, and Robert W. Cohn of the University of Louisville for **Goddard Space Flight Center**. *Further information is contained in a TSP (see page 1).*
GSC-14440

Water-Based Pressure-Sensitive Paints

Toxicity, and thus costs of ventilation and cleanup, is substantially reduced.

Langley Research Center, Hampton, Virginia

Water-based pressure-sensitive paints (PSPs) have been invented as alternatives to conventional organic-solvent-based pressure-sensitive paints, which are used primarily for indicating distributions of air pressure on wind-tunnel models. Typically, PSPs are sprayed onto aerodynamic models after they have been mounted in wind tunnels. When conventional organic-solvent-based PSPs are used, this practice creates a problem of removing toxic fumes from inside the wind tunnels. The use of water-based PSPs eliminates this problem. The water-based PSPs offer high performance as pressure indicators, plus all the advantages of common water-based paints (low toxicity, low concentrations of volatile organic compounds, and easy cleanup by use of water).

A typical PSP (whether conventional or of the present innovative type) contains the following:

• A luminescent compound, the luminescence of which is quenched by oxygen;
• An oxygen-permeable polymeric binder;
• Pigment materials to hide the painted surface and to increase reflectance of the light emitted from the luminescent compound; and
• Solvents.

The paint is applied to a surface of interest on a model and allowed to dry. During a subsequent wind-tunnel test, under the appropriate illumination, the intensity of luminescence emitted by the PSP is inversely proportional to the concentration of oxygen, hence, to the air pressure at the painted surface.

A water-based PSP contains all the basic ingredients of a conventional PSP (see table), except that the organic-solvent content (if any) is much smaller and the basic ingredients are incorpo-

Ingredient	Proportion in Weight Percent
water emulsion of poly-trifluoroethylmethacrylate-co-isobutylmethacrylate (1:1)	42 to 68.4
propylene glycol	2.28
a glycol ether	10.26
TiO_2 (pigment)	11.35
N-methyl pyrrolidinone	6.00
Byk 346 (or equivalent solution of polyether-modified dimethylpolysiloxane)	0.68
Lubrizol 2062 (or equivalent) aliphatic/aromatic phosphate ester for solvent-borne and water-borne coatings	1.03
platinum tetra(pentafluorphenyl)porphyrin (a luminophore)	0.1

A **Typical Water-Based PSP Formulation** is shown here.

rated in a water matrix. The oxygen-permeable polymer is prepared as a water-borne emulsion. This is blended with the necessary coalescing agents, coupling solvents, luminophore, and pigments. The resulting water-based PSP can be applied by spraying to obtain a single coat, which cures to touch in less than one hour and cures for use in 12 hours at room temperature. The cured paint is smooth and has good adhesion to most metal and plastic substrates.

This work was done by Jeffrey D. Jordan and A. Neal Watkins of **Langley Research Center** *and Donald M. Oglesby and JoAnne L. Ingram of Swales Aerospace. 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:*

Swales Aerospace
LaRC On-Site Offices
1224T11 N. Wright Street, MS186A
Hampton, VA 23681-9668
Phone: (757) 864-9857
Refer to LAR-16603-1, volume and number of this NASA Tech Briefs *issue, and the page number.*

System Finds Horizontal Location of Center of Gravity

Mass and center-of-mass data are updated at a rate of ≈267 Hz.
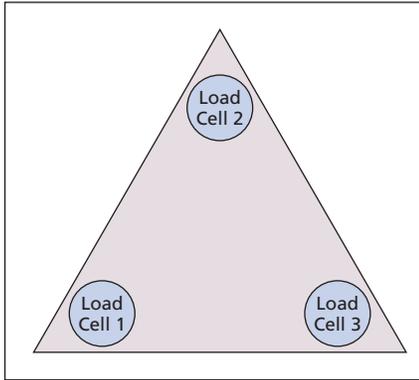
Marshall Space Flight Center, Alabama

Figure 1. **Three Load Cells** measure the weights applied to three air bearings at the corners of a triangle.

An instrumentation system rapidly and repeatedly determines the horizontal location of the center of gravity of a laboratory vehicle that slides horizontally on three air bearings (see Figure 1). Typically, knowledge of the horizontal center-of-mass location of such a vehicle is needed in order to balance the vehicle properly for an experiment and/or to assess the dynamic behavior of the vehicle.

The system includes a load cell above each air bearing, electronic circuits that generate digital readings of the weight on each load cell, and a computer equipped with software that processes the readings. The total

weight and, hence, the mass of the vehicle are computed from the sum of the load-cell weight readings. Then the horizontal position of the center of gravity is calculated straightforwardly as the weighted sum of the known position vectors of the air bearings, the contribution of each bearing being proportional to the weight on that bearing. In the initial application for which this system was devised, the center-of-mass calculation is particularly simple because the air bearings are located at corners of an equilateral triangle. However, the system is not restricted to this simple geometry.

The system acquires and processes weight readings at a rate of 800 Hz for each load cell. The total weight and the horizontal location of the center of gravity are updated at a rate of $800/3 \approx 267$ Hz.

In a typical application, a technician would use the center-of-mass output of this instrumentation system as a guide to the manual placement of small weights on the vehicle to shift the center of gravity to a desired horizontal position. Usually, the desired horizontal position is that of the geometric center. Alternatively, this instrumentation system could be used to provide position feedback for a control system that would cause weights to be shifted automatically (see Figure 2) in an effort to keep the center of gravity at the geometric center.

This work was done by Albert S. Johnston, Richard T. Howard, and Linda L. Brewster of **Marshall Space Flight Center**. *Further information is contained in a TSP (see page 1).*
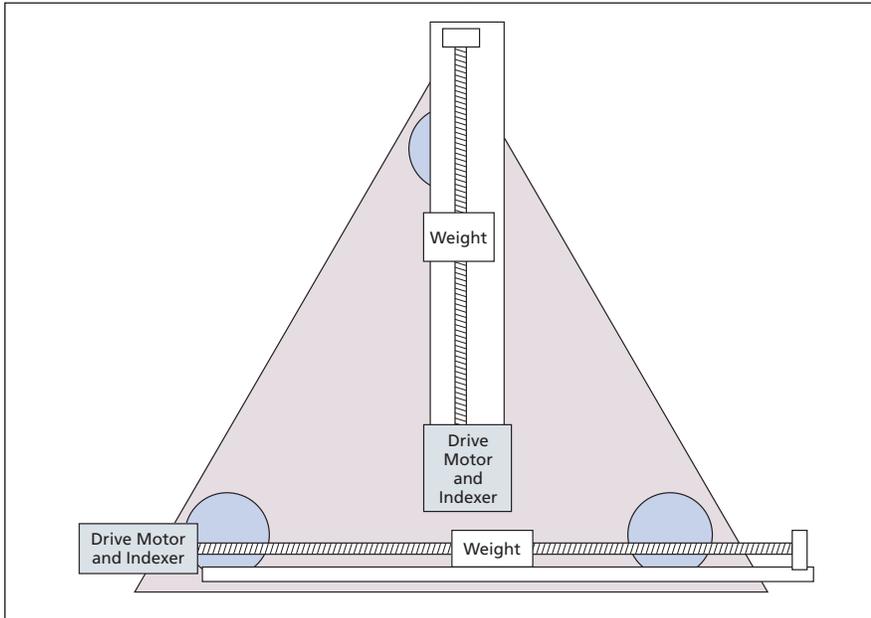MFS-31999-1

Figure 2. **Motor-Driven Lead Screws** would reposition weights, in response to load-cell readings, to counteract any deviation of the center of gravity from the geometric center.

Predicting Tail Buffet Loads of a Fighter Airplane

Airframes can be designed to be more robust.

Langley Research Center, Hampton, Virginia

Buffet loads on aft aerodynamic surfaces pose a recurring problem on most twin-tailed fighter airplanes: During maneuvers at high angles of attack, vortices

emanating from various surfaces on the forward parts of such an airplane (engine inlets, wings, or other fuselage appendages) often burst, immersing the tails

in their wakes. Although these vortices increase lift, the frequency contents of the burst vortices become so low as to cause the aft surfaces to vibrate destructively.

This type of buffeting has reduced the airframe fatigue lives and the system reliabilities of several legacy aircraft. This situation has been brought on largely because tail buffet loads have generally been ignored in the design of twin-tailed fighter airplanes. There are several reasons for this oversight: Fundamentally, tail buffet loads have not been identified as a major concern in designing fighter airframes. More practical reasons are that, until recently, (1) there was a lack of quantitative data on buffet forces; and (2) no readily available and cohesive analysis method could be used to predict buffet loads during the design of fighter airplanes.

Now, there exists a new analysis capability for predicting buffet loads during the earliest design phase of a fighter-aircraft program. In effect, buffet pressures are applied to mathematical models in the framework of a finite-element code, complete with aeroelastic properties and working knowledge of the spatiality of the buffet pressures for all flight conditions. The results of analysis performed by use of this capability illustrate those vibratory modes of a tail fin that are most likely to be affected by buffet loads. Hence, the results help in identifying the flight conditions during which to expect problems. Using this capability, an aircraft designer can make adjustments to the airframe and possibly the aerodynamics, leading to a more robust design.

This capability has been utilized in the design of the Joint Strike Fighter, leading to better understanding of buffet loads and to total redesign of the airframe to avoid fatigue-life issues.

*This work was done by Robert W. Moses and Anthony S. Pototzky of **Langley Research Center**. For further information, contact the Intellectual Property Team at (757) 864-3521. LAR-16515*

Water Containment Systems for Testing High-Speed Flywheels

Water-filled containers are stacked like bricks.

John H. Glenn Research Center, Cleveland, Ohio

Water-filled containers are used as building blocks in a new generation of containment systems for testing high-speed flywheels. Such containment systems are needed to ensure safety by trapping high-speed debris in the event of centrifugal breakup or bearing failure. Traditional containment systems for testing flywheels consist mainly of thick steel rings. While steel rings are effective for protecting against fragments from conventional and relatively simple metal flywheels, they are also expensive. Moreover, it is difficult and expensive to configure steel-ring containment systems for testing of advanced flywheel systems that can include flywheels made of composite materials, counter-rotating flywheels, and/or multiple flywheels rotating about different axes. In contrast, one can quickly, easily, and inexpensively stack water-filled containers like bricks to build walls, (and, if needed, floors, and ceilings) of sufficient thickness to trap debris traveling in any possible direction at the maximum possible kinetic energy that could be encountered in testing a given flywheel system.

Water is remarkably effective in decelerating high-speed debris: In an analysis performed in 1998, it was found that for a fragment that has a characteristic dimension L and an initial kinetic energy E_0, the kinetic energy E after traveling a distance d through water is approximated by $E = E_0 e^{-d/L}$. For typical fragment sizes and speeds expected to be encountered in tests of advanced flywheel systems, this equation leads to the expectation that a wall of water only 0.6 m thick would suffice to dissipate practically all the kinetic energy.

The effectiveness of this approach to shielding against high-speed debris was demonstrated in a series of tests, including one in which a bullet was fired into a stack of two cubic cardboard boxes, 0.28 m on each side, containing water-filled bladders (see figure). The bullet had a mass of 9.7 g and an initial speed of 790 m/s. Upon impact, the first container was split, the water in the container was widely dispersed, and the bullet was deformed. The bullet did not reach the second container. In other words, the bullet was stopped by less than 0.28 m of water. Limited composite fragment testing was also performed in the Ballistics Impact

A **Bullet Was Fired** from the left toward two cubic water-filled containers. The bullet was stopped by the first container.

Laboratory at Glenn Research Center, which demonstrated the ability to stop a $2.5 \times 2.5 \times 1.0$ cm fragment with a velocity of approximately 730 m/s within 30.5 cm of water.

*This work was done by Larry Trase and Dennis Thompson 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: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17608-1.

✿ Vapor-Compression Heat Pumps for Operation Aboard Spacecraft

Lyndon B. Johnson Space Center, Houston, Texas

Vapor-compression heat pumps (including both refrigerators and heat pumps) of a proposed type would be capable of operating in microgravity and would be safe to use in enclosed environments like those of spacecraft. The designs of these pumps would incorporate modifications of, and additions to, vapor-compression cycles of heat pumps now used in normal Earth gravitation, in order to ensure efficiency and reliability during all phases of operation, including startup, shutdown, nominal continuous operation, and peak operation. Features of such a design might include any or all of the following:

(1) Configuring the compressor, condenser, evaporator, valves, capillary tubes (if any), and controls to function in microgravitation;
(2) Selection of a working fluid that satisfies thermodynamic requirements and is safe to use in a closed crew compartment;
(3) Incorporation of a solenoid valve and/or a check valve to prevent influx of liquid to the compressor upon startup (such influx could damage the compressor);
(4) Use of a diode heat pipe between the cold volume and the evaporator to limit the influx of liquid to the compressor upon startup; and
(5) Use of a heated block to vaporize any liquid that arrives at the compressor inlet.

This work was done by Warren Ruemmele, Eugene Ungar, and John Cornwell of **Johnson Space Center**. *For further information, contact the Johnson Innovative Partnerships Office at (281) 483-3809. MSC-23746*

✿ Multistage Electrophoretic Separators
Separations can be performed in preparative quantities and can be automated.

Lyndon B. Johnson Space Center, Houston, Texas

A multistage electrophoresis apparatus has been invented for use in the separation of cells, protein molecules, and other particles and solutes in concentrated aqueous solutions and suspensions. The design exploits free electrophoresis but overcomes the deficiencies of prior free-electrophoretic separators by incorporating a combination of published advances in mathematical modeling of convection, sedimentation, electro-osmotic flow, and the sedimentation and aggregation of droplets. In comparison with other electrophoretic separators, these apparatuses are easier to use and are better suited to separation in relatively large quantities characterized in the art as preparative (in contradistinction to smaller quantities characterized in the art as analytical).

In a multistage electrophoretic separator according to the invention, an applied vertical steady electric field draws the electrically charged particles of interest from within a cuvette to within a collection cavity that has been moved into position of the cuvette. There are multiple collection cavities arranged in a circle; each is aligned with the cuvette for a prescribed short time. The multistage, short-migration-path character of the invention solves, possibly for the first time, the fluid-instability problems associated with free electrophoresis.

The figure shows a prototype multistage electrophoretic separator that includes four sample stations and five collection stages per sample. At each sample station, an aqueous solution or
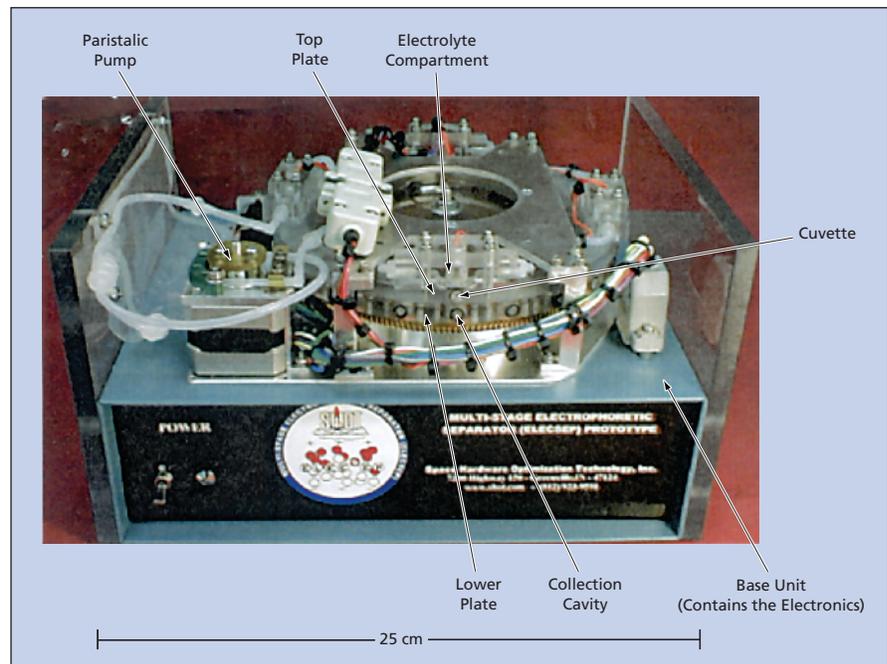
This **Multistage Electrophoretic Separator** contains four sample stations, of which one faces front in this view.

suspension containing charged species to be separated is loaded into a cuvette, which is machined into a top plate. The apparatus includes a lower plate, into which 20 collection cavities have been milled. Each cavity is filled with an electrophoresis buffer solution. For the collection of an electrophoretic fraction, the lower plate is rotated to move a designated collection cavity into alignment with the opening of the cuvette.

An electric field is then applied between a non-gassing electrode in the collection cavity and an electrolyte compartment, which is separated from the cuvette by a semipermeable mem-

brane. The electrolyte is refreshed by circulation by use of a peristaltic pump. In subsequent steps, the lower plate is rotated to collect other electrophoretic fractions. Later, the collected fractions are removed from the collection cavities through ports that have threaded plugs.

The base of the apparatus contains power supplies and a computer interface. The design includes provisions for monitoring and feedback control of cavity position, electric field, and temperature. The operation of the apparatus can easily be automated, as demonstrated by use of software that has already been written for this purpose.

Recovering Residual Xenon Propellant for an Ion Propulsion System
Most of the otherwise unusable xenon is recovered.

NASA's Jet Propulsion Laboratory, Pasadena, California

Future nuclear-powered Ion-Propulsion-System-propelled spacecraft such as Jupiter Icy Moon Orbiter (JIMO) will carry more than 10,000 kg of xenon propellant. Typically, a small percentage of this propellant cannot be used towards the end of the mission because of the pressure drop requirements for maintaining flow. For large missions such as JIMO, this could easily translate to over 250 kg of unusable xenon.

A proposed system, the Xenon Recovery System (XRS), for recovering almost all of the xenon remaining in the tank, would include a cryopump in the form of a condenser/evaporator that would be alternatively cooled by a radiator, then heated electrically. When the pressure of the xenon in the tank falls below 0.7 MPa (100 psia), the previously isolated XRS will be brought online and the gas from the tank would enter the cryopump that is initially cooled to a temperature below saturation temperature of xenon. This causes xenon liquefaction and further cryopumping from the tank till the cryopump is full of liquid xenon. At this point, the cryopump is heated electrically by small heaters (70 to 80 W) to evaporate the liquid that is
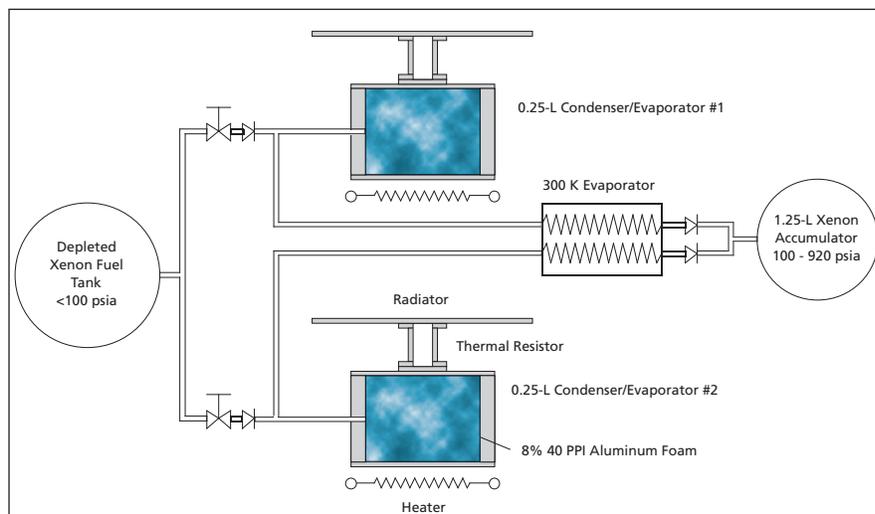
A **Proposed Xenon Recovery System** promises to reduce waste of valuable cargo space on distant missions.

collected as high-pressure gas (<7 MPa; 1,000 psia) in an intermediate accumulator. Check valves between the tank and the XRS prevent the reverse flow of xenon during the heating cycle. The accumulator serves as the high-pressure source of xenon gas to the Xenon Feed System (XFS) downstream of the XRS. This cycle is repeated till almost all the

xenon is recovered. Currently, this system is being baselined for JIMO.

Manufacturing

Automated Solvent Seaming of Large Polyimide Membranes
Success depends on precise control of all relevant process details.

Marshall Space Flight Center, Alabama

A solvent-based welding process enables the joining of precise, cast polyimide membranes at their edges to form larger precise membranes. The process creates a homogeneous, optical-quality seam between abutting membranes, with no overlap and with only a very localized area of figure disturbance. The seam retains 90 percent of the strength of the parent material. The process was developed for original use in the fabrication of wide-aperture membrane optics, with areal densities of less than 1 kg/m^2, for lightweight telescopes, solar concentrators, antennas, and the like to be deployed in outer space. The process is just as well applicable to the fabrication of large precise polyimide membranes for flat or inflatable solar concentrators and antenna reflectors for terrestrial applications.

The process is applicable to cast membranes made of CP1 (or equivalent) polyimide. The process begins with the precise fitting together and fixturing of two membrane segments. The seam is formed by applying a metered amount of a doped solution of the same polyimide along the abutting edges of the membrane segments. After the solution has been applied, the fixtured films are allowed to dry and are then cured by convective heating. The weld material is the same as the parent material, so that what is formed is a homogeneous, strong joint that is almost indistinguishable from the parent material.

The success of the process is highly dependent on formulation of the seaming solution from the correct proportion of the polyimide in a suitable solvent. In addition, the formation of reliable seams depends on the deposition of a precise amount of the seaming solution along the seam line. To ensure the required precision, deposition is performed by use of an automated apparatus comprising a modified commercially available, large-format, ink-jet print head on an automated positioning table. The printing head jets the seaming solution into the seam area at a rate controlled in coordination with the movement of the positioning table.

This work was done by Robert Rood of **Marshall Space Flight Center** *and James D. Moore, Chris Talley, and Paul A. Gierow of SRS Technologies, Inc. Further information is contained in a TSP (see page 1).*
MFS-32129

Manufacturing Precise, Lightweight Paraboloidal Mirrors
Success depends on the proper selection of materials and process conditions.

Marshall Space Flight Center, Alabama

A process for fabricating a precise, diffraction-limited, ultra-lightweight, composite-material (matrix/fiber) paraboloidal telescope mirror has been devised. Unlike the traditional process of fabrication of heavier glass-based mirrors, this process involves a minimum of manual steps and subjective judgment. Instead, this process involves objectively controllable, repeatable steps; hence, this process is better suited for mass production.

Other processes that have been investigated for fabrication of precise composite-material lightweight mirrors have resulted in "print-through" of fiber patterns onto reflecting surfaces, and have not provided adequate structural support for maintenance of stable, diffraction-limited surface figures. In contrast, this process does not result in "print-through" of the fiber pattern onto the reflecting surface and does provide a lightweight, rigid structure capable of maintaining a diffraction-limited surface figure in the face of changing temperature, humidity, and air pressure.

The process consists mainly of the following steps:
1. A precise glass mandrel is fabricated by conventional optical grinding and polishing.
2. The mandrel is coated with a release agent and covered with layers of a carbon-fiber composite material.
3. The outer surface of the outer layer of the carbon-fiber composite material is coated with a surfactant chosen to provide for the proper flow of an epoxy resin to be applied subsequently.
4. The mandrel as thus covered is mounted on a temperature-controlled spin table.
5. The table is heated to a suitable temperature and spun at a suitable speed as the epoxy resin is poured onto the coated carbon-fiber composite material.
6. The surface figure of the optic is monitored and adjusted by use of traditional Ronchi, Focault, and interferometric optical measurement techniques while the speed of rotation and the temperature are adjusted to obtain the desired figure. The proper selection of surfactant, speed or rotation, viscosity of the epoxy, and temperature make it possible to obtain the desired diffraction-limited, smooth (1/50th wave) parabolic outer surface, suitable for reflective coating.
7. A reflective coat is applied by use of conventional coating techniques.
8. Once the final figure is set, a lightweight structural foam is applied to the rear of the optic to ensure stability of the figure.

This work was done by Frederick Thomas Herrmann of **Marshall Space Flight Center**. *Further information is contained in a TSP (see page 1).*

This invention is owned by NASA, and a patent application has been filed. For further information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-31595-1.

Analysis of Membrane Lipids of Airborne Micro-Organisms

Lyndon B. Johnson Space Center, Houston, Texas

A method of characterization of airborne micro-organisms in a given location involves (1) large-volume filtration of air onto glass-fiber filters; (2) accelerated extraction of membrane lipids of the collected micro-organisms by use of pressurized hot liquid; and (3) identification and quantitation of the lipids by use of gas chromatography and mass spectrometry. This method is suitable for use in both outdoor and indoor environments; for example, it can be used to measure airborne microbial contamination in buildings

("sick-building syndrome"). The classical approach to analysis of airborne micro-organisms is based on the growth of cultureable micro-organisms and does not provide an account of viable but nonculturable micro-organisms, which typically amount to more than 90 percent of the micro-organisms present. In contrast, the present method provides an account of all micro-organisms, including cultureable, nonculturable, aerobic, and anaerobic ones. The analysis of lipids according to this method makes it possible

to estimate the number of viable airborne micro-organisms present in the sampled air and to obtain a quantitative profile of the general types of micro-organisms present along with some information about their physiological statuses.

This work was done by Sarah Macnaughton of Microbial Insights, Inc., for **Johnson Space Center**. *For further information, contact the Johnson Commercial Technology Office at (281) 483-3809.*
*MSC-22984*

Noninvasive Diagnosis of Coronary Artery Disease Using 12-Lead High-Frequency Electrocardiograms

Diagnostically significant signal features can be identified automatically by computational analysis.

Lyndon B. Johnson Space Center, Houston, Texas

A noninvasive, sensitive method of diagnosing certain pathological conditions of the human heart involves computational processing of digitized electrocardiographic (ECG) signals acquired from a patient at all 12 conventional ECG electrode positions. In the processing, attention is focused on low-amplitude, high-frequency components of those portions of the ECG signals known in the art as QRS complexes. The unique contribution of this method lies in the utilization of signal features and combinations of signal features from various combinations of electrode positions, not reported previously, that have been found to be helpful in diagnosing coronary artery disease and such related pathological conditions as myocardial ischemia, myocardial infarction, and congestive heart failure.

The electronic hardware and software used to acquire the QRS complexes and perform some preliminary analyses of their high-frequency components were summarized in "Real-Time, High-Frequency QRS Electrocardiograph" (MSC-23154), *NASA Tech Briefs*, Vol. 27, No. 7 (July 2003), pp. 26-28. To recapitulate, signals from standard electrocardiograph electrodes are preamplified, then
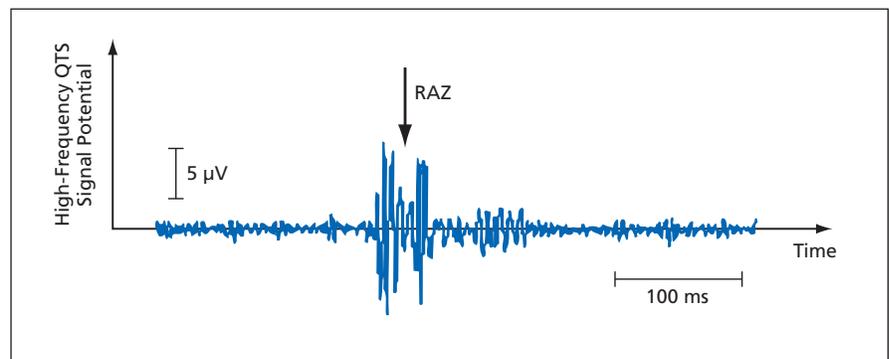
This **High-Frequency QRS Signal** was acquired from a patient having myocardial ischemia. The dip in the amplitude envelope (the RAZ) is a key feature utilized in the present method.

digitized at a sampling rate of 1,000 Hz, then analyzed by the software that detects R waves and QRS complexes and analyzes them from several perspectives. The software includes provisions for averaging signals over multiple beats and for special-purpose nonrecursive digital filters with specific low- and high-frequency cutoffs. These filters, applied to the averaged signal, effect a band-pass operation in the frequency range from 150 to 250 Hz. The output of the band-pass filter is the desired high-frequency QRS signal. Further processing is then performed in real time to obtain the

beat-to-beat root mean square (RMS) voltage amplitude of the filtered signal, certain variations of the RMS voltage, and such standard measures as the heart rate and R-R interval at any given time.

A key signal feature analyzed in the present method is the presence versus the absence of reduced-amplitude zones (RAZs). In terms that must be simplified for the sake of brevity, an RAZ comprises several cycles of a high-frequency QRS signal during which the amplitude of the high-frequency oscillation in a portion of the signal is abnormally low (see figure). A given signal sample exhibiting an in-

terval of reduced amplitude may or may not be classified as an RAZ, depending on quantitative criteria regarding peaks and troughs within the reduced-amplitude portion of the high-frequency QRS signal. This analysis is performed in all 12 leads in real time.

Several RAZ criteria are used in this method, including some, heretofore used only by NASA, that involve the calculation of the kurtosis of the high-frequency QRS signal. (Kurtosis is a statistical measure of the degree to which the distribution of data in a given set is peaked or flat, relative to a normal distribution.) In this method, the various RAZ criteria are applied to the ECG signals acquired from various combinations of contiguous conventional ECG electrode positions selected from among all 12 such positions. The sets of criteria and electrode combinations were developed from an analysis of ECG readings from several young and healthy subjects and from several patients with varying degrees of coronary artery disease and/or heart failure.

Again, in terms that must be simplified for brevity, a positive or negative diagnosis is suggested, depending on whether or not one of the RAZ criteria applied to the associated electrode combination is satisfied. For example, the presence of a "kurtosis RAZ" (characterized by a kurtosis value less than about 2.6) in four or more contiguous electrode positions suggests a positive diagnosis. A computer that runs software that implements the sets of RAZ criteria and electrode combinations can be incorporated into an ECG system to construct an automated diagnostic system. Inasmuch as electrocardiography is already a standard part of procedures for diagnosis of cardiac conditions, this method has potential to increase productivity and accuracy at minimal additional cost and without exposing patients to additional risks.

Dual-Laser-Pulse Ignition

This scheme provides a more reliable ignition source and more efficient energy delivery than a single-pulse format.

Marshall Space Flight Center, Alabama

A dual-pulse laser (DPL) technique has been demonstrated for generating laser-induced sparks (LIS) to ignite fuels. The technique was originally intended to be applied to the ignition of rocket propellants, but may also be applicable to ignition in terrestrial settings in which electric igniters may not be suitable. Laser igniters have been sought as alternatives to such conventional devices as electrical spark plugs and torch igniters for the following main reasons:

1. A typical electric spark igniter generates sparks at its electrode near a wall, which potentially quenches combustion. Hence, more spark energy is needed to ensure ignition. A large combustion chamber would require a torch igniter, which comprises an electric-spark source, a premixing chamber, and propellant valves. In contrast, the laser igniter is capable of creating sparks directly in a main chamber at specific optimal locations, which can be out away from the chamber walls, and without the need of other subsystems.

2. Laser igniters can generate LIS with very precise timing, on the order of nanoseconds. This accurate timing precision may be helpful in certain ignition applications. Furthermore, this ignition generates significantly less electromagnetic emission noise than electrical igniters. Such noise can interfere with other electronic signals of engine sensors and control components.

Years of research on laser ignition have produced viable single-pulse laser ignition concepts; however, the transmission of high laser energy through fiber optics required by these single-pulse schemes has been problematic due to potential fiber damage and reduction in transmission efficiency. In comparison, optical energy for the DPL method can be stretched out and transmitted through multiple fiber lines, effectively reducing the energy intensity. In addition, the lifetime of the plasmas generated by use of the DPL exceeds those of plasmas generated by single-laser pulses, which increases their efficacy as an ignition source.

In the present DPL technique, the first pulse is used to generate a small plasma kernel. The second pulse is subsequently used to irradiate the plasma kernel. The transfer of laser energy into the kernel is much more efficient because the radiation-absorption characteristics of the plasma kernel are greatly enhanced, relative to the single-pulse approach. Consequently, the kernel can develop into a more effective ignition source.

Comparative experiments on single- and dual-pulse laser ignition were performed in a small test-bed rocket thrust chamber, at Marshall Space Flight Center, using gaseous oxygen and kerosene. Sapphire windows were used for optical access to the chamber. In the tests, the DPL technique was found to provide a repeatable ignition source for combustion with an optimal energy level.

This work was done by Huu Trinh of **Marshall Space Flight Center**, *James W. Early of Los Alamos National Laboratory, Matthew E. Thomas of CFD Research Corp., and John A. Bossard, formerly of CFD Research Corp. Further information is contained in a TSP (see page 1).*
MFS-31922

Enhanced-Contrast Viewing of White-Hot Objects in Furnaces

Band-pass- and polarization-filtered laser light exceeds polarization-suppressed blackbody light.

Marshall Space Flight Center, Alabama

An apparatus denoted a laser image contrast enhancement system (LICES) increases the contrast with which one can view a target glowing with blackbody radiation (a white-hot object) against a background of blackbody radiation in a furnace at a temperature as high as ≈1,500 °C. The apparatus utilizes a combination of narrowband illumination, along with band-pass filtering and polarization filtering to pass illumination reflected by the target while suppressing blackbody light from both the object and its background.

In a typical application, the target is about 1 cm in size and located as far as 30 in. (≈76 cm) into the furnace. In the absence of this or another contrast-enhancing apparatus, a white-hot target in a furnace is nearly or totally indistinguishable from the white-hot background. Unlike a prior contrast-enhancing apparatus that utilizes two intersecting optical axes for viewing and illumination of the target and requires a furnace opening as wide as 3 in. (≈8 cm) the LICES provides for both illumination and viewing of the target along the same path. Hence, the LICES makes it possible to utilize a narrower opening into the furnace: the LICES can function with an illumination/viewing tube only about half an inch (≈1.3 cm) wide.

The LICES (see figure) includes a laser aimed perpendicularly to the optical path to the target. (Optionally, another source of narrowband illumination could be used.) The laser light impinges on a polarizing beam splitter that turns the light onto the optical path to the target. The laser light passes through a quarter-wave retardation plate, which causes the light to become
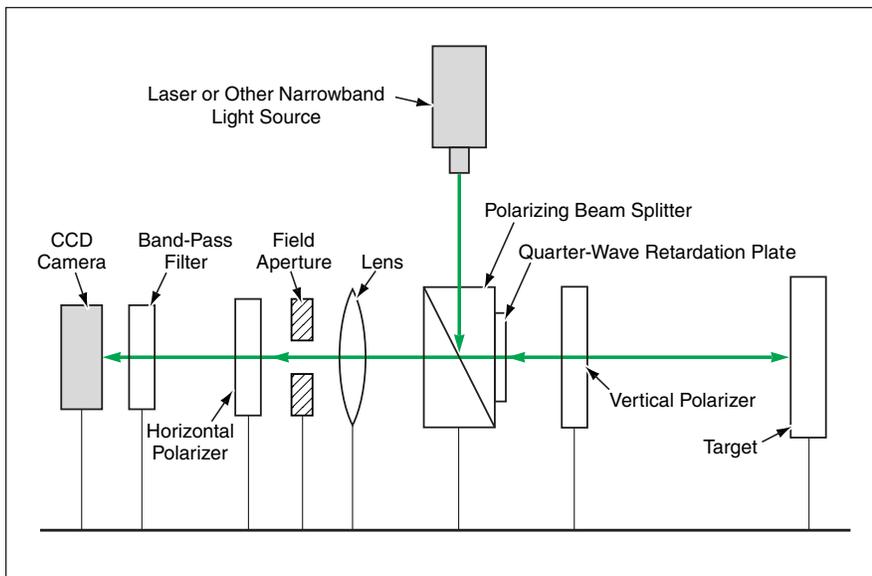
Only One Optical Path is used for both illuminating and viewing the target with laser light. Blackbody radiation from the target is suppressed by the crossed (horizontal and vertical) polarizers.

circularly polarized. The circularly polarized laser light passes undisturbed through a vertical polarizer, then travels along the optical axis to the target. Reflection from the target reverses the circular polarization. The reflected laser light passes again through the vertical polarizer and then through the quarter-wave retardation plate, which converts the reverse circular polarization to horizontal polarization.

The polarizing beam splitter passes the horizontally polarized reflected laser light, which then passes through a lens, a field aperture (which helps to increase contrast by blocking background light), a horizontal polarizer, and a filter having a 20-nm-wide wavelength pass band. The reflected laser light ultimately comes to focus in a charge-coupled-device (CCD) camera. At the same time, the crossed polarizers and the band-pass filter discriminate the wideband, randomly polarized blackbody light from both the target and the background.

Because the intensity of blackbody radiation is proportional to the fourth power of absolute temperature, it could be necessary to increase the laser power to maintain adequate contrast at higher temperatures. A prototype LICES has been found to yield high-contrast images at temperatures 1,500 °C.

Electrically Tunable Terahertz Quantum-Cascade Lasers

These devices would supplant gas lasers as far-infrared sources.

NASA's Jet Propulsion Laboratory, Pasadena, California

Improved quantum-cascade lasers (QCLs) are being developed as electrically tunable sources of radiation in the far infrared spectral region, especially in the frequency range of 2 to 5 THz. (Heretofore, the wavelengths of QCLs have been adjusted by changing temperatures, but not by changing applied voltages or currents.) In comparison with gas lasers now used as far-infrared sources, these QCLs would have larger wavelength tuning ranges, would be less expensive, and would be an order of magnitude less massive and power-hungry. It is planned to use the improved QCLs initially as the active components of local oscillators in spaceborne heterodyne instruments for studying infrared spectral lines of molecules of scientific interest. On Earth, the QCLs could be used as far-infrared sources for medical glucose-monitoring and heart-monitoring instruments, chemical-analysis and

spectral-imaging systems, and imaging instruments that exploit the ability of terahertz radiation to penetrate cloth and walls for detection of contraband weapons.

The structures of QCLs and the processes used to fabricate them have much in common with those of multiple-quantum-well infrared photodetectors described in numerous previous *NASA Tech Briefs* articles. In one of four approaches being followed in the present development effort, the focus is upon designing and fabricating the structures to obtain heterogeneous cascades for different electric fields and different wavelengths in order to enable electrical tuning of laser emission wavelengths. Both the variation of the emission wavelength and the targeted range of the electric-field strength for each cascade would be kept small so the spectral gains of adjacent cascades at any given electric-field strength in the target

range would overlap. This approach is expected to afford the desired variation of the gain maximum with electric-field strength, so that a change in applied bias voltage would result in a wavelength change.

In the second approach, layers of a QCL structure are to be graded to modify the shapes and depths of quantum wells, such that the electronic wave functions in the quantum wells and the transition energies between them would change with an intentional variation of the applied bias electrical field. A change of the bias applied to such a structure would result in a change in the energy and, hence, of the wavelength of the lasing transition.

In the third approach, the focus is on exploiting distributed-feedback and distributed-Bragg-reflector QCL architectures to achieve wavelength tuning through variation of applied electric current.

In the fourth approach, which is complementary to the other three, the focus

is on increasing maximum operating temperatures and output power levels in continuous-wave operation. In a given QCL, this approach may involve one or more of the following changes: reducing the threshold current density, improving mounting and packaging to enhance removal of heat and reduce stresses, and optimizing designs of the active regions, injectors, and waveguide. Moreover, optimization of design for increasing maximum operating temperature and output power must include finding the most advantageous combination of the designs of the active regions and waveguide for optimal tuning performance.

This work was done by Sarath Gunapala, Alexander Soidel, and Kamjou Mansour of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

In accordance with Public Law 96-517, the contractor has elected to retain title to this

Few-Mode Whispering-Gallery-Mode Resonators

Simple structures function similarly to single-mode optical fibers.

NASA's Jet Propulsion Laboratory, Pasadena, California

Whispering-gallery-mode (WGM) optical resonators of a type now under development are designed to support few well-defined waveguide modes. In the simplest case, a resonator of this type would support one equatorial family of WGMs; in a more complex case, such a resonator would be made to support two, three, or some other specified finite number of modes. Such a resonator can be made of almost any transparent material commonly used in optics. The

An **Integral Thin, Narrow Belt** around a transparent rod acts as a circumferential optical waveguide. With suitable choice of *d* and *w* in conjunction with *R*, this structure can be made to act as a single- or few-mode WGM resonator.

nature of the supported modes does not depend on which material is used, and the geometrical dispersion of this resonator is much smaller than that of a typical prior WGM resonator. Moreover, in principle, many such resonators could be fabricated as integral parts of a single chip.

Basically, a resonator of this type consists of a rod, made of a suitable transparent material, from which protrudes a thin circumferential belt of the same material. The belt is integral with the rest of the rod (see figure) and acts as a circumferential waveguide. If the depth (d) and width (w) of the belt are made appropriately small, then the belt acts as though it were the core of a single-mode optical fiber: the belt and its adjacent supporting rod material support a single, circumferentially propagating mode or family of modes.

It has been shown theoretically that the fiber-optic-like behavior of the belt-on-rod resonator structure can be summarized, in part, by the difference, Δn, between (1) an effective index of refraction of an imaginary fiber core and (2) the index of refraction (n) of the transparent rod/belt material. It has also been shown theoretically that for a given required value of Δn, the required depth of the belt can be esti-

mated as $d \approx R\Delta n$, where R is the radius of the rod. It must be emphasized that this estimated depth is independent of n and, hence, is independent of the choice of rod material.

As in the cases of prior WGM resonators, input/output optical coupling involves utilization of evanescent fields. In the present case, there are two evanescent fields: one at the belt/air interface and one in the boundary region between the belt and the rest of the rod.

Conflict-Aware Scheduling Algorithm

An algorithm is being developed to automate NASA's Deep Space Network antenna allocation.

NASA's Jet Propulsion Laboratory, Pasadena, California

A conflict-aware scheduling algorithm is being developed to help automate the allocation of NASA's Deep Space Network (DSN) antennas and equipment that are used to communicate with interplanetary scientific spacecraft. The current approach for scheduling DSN ground resources seeks to provide an equitable distribution of tracking services among the multiple scientific missions and is very labor intensive. Due to the large (and increasing) number of mission requests for DSN services, combined with technical and geometric constraints, the DSN is highly oversubscribed. To help automate the process, and reduce the DSN and spaceflight project labor effort required for initiating, maintaining, and negotiating schedules, a new scheduling algorithm is being developed.

The scheduling algorithm generates a "conflict-aware" schedule, where all requests are scheduled based on a dynamic priority scheme. The conflict-aware scheduling algorithm allocates all requests for DSN tracking services while identifying and maintaining the conflicts to facilitate collaboration and negotiation between spaceflight missions. These contrast with traditional "conflict-free"

scheduling algorithms that assign tracks that are not in conflict and mark the remainder as unscheduled. In the case where full schedule automation is desired (based on mission/event priorities, fairness, allocation rules, geometric constraints, and ground system capabilities/constraints), a conflict-free schedule can easily be created from the conflict-aware schedule by removing lower priority items that are in conflict.

Unlike most existing scheduling engines that require fixed length schedule items in the request, the conflict-aware schedule provides a dynamic scheduling engine to determine allocation length during the scheduling process. This is made necessary by the variety of mission-tracking request types faced by the DSN. In addition to fixed track requests, missions may also need continuous coverage or may need to segment a track related to multiple ground assets to support a given request for service. In these cases, the schedule allocation length (time) will depend on the availability of each resource.

The conflict-aware scheduling algorithm combines scheduling heuristics, optimization, a search algorithm, and computational intelligence. At the be-

ginning of the procedure, all requests pass through a scoring system (chosen from a simple mathematical equation or fuzzy logic) that determines the priority of each request on the basis of measures of fairness of the allocation, importance of the request, the type of request, and the allocation length. Starting with the highest priority request, all technical and geometric constraints are combined to determine the available "timeline/antenna groups" for scheduling. A scoring system that considers items already in the schedule and the request characteristics then identifies the best timeline/antenna group and start times for each request. This then continues for each successive priority request (priority is recomputed dynamically) until all requests are scheduled.

The conflict-aware algorithm is not limited to DSN application. It can also be applicable to solution of scheduling problems in areas such as manufacturing and traffic control.

This work was done by Yeou-Fang Wang and Chester Borden for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-41320

Real-Time Diagnosis of Faults Using a Bank of Kalman Filters

Gradual changes associated with aging are taken into account in the diagnostic process.

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

A new robust method of automated real-time diagnosis of faults in an aircraft engine or a similar complex system involves the use of a bank of Kalman filters. In order to be highly reliable, a diagnostic system must be designed to account for the numerous failure conditions that an aircraft engine may encounter in operation. The method achieves this objective though the utilization of multiple Kalman filters, each of which is uniquely designed based on a specific failure hypothesis. A fault-detection-and-isolation (FDI) system, developed based on this method, is able to isolate faults in sensors and actuators while

detecting component faults (abrupt degradation in engine component performance). By affording a capability for real-time identification of minor faults before they grow into major ones, the method promises to enhance safety and reduce operating costs.

The robustness of this method is further enhanced by incorporating information regarding the aging condition of an engine. In general, real-time fault diagnostic methods use the nominal performance of a "healthy" new engine as a reference condition in the diagnostic process. Such an approach does not ac-

count for gradual changes in performance associated with aging of an otherwise healthy engine. By incorporating information on gradual, aging-related changes, the new method makes it possible to retain at least some of the sensitivity and accuracy needed to detect incipient faults while preventing false alarms that could result from erroneous interpretation of symptoms of aging as symptoms of failures.

The figure schematically depicts an FDI system according to the new method. The FDI system is integrated with an engine, from which it accepts two
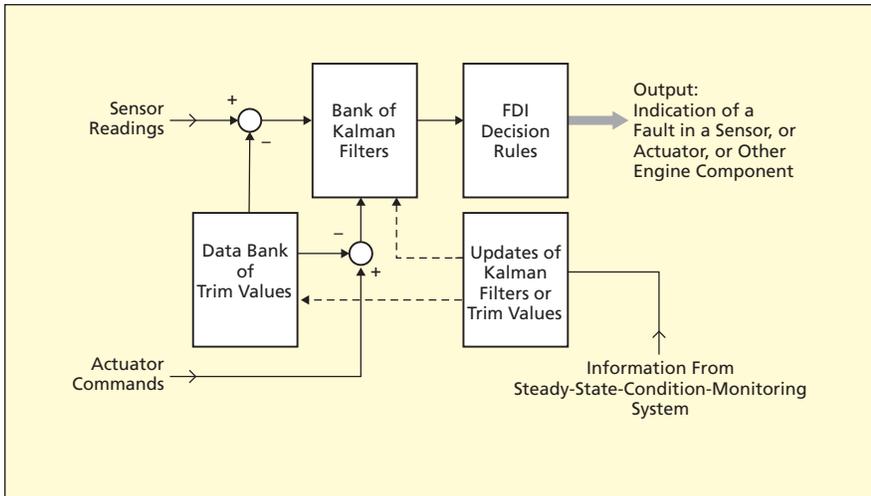
This **FDI System** accepts information on gradual aging of an engine to retain its effectiveness in fault diagnosis.

sets of input signals: sensor readings and actuator commands. Two main parts of the FDI system are a bank of Kalman filters and a subsystem that implements FDI decision rules. Each Kalman filter is designed to detect a specific sensor or actuator fault. When a sensor or actuator fault occurs, large estimation errors are generated by all filters except the one using the correct hypothesis. By monitoring the residual output of each filter, the specific fault that has occurred can be detected and isolated on the basis of the decision rules.

A set of parameters that indicate the performance of the engine components is estimated by the "correct" Kalman filter for use in detecting component faults. To reduce the loss of diagnostic accuracy and sensitivity in the face of aging, the FDI system accepts information from a steady-state-condition-monitoring system. This information is used to update the Kalman filters and a data bank of trim values representative of the current aging condition.

National Aeronautics and
Space Administration