INTRODUCTION

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TECH BRIEFS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Hidden Identification on Parts: Magnetic Machine-Readable Matrix Symbols

These symbols could be read even when covered with paint.

Marshall Space Flight Center, Alabama

Have you ever seen a piece of space-flight hardware? When you do, you will notice some letters and numbers etched or inscribed on it. All NASA parts have identification, usually expressed in terms of part number, serial number, and the like. In most cases, this identification is permanently marked directly on the part for tracking throughout its life cycle. The recently approved NASA Technical Standard 6002 and Handbook 6003 (found at *http://standards.nasa.gov*) added the matrix symbol to the identification scheme as shown in Figure 1. This put a checkerboard bar code on the part so that an optical scanner could read it. The intent was to make tracking parts as easy as checking out at the grocery store. The system works well as long as the matrix symbol is visible.

But what if the matrix symbol identification gets covered with paint or a similar coating? NASA has developed a method for reading the matrix symbol through up to 15 mils (25 µm) of paint (5 or 6 layers). This method of part identification involves coating selected patches on the objects with magnetic materials in matrix symbol patterns and reading the patterns by use of magneto-optical imaging equipment. The hand-held magnetic scanner, shown in Figure 2, is easy to use and is commercially available through a NASA licensee. It decodes the matrix symbol just like any other scanner. The magnetic marks can be read under conditions that would render optical methods useless. For example, the magnetic scanner can read magnetic marks in the dark or under bright ambient light that might interfere with optical reading of visible marks, symbols that are obscured by discoloration or contamination, in addition to symbols that are covered by paint. Furthermore, inasmuch as magnetic marks can be hidden from unaided view, they are less likely to be deliberately damaged or destroyed. They can even be hidden deliberately for security reasons.

Magnetic material can be applied as viscous ink or paste and even can be
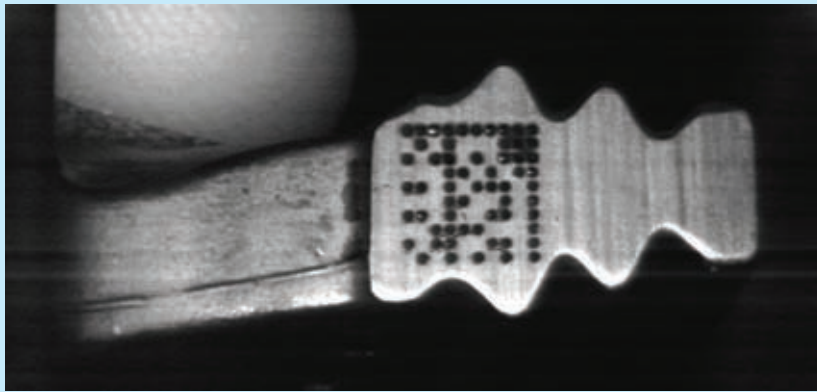

Figure 1. A **Space Shuttle Component** shows matrix symbol identification markings.

Figure 2. This **Hand-Held Scanner** would contain all the equipment (except a source of electric power) needed to read and decode magnetic matrix symbols.

mixed with spray paint. The magnetic material should be one of high retentivity and high coercivity. The matrix symbol pattern can be defined by use of a stencil, or recesses to hold the magnetic material in the matrix symbol pattern can be formed by laser engraving, machine engraving, micro-abrasive blasting, laser etching, or any other suitable marking method. If the magnetic material as applied is not magnetized strongly enough to enable reliable detection over time, it can be magnetized again by use of a permanent magnet or electromagnet.

Bar codes were seldom seen before 1975 but are now common in every commercial outlet. They are on tags and labels of virtually every product. Likewise, direct part marking is now being popularized for tracking things that cannot be labeled. NASA tracks parts using direct part marking. The Department of Defense revised MIL STD 130 to include matrix symbols for direct part marking, and the automotive industry now complies with its B-17 specification for application of matrix symbols on many automobile parts. Now all those little marks that get covered with paint, whether they are on your auto-

mobile, jet fighter, weapon, or space shuttle, can be read with ease.

System for Processing Coded OFDM Under Doppler and Fading

Advanced techniques would help to realize the anti-fading potential of OFDM.

NASA's Jet Propulsion Laboratory, Pasadena, California

An advanced communication system has been proposed for transmitting and receiving coded digital data conveyed as a form of quadrature amplitude modulation (QAM) on orthogonal frequency-division multiplexing (OFDM) signals in the presence of such adverse propagation-channel effects as large dynamic Doppler shifts and frequency-selective multipath fading. Such adverse channel effects are typical of data communications between mobile units or between mobile and stationary units (e.g., telemetric transmissions from aircraft to ground stations). The proposed system incorporates novel signal processing techniques intended to reduce the losses associated with adverse channel effects while maintaining compatibility with the high-speed physical layer specifications defined for wireless local-area networks (LANs) as the standard

802.11a of the Institute of Electrical and Electronics Engineers (IEEE 802.11a).

OFDM is a multi-carrier modulation technique that is widely used for wireless transmission of data in LANs and in metropolitan area networks (MANs). OFDM has been adopted in IEEE 802.11a and some other industry standards because it affords robust performance under frequency-selective fading. However, its intrinsic frequency-diversity feature is highly sensitive to synchronization errors; this sensitivity poses a challenge to preserve coherence between the component subcarriers of an OFDM system in order to avoid intercarrier interference in the presence of large dynamic Doppler shifts as well as frequency-selective fading. As a result, heretofore, the use of OFDM has been limited primarily to applications involving small or zero

Doppler shifts. The proposed system includes a digital coherent OFDM communication system that would utilize enhanced 802.11a-compatible signal-processing algorithms to overcome effects of frequency-selective fading and large dynamic Doppler shifts. The overall transceiver design would implement a two-frequency-channel architecture (see figure) that would afford frequency diversity for reducing the adverse effects of multipath fading. By using parallel concatenated convolutional codes (also known as Turbo codes) across the dual-channel and advanced OFDM signal processing within each channel, the proposed system is intended to achieve at least an order of magnitude improvement in received signal-to-noise ratio under adverse channel effects while preserving spectral efficiency.
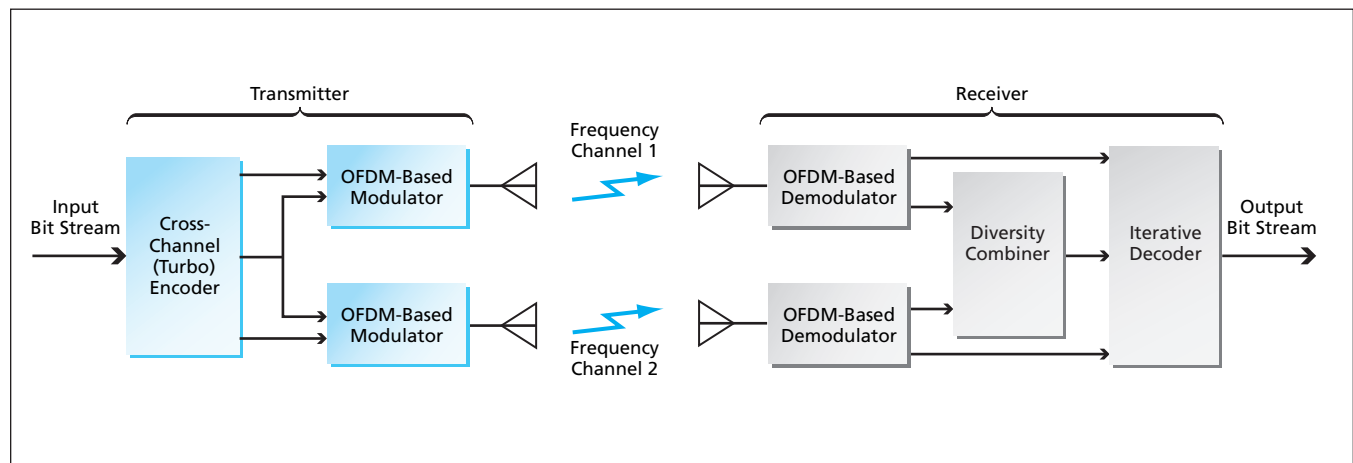
A **Two-Frequency-Channel, Cross-Coded OFDM System** would contain the proposed signal-processing system, parts of which would reside in both transmitting and receiving subsystems.

One of the novel techniques adopted for the proposed system would be multipass processing of packet preamble for acquisition of frequencies and timing of carrier and data symbols. The multipass approach is intended to eliminate as much synchronization error as possible at an early stage of packet preamble processing in order to reduce the inter-carrier interference, which can contribute significantly to the bit-error rate under adverse channel conditions.

Another novel signal-processing technique would be joint pilot- and data-aided channel estimation, tracking, and equalization in each of the two frequency channels. This technique would not only increase the accuracy in the estimate of the channel effects, but also would support tracking of dynamic Doppler shifts, resulting in a much improved channel equalization under adverse channel conditions.

Another novel aspect of the design would be the use of (1) turbo cross-channel coding in the transmitter in conjunction with (2) diversity combining of signals in the receiver. The gain afforded by this combination of coding and frequency and time diversity would help to counteract severe fading, especially for the case when both channels are simultaneously affected by deep fades.

This work was done by Haiping Tsou, Scott Darden, Dennis Lee, and Tsun-Yee Yan 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-40205.

Multipurpose Hyperspectral Imaging System
Features include high spectral and spatial resolution, without camera/target relative motion.

Marshall Space Flight Center, Alabama

A hyperspectral imaging system of high spectral and spatial resolution that incorporates several innovative features has been developed to incorporate a focal-plane scanner (U.S. Patent 6,166,373). This feature enables the system to be used for both airborne/spaceborne and laboratory hyperspectral imaging with or without relative movement of the imaging system, and it can be used to scan a target of any size as long as the target can be imaged at the focal plane; for example, automated inspection of food items and identification of single-celled organisms. The spectral resolution of this system is greater than that of prior terrestrial multispectral imaging systems. Moreover, unlike prior high-spectral-resolution airborne and spaceborne hyperspectral imaging systems, this system does not rely on relative movement of the target and the imaging system to sweep an imaging line across a scene.

This compact system (see figure) consists of a front objective mounted at a translation stage with a motorized actuator, and a line-slit imaging spectrograph mounted within a rotary assembly with a rear adaptor to a charged-coupled-device (CCD) camera. Push-broom scanning is carried out by the motorized actuator which can be controlled either manually by an operator or automatically by a computer to drive the line-slit across an image at a focal plane of the front objective. To reduce the cost, the system has been designed to integrate as many as possible off-the-shelf components including the CCD camera and spectrograph. The system has achieved high spectral and spatial resolutions by using a high-quality CCD camera, spectrograph, and front objective lens. Fixtures for attachment of the system to a microscope (U.S. Patent 6,495,818 B1) make it possible to acquire multispectral images of single cells and other microscopic objects.

To make it unnecessary to move the camera relative to the target or vice versa, the design of the system provides for lateral motion of the image on the focal plane. For this purpose, the front lens is mounted on a translational stage driven by a computer-controlled motor.

The system also includes a computer programmed with special-purpose operational software; frame-grabber, and motor-control circuit boards connected between the computer on one hand and the CCD and motor, respectively, on the other hand; and light sources. The system can collect image data in as many as 1,040 spectral bands in the wavelength range from 400 to 1,000 nm.

The special-purpose operational software is a single computer program that controls all aspects of the acquisition and preprocessing of image data, performing functions that, heretofore, entailed the use of several different programs: The software controls the camera, scanning speed, and start and stop positions, and automatically drives the motorized actuator in push-
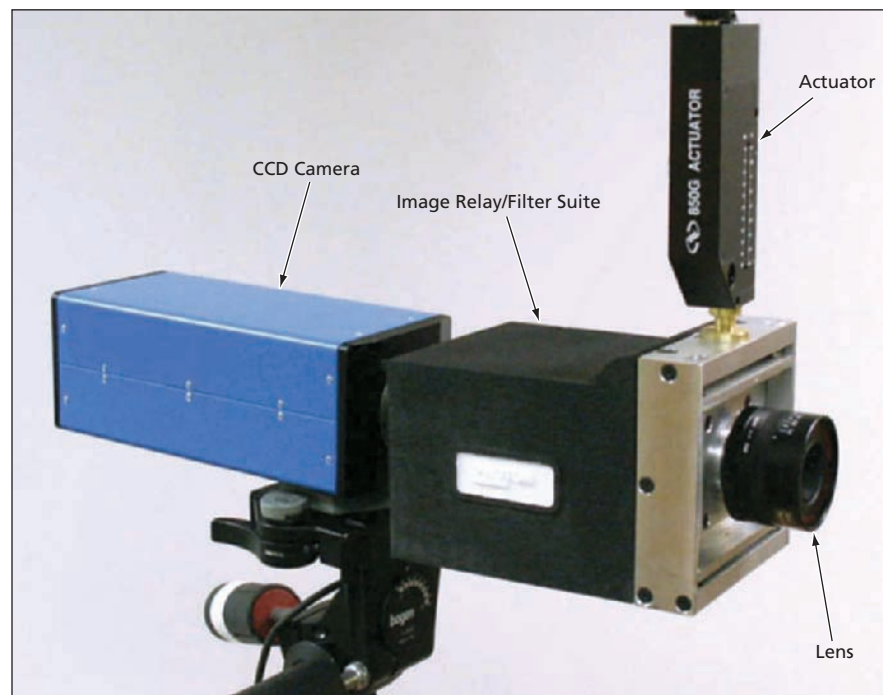
The **Main Front Components** of the imaging system are shown mounted on the tripod.

broom scanning. A user may utilize the program to invoke the CCD camera's user interface for customized configuration. Different spectral band-pass and spatial resolutions may be changed by different CCD vertical/horizontal binning factors. A calibration function is implemented for correcting spectral and spatial errors due to optical distortion of the front objective and spectrograph. The software then preprocesses the image data into hyperspectral image cubes (three-dimensional arrays of data indexed according to two spatial coordinates and a spectral coordinate). Next, the software can perform calibration, noise-removal, data-formatting, and subset-ting operations; correct for spectral distortions; and create headers for image-data files to be subjected to further processing by other software (for example, the software described below), as instructed by the user. The program can also perform some image-inversion calculations and some statistical analysis of image data, and can detect image saturation.

By suitably modifying the operational software and adding special-purpose image-processing software, the system can be configured for automated inspection of food items on production lines. An example of this functionality is the development of a prototype version to process three- or four-spectral-band images to detect fecal contamination of poultry carcasses on a conveyor belt at a rate of 180 carcasses per minute — about double the rate of a modern poultry-processing line.

Electronics/Computers

Magnetic-Flux-Compensated Voltage Divider
Spurious voltages generated by lightning and other transient phenomena would be suppressed.

John F. Kennedy Space Center, Florida

A magnetic-flux-compensated voltage-divider circuit has been proposed for use in measuring the true potential across a component that is exposed to large, rapidly varying electric currents like those produced by lightning strikes. An example of such a component is a lightning arrester, which is typically exposed to currents of the order of tens of kiloamperes, having rise times of the order of hundreds of nanoseconds. Traditional voltage-divider circuits are not designed for magnetic-flux-compensation: They contain uncompensated loops having areas large enough that the

transient magnetic fluxes associated with large transient currents induce spurious voltages large enough to distort voltage-divider outputs significantly.

A drawing of the proposed circuit was not available at the time of receipt of information for this article. What is known from a summary textual description is that the proposed circuit would contain a total of four voltage dividers: There would be two mixed dividers in parallel with each other and with the component of interest (e.g., a lightning arrester), plus two mixed dividers in parallel with each other and in series with the component of interest in

the same plane. The electrical and geometric configuration would provide compensation for induced voltages, including those attributable to asymmetry in the volumetric density of the lightning or other transient current, canceling out the spurious voltages and measuring the true voltage across the component.

*This work was done by Carlos T. Mata of Dynacs, Inc., for **Kennedy Space Center**. For further information, contact the Kennedy Innovative Partnerships Office at (321) 867-8130.*
KSC-12381/448

High-Performance Satellite/Terrestrial-Network Gateway
This apparatus affords flexibility in the choice of data rates.

Lyndon B. Johnson Space Center, Houston, Texas

A gateway has been developed to enable digital communication between (1) the high-rate receiving equipment at NASA's White Sands complex and (2) a standard terrestrial digital communication network at data rates up to 622 Mb/s. The design of this gateway can also be adapted for use in commercial Earth/satellite and digital communication networks, and in terrestrial digital communication networks that include wireless subnetworks.

"Gateway" as used here signifies an electronic circuit that serves as an interface between two electronic communication networks so that a computer (or other terminal) on one network can communicate with a terminal on the other network. The connection between this gateway and the high-rate receiving equipment is made via a synchronous serial data interface at the emitter-coupled-logic (ECL) level. The connection between this gateway and a standard asynchronous transfer mode (ATM) terrestrial communication network is made via a standard user network interface with a synchronous optical network (SONET) connector. The gateway contains circuitry that per-

forms the conversion between the ECL and SONET interfaces. The data rate of the SONET interface can be either 155.52 or 622.08 Mb/s. The gateway derives its clock signal from a satellite modem in the high-rate receiving equipment and, hence, is agile in the sense that it adapts to the data rate of the serial interface.

Although the ECL interface is synchronous, it bears ATM cells (in effect, data packets for asynchronous transmission) according to Telecommunications Industry Association (TIA) Standard 787. This characteristic renders the gateway transparent to any protocols above ATM, including the Internet Protocol (IP), the User Datagram Protocol (UDP), and the Transmission Control Protocol (TCP). The gateway can perform Reed-Solomon encoding for forward error correction (FEC) during operation with a satellite source that is not equipped for FEC.

The primary advantage afforded by this gateway is that it enables a satellite/Earth network or the wireless subnetwork of a terrestrial network to operate at a data rate independent of that of

the network components at either end of a data-communication link. Because terrestrial networks must subscribe to stratified, standard data rates, the data rates of the terminals of the networks often limit the performances of the wireless links. Often, the optimal data rate for a wireless link in a terrestrial network lies between the standard data rates supported by the remainder of the network. A gateway like this one would enable a wireless portion of a terrestrial network segment to operate at its optimal data rate, while preserving the standardization of data rates at the network terminals.

*This work was done by David R. Beering of Infinite Global Infrastructures, LLC, for **Johnson 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 MSC-23316, volume and number of this NASA Tech Briefs *issue, and the page number.*

Internet-Based System for Voice Communication With the ISS

This system offers advantages over a prior telephony-based system.

Marshall Space Flight Center, Alabama

The Internet Voice Distribution System (IVoDS) is a voice-communication system that comprises mainly computer hardware and software. The IVoDS was developed to supplement and eventually replace the Enhanced Voice Distribution System (EVoDS), which, heretofore, has constituted the terrestrial subsystem of a system for voice communications among crewmembers of the International Space Station (ISS), workers at the Payloads Operations Center at Marshall Space Flight Center, principal investigators at diverse locations who are responsible for specific payloads, and others. The IVoDS utilizes a communication infrastructure of NASA and NASA-related intranets in addition to, as its name suggests, the Internet. Whereas the EVoDS utilizes traditional circuit-switched telephony, the IVoDS is a

packet-data system that utilizes a voice over Internet protocol (VOIP). Relative to the EVoDS, the IVoDS offers advantages of greater flexibility and lower cost for expansion and reconfiguration.

The IVoDS is an extended version of a commercial Internet-based voice conferencing system that enables each user to participate in only one conference at a time. In the IVoDS, a user can receive audio from as many as eight conferences simultaneously while sending audio to one of them. The IVoDS also incorporates administrative controls, beyond those of the commercial system, that provide greater security and control of the capabilities and authorizations for talking and listening afforded to each user.

The IVoDS has a client/ server architecture. It utilizes the H.323 VOIP with

custom extensions as required to support operations unique to the ISS mission. An authorized user can gain access to the IVoDS by means of a standard desktop personal computer and modem capable of intranet or Internet communication with the Payload Operations Center at a rate of at least 128 kb/s. The subsystems of the IVoDS (see figure) include the following:

- Conference or voice servers: These are computers that host conferences (voice loops) to which client computers connect.
- Conference or voice clients: These are the aforementioned client computers, which are located at the remote work sites of individual users.
- Administrator server: This is a computer that processes requests from the administrator client described below.
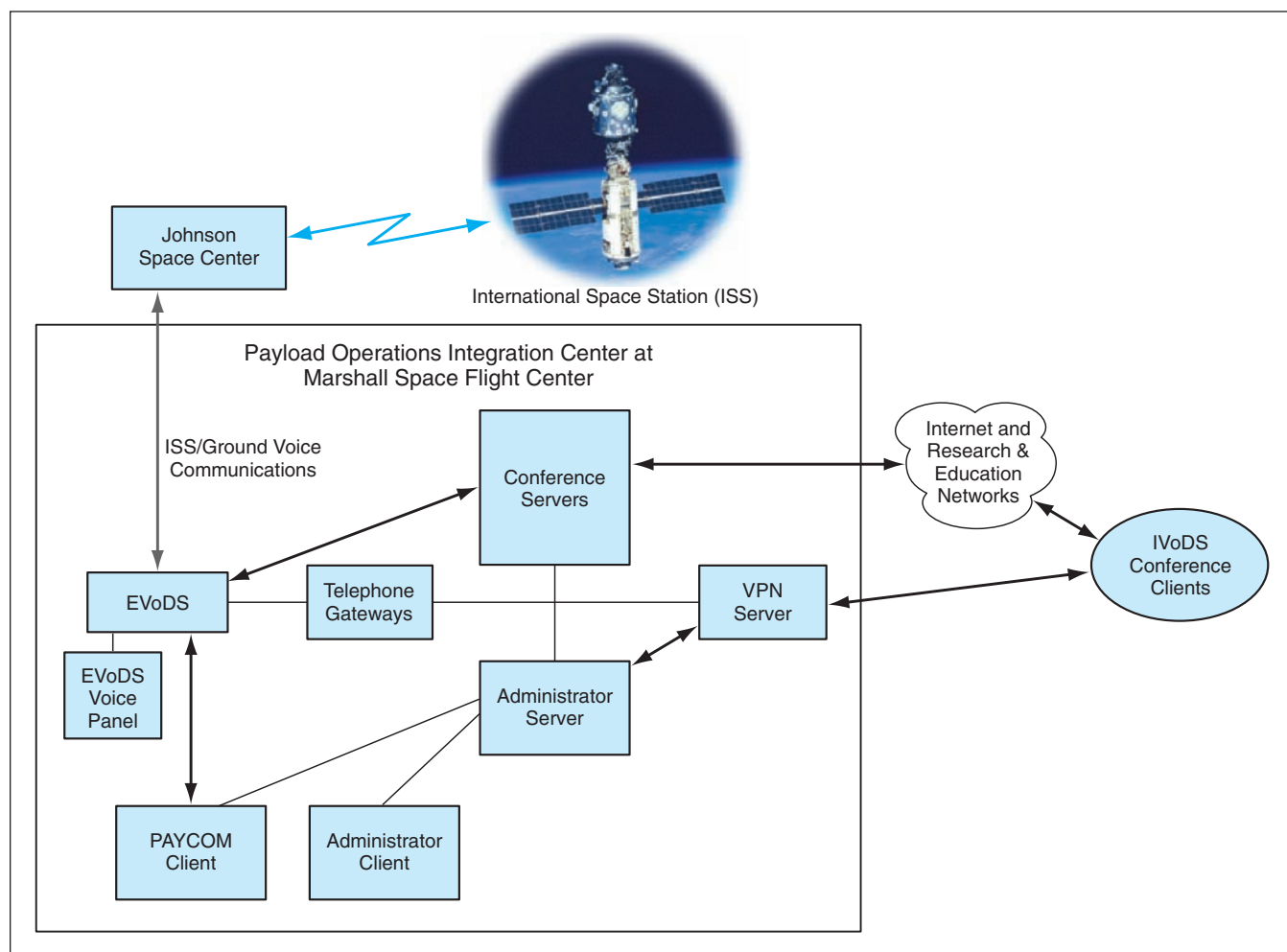
The **IVoDS** manages voice communications among users aboard the ISS and users at diverse terrestrial locations.

This computer maintains collections of network, user, and conference data, and controls the conference or voice servers.
- Administrator client: This computer manages users, conferences, and the database in the administrator server.
- Payload communications manager (PAYCOM) client: This is a computer that exerts control over who talks in such restricted conferences as those

that include direct communication with crewmembers of the ISS.
- Virtual public network (VPN) server: Like other VPN servers, this serves to authenticate, by use of identification numbers and encryption, the computers of remote users (in this case, conference clients) who seek access to the IVoDS.
- Telephony gateways: These are interfaces between (1) the EVoDS voice loops,

which are of public switched telephone network type, and (2) the IVoDS Internet-Protocol-based conferences.

Stripline/Microstrip Transition in Multilayer Circuit Board

Transitions like this one could be useful in microwave communication products.

NASA's Jet Propulsion Laboratory, Pasadena, California

A stripline-to-microstrip transition has been incorporated into a multilayer circuit board that supports a distributed solid-state microwave power amplifier, for the purpose of coupling the microwave signal from a buried-layer stripline to a top-layer microstrip. The design of the transition could be adapted to multilayer circuit boards in such products as cellular telephones (for connecting between circuit-board signal lines and antennas), transmitters for Earth/satellite communication systems, and computer mother boards (if processor speeds increase into the range of tens of gigahertz).

The transition is designed to satisfy the following requirements in addition to the basic coupling requirement described above:
- The transition must traverse multiple layers, including intermediate layers that contain DC circuitry.
- The transition must work at a frequency of 32 GHz with low loss and low reflection.
- The power delivered by the transition to top-layer microstrip must be split equally in opposite directions along the microstrip. Referring to the figure, this amounts to a requirement that when power is supplied to input port 1, equal amounts of power flow through output ports 2 and 3.
- The signal-line via that is necessarily a part of such a transition must not be what is known in the art as a blind via; that is, it must span the entire thickness of the circuit board.

The lower end of the via is connected to a circular pad on the bottom (ground) layer. Electrically, this pad is a dead-end or no-connection point. The pad is surrounded by a cutout in the ground layer; the cutout includes a rec-
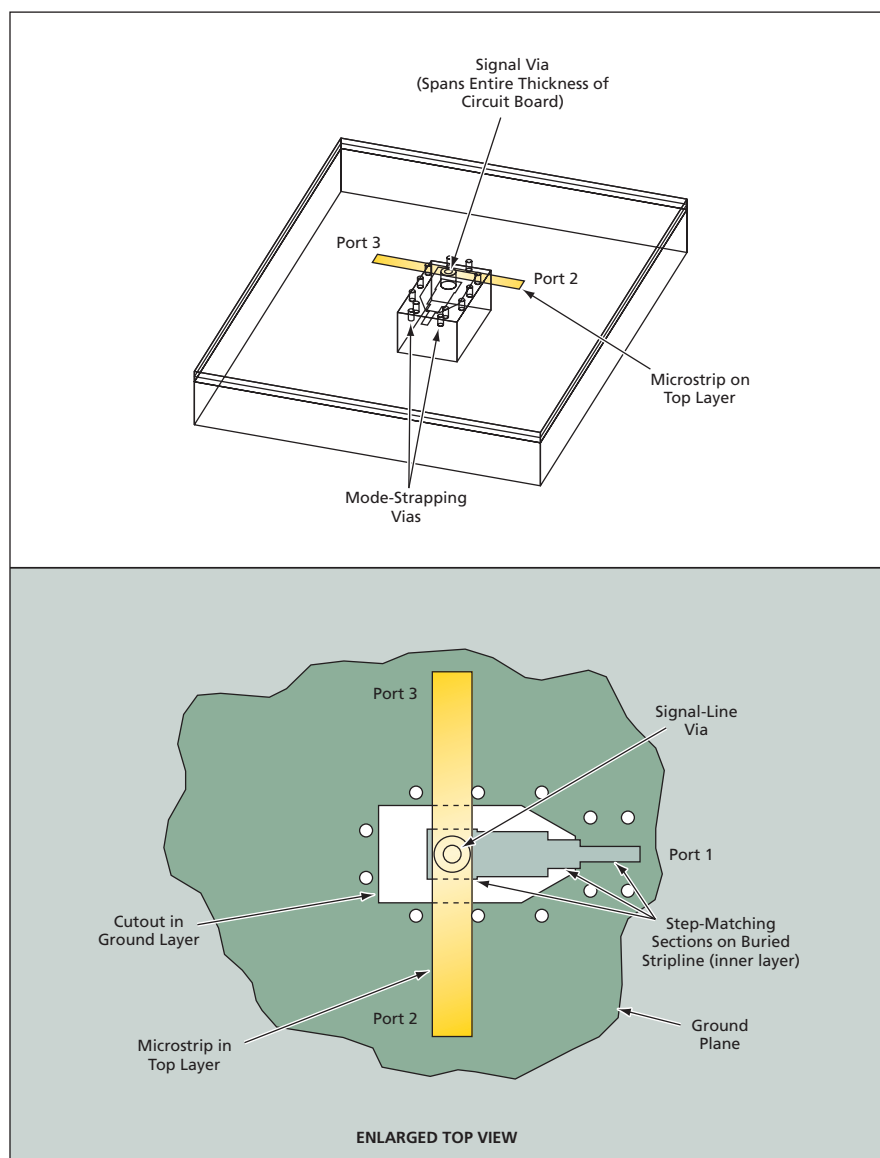
Built Into a Multilayer Circuit Board, the stripline-to-microstrip transition couples power from port 1 to ports 2 and 3.

tangular main portion that ends in a triangular taper at the input end.

The cutout lies above a standard rectangular cavity. The combination of the triangular-taper portion of the cutout and the rectangular cavity serves to focus the electromagnetic field to propagate up the signal-line via. The cavity also prevents coupling of the signal to neighboring circuits. The rectangular cavity can be fabricated easily by conventional machining techniques; the triangular-taper portion of the cutout is fabricated easily by printed-circuit techniques. To compensate for reflections from the transition, step-matching sections are included in the vicinity of the triangular taper.

Mode-strapping vias are also included. These vias are blind; that is, they terminate at, and are connected to, an intermediate layer. These vias can be blind because they do not carry the signal. These can be closely spaced. The closeness of the spacing compensates somewhat for the unreliability of connections formed in the process of fabrication of blind vias.

Dual-Band Feed for a Microwave Reflector Antenna
Two coaxial waveguides carry radiation in two frequency bands.

NASA's Jet Propulsion Laboratory, Pasadena, California
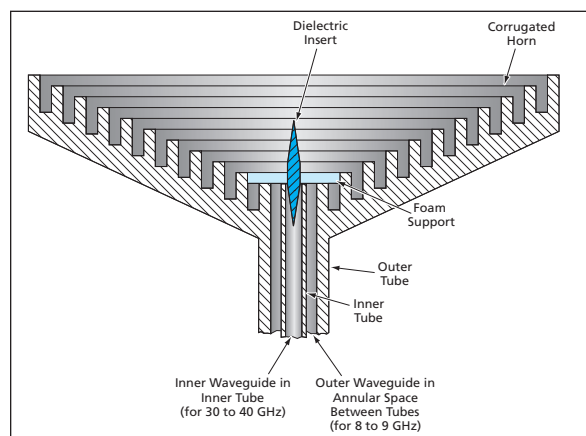
A **Corrugated Horn and a Dielectric Rod Insert** help to shape the beams radiated from the ends of the outer and inner waveguide, respectively.

A waveguide feed has been designed to provide specified illumination patterns for a dual-reflector antenna in two wavelength bands: 8 to 9 GHz and 30 to 40 GHz. The feed (see figure) has a coaxial configuration: A wider circular tube surrounds a narrower circular tube that serves as a waveguide for the signals in the 30-to-40-GHz band. The annular space between the narrower and the wider tube serves as a coaxial waveguide for the signals in the 8-to-9-GHz band. The nominal design frequencies of the outer and inner waveguides are 8.45 and 32 GHz, respectively.

Each of the two waveguides is terminated in a component that is sized and shaped to help focus the radiation in its respective frequency band into the specified illumination pattern. For the outer waveguide, the beam-shaping termination is a corrugated horn; for the inner waveguide, the beam-shaping termination is a dielectric rod insert.

Software

Quadratic Programming for Allocating Control Effort

A computer program calculates an optimal allocation of control effort in a system that includes redundant control actuators. The program implements an iterative (but otherwise single-stage) algorithm of the quadratic-programming type. In general, in the quadratic-programming problem, one seeks the values of a set of variables that minimize a quadratic cost function, subject to a set of linear equality and inequality constraints. In this program, the cost function combines control effort (typically quantified in terms of energy or fuel consumed) and control residuals (differences between commanded and sensed values of variables to be controlled). In comparison with prior control-allocation software, this program offers approximately equal accuracy but much greater computational efficiency. In addition, this program offers flexibility, robustness to actuation failures, and a capability for selective enforcement of control requirements. The computational efficiency of this program makes it suitable for such complex, real-time applications as controlling redundant aircraft actuators or redundant spacecraft thrusters. The program is written in the C language for execution in a UNIX operating system.

This program was written by Gurkirpal Singh of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

This 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-40592.

Range Process Simulation Tool

Range Process Simulation Tool (RPST) is a computer program that assists managers in rapidly predicting and quantitatively assessing the operational effects of proposed technological additions to, and/or upgrades of, complex facilities and engineering systems such as the Eastern Test Range. Originally designed for application to space transportation systems, RPST is also suitable for assessing effects of proposed changes in industrial facilities and large organizations. RPST follows a model-based approach that includes finite-capacity schedule analysis and discrete-event process simulation. A component-based, scalable, open architecture makes RPST easily and rapidly tailorable for diverse applications. Specific RPST functions include: (1) definition of analysis objectives and performance metrics; (2) selection of process templates from a process-template library; (3) configuration of process models for detailed simulation and schedule analysis; (4) design of operations-analysis experiments; (5) schedule and simulation-based process analysis; and (6) optimization of performance by use of genetic algorithms and simulated annealing. The main benefits afforded by RPST are provision of information that can be used to reduce costs of operation and maintenance, and the capability for affordable, accurate, and reliable prediction and exploration of the consequences of many alternative proposed decisions.

This program was written by Dave Phillips, William Haas, and Tim Barth of **Kennedy Space Center,** *and Perakath Benjamin, Michael Graul, and Olga Bagatourova of Knowledge Based Systems.*

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-12511, volume and number of this NASA Tech Briefs *issue, and the page number.*

Simulator of Space Communication Networks

Multimission Advanced Communications Hybrid Environment for Test and Evaluation (MACHETE) is a suite of software tools that simulates the behaviors of communication networks to be used in space exploration, and predict the performance of established and emerging space communication protocols and services. MACHETE consists of four general software systems: (1) a system for kinematic modeling of planetary and spacecraft motions; (2) a system for characterizing the engineering impact on the bandwidth and reliability of deep-space and *in-situ* communication links; (3) a system for generating traffic loads and modeling of protocol behaviors and state machines; and (4) a system of user-interface for performance metric visualizations. The kinematic-modeling system makes it possible to characterize space link connectivity effects, including occultations and signal losses arising from dynamic slant-range changes and antenna radiation patterns. The link-engineering system also accounts for antenna radiation patterns and other phenomena, including modulations, data rates, coding, noise, and multipath fading. The protocol system utilizes information from the kinematic-modeling and link-engineering systems to simulate operational scenarios of space missions and evaluate overall network performance. In addition, a Communications Effect Server (CES) interface for MACHETE has been developed to facilitate hybrid simulation of space communication networks with actual flight/ground software/hardware embedded in the overall system.

This work was done by Loren Clare, Esther Jennings, Jay Gao, John Segui, and Winston Kwong of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

This 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-41373.

Computing Q-D Relationships for Storage of Rocket Fuels

The Quantity Distance Measurement Tool is a GIS BASEP computer program that aids safety engineers by calculating quantity-distance (Q-D) relationships for vessels that contain explosive chemicals used in testing rocket engines. (Q-D relationships are standard relationships between specified quantities of specified explosive materials and minimum distances by which they must be separated from persons, objects, and other explosives to obtain specified types and degrees of protection.) The program uses customized geographic-information-system (GIS) software and calculates Q-D relationships in accordance with NASA's Safety Standard For Explosives, Propel-

lants, and Pyrotechnics. Displays generated by the program enable the identification of hazards, showing the relationships of propellant-storage-vessel safety buffers to inhabited facilities and public roads. Current Q-D information is calculated and maintained in graphical form for all vessels that contain propellants or other chemicals, the explosiveness of which is expressed in TNT equivalents [amounts of trinitrotoluene (TNT) having equivalent explosive effects]. The program is useful in the acquisition, siting, construction, and/or modification of storage vessels and other facilities in the development of an improved test-facility safety program.

This program was written by Keith Jester of General Dynamics for **Stennis Space Center***.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Intellectual Property Manager, Stennis Space Center, (228) 688-1929. Refer to SSC-00209.

⟲ Contour Error Map Algorithm

The contour error map (CEM) algorithm and the software that implements the algorithm are means of quantifying correlations between sets of time-varying data that are binarized and registered on spatial grids. The present version of the software is intended for use in evaluating numerical weather forecasts against observational sea-breeze data. In cases in which observational data come from off-grid stations, it is necessary to preprocess the observa-

tional data to transform them into gridded data. First, the wind direction is gridded and binarized so that $D(i,j;n)$ is the input to CEM based on forecast data and $d(i,j;n)$ is the input to CEM based on gridded observational data. Here, i and j are spatial indices representing 1.25-km intervals along the west-to-east and south-to-north directions, respectively; and n is a time index representing 5-minute intervals. A binary value of D or $d = 0$ corresponds to an offshore wind, whereas a value of D or $d = 1$ corresponds to an onshore wind. CEM includes two notable subalgorithms: One identifies and verifies sea-breeze boundaries; the other, which can be invoked optionally, performs an image-erosion function for the purpose of attempting to eliminate river-breeze contributions in the wind fields.

This work was done by Francis Merceret of **Kennedy Space Center***; John Lane and Christopher Immer of Dynacs, Inc.; and Jonathan Case and John Manobianco of ENSCO, Inc. For further information, contact the Kennedy Innovative Partnerships Office at (321) 867-8130.*
KSC-12489

⟲ Portfolio Analysis Tool

Portfolio Analysis Tool (PAT) is a Web-based, client/server computer program that helps managers of multiple projects funded by different customers to make decisions regarding investments in those projects. PAT facilitates analysis on a macroscopic level, without distraction by parochial concerns or tactical details of

individual projects, so that managers' decisions can reflect the broad strategy of their organization. PAT is accessible via almost any Web-browser software. Experts in specific projects can contribute to a broad database that managers can use in analyzing the costs and benefits of all projects, but do not have access for modifying criteria for analyzing projects: access for modifying criteria is limited to managers according to levels of administrative privilege. PAT affords flexibility for modifying criteria for particular "focus areas" so as to enable standardization of criteria among similar projects, thereby making it possible to improve assessments without need to rewrite computer code or to rehire experts, and thereby further reducing the cost of maintaining and upgrading computer code. Information in the PAT database and results of PAT analyses can be incorporated into a variety of ready-made or customizable tabular or graphical displays.

This program was written by Tim Barth and Edgar Zapata of **Kennedy Space Center,** *and Perakath Benjamin, Mike Graul, and Doug Jones of KBSI, Inc.*

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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College Station, TX 77840
Phone: (979) 260-5274

Refer to KSC-12510, volume and number of this NASA Tech Briefs *issue, and the page number.*

Materials

Glass Frit Filters for Collecting Metal Oxide Nanoparticles

Lyndon B. Johnson Space Center, Houston, Texas

Filter disks made of glass frit have been found to be effective as means of high-throughput collection of metal oxide particles, ranging in size from a few to a few hundred nanometers, produced in gas-phase condensation reactors. In a typical application, a filter is placed downstream of the reactor and a valve is used to regulate the flow of reactor exhaust through the filter. The exhaust stream includes a carrier gas, particles, byproducts, and unreacted particle-precursor gas. The filter selectively traps the particles while allowing the carrier gas, the byproducts, and, in some cases, the unreacted precursor, to flow through unaffected. Although the pores in the filters are much larger than the particles, the particles are nevertheless trapped to a high degree: Anecdotal information from an experiment indicates that 6-nm-diameter particles of MnO_2 were trapped with >99-percent effectiveness by a filtering device comprising a glass-frit disk having pores 70 to 100 μm wide immobilized in an 8-cm-diameter glass tube equipped with a simple twist valve at its downstream end.

This work was done by John Ackerman, Dan Buttry, Geoffrey Irvine, and John Pope of Blue Sky Batteries, Inc., for **Johnson Space Center**. *For further information, contact the Johnson Innovative Partnerships Office at (281) 483-3809.*
MSC-23425

Anhydrous Proton-Conducting Membranes for Fuel Cells
Operating temperatures could be as high as 200 °C.

NASA's Jet Propulsion Laboratory, Pasadena, California

Polymeric electrolyte membranes that do not depend on water for conduction of protons are undergoing development for use in fuel cells. Prior polymeric electrolyte fuel-cell membranes (e.g., those that contain perfluorosulfonic acid) depend on water and must be limited to operation below a temperature of 125 °C because they retain water poorly at higher temperatures. In contrast, the present developmental anhydrous membranes are expected to function well at temperatures up to 200 °C.

The developmental membranes exploit a hopping-and-reorganization proton-conduction process that can occur in the solid state in organic amine salts and is similar to a proton-conduction process in a liquid. This process was studied during the 1970s, but until now, there has been no report of exploiting organic amine salts for proton conduction in fuel cells.

The present development work exploits and extends the previous research on water-free proton conduction in organic amine salts. This work has included an investigation of acid salts of triethylenediamine in which each molecule contains two tertiary nitrogen atoms that can be quaternized. It has been demonstrated that by combining such a proton conductor with nanoparticles of suitable oxide (for example, silica) and a stable binder [for example, poly(tetrafluoroethylene)], one can fabricate a polymeric electrolyte membrane inexpensively. The figure depicts the results of measurements of the ionic conductivity of such a membrane made from triethylenediamine sulfate. The activation energy for proton transport, obtained from the slope of the plot, lies in the range of 0.15 to 0.20 eV — a low range indicative of facile transport of protons.

Proton-conducting membranes to be investigated in the continuing development effort are divided into the following three classes according to the amine salts and related compounds on which they are based:

Type I: Organic tertiary amine bisulfates, triflates (trifluoromethanesulfomates), and hydrogen phosphates.

Type II: Polymeric quaternized amine bisulfates, triflates, and hydrogen phosphates.

Type III: Polymeric quaternized bisulfates, hydrogen phosphates, and triflates combined with perfluorosulfonic acid-based polymers.

As in the case of the membrane described in the preceding paragraph, a proton-conducting membrane of type I would
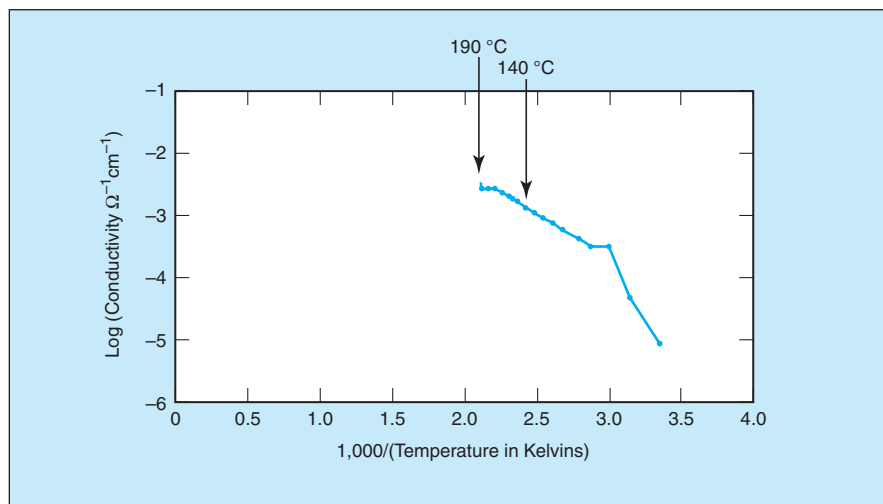
The **Ionic Conductivity** of a triethylenediamine sulfate membrane was measured as a function of temperature. The conductivity vales are here plotted on a logarithmic scale versus reciprocal of temperature data — a form of plot that facilitates the estimation of activation energy.

be fabricated from one or more salts of type I by processing a mixture of fine salt particles, oxide nanoparticles, and poly(tetrafluoroethylene).

Fabrication of membranes of type II would involve synthesis of polymers, followed by casting of the polymers into membranes. Depending on the starting ingredients and process used to make a given membrane, either the quaternized nitrogen atoms would automatically be incorporated into the membrane during polymerization, or else it would be necessary to quaternize the membrane in a bisulfate or a hydrogen phosphate.

A membrane of type III would be a two-component polymeric system cast from a solution containing a perfluorosulfonic acid-based polymer and a quaternary-nitrogen-containing polymer salt of type II. This polymer would make it possible to exploit the strong acidity of the dry perfluorosulfonic acid and the flexibility of its polymer back bone. The general objective in formulating such a two-component system is to increase the number of sites available for proton hopping and provide for additional relaxation and reorganization mechanisms in order to reduce the heights of barrier to the transport of protons.

Portable Electron-Beam Free-Form Fabrication System

The electron beam in this system will be of relatively low voltage.

Lyndon B. Johnson Space Center, Houston, Texas

A portable electron-beam free-form fabrication (EB F^3) system, now undergoing development, is intended to afford a capability for manufacturing metal parts in nearly net sizes and shapes. Although the development effort is oriented toward the eventual use of systems like this one to supply spare metal parts aboard spacecraft in flight, the basic system design could also be adapted to terrestrial applications in which there are requirements to supply spare parts on demand at locations remote from warehouses and conventional manufacturing facilities.

Prior systems that have been considered for satisfying the same requirements (including prior free-form fabrication systems) are not easily portable because of their bulk and massive size. The mechanical properties of the components that such systems produce are often inferior to the mechanical properties of the corresponding original, conventionally fabricated components. In addition, the prior systems are not efficient in the utilization of energy and of feedstock. In contrast, the present developmental system is designed to be sufficiently compact and lightweight to be easily portable, to utilize both energy and material more efficiently, and to produce components that have mechanical properties approximating those of the corresponding original components.

The developmental EB F^3 system will include a vacuum chamber and associated vacuum pumps, an electron-beam gun and an associated power supply, a multiaxis positioning subsystem, a precise wire feeder, and an instrumentation system for monitoring and control. The electron-beam gun, positioning subsystem, and wire feeder will be located inside the vacuum chamber (see figure). The electron-beam gun and the wire feeder will be mounted in fixed positions inside the domed upper portion of the vacuum chamber. The positioning subsystem and ports for the vacuum pumps will be located on a base that could be dropped down to provide full access to the interior of the chamber when not under vacuum.

During operation, wire will be fed to a fixed location, entering the melted pool created by the electron beam. Heated by the electron beam, the wire will melt and fuse to either the substrate or with the previously deposited metal wire fused on top of the positioning table. Based on a computer aided design (CAD) model and controlled by a computer, the positioning subsystem

ARTIST'S CONCEPTION OF VACUUM CHAMBER AND EQUIPMENT WITHIN

SCHEMATIC DIAGRAM OF SYSTEM

A **Metal Workpiece Will Be Formed** by using an electron beam to melt feed wire over a substrate that will be moved by a four-axis positioning subsystem.

will move the substrate so that the metal deposited from the wire will accumulate to form a component of the desired size and shape.

Whereas conventional electron-beam welding systems generally utilize electron-accelerating potentials of the order of 60 kV, the proposed system will utilize a potential between 8 and 15 kV. Consequently, the shielding needed to protect personnel and equipment against x rays generated by impingement of the electrons on the workpiece can be considerably less massive. The electron beam will deliver a maximum power between 3 and 5 kW and be focused to heat a small spot. Because a considerably higher fraction of an electron beam's energy is converted into heat (relative to a laser beam, for example) in a small spot on the workpiece, the use of the electron beam will contribute to the energy efficiency of the system. The use of the precise wire feeder will enable efficient utilization of feedstock. The operational parameters will be selected to ensure the proper feeding, melting, and consolidation of the feedstock to yield a deposit that will be nearly 100 percent dense (that is, will contain little or no porosity) and will have a very fine grain structure, as needed to ensure superior mechanical properties.

Miniature Laboratory for Detecting Sparse Biomolecules

Specimens would be concentrated and sorted before detection.

NASA's Jet Propulsion Laboratory, Pasadena, California

The figure schematically depicts a miniature laboratory system that has been proposed for use in the field to detect sparsely distributed biomolecules. By emphasizing concentration and sorting of specimens prior to detection, the underlying system concept would make it possible to attain high detection sensitivities without the need to develop ever more sensitive biosensors. The original purpose of the proposal is to aid the search for signs of life on a remote planet by enabling the detection of specimens as sparse as a few molecules or microbes in a large amount of soil, dust, rocks, water/ice, or other raw sample material. Some ver-

sion of the system could prove useful on Earth for remote sensing of biological contamination, including agents of biological warfare.

Processing in this system would begin with dissolution of the raw sample material in a sample-separation vessel. The solution in the vessel would contain floating microscopic magnetic beads coated with substances that could engage in chemical reactions with various target functional groups that are parts of target molecules. The chemical reactions would cause the targeted molecules to be captured on the surfaces of the beads.

By use of a controlled magnetic field, the beads would be concentrated

in a specified location in the vessel. Once the beads were thus concentrated, the rest of the solution would be discarded. This procedure would obviate the filtration steps and thereby also eliminate the filter-clogging difficulties of typical prior sample-concentration schemes. For ferrous dust/soil samples, the dissolution would be done first in a separate vessel before the solution is transferred to the microbead-containing vessel.

A small amount of a solvent solution would be used to elute the captured target molecules from the surfaces of the beads. The resulting solution would be made to flow through a se-
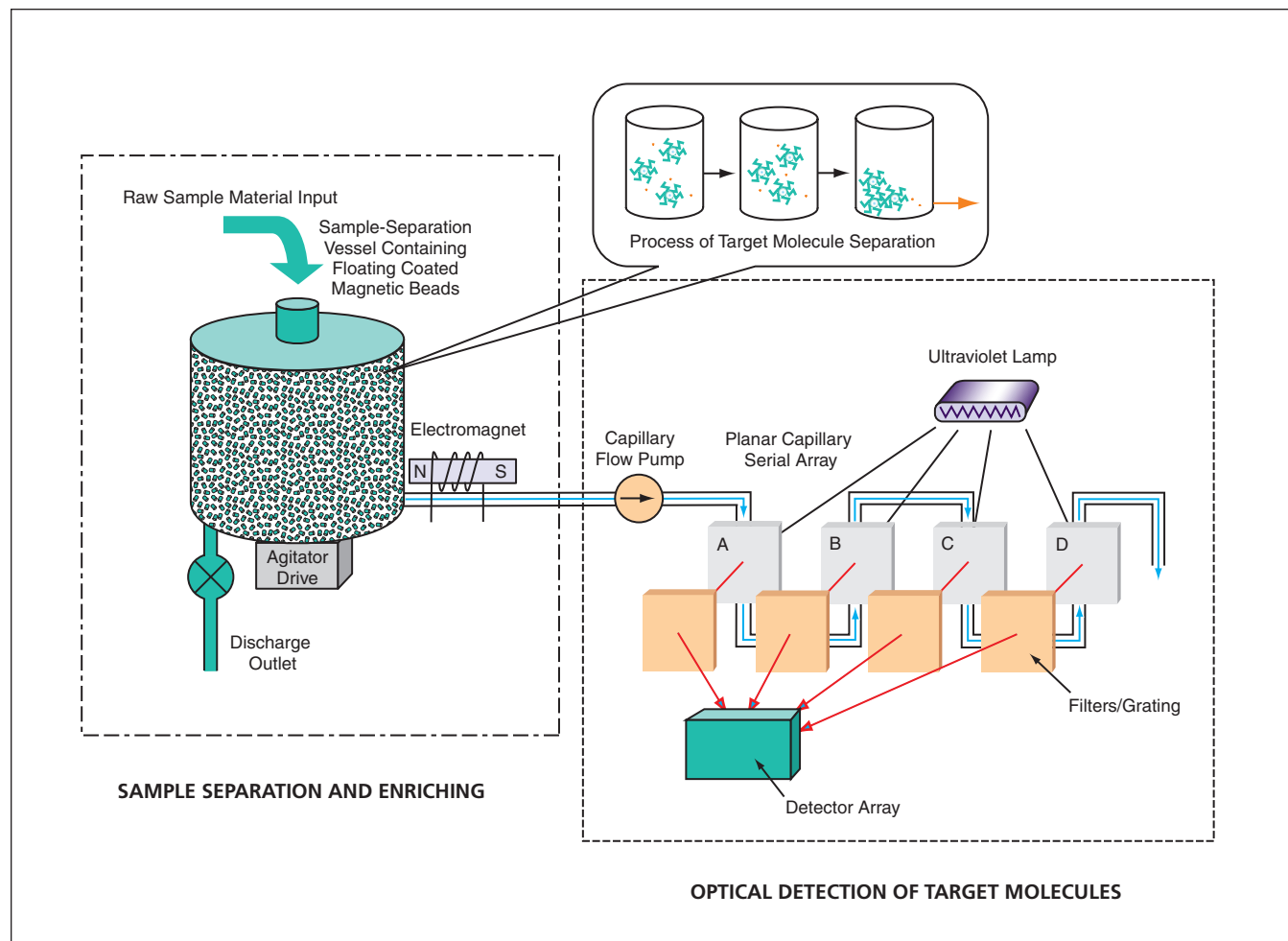
Raw Sample Material Would Be Processed to concentrate and sort specimens (specifically, target molecules), which would then be detected by optical or other means.

ries of capillary detection channels, which would be coated with probe molecules, each designed to capture a specific functional group. Once the flow had run its course, an instrument yet to be developed (perhaps an inte-grated optical spectrometer) would be used to detect and analyze molecules of interest that had accumulated in the channels. The outputs of the instrument would be used to construct a matrix of data from which the concen-trations of the target molecules would be estimated.

Multicompartment Liquid-Cooling/Warming Protective Garments

Lyndon B. Johnson Space Center, Houston, Texas

Shortened, multicompartment liquid-cooling/warming garments (LCWGs) for protecting astronauts, firefighters, and others at risk of exposure to extremes of temperature are undergoing development. Unlike prior liquid-circulation thermal-protection suits that provide either cooling or warming but not both, an LCWG as envisioned would provide cooling at some body locations and/or heating at other locations, as needed: For example, sometimes there is a need to cool the body core and to heat the extremities simultaneously. An LCWG garment of the type to be developed is said to be shortened because the liquid-cooling and -heating zones would not cover the whole body and, instead, would cover reduced areas selected for maximum heating and cooling effectiveness. Physiological research is under way to provide a rational basis for selection of the liquid-cooling and -heating areas. In addition to enabling better (relative to prior liquid-circulation garments) balancing of heat among different body regions, the use of selective heating and cooling in zones would contribute to a reduction in the amount of energy needed to operate a thermal-protection suit.

Laser Metrology for an Optical-Path-Length Modulator

Sensitivity is of the order of picometers.

NASA's Jet Propulsion Laboratory, Pasadena, California

Laser gauges have been developed to satisfy requirements specific to monitoring the amplitude of the motion of an optical-path-length modulator that is part of an astronomical interferometer. The modulator includes a corner-cube retroreflector driven by an electromagnetic actuator. During operation of the astronomical interferometer, the electromagnet is excited to produce linear reciprocating motion of the corner-cube retroreflector at an amplitude of 2 to 4 mm at a frequency of 250, 750, or 1,250 Hz. Attached to the corner-cube retroreflector is a small pick-off mirror. To suppress vibrations, a counterweight having a mass equal to that of the corner-cube retroreflector and pick-off mirror is mounted on another electromagnetic actuator that is excited in opposite phase. Each gauge is required to measure the amplitude of the motion of the pick-off mirror, assuming that the motions of the pick-off mirror and the corner-cube retroreflector are identical, so as to measure the amplitude of motion of the corner-cube retroreflector to within an error of the order of picometers at each excitation frequency.

Each gauge is a polarization-insensitive heterodyne interferometer that includes matched collimators, beam separators, and photodiodes (see figure). The light needed for operation of the gauge comprises two pairs of laser beams, the beams in each pair being separated by a beat frequency of 80 kHz. The laser beams are generated by an apparatus, denoted the heterodyne plate, that includes stabilized helium-neon lasers, acousto-optical modulators, and associated optical and electronic subsystems. The laser beams are coupled from the heterodyne plate to the collimators via optical fibers.

The basic heterodyne-interferometer architecture is not new, but prior systems based on the architecture have not afforded accuracies as great as those of the present gauges. The novelty of the present gauges lies in numerous details of design, construction, and setup that, taken together, make it possible to obtain the required level of accuracy. Within the limited space available for this article, it is possible only to summarize a few major details:

- The gauge utilizes an inner beam pair in one of the interferometer arms (the probe arm) and an outer beam pair in the other interferometer arm (the reference arm). The beams are separated by (1) an inner mask and a mirror with a hole in the reference arm, and (2) an outer mask in the probe arm. Care is taken to provide a small radial separation between the beams to minimize leakage between them.
- In the design, construction, and setup of the collimators, great care is taken to eliminate scattered light, to adjust the collimator lenses to the collimating positions, and to match the collimator outputs. Although the wave fronts coming out of the collimators are not very flat, they are matched to within a fraction of the 633-nm laser wavelength. Once the collimators are adjusted to the required match, they are permanently glued in position.
- The photodetectors, and lenses that focus light on the photodetectors, are mounted in receiver assemblies, the optical configuration of which is the inverse of that of the collimators. The photodiodes are only 100 mm in diameter and are mounted at the precise focal points of the lenses. The precise placement and the smallness of the photodiodes helps to discriminate against leakage in the form of diffracted light, which travels at slight angles to the optical axes of the main masked beams.

Two of the gauges have been built and have been demonstrated to be capable of a sensitivity of ≤ 3 pm/Hz$^{1/2}$ within 1-Hz-wide bands at each of 250, 750, and 1,250 Hz. When the gauges were tested while monitoring the same optical-path-length modulator, the root-mean-square systematic error per gauge was found to be about 25 pm. However, the systematic errors do not constitute a major drawback, inasmuch as they can be reduced by cyclic averaging and they occur at a frequency above 1,250 Hz.

This work was done by Yekta Gursel of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-30799
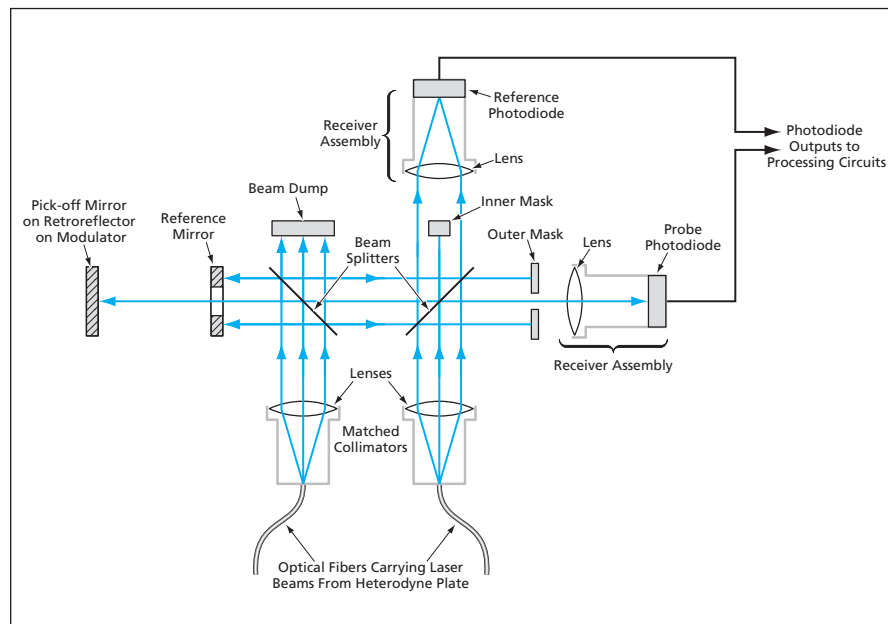
This **Laser Heterodyne Interferometer** utilizes an inner probe beam pair and an outer reference beam pair. High sensitivity and high accuracy are achieved through innovative design features and careful attention to detail in construction and alignment.

# PCM Passive Cooling System Containing Active Subsystems

A PCM would absorb intense heat bursts and would be regenerated between them.

Lyndon B. Johnson Space Center, Houston, Texas

A multistage system has been proposed for cooling a circulating fluid that is subject to intermittent intense heating. The system would be both flexible and redundant in that it could operate in a basic passive mode, either sequentially or simultaneously with operation of a first, active cooling subsystem, and either sequentially or simultaneously with a second cooling subsystem that could be active, passive, or a combination of both. This flexibility and redundancy, in combination with the passive nature of at least one of the modes of operation, would make the system more reliable, relative to a conventional cooling system.

The system would include a tube-in-shell heat exchanger, within which the space between the tubes would be filled with a phase-change material (PCM). The circulating hot fluid would flow along the tubes in the heat exchanger. In the basic passive mode of operation, heat would be conducted from the hot fluid into the PCM, wherein the heat would be stored temporarily by virtue of the phase change.

Of course, it would become necessary to remove heat from the PCM to maintain or restore its heat-absorption capacity. This would be accomplished by means of the first, active cooling subsystem, which would circulate a cooling fluid through one or more tube(s) in thermal contact with the PCM. For example, such a cooling tube could be wrapped in a spiral around the heat-exchanger shell as shown in the figure.
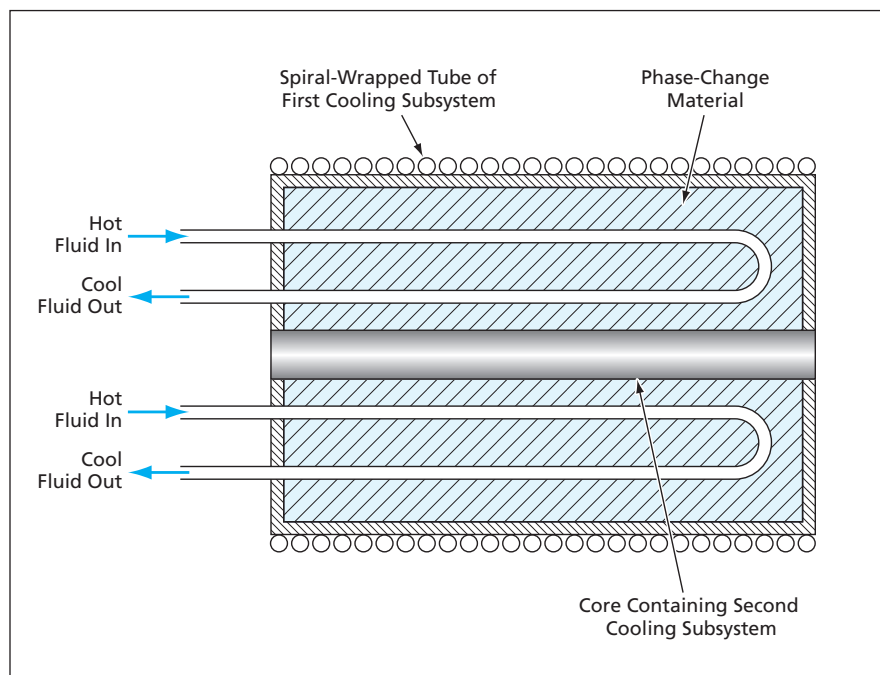
This **Cross Section Is Greatly Simplified** to show only selected major features of a heat exchanger according to the proposal.

The heat exchanger would include an inner core that would accommodate the second cooling subsystem. As mentioned above, the second cooling subsystem could be active, passive, or both. This subsystem would remove heat from the core by means of heat pipes, a water membrane evaporator, and/or one or more active refrigeration devices. In the case of a water membrane evaporator,

heat would be dissipated in the environment by releasing the steam generated at the membrane.

This work was done by David E. Blanding and David I. Bass of the Boeing Co. for **Johnson Space Center**. *For further information, contact the Johnson Innovative Partnerships Office at (281) 483-3809.*
MSC-23652

Automated Electrostatics Environmental Chamber

Atmospheric temperature and pressure can be varied between the extremes of Mars and Earth.

John F. Kennedy Space Center, Florida

The Mars Electrostatics Chamber (MEC) is an environmental chamber designed primarily to create atmospheric conditions like those at the surface of Mars to support experiments on electrostatic effects in the Martian environment. The chamber is equipped with a vacuum system, a cryogenic cooling system, an atmospheric-gas replenishing and analysis system, and a computerized control system that can be programmed by the user and that provides both au-

tomation and options for manual control. The control system can be set to maintain steady Mars-like conditions or to impose temperature and pressure variations of a Mars diurnal cycle at any given season and latitude. In addition, the MEC can be used in other areas of research because it can create steady or varying atmospheric conditions anywhere within the wide temperature, pressure, and composition ranges between the extremes of Mars-like and

Earth-like conditions.

The MEC (see figure) includes access ports for installation and removal of experimental devices, and vacuum-feed-through ports for connecting to the devices from the outside. Also included are feed-through ports for pressure sensors, thermocouples, and gas-supply tubes that are permanent parts of the apparatus. There also are access ports for visual monitoring of experimental devices.

The temperature in the chamber can

The **Mars Electrostatics Chamber** has an external length of 2 m, external diameter of 1.3 m, and interior volume of 1.5 m³. The chamber houses an experiment deck measuring 1.43 by 0.80 m. This apparatus is versatile enough to be useful for general research in addition to research on electrostatics in the Martian environment.

range from a minimum of 150 K to a maximum of 473 K. The temperature at 48 different locations within the chamber is monitored by use of thermocouples. Temperature is controlled mainly by balancing (1) the inward leakage of heat from ambient temperature against (2) the removal of heat by circulation of a mixture of warm gaseous nitrogen and cold vaporized liquid nitrogen through a cooling shroud inside the chamber. The rates of flow of the warm and cold nitrogen are monitored by flowmeters and regulated by controllable valves. Additional heating is provided by tape heaters outside the chamber and additional cooling by a liquid-nitrogen cold plate.

Following initial evacuation, the chamber is backfilled with an atmospheric gas mixture (e.g., CO_2 with small amounts of N_2, Ar, O_2, and H_2O to simulate the Martian atmosphere) at low pressure [typically between 6 and 9 millibars (between 600 and 900 Pa) for the Martian atmosphere]. Thereafter, pressure is brought to and maintained at the required value by use of a feedback control system that balances the rate of flow of atmospheric gas into the system against the rates of leakage and of vacuum pumping. The feedback control system includes a pressure sensor and a gas-feed throttle valve.

The composition of the gas is monitored by use of a separately operated residual-gas analyzer, the output of which is sent to the computerized control system. A mass flow controller maintains the desired relative concentrations of the gases in the atmospheric gas mixture.

A programmable logic controller (PLC) is the heart of the computerized control system. The PLC accepts inputs from a manual control panel, capacitance manometers, flowmeters, pressure controllers, and thermocouples. The PLC provides outputs to indicators on the manual control panel, and to the vacuum, heating, cooling, pressure, and gas-composition systems described above. Numerous outputs are sent to a graphical user interface (GUI) that features "soft" controls and indicators that emulate those of the manual control panel with the addition of elaborate graphical management capabilities. The GUI notifies the PLC when it is ready to accept or provide information relative to the control process. Optionally, the operation of the MEC can be controlled by use of the manual control panel alone, or partly by use of the manual control panel and partly by use of the GUI. This option affords flexibility for manually performing tests while maintaining safe operation by use of automatic control.

Automated Electrostatics Environmental Chamber

Lyndon B. Johnson Space Center, Houston, Texas

A solid-phase extraction (SPE) process has been developed for removing alcohols, carboxylic acids, aldehydes, ketones, amines, and other polar organic compounds from water. This process can be either a subprocess of a water-reclamation process or a means of extracting organic compounds from water samples for gas-chromatographic analysis. This SPE process is an attractive alternative to an Environmental Protection Administration liquid-liquid extraction process that generates some pollution and does not work in a microgravitational environment. In this SPE process, one forces a water sample through a resin bed by use of positive pressure on the upstream side and/or suction on the downstream side, thereby causing organic compounds from the water to be adsorbed onto the resin. If gas-chromatographic analysis is to be done, the resin is dried by use of a suitable gas, then the adsorbed compounds are extracted from the resin by use of a solvent. Unlike the liquid-liquid process, the SPE process works in both microgravity and Earth gravity. In comparison with the liquid-liquid process, the SPE process is more efficient, extracts a wider range of organic compounds, generates less pollution, and costs less.

Estimating Aeroheating of a 3D Body Using a 2D Flow Solver

Lyndon B. Johnson Space Center, Houston, Texas

A method for rapidly estimating the aeroheating, shear stress, and other properties of hypersonic flow about a three-dimensional (3D) blunt body has been devised. First, the geometry of the body is specified in Cartesian coordinates. The surface of the body is then described by its derivatives, coordinates, and principal curvatures. Next, previously relatively simple equations are used to find, for each desired combination of angle of attack and meridional angle, a scaling factor and the shape of an equivalent axisymmetric body. These factors and equivalent shapes are entered as inputs into a previously developed computer program that solves the two-dimensional (2D) equations of flow in a non-equilibrium viscous shock layer (VSL) about an axisymmetric body. The coordinates in the output of the VSL code are transformed back to the Cartesian coordinates of the 3D body, so that computed flow quantities can be registered with locations in the 3D flow field of interest. In tests in which the 3D bodies were elliptic paraboloids, the estimates obtained by use of this method were found to agree well with solutions of 3D, finite-rate-chemistry, thin-VSL equations for a catalytic body.

Artificial Immune System for Recognizing Patterns

This method offers robust performance in analysis of large sets of data.

NASA's Jet Propulsion Laboratory, Pasadena, California

A method of recognizing or classifying patterns is based on an artificial immune system (AIS), which includes an algorithm and a computational model of nonlinear dynamics inspired by the behavior of a biological immune system. The method has been proposed as the theoretical basis of the computational portion of a star-tracking system aboard a spacecraft. In that system, a newly acquired star image would be treated as an antigen that would be matched by an appropriate antibody (an entry in a star catalog). The method would enable rapid convergence, would afford robustness in the face of noise in the star sensors, would enable recognition of star images acquired in any sensor or spacecraft orientation, and would not make an excessive demand on the computational resources of a typical spacecraft. Going beyond the star-tracking application, the AIS-based pattern-recognition method is potentially applicable to pattern-recognition and -classification processes for diverse purposes — for example, reconnaissance, detecting intruders, and mining data.

This AIS method is capable of efficient analysis of large sets of data, including sets that are characterized by high dimensionality and/or are acquired over long time intervals. When the method is used for unsupervised or supervised classification, the amount of computation scales linearly with the number of dimensions and offers performance that is both (a) nearly independent of the total size of the set of data and (b) equal to or better than the performances of traditional clustering methods. When used for pattern recognition, the method efficiently finds appropriate matches in the data. The method enables efficient classification of a high-dimensional set of data in a single pass through the data, and quickly flags outliers in much the same way as the human immune system produces antibodies to invading antigens.

The AIS model in this method is embodied in a set of partial differential equations that approximate some aspects of the dynamics of a network of immune-system B cells:

$$\frac{\partial b_i}{\partial t} = s + b_i \left[\frac{p\theta}{\theta + b_i} f(h_i, h_i') + K_{iA} - d \right]$$

where b_i is the number of cells of clone i, t is time, s is a rate of influx, p is a maximal growth rate, θ is a growth clone-size threshold, $f(h_i, h_i')$ is a cell activation function, h_i is a binding field, h_i' is a cross-link-ing field, K_{iA} is a measure of the affinity of a clone-i antibody for the antigen (the pattern to be recognized), and d is a death rate. The functions $f(h_i, h_i')$, h_i, and h_i' are defined by additional equations that must be omitted here for the sake of brevity. Suffice it to say that the cell activation function, $f(h_i, h_i')$, depends on the binding between the B-cell populations in the network. Cells having greater affinity with the incoming pattern (cells representing closer matches to the pattern) clone themselves (with or without mutation) faster than do those having lesser affinities (representing poorer matches).

The unsupervised classification process for this model starts with a single sequential presentation of the data to a randomly initialized set of cell populations. As a result of this mode of presentation, the amount of computation in the classification process is of the order of a number proportional to the number of dimensions of the input data. An affinity radius around each incoming pattern is used to cull the number of clone populations that respond each time. The system is allowed to evolve in time, and the clone population that survives is used as the class for each pattern. Typically, 10 to 20 computational cycles are all that are needed for convergence for each incoming item.
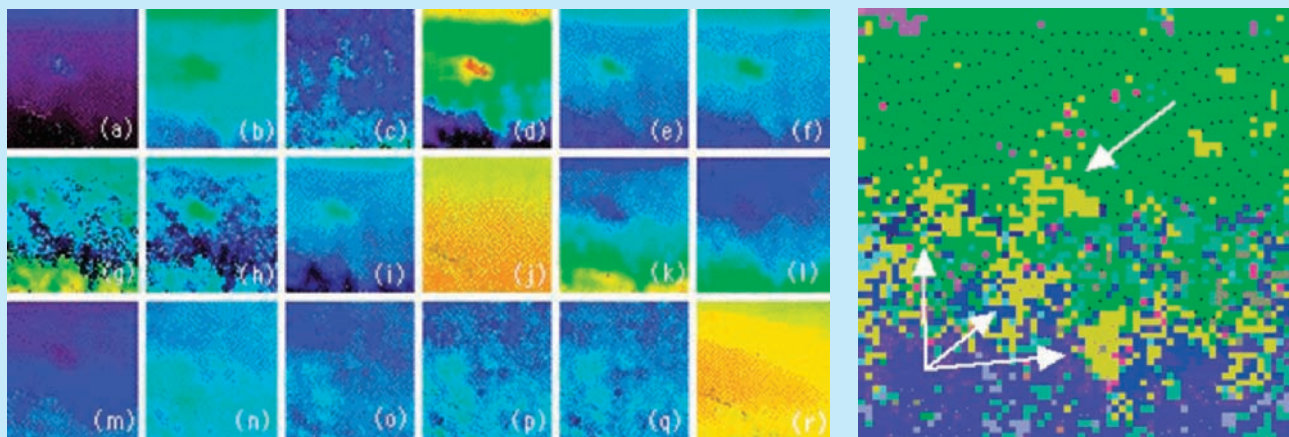
Spectral Images and Attribute Images derived from spectral images were generated from images of the Marquesas Islands acquired by a spaceborne imaging spectrometer in 18 wavelength bands at 36-km resolution. AIS classification of the data of the 18 images yielded an image in which Islands can be discerned more easily.

The method has been demonstrated by applying it to a high-dimensional data set representing images, synthesized from images acquired by a spaceborne imaging spectrometer in 18 wavelength bands, that show various attributes of the Marquesas Islands and vicinity (see figure). Details of individual islands are difficult to discern in any one of the images, but after classification of the image data by the present AIS method, the dominant island groups can be discerned more easily.

This work was done by Terrance Huntsberger of Caltech for **NASA's Jet Propulsion**

Computing the Thermodynamic State of a Cryogenic Fluid
A quasi-steady-state thermodynamical model is iterated over time steps.

Lyndon B. Johnson Space Center, Houston, Texas

The Cryogenic Tank Analysis Program (CTAP) predicts the time-varying thermodynamic state of a cryogenic fluid in a tank or a Dewar flask. CTAP is designed to be compatible with EASY5x, which is a commercial software package that can be used to simulate a variety of processes and equipment systems.

The need for CTAP or a similar program arises because there are no closed-form equations for the time-varying thermodynamic state of the cryogenic fluid in a storage-and-supply system. Manual calculations cannot incorporate all the pertinent variables and provide only steady-state solutions of limited accuracy. The heat energy flowing into and out of the system, the inflow and outflow of fluid, the thermal capacitance and elasticity of the storage vessel, and the thermodynamic properties of the cryogenic fluid at each instant of time are needed. In other words, to define the time varying state of the cryogenic fluid, it is necessary to calculate all the pertinent variables and iterate quasi-steady-state solutions at successive instants of time. It is impractical to attempt to do this without the help of a computer program.

The basic tank system (see figure) modeled in CTAP consists of a pressure vessel (the tank) that contains the cryogen; the insulation on the tank; the tank supports; and the fill, vent, and outflow tubes. The thermodynamic system is considered to be bounded by the outside surface of the pressure vessel, with provisions for flow of both liquid and gas into or out of the tank. The volume of the tank is treated as a variable to account for contraction and expansion of the pressure vessel with changes in pressure.

The mathematical model implemented in CTAP is a first-order differential equation for the pressure as a function of time. The equation is derived as a quasi-steady-state expression of the first law of thermodynamics for the system regarded as closed and isothermal. The equation includes terms for the parasitic leakage of heat through the insulation, for pressurization energy (supplied by heaters) to be added to the tank fluid, for expulsion of liquid or vapor, for the thermal capacitance of the tank wall, and for stretching of the tank under pressure. CTAP incorporates fluid-property subroutines based on equations of state developed at the National Institute of Standards and Technology. At present, the fluids represented in CTAP are hydrogen and oxygen.

CTAP is set up as a large subroutine to be called from within EASY5x. CTAP requires 28 input variables and returns 12 values for use in execution of EASY5x. The input variables define the fluid (oxygen or hydrogen), the initial state of the fluid, the tank and its parameters, the thermal environment, and the fluid scenario (defined next). The user can select any one of the following 12 options or fluid scenarios:
1. Program calculates rates of boil-off or expulsion for a supercritical fluid at constant pressure.
2. Program calculates rate of expulsion of liquid at constant pressure.
3. Program calculates rate of expulsion of vapor at constant pressure.
4. Program calculates the rate of increase of pressure under a condition of tank lockup.
5. Program calculates the rates of inflow of heat required for a given mass flow rate of supercritical fluid at constant pressure.
6. Program calculates the rates of inflow of heat required for a given mass flow rate of liquid at constant pressure.
7. Program calculates the rates of inflow of heat required for a given mass flow rate of vapor at constant pressure.
8. Program simulates tank blowdown — the expulsion of initially supercritical fluid from the tank. This calculation includes effects of stretching of the tank under pressure.
9. Program calculates variable-pressure expulsion of liquid under heater and mass-flow conditions specified by the user.
10. Program calculates variable-pressure expulsion of vapor under heater and mass-flow conditions specified by the user.
11. Program calculates heat loss through thermodynamic vent system.
12. Program calculates pressure rise in the tank from helium pressurant.
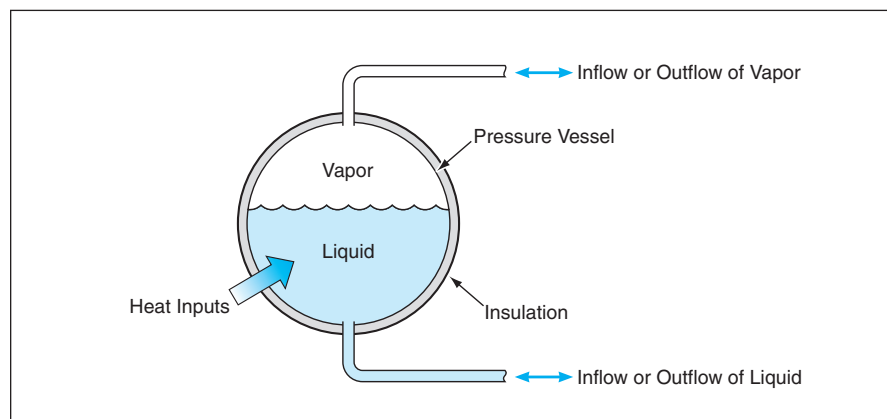
A **Cryogenic Fluid and Tank,** taken together as a time-varying system, are modeled in CTAP by a quasi-steady-state differential equation based on the first law of thermodynamics.

For steady-state solutions, CTAP returns single values (temperatures, heat flows, and/or mass flows) that describe the state of the cryogenic system. For transient solutions, CTAP returns rates of change of pressure and density, so that EASY5x can update the pressure and density accordingly at each time step, then pass new values of pressure, density, and any other parameters (e.g., external temperature) that might change with time back to CTAP.

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Safety and Mission Assurance Performance Metric
Relevant data are presented in formats that help managers make decisions.

Lyndon B. Johnson Space Center, Houston, Texas

The safety and mission assurance (S&MA) performance metric is a method that provides a process through which the managers of a large, complex program can readily understand and assess the accepted risk, the problems, and the associated reliability of the program. Conceived for original use in helping to assure the safety and success of the International Space Station (ISS) program, the S&MA performance metric also can be applied to other large and complex programs and projects. The S&MA-performance-metric data products comprise one or more tables (possibly also one or more graphs) that succinctly display all of the information relevant (and no information that is irrelevant) to management decisions that must be made to assure the safety and success of a program or project, thereby facilitating such decisions.

S&MA organizations within NASA have traditionally provided data products that target specific stages of the life cycles of projects and are generally independent of each other. Such data products have included (1) critical-items lists (CILs) generated through failure-modes-and-effects analyses (FMEAs); (2) noncompliance reports (NCRs) — more specifically, reports of noncompliance with safety requirements as revealed through safety-oriented analyses and reviews; and (3) problem reporting and corrective action (PRACA) documents, which are used in tracking and classifying hardware failures that occur during testing, assembly, and operations. Notwithstanding the value of these data products, it is difficult to assess the effects on the overall program or project from the contents of such a data product considered by itself. Prior to the conception of the S&MA performance metric, there was no process for integrating the individual S&MA data products into a data product that could enhance the decisions of program managers.

The S&MA-performance-metric process is one of gathering information generated according to the various S&MA disciplines (for example, data products like those described above). The gathered information is differentiated into four categories:

- *Accepted Risk* — This category includes information from CILs and NCRs. The critical items and noncompliances can be classified against specific affected subsystems of the ISS or other system that is the focus of the program or project.
- *Anomalies* — For the purpose of S&MA, anomalies are defined as hardware or software failures, or adverse discrete events that have occurred during development and operation of the system. Anomalies include the subject matter of PRACA reports and of the corresponding reports for software, denoted S/W PRs. The PRACAs and S/W PRs can also be classified against specific subsystems.
- *Capability Reliability* — This category is particularly relevant to the ISS because the ISS is being assembled in stages over a period of several years, and its configuration and required capabilities for each stage are different. A predicted-reliability analysis is performed for each capability, and consequently for each stage. This analysis is based on the planned times between assembly flights, the predicted failure rates of the components, the system architecture, the profile of operations for each stage, and data pertaining to failures observed in flight.
- *Subsystem/Capability Dependencies* — The final piece of the ISS S&MA metric is the dependency of subsystem and stage capabilities. One relies on the ISS subsystems to realize the capabilities required at each stage. This dependency of capabilities upon subsystems provides an integrated system perspective that helps in the correlation of capability performance with anomalies and accepted risk across subsystems.

This work was done by Jerry Holsomback, Fred Kuo, and Jim Wade of **Johnson Space Center**. *For further information, contact Jim Wade at jwwade@nasa.gov.*
MSC-23279

Books & Reports

Magnetic Control of Concentration Gradient in Microgravity

A report describes a technique for rapidly establishing a fluid-concentration gradient that can serve as an initial condition for an experiment on solutal instabilities associated with crystal growth in microgravity. The technique involves exploitation of the slight attractive or repulsive forces exerted on most fluids by a magnetic-field gradient. Although small, these forces can dominate in microgravity and therefore can be used to hold fluids in position in preparation for an experiment. The magnetic field is applied to a test cell, while a fluid mixture containing a concentration gradient is prepared by introducing an undiluted solution into a diluting solution in a mixing chamber. The test cell is then filled with the fluid mixture. Given the magnetic susceptibilities of the undiluted and diluting solutions, the magnetic-field gradient must be large enough that the magnetic force exceeds both (1) forces associated with the flow of the fluid mixture during filling of the test cell and (2) forces imposed by any residual gravitation and fluctuations thereof. Once the test cell has been filled with the fluid mixture, the magnetic field is switched off so that the experiment can proceed, starting from the proper initial conditions.

This work was done by Fred Leslie of **Marshall Space Flight Center** *and Narayanan Ramachandran formerly of Universities Space Research Association. For further information, contact Paul Hale at paul.hale@msfc.nasa.gov. MFS-31972*

Avionics for a Small Robotic Inspection Spacecraft

A report describes the tentative design of the avionics of the Mini-AERCam — a proposed 7.5-in. (≈19-cm)-diameter spacecraft that would contain three digital video cameras to be used in visual inspection of the exterior of a larger spacecraft (a space shuttle or the International Space Station). The Mini-AERCam would maneuver by use of its own miniature thrusters under radio control by astronauts inside the larger spacecraft. The design of the Mini-AERCam avionics is subject to a number of constraints, most of which can be summarized as severely competing requirements to maximize radiation hardness and maneuvering, image-acquisition, and data-communication capabilities while minimizing cost, size, and power consumption. The report discusses the design constraints, the engineering approach to satisfying the constraints, and the resulting iterations of the design. The report places special emphasis on the design of a flight computer that would (1) acquire position and orientation data from a Global Positioning System receiver and a micro-electromechanical gyroscope, respectively; (2) perform all flight-control (including thruster-control) computations in real time; and (3) control video, tracking, power, and illumination systems.

This work was done by Larry Abbott and Robert L. Shuler, Jr., of **Johnson Space Center**. *For further information, contact the Johnson Innovative Partnerships Office at (281) 483-3809.*
MSC-23315

Simulation of Dynamics of a Flexible Miniature Airplane

A short report discusses selected aspects of the development of the University of Florida micro-aerial vehicle (UFMAV) — basically, a miniature airplane that has a flexible wing and is representative of a new class of airplanes that would operate autonomously or under remote control and be used for surveillance and/or scientific observation. The flexibility of the wing is to be optimized such that passive deformation of the wing in the presence of aerodynamic disturbances would reduce the overall response of the airplane to disturbances, thereby rendering the airplane more stable as an observation platform. The aspect of the development emphasized in the report is that of computational simulation of dynamics of the UFMAV in flight, for the purpose of generating mathematical models for use in designing control systems for the airplane. The simulations are performed by use of data from a wind-tunnel test of the airplane in combination with commercial software, in which are codified a standard set of equations of motion of an airplane, and a set of mathematical routines to compute trim conditions and extract linear state space models.

This work was done by Martin R. Waszak of **Langley Research Center**. *Further information is contained in a TSP (see page 1).*
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