NASA Tech Briefs

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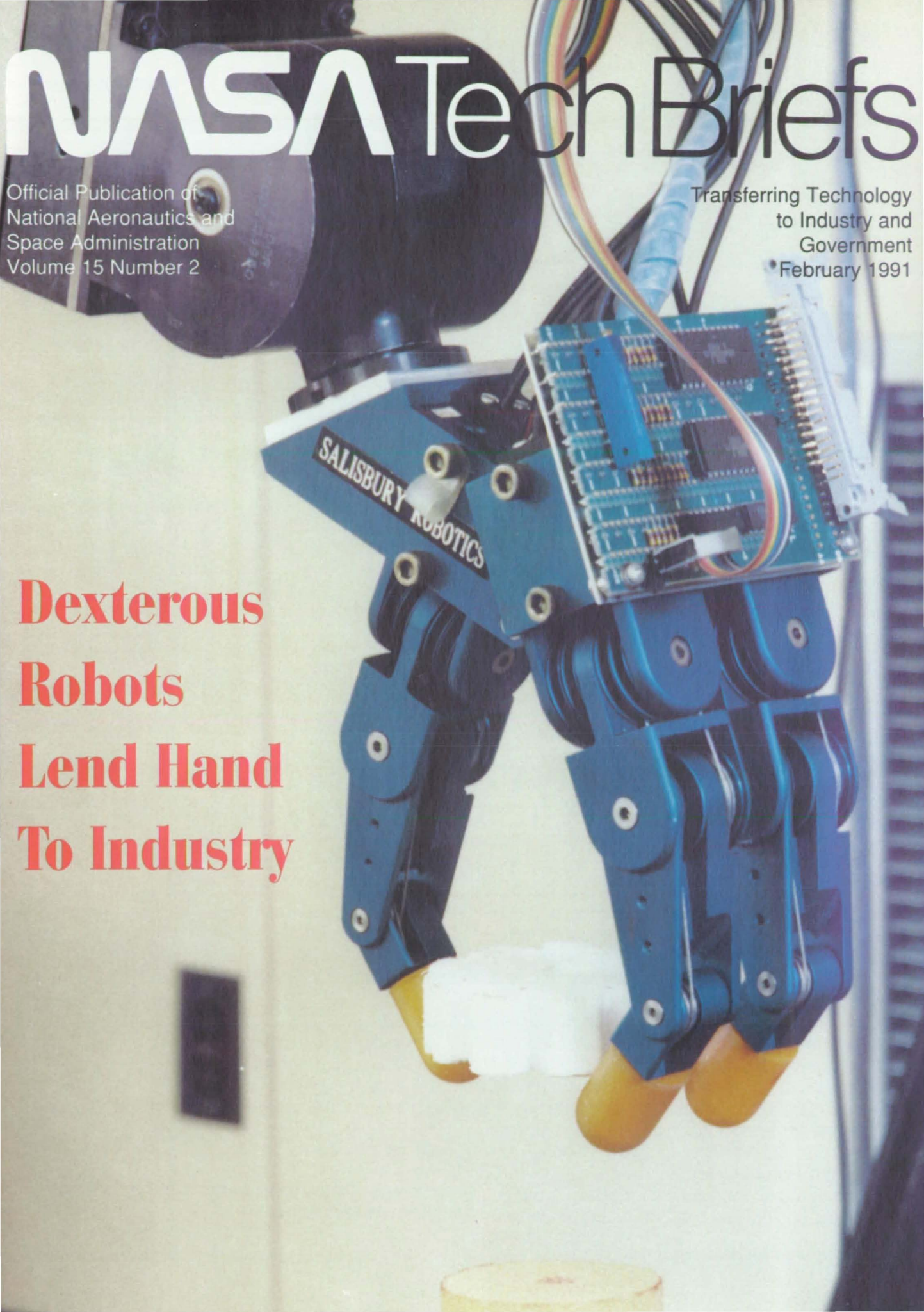
Volume 15 Number 2

Transferring Technology
to Industry and
Government
February 1991



Dexterous Robots Lend Hand To Industry

Science Teacher Fred Holtzclaw Has Successfully Created Energy In A Classroom.

In the nearly 20 years that Mr. Holtzclaw has been teaching high school science in Tennessee, he's learned a lot about energy. How to impart enthusiasm, for instance. The hard work needed to overcome inertia. And most difficult of all, what to do about burn-out.

He's not alone. Every day, teachers all over the country face the same challenges.

That's why Martin Marietta is helping to underwrite a new regional Academy for Teachers of Science and Math at the University of Tennessee. It's an intensive program of study and discussion for Martin Marietta Fellows; outstanding educators in all grade levels. Through the Academy, the private sector, government and academia are all joining together to support a critical educational initiative by President Bush.

It's important to help keep things moving in the classroom, and teachers like Fred Holtzclaw are the right place to start. If we want to fire-up the masterminds of tomorrow, the best thing we can do is keep our outstanding teachers energized today.

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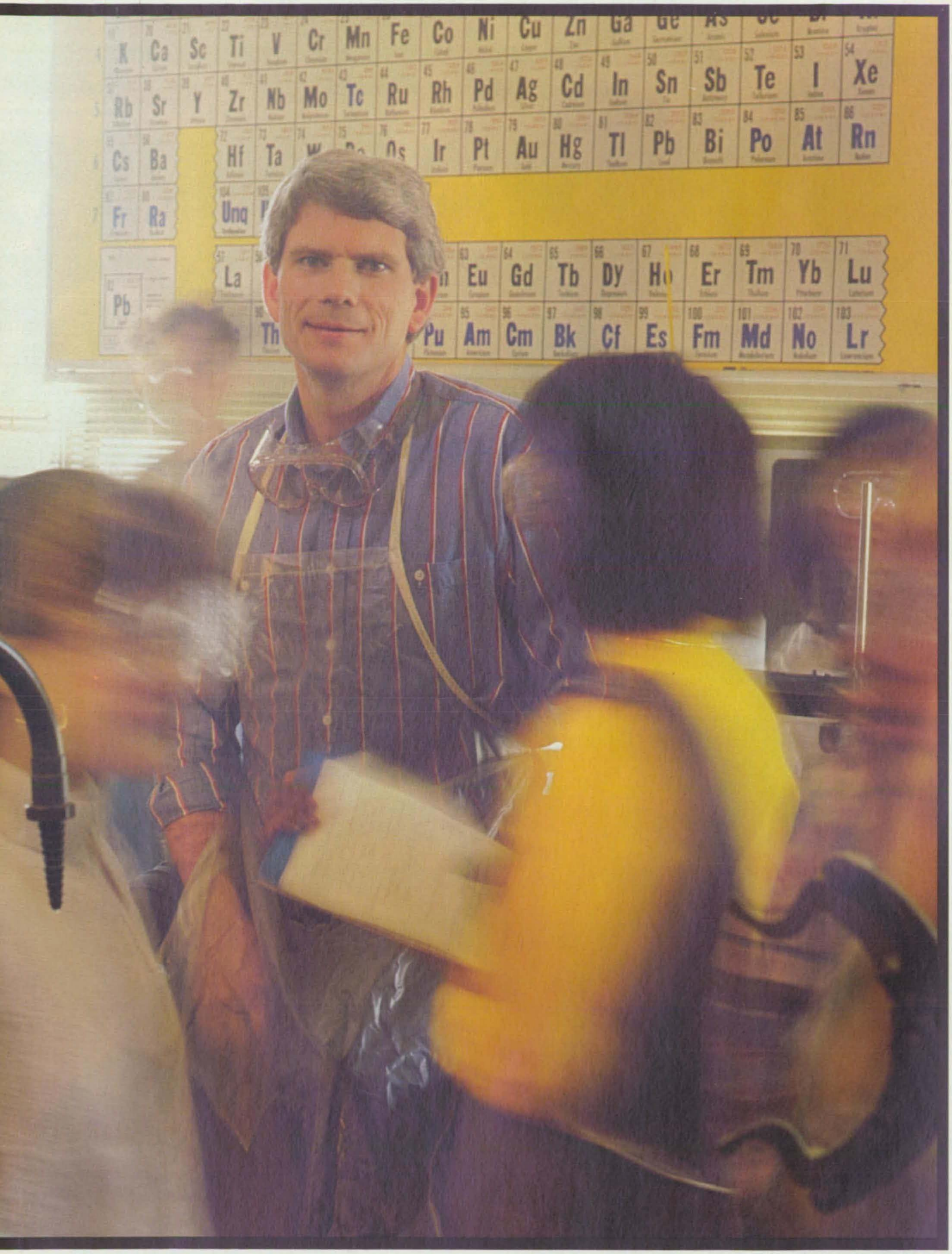

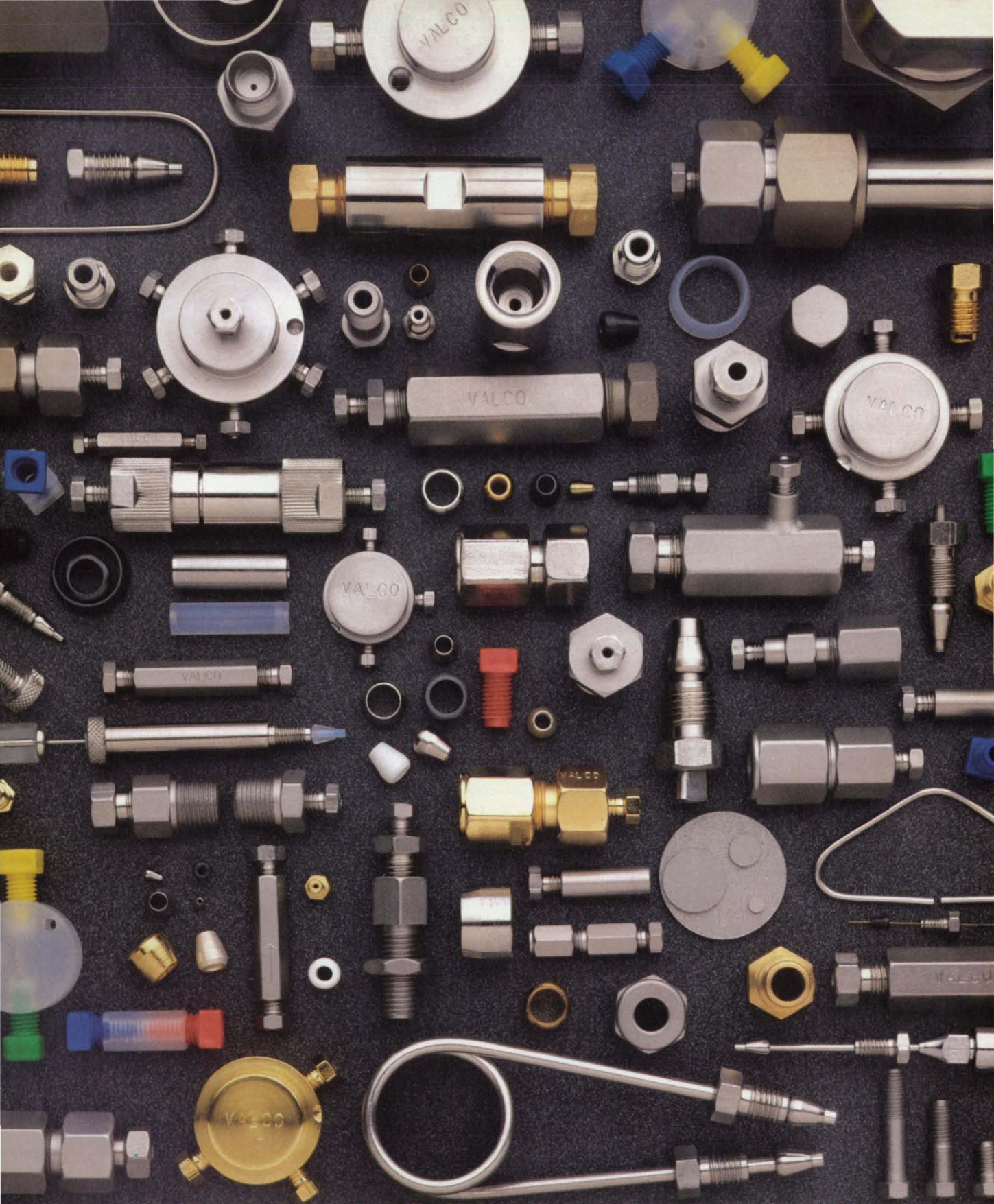

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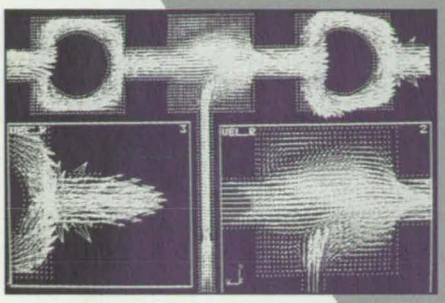
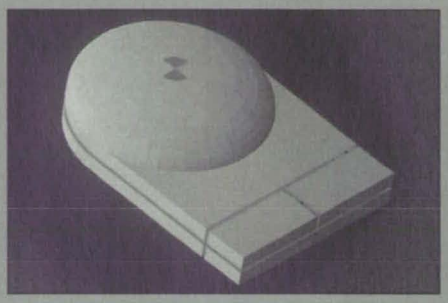
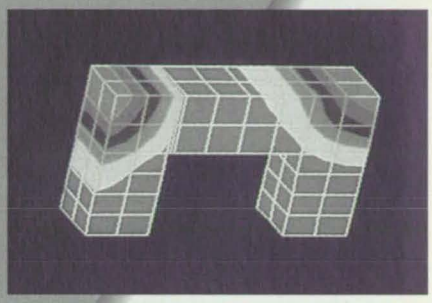


3-D Fluid Flow



Shaded Plot



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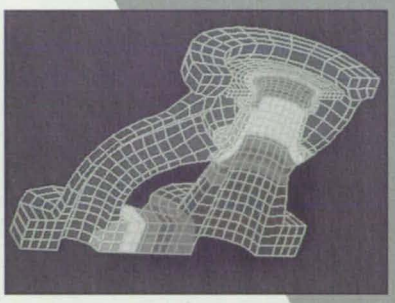
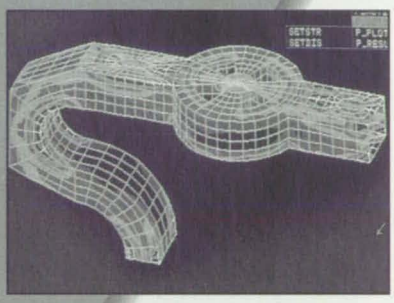


Temperature Distribution in Cryogenic Turboexpander Housing*



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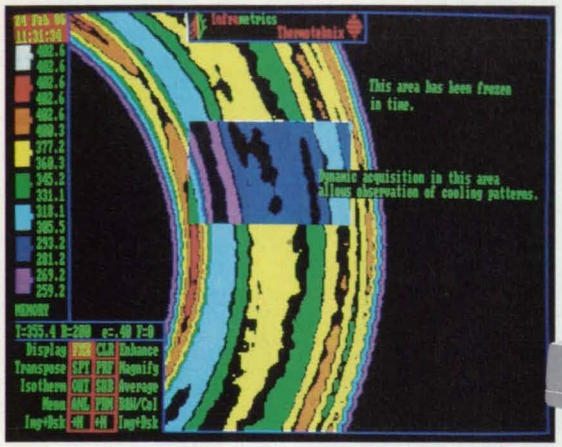
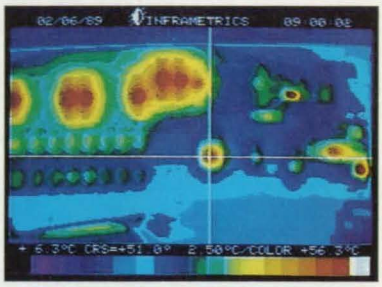


ThermaGRAM® image of an automotive brake rotor.



Model 600 provides spot temperatures of components on PC board. Line scan profiling, isotherm contouring and area measurement are all standard, without computer interface.

Model 600 on the lab bench...stalwart of sophisticated radiometers.

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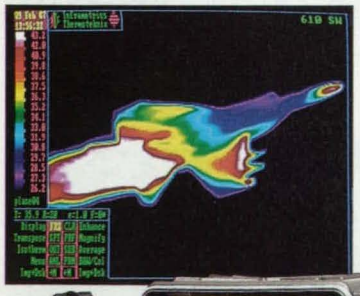
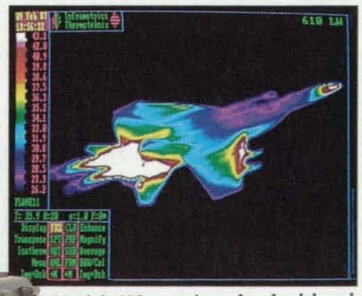
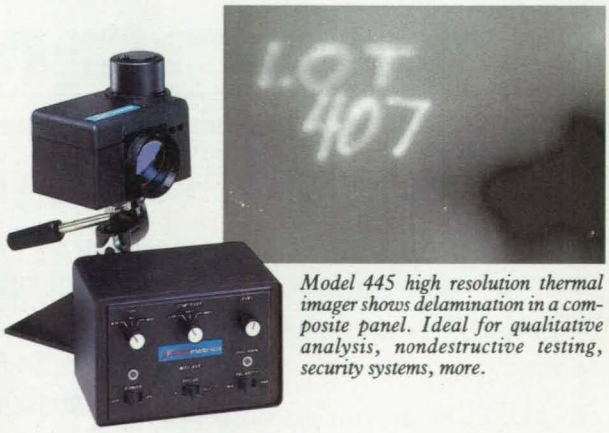




Model 610 acquires the dual-band IR signature of a fighter.



Model 445 high resolution thermal imager shows delamination in a composite panel. Ideal for qualitative analysis, nondestructive testing, security systems, more.

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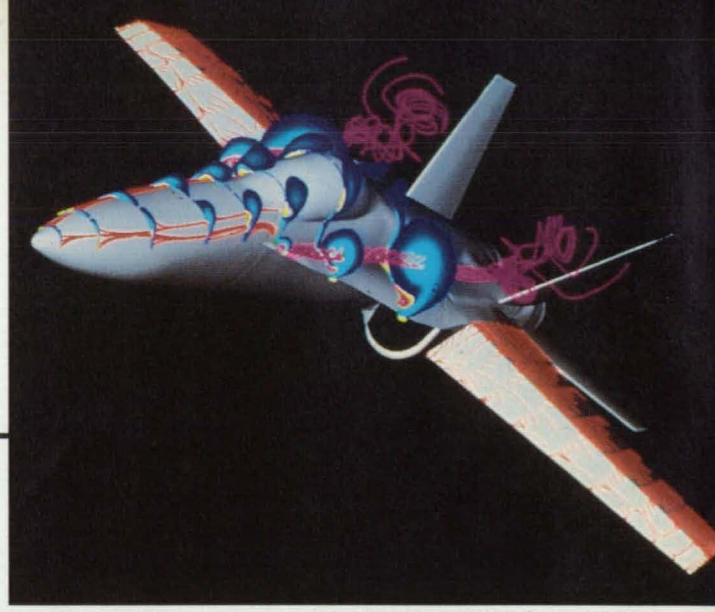

Photo courtesy Ames Research Center

This computer-generated image shows the fluid flow over an F-18 fighter jet. For more on the computer simulation of physical phenomena, turn to page 32.

SPECIAL FEATURES

TECHNICAL SECTION

DEPARTMENTS

***On The Cover:** A dexterous mechanical hand is used as a testbed for a knowledge-based robotic system, developed at Sandia National Laboratories, which generates and executes grasps of objects (such as the gear shown) without need of a database of object models. A NASA-owned invention, the three-fingered hand can move objects about, twist them, and otherwise manipulate them by finger motion alone, and can be adapted to different arms.* *See page 82.*
(Photo courtesy Sandia National Laboratories)

New This Month

This issue we introduce two new features to NASA Tech Briefs:

NASA's Innovators—A bimonthly series focusing on NASA engineers and scientists who define the cutting edge in their respective fields (page 10);

NASA Patents—A quarterly column describing recently patented NASA inventions available for license by industry (page 82).

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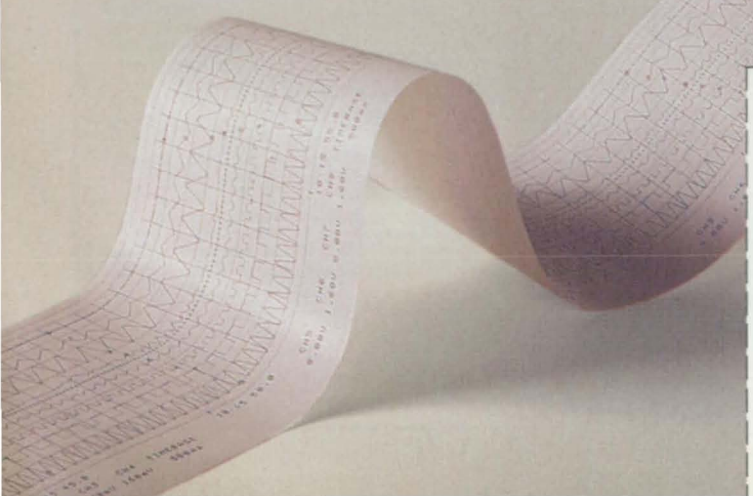

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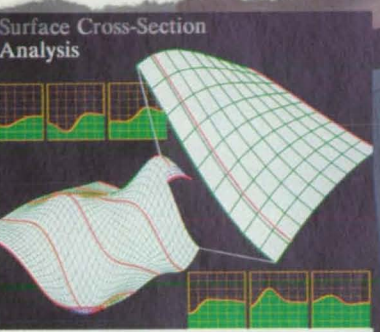

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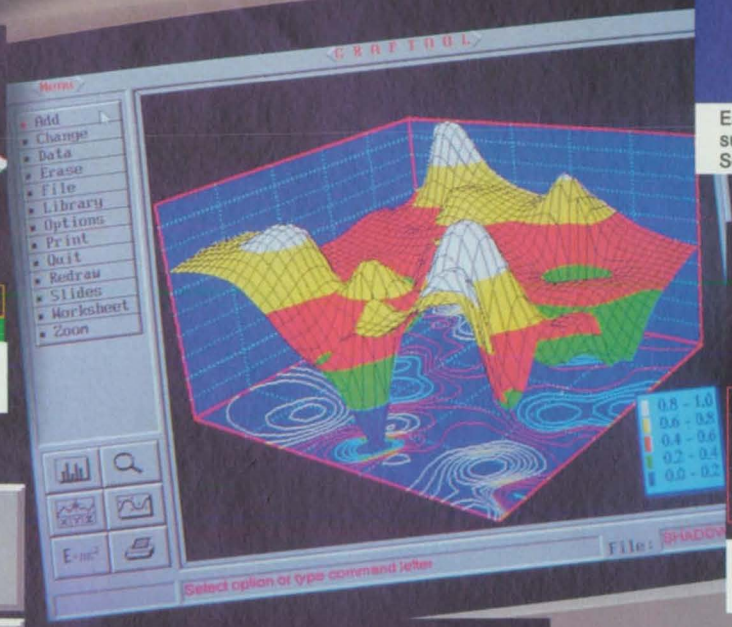

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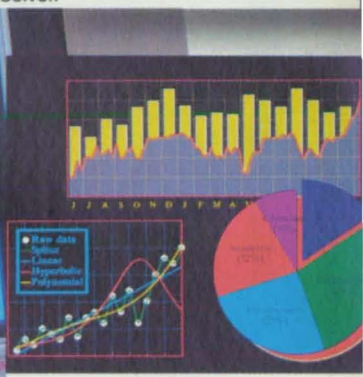

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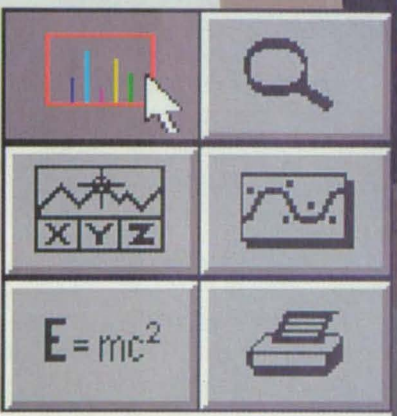

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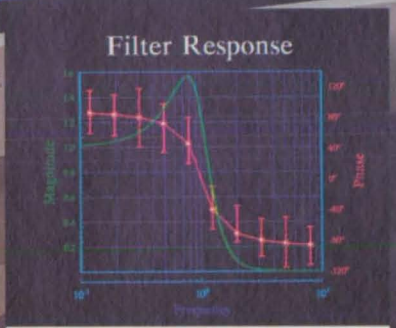

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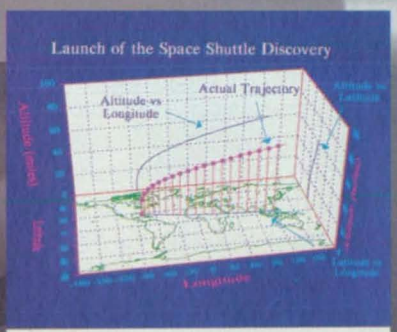

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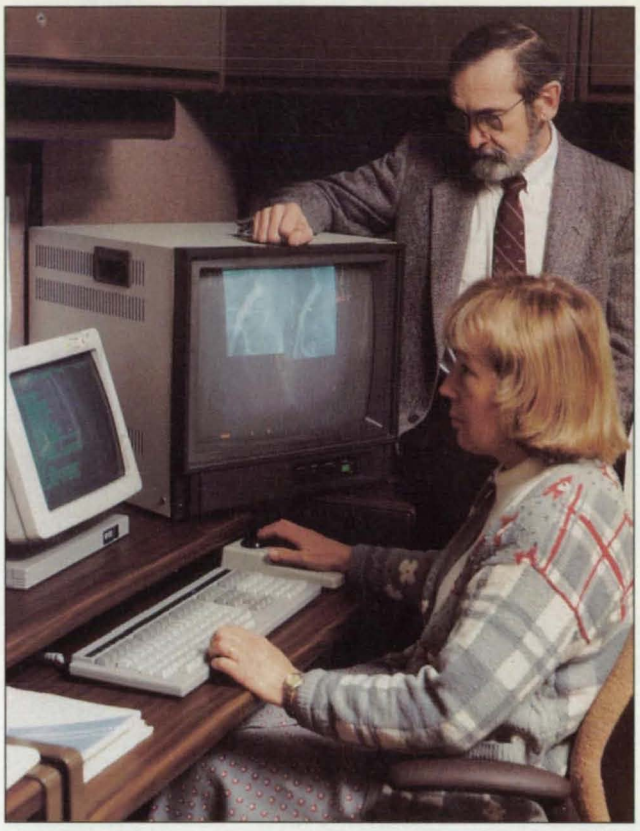

Photo courtesy NASA

Robert Selzer, supervisor of the Biomedical Image Processing Laboratory, and staff member Anne Shircore process angiograms as part of an ongoing study to determine whether lowering serum cholesterol has a beneficial effect on atherosclerosis.

A team of scientists at NASA's Jet Propulsion Laboratory is creating computerized images of the human body to help researchers solve medical mysteries. Using image processing techniques first developed to visualize data captured by spacecraft, they are enabling researchers to quickly "see" how new drugs fight disease, and to better understand changes in the body over time.

Conventional methods of drug testing in clinical trials often involve thousands of subjects and many years of study, and can cost upward of $50 million. Computer analysis techniques accelerate the testing process, reduce costs, and allow more precise evaluations of test data, according to **Robert Selzer**, supervisor of JPL's five-member Biomedical Image Processing Laboratory. Funded by NASA's Life Sciences Division and the National Institutes of Health, the laboratory's projects range from visualizing atherosclerosis in heart patients to testing muscle loss during prolonged inactivity.

Images Of The Heart

Since the mid-1970s, the laboratory has been a national leader in the processing of coronary angiograms, designed to help surgeons pinpoint the location of atherosclerotic lesions in order to determine the best way to treat coronary disease. Called angiography, the process is also used for intervention studies: Selzer's group, in conjunction with the University of Southern California Medical School, is investigating whether the lowering of blood cholesterol has a positive effect on coronary disease. The project involves the testing of 260 men who have had bypass surgery. Half of the subjects received the cholesterol-lowering drug Lovastatin, the others a placebo. Angiograms of their coronary arteries were made three times: at the beginning of the study, after two years, and after four years.

X-ray images captured at 60 frames per second on 35 mm film were used to track the flow of an iodine compound into the subjects' arteries. Selzer's group is processing the film on two projectors, each equipped with a 1000-line video camera. The camera's output goes to a frame grabber that digitizes the image and transmits it to a MicroVax II for display on a computer screen.

The next step involves measurement of the arterial walls by tracking the inner edges of the artery. The computer searches in a direction perpendicular to the vessel for the point of maximum density gradient—where the image intensity changes the quickest. Once the edges are detected, the computer estimates the location of the prediseased arterial wall and measures the percentage of narrowing.

"We are comparing identical measurements of the vessels over

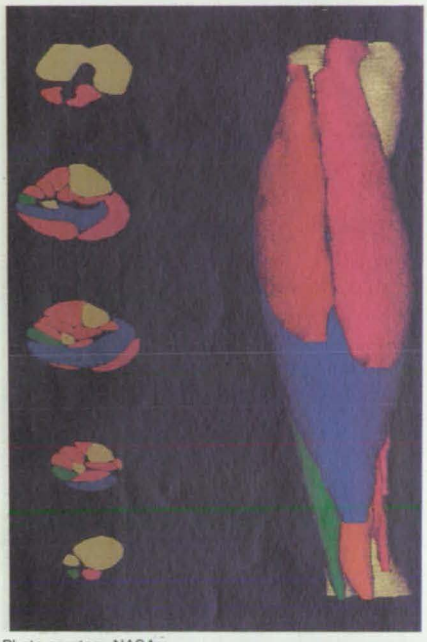

Photo courtesy NASA

Computer-generated image of lower leg muscles, part of a study of muscle atrophy.

time in order to detect changes," Selzer, 58, explained. The advantage of using a computer, he said, is it can detect much smaller changes than possible through visual analysis. "This saves time and drastically reduces the number of test subjects needed."

Selzer's team is exploring other technologies that are less invasive or dangerous to the patient, such as ultrasound imaging. While too low in resolution to view coronary arteries, ultrasound imaging is useful for locating blockages in the carotid artery, which transports blood to the brain. Sound waves are employed to trace the artery's walls and determine their thickness. A computer then processes the data and generates a three-dimensional picture of the vessel, which helps the researchers to precisely match the location of measurements during repeated tests.

Studying Muscle Loss

Another noninvasive tool for looking inside the body is magnetic resonance imaging (MRI). The Biomedical Image Processing Laboratory is using MRI to study the muscle atrophy that afflicts astronauts in space and hospital patients bedridden for long periods. MRI data is collected by measuring the energy the muscle's protons release after the temporary imposition of a high-strength electromagnetic field. With the aid of a MicroVax computer, the researchers create pictures of muscle cross sections. By combining the cross-sectional images into a composite 3D image, they can determine the total volume of each muscle and, with repeated measurements, the rate of atrophy.

As part of a month-long bed-rest study managed by NASA's Ames Research Center, Selzer's group applied MRI technology to visualize the muscle loss in the lower legs of 19 test subjects. Images taken at the end of the study showed, on average, a seven percent loss in the subjects' muscle mass. Such data could prove useful in developing special exercises and other measures to counter atrophy, said Selzer, who holds a masters degree in physics.

Valuable Solutions

The laboratory has launched a new project with Beth Israel Medical Hospital in Boston using imaging technology to detect changes in skin lesions over time. Such changes can signal the onset of melanoma, a type of cancer that is difficult to treat if not detected early. Some patients have large numbers of lesions, which makes it difficult for the dermatologist to accurately detect all changes. Image processing techniques will be used to match photographs of the skin taken over time and to document changes.

"The nice thing about what we're doing in this laboratory," commented Selzer, "is that there's no ambiguity about the value of the solutions to the problems. It's clear that this work is important to people's health." ❑

For further information about the technologies described in this article, contact:
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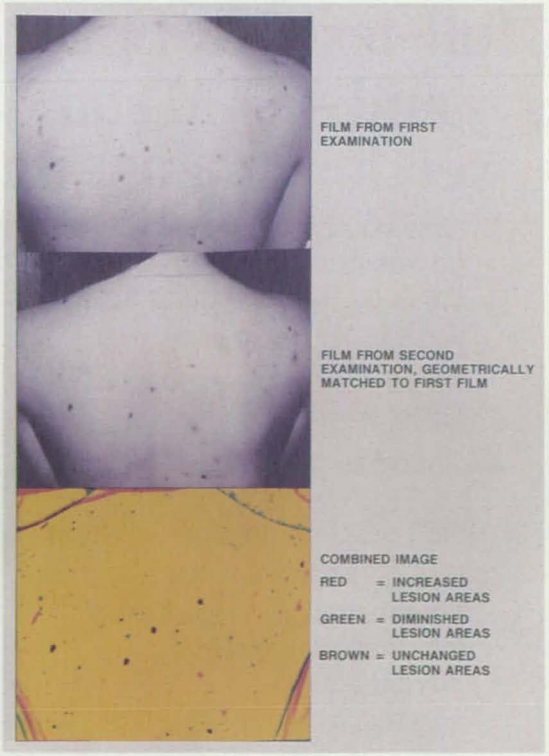

Photo courtesy NASA

Selzer's team is using imaging techniques to detect changes in skin lesions over time.

New Product Ideas

New Product Ideas are just a few of the many innovations described in this issue of *NASA Tech Briefs* and having promising commercial applications. Each is discussed further on the referenced page in the appropriate sections in this issue. If you are interested in developing a product from these or other NASA innovations, you can receive further technical information by requesting the TSP referenced at the end of the full-length article or by writing the Technology Utilization Office of the sponsoring NASA center (see page 14). NASA's patent-licensing program to encourage commercial development is described on page 14.

Rotationally Actuated Prosthetic Hand

A prosthetic hand includes two pincerlike fingers that are actuated by rotation of the forearm. The device features simpler design and operation, less weight, and takes up less space than conventional mechanisms of this type.
(See page 69)

Long-Lifetime Laser Materials for Effective Diode Pumping

While Nd lasers have proved to be quite useful, they would be even more so if they could be pumped by laser diodes. Because the cost of the diodes outweighs the cost of the laser material by perhaps two orders of magnitude, the cost would be reduced significantly.
(See page 42)

Semiconductor Laser With Multilayer Dielectric Reflector

A multilayer dielectric reflector would be included in a proposed surface-emitting, distributed-feedback, grating semiconductor laser (e.g., a GaAlAs device). The reflector would contribute to the efficiency and output power of the laser.
(See page 18)

Modified Furnace Makes More Silicon Ribbon

The rate of growth of silicon ribbon by the dendritic-web process is increased by a modification in the lid of the growth crucible. The modified furnace produces silicon ribbon at the rate of 8.9 cm^2/min — 44 percent higher than the previous rate.
(See page 64)

Low-Wear Ball-Bearing Separator

A proposed ball-bearing separator for use in a cryogenic pump would be stronger and more resistant to wear than present separators made of polytetrafluoroethylene reinforced with glass fibers. The new separator would consist of a molded plastic-and-metal composite ring imbued with solid lubricant and containing an embedded metal ring.
(See page 56)

Self-Testing Static Random-Access Memory

A proposed static random-access memory for a computer would feature improved error-detecting and -correcting capabilities. The new self-testing scheme would provide for the detection and correction of errors at any time during normal operation — even while data are being written into the memory.
(See page 30)

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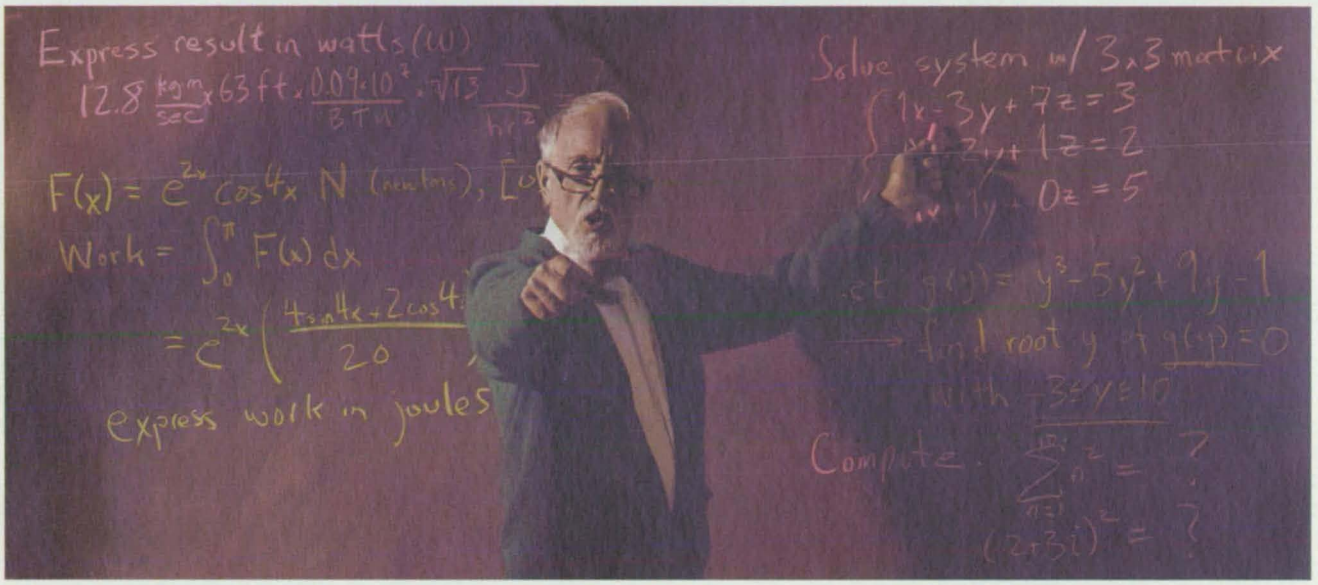

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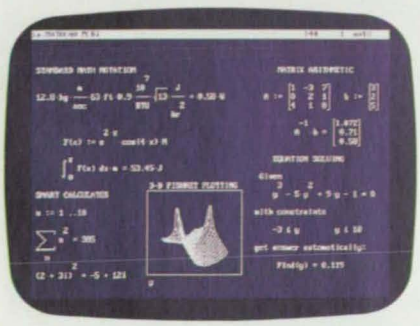

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Electronic Components and Circuits

Hardware, Techniques, and Processes

V-Grooved GaAs Solar Cell

Greater optical coupling provides more conversion of light to electricity.

Lewis Research Center, Cleveland, Ohio

V-grooved GaAs solar photovoltaic cells promise increased optical coupling and, consequently, greater conversion of light into electricity, in comparison with planar GaAs cells. The V-groove geometry (see Figure 1) increases both the trapping of incident light and the lengths of optical paths in the cell material. The net effect is an increase in total absorptivity, tolerance to damage by energetic particles, and short-circuit current. These improvements are expected to follow from similar improvements obtained in silicon solar cells during recent years.

The fabrication of a typical experimental cell of the new type began with the selection of a (100) n^+-type wafer of GaAs with a carrier concentration of 2.8×10^{18} cm^{-3}. The wafer was baked in a horizontal, cold-wall, sub-atmospheric-pressure metal-organic chemical-vapor-deposition (MOCVD) reactor in an atmosphere of H_2 and AsH_3. A thin buffer layer followed by a 4.5-μm-thick epitaxial base layer with n doping of 2.1×10^{17} cm^{-3} was then grown. The growth temperature was 620 °C, the ratio of the number density of atoms of arsenic to that of gallium was 46, the dopant was a mixture of 500 parts per million of hydrogen sulfide in ultra-high-purity hydrogen, and the pressure in the chamber was 100 torr (133 kPa).

The V-groove pattern was established on the n base epilayer by masking the surface with a photoresist pattern of parallel lines 4 μm wide and spaces 3 μm wide, aligned along the $(01\bar{1})$ axis. The grooves were then formed by anisotropic etching for 150 s at 24 °C in a solution of H_2SO_4:H_2O_2:H_2O in the ratio of 5:1:1.

The grooved wafer was again baked in an atmosphere of H_2 and AsH_3. The V-grooves were oriented parallel to the flow of gas, and the atmosphere and temperature for growth were resumed except that the dopant was changed to diethyl zinc. Under these conditions, the 0.1-μm-thick p emitter layer with carrier concentration of 4.2×10^{18} cm^{-3} was grown on the V-grooves. Au/Zn contacts were electron-beam-evaporated onto the p emitter, and Au/Ge/Ni contacts were deposited similarly on the back of the substrate. An antireflection coat of Ta_2O_5 was then applied to the grooves.

Although the thickness of the antireflection coat was not optimized in the experimental grooved cells, the short-circuit current density was 13 percent above that of comparable planar cells. The quantum efficiency of the new cells was also greater (see Figure 2).

This work was done by S. G. Bailey, G. R. Landis, D. M. Wilt, R. D. Thomas, and A. Arrison of **Lewis Research Center** *and N. S. Fatemi of Sverdrup Technology, Inc. Further information may be found in NASA TM-101970 [N89-22177], "A V-Grooved GaAs Solar Cell."*

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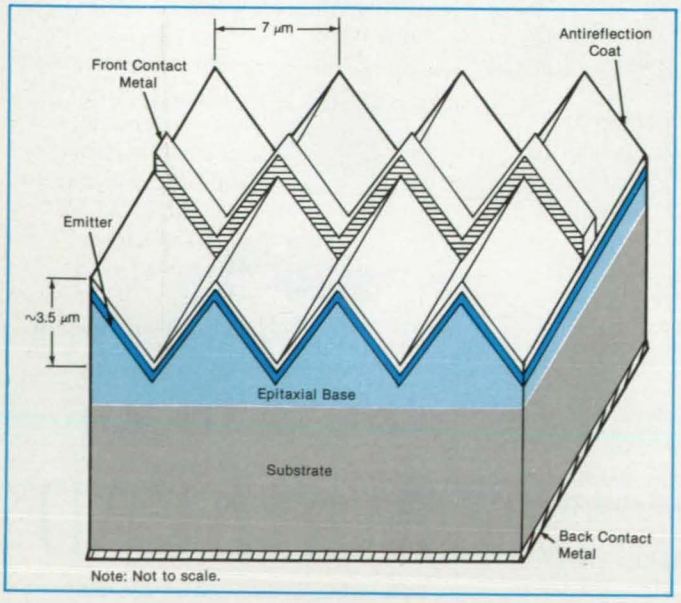

Figure 1. The **Grooved Photovoltaic Cell** converts more of the incoming light into electricity than does a comparable planar photovoltaic cell. The increase in energy-conversion efficiency is the result of longer optical paths and greater trapping of light.

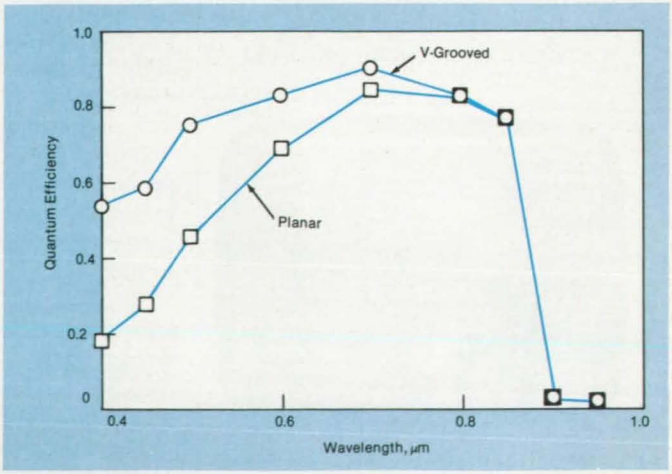

Figure 2. The **Quantum Efficiencies** of V-grooved and planar GaAs cells are compared.

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INSTRUMENTS OF DISC

Semiconductor Laser With Multilayer Dielectric Reflector

The reflector would increase output by reducing absorption in the substrate.

NASA's Jet Propulsion Laboratory, Pasadena, California

A multilayer dielectric reflector would be included in a proposed surface-emitting, distributed-feedback, grating semiconductor laser (e.g., a GaAlAs device). The reflector would contribute to the efficiency and output power of the laser by reducing the amount of light that enters the substrate, where it is wasted by absorption.

A device of this type includes a double-heterostructure laser bounded at both ends by passive waveguides. The passive waveguides contain grooves perpendicular to the axis of propagation. These grooves have a spatial period equal to the wavelength of the laser light and act as diffraction gratings (see Figure 1). The second-order component of diffracted light in each grating is reflected back toward the laser, thus providing feedback for the laser resonator. Two first-order components of refracted light travel perpendicularly to the grating surfaces: one outward, the other inward, toward the substrate. In prior devices of this type, most of the light in the inward-diffracted component is absorbed in the substrate, with a consequent loss of some output and efficiency.

In the proposed device, the multilayer dielectric reflector would be interposed between the substrate and the active and waveguide layers. It would reverse the propagation of light entering the substrate, returning it to the feedback and output beams. This layer would consist of 10 or more pairs of quarter-wavelength-thick sublayers of alternating higher and lower index of refraction. The reflector would be grown on the substrate before depositing the lower-cladding, active, and waveguide layers. The reflector sublayers would be made of the same materials as those of the cladding layers to preserve the epitaxial nature of subsequent growth, and would be deposited by such high-quality material-growing processes as molecular-beam epitaxy or metal/organic chemical-vapor deposition. Other than the deposition of the reflector sublayers, no additional processing would be required beyond that required to fabricate a surface-emitting laser without the reflector. The reflector could be integrated with grating structures of several different types; for example, the gratings could be formed on the outside or the inside of the cladding layers and/or made of such other materials as InGaAsP.

Two major issues govern the selection of the indexes of refraction. One is that the reflectivity of the reflector layer increases with both the number of sublayers and the difference between the two indexes of refraction in them. Therefore, in designing a device, one can trade off the number of sublayers against the index difference while maintaining the desired reflectivity. The other is that to confine the laser electromagnetic mode to the waveguide, it is necessary to make the effective index of refraction (a function of both the index of refraction and the width) of the waveguide greater than the index of refraction of any of the reflector sublayers; this imposes an upper limit on the difference between the two indexes in the sublayers.

This work was done by Robert J. Lang of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 39 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 14]. Refer to NPO-17763.

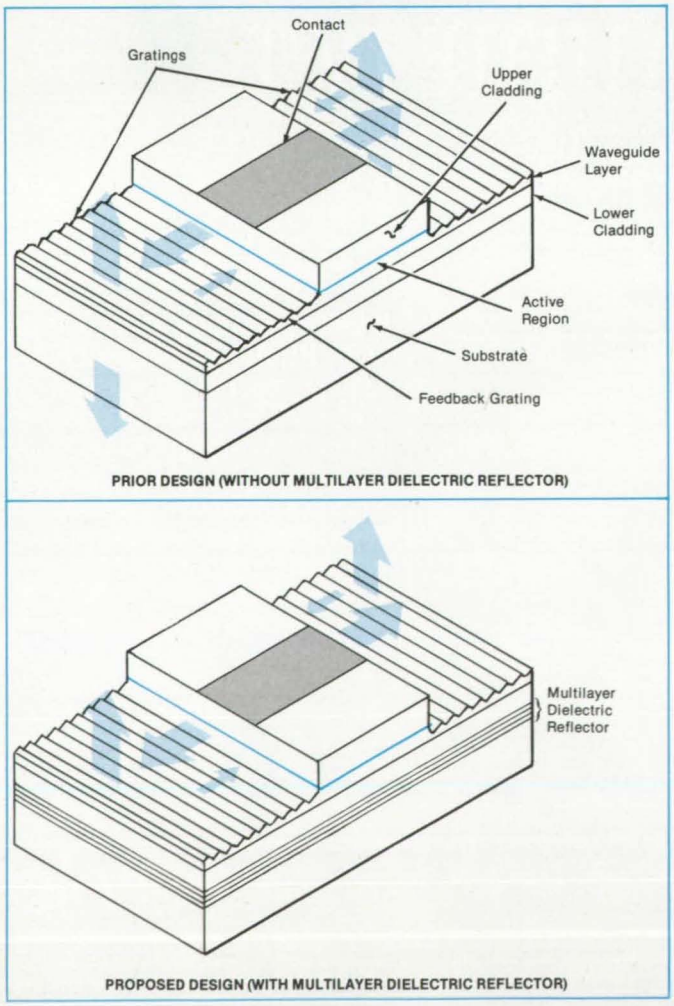


Figure 1. The **Multilayer Dielectric Reflector** added to a surface-emitting, distributed-feedback, grating semiconductor laser would reflect light away from the substrate, thereby increasing the output.

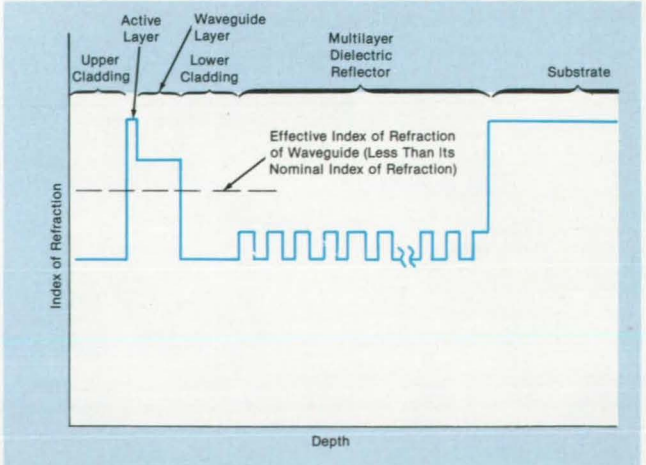
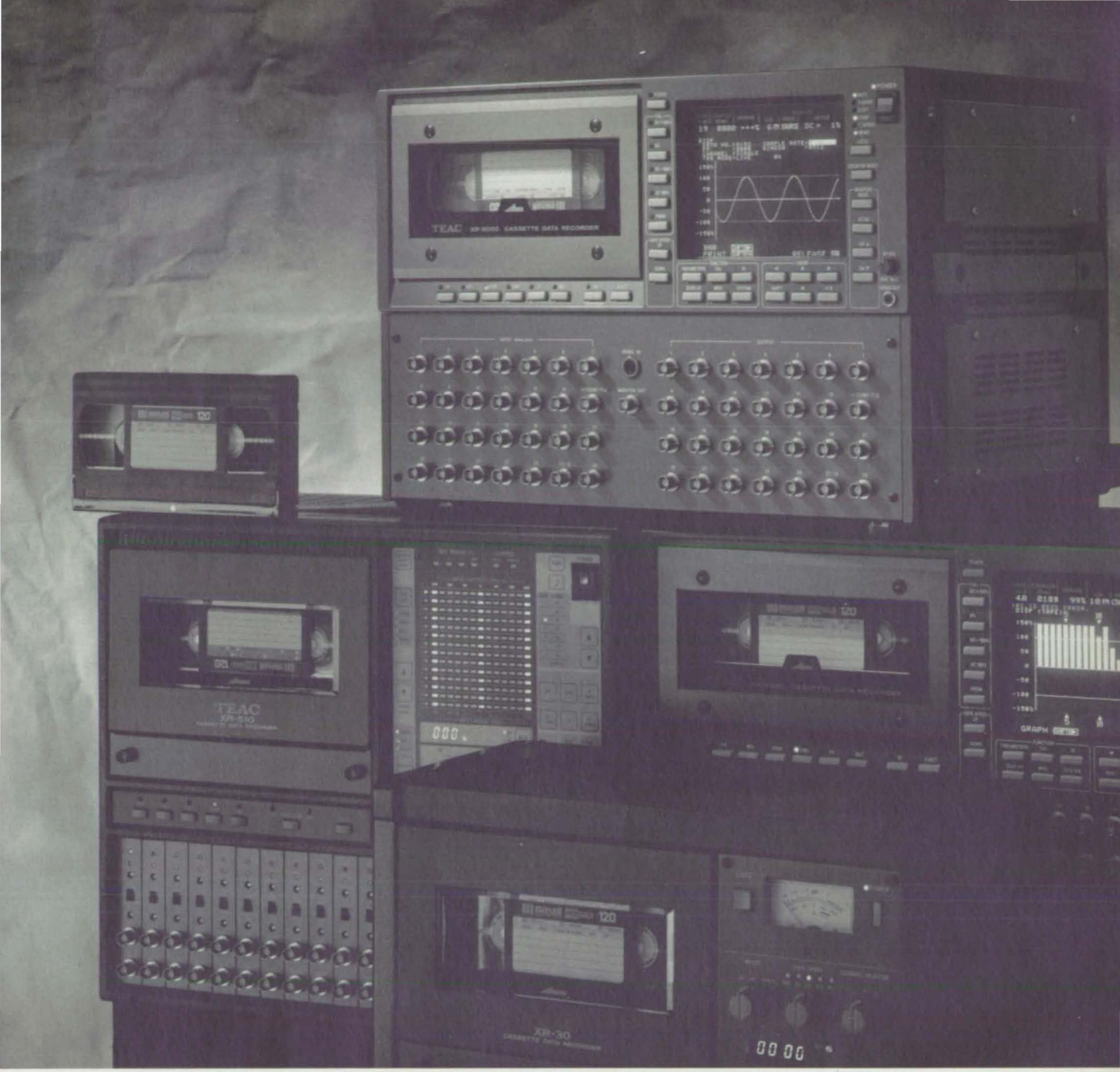


Figure 2. The **Index of Refraction** in the reflector sublayers would alternate between a higher and a lower value. The higher value would be less than the effective index of refraction of the waveguide layer.



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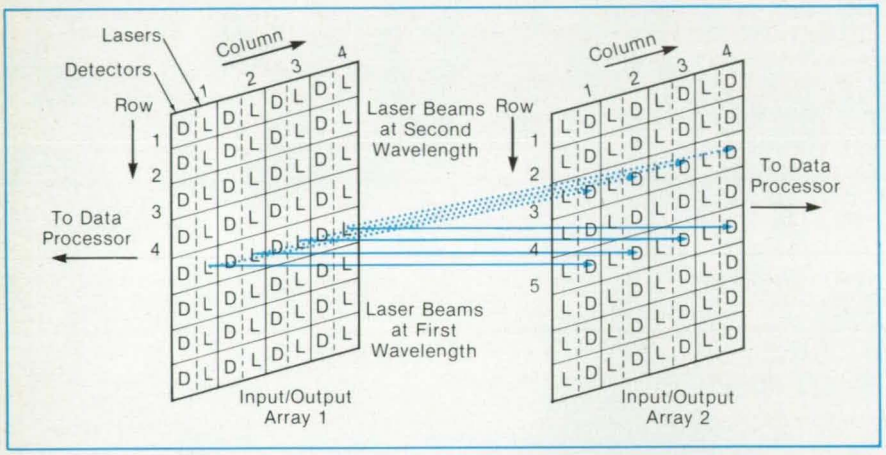
Optical Backplane Interconnection

Output and input devices would be switched by changing wavelengths.

Langley Research Center, Hampton, Virginia

The optical backplane interconnection (OBIT) is a method of optically interconnecting many parallel outputs from a data processor to many parallel inputs of other data processors by optically changing the wavelength of the output optical beam. Heretofore, most interconnections in the backplanes of data processors have been made by electronic switch connections, and both a command and an electrical or optical connection have been required for each switch connection. For example, an optical matrix•vector switch, in which a column of optical emitters can communicate with a row of optical detectors by use of a liquid-crystal light valve placed between the emitters and detectors, requires a column and row address for each switch connection. More than one connection can be made, but each connection requires a column and a row switch address. The OBIT requires only one command: the exact wavelength necessary to make the connection between the two desired processors.



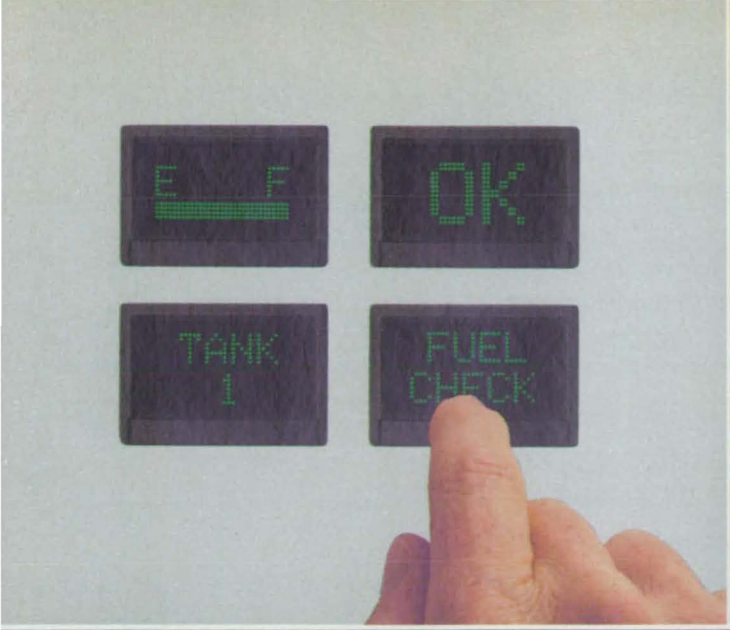
A Change in Wavelength in light emitted by a laser in array 1 would cause a change in the angle of the laser beam, causing the beam to strike a different detector in array 2.

The OBIT is envisioned to have an array of outputs and inputs, such as those shown in the figure. The selection of which output is to be connected to which input would be made by use of a wavelength that undergoes a particular angle of deflection. The method and means for generating and selecting a given wavelength is provided by an opto-electronic integrated circuit (not shown) that is part of the overall design. The array control would basically select the wavelengths by which the processors could communicate. In addition, it could be possible, depending upon the design configuration, to have one laser/detector array emit more than one wavelength and communicate with an adjacent array in more than one location simultaneously.

The limits to the numbers of rows and columns of the arrays would depend on the limits on the change in the angle of deflection caused by a change in wavelength when the emitting beam is passed through a diffraction-grating or other optical deflector. The limits would be a function of the properties of the gratings and the ability to shift wavelengths in the lasers or other sources of light. The numbers of parallel interconnections that could be made would be limited by the loss mechanisms in the coupling scheme and the availability of optical amplification.

One of the materials from groups III and V of the periodic table of the elements, probably GaAs/AlGaAs or InP/InGaAs/InGaAsP, would be the medium for fabrication of the integrated optical structure. An approximate physical model of the device was implemented with fiber-optic couplers, lasers of different wavelengths, and a diffraction grating. Many features, including smallness, would make it advantageous to incorporate an OBIT (as opposed to an electrical or matrix•vector optical switching device) into an integrated optical device. The OBIT technique would simplify or eliminate wiring and would speed the transfer of data over existing electrical or optical interconnections. Computer hookups and fiber-optical communication networks would benefit from this concept.

This work was done by Herbert D. Hendricks of **Langley Research Center**. *For further information, Circle 50 on the TSP Request Card.* *LAR-14052*



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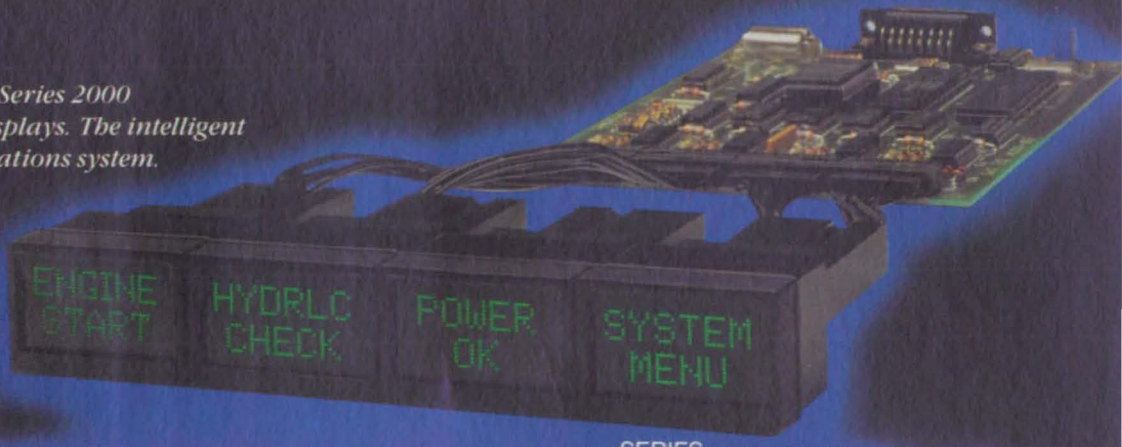


SERIES

VIVISUN 2000™

Circle Reader Action No. 309

Algorithmically Specialized Parallel Architecture for Robotics

The system is an MIMD-SIMD parallel architecture capable of exploiting parallelism in different forms and at several computational levels.

NASA's Jet Propulsion Laboratory, Pasadena, California

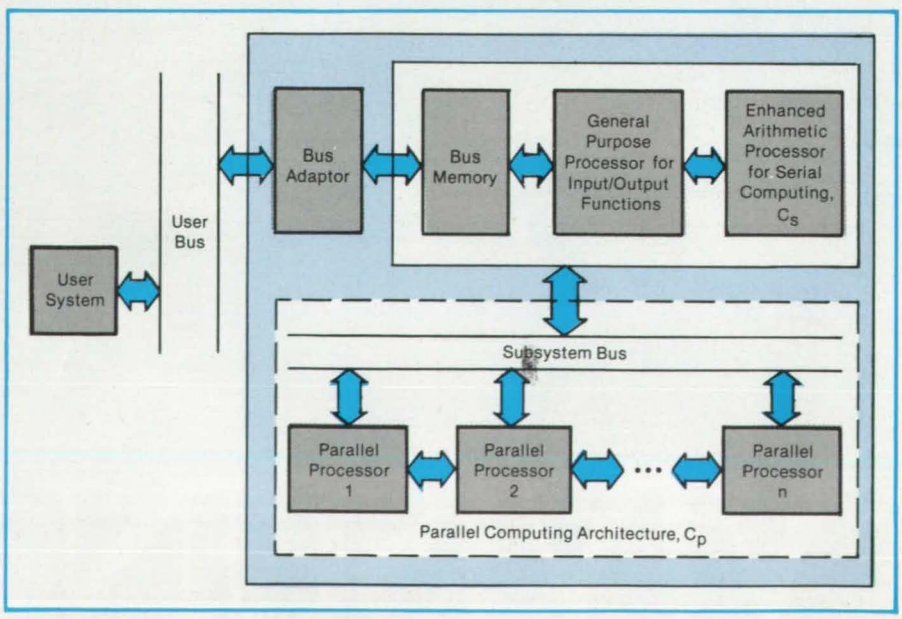
A computing system called the Robot Mathematics Processor (RMP) contains a large number of processor elements (PE's) connected in various parallel and serial combinations that are reconfigurable via software. The RMP is a special-purpose architecture designed for solving diverse computational problems in robot control, simulation, trajectory generation, workspace analysis, and the like. It is an algorithmically specialized parallel architecture capable of exploiting the common properties of the parallel algorithms developed for this class of problems. It can exploit parallelism in different forms and at several computational levels in these computation-intensive applications.

From the perspective of interaction with other computing equipment, the system can be regarded as a processor that can be attached to the bus of the external host as a part of bus memory. The system interacts with the external host processor(s) controlled by the user(s). The external host processor can be any stand-alone computer or a bus-oriented multiprocessor system. The data and instructions from the external host to the RMP and the results from the RMP to the external host are communicated through a dual-access shared memory that is part of the bus memory. The RMP is activated by a procedure call from the external host, which is executed via a "write" operation in a designated address and is interpreted as an "interrupt" by the RMP. This memory mapping scheme provides maximum flexibility and speed inasmuch as the data-transfer rate is limited by the read/write cycle of the external host. A bus adapter provides the required interface for different buses.

The system (see figure) contains a general-purpose processor, which is called the internal host, and *n* single-instruction multiple-data (SIMD) parallel processors, which are called "cells." The host processor is the control unit of the system: it handles the interface with the external host, controls the activities of the cells, and performs the required input/output operations. It also handles the serial and data-dependent computation. The ensemble of cells performs parallel computation. By using two synchronization mechanisms, the ensemble can perform parallel computation in different combinations of multiple-instruction multiple-data (MIMD) and SIMD modes. The first mechanism is a global clock-based one similar to systolic arrays. The cells are driven by a common clock that allows the ensemble to perform parallel computation in a two-level SIMD/SIMD mode. The second mechanism is a local data-driven one similar to wave front arrays that allows each cell to operate asynchronously and the ensemble to perform parallel computation in a two-level MIMD/SIMD mode.

The major advantage of the system lies in the design of the cells, which provides flexibility and reconfigurability superior to those of previous SIMD processors. Each cell contains six processor elements (PE's), which are simple floating-point processors capable of performing such primitive operations as multiplication, addition, and the like. Each PE has a three-bus architecture with an internal data path that enables such accumulative operations as sum-of-product and Newton–Raphson iterations for performing division. Two table lookup units (TLU's) provide the seed values for initiating the division operations by Newton–Raphson method. They are also used for trigonometric-functions evaluation.

Basically, the PE's are organized in two groups, each containing three PE's. In solving problems for robot control and simulation, the two groups can perform two basic (matrix-vector) operations in parallel, while each group can exploit parallelism in the operation. Also, each group can be considered as an independent SIMD subsystem or a pipeline stage, making it possible to decompose the whole system into two independent MIMD-SIMD parallel architectures or two *n*-stage pipes. The cell control mechanism is designed to provide such flexibility and reconfigurability while also minimizing the instruction length and complexity. Each cell has three control units: one master control unit (or microcontroller) and two slave control units (or nanocontrollers). The master control unit controls the overall activities of the cell and provides the instruc-



The **ARASH-URCH** is a flexible parallel processing system that is reconfigurable via software. It is designed to exploit parallelism to a high degree to speed computations in robotic and image-processing applications.

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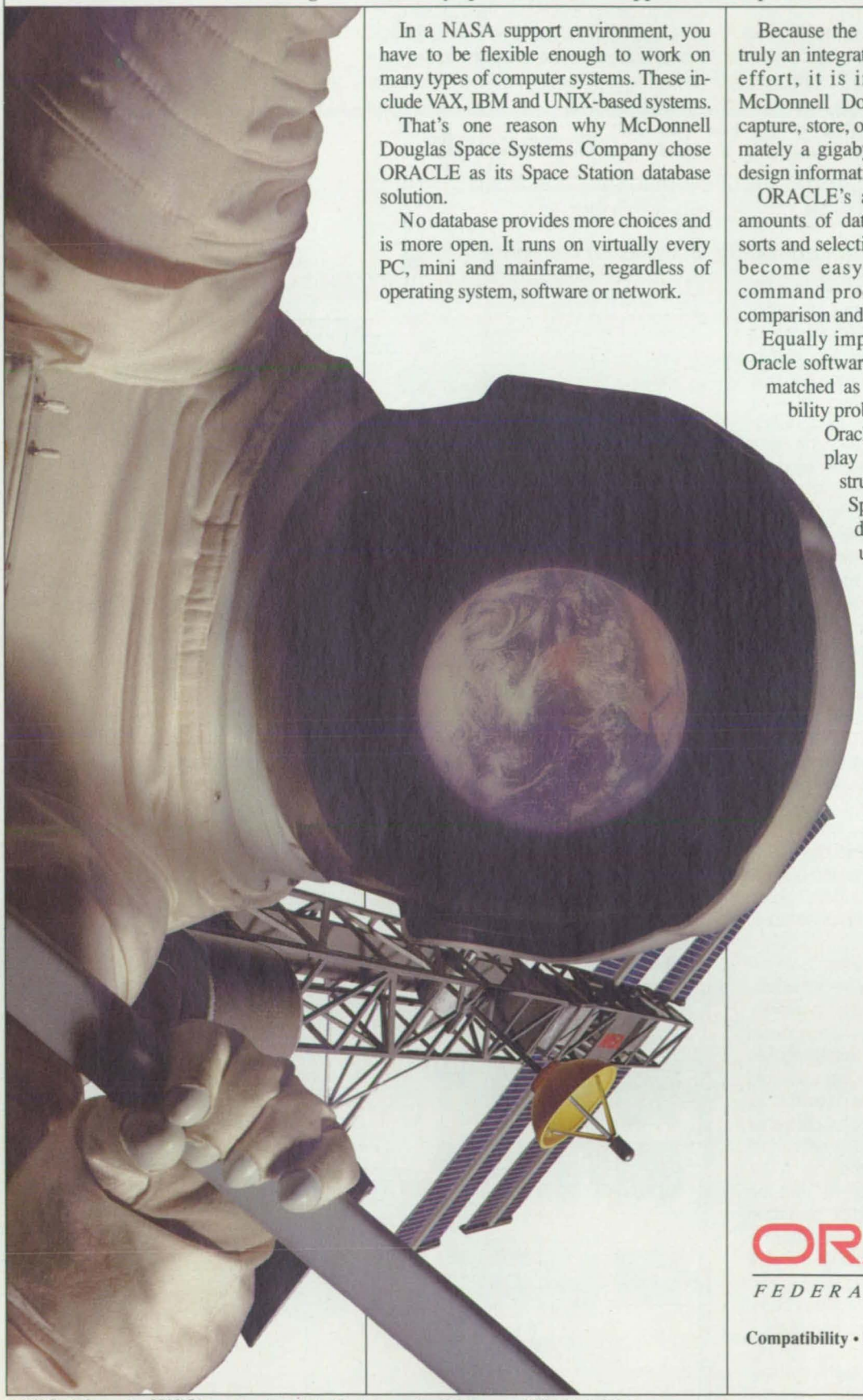
McDonnell Douglas selects truly open database to support NASA Space Station effort.



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tions to be executed by all the PE's. Each slave control unit performs the read/write operations for one group of PE's. The slave control units are run by a clock twice faster than that of the master control unit. This allows a complete overlapping of the read/write and arithmetic operations. In addition, data can be fed to the PE's with adequate speed while also reducing the memory architecture complexity.

The direct path among the PE's of each group enables a linear interconnection among them. A multiplexer is used to provide other topologies among the PE's of each cell. Under the control of the master control unit, the multiplexer can establish a ring topology for each group, or a ring topology among all PE's of the cell, or a linear topology among all PE's of the cell. The latter case is used to transform the whole system into a uniform "pipe."

This work was done by Amir Fijany and Antal K. Bejczy of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 13 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office — JPL [see page 14]. Refer to NPO-17632.

Neural Networks of VLSI Components

"Building-block" electronic circuits would be assembled into analog/digital parallel-processing networks.

NASA's Jet Propulsion Laboratory, Pasadena, California

A concept for the design of an electronic neural network calls for the assembly of very-large-scale integrated (VLSI) circuits of a few standard types. Each VLSI chip, which would contain both analog and digital circuitry, would be used in modular or "building-block" fashion by interconnecting it in any of a variety of ways with other chips. Depending on the specific modular components and connection pattern selected to represent the input, output, and hidden (intermediate between input and output) layers of neurons, the assembly could be made to perform a specified feedforward and/or feedback neural-network function in which the neurons in each layer would process data signals concurrently (in parallel).

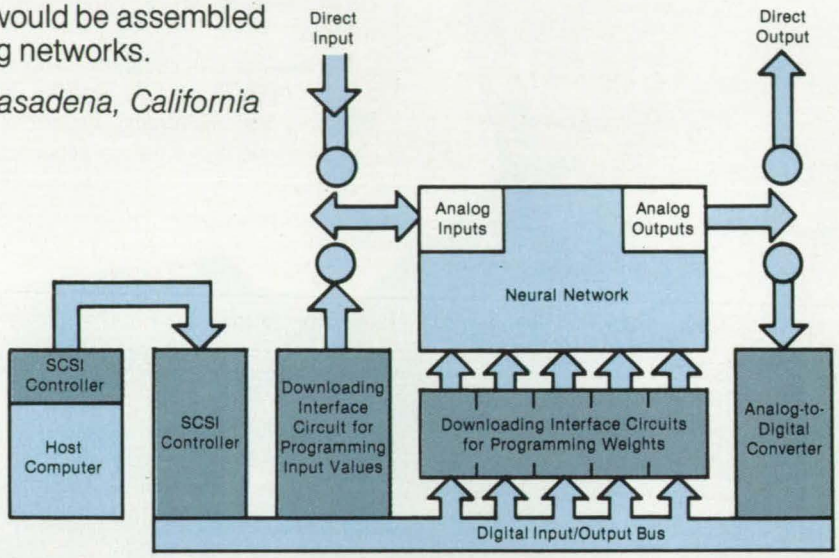

Figure 1. A **Feedforward Neural Network** in a typical situation would operate under the control of a host computer and would receive inputs from, and send outputs to, other equipment.

Figure 1 illustrates a generic feedforward neural network operating under the control of a host digital computer. A small-computer-system-interface (SCSI) bus would be used to transfer all network weight (that is, synaptic-connection-strength), input, and output values between the host computer and the neural network. In addition, inputs to and outputs from the network could be switched directly to signal lines associated with an application.

Digital weight and input values from the host computer would be converted to analog signals that would be stored in capacitors on the VLSI circuit chips. Because an analog-to-digital converter typically requires much space on a VLSI chip, space would be saved by the use of only one off-chip, a highly precise analog-to-digital converter multiplexed in time to serially refresh all the capacitor charges on one chip. A disadvantage of this approach — that the analog weight signals would be quantized by the lengths of the digital words and the precision of the analog-to-digital converter — would be more than compensated by the ease with which the weights could be manipulated by the host computer.

A neural network for a typical application might contain as many as 1,000 neurons in the input layer and smaller numbers of neurons in the hidden and output layers. Such a network might be used to process images, for example. The network illustrated in Figure 2 would contain custom-designed complementary metal oxide/semiconductor mixed analog/digital circuits of three types. Input signals would be fed to the network via multiplexing input neuron chips that would store and buffer the input voltages. Hidden- and output-layer neurons would be implemented by variable-gain neuron chips that would apply variable-slope sigmoidal activation functions to the sums of signals coming from the previous synaptic layer. Each connection (synapse) chip would have 32 summed outputs that would be fully connected to 32 inputs, for a total of 1,024 on-chip synapse cells. Inputs and outputs could be directly connected to other synapse chips to obtain larger synaptic layers. Downloading interface circuits would store weights and input values in digital form and would periodically update the charges on the appropriate storage capacitors.

This work was done by Silvio P. Eberhardt of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 129 on the TSP Request Card. NPO-17833*

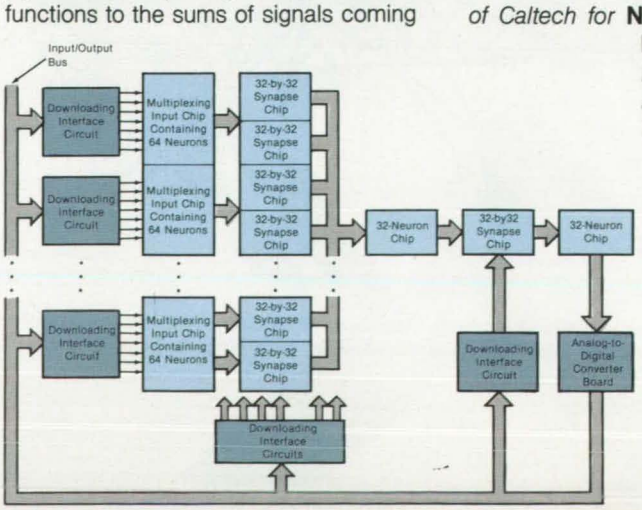

Figure 2. **Modular VLSI "Building-Block"** circuits would be assembled into a neural network.

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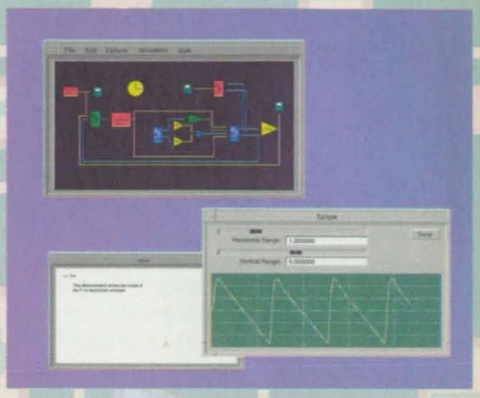

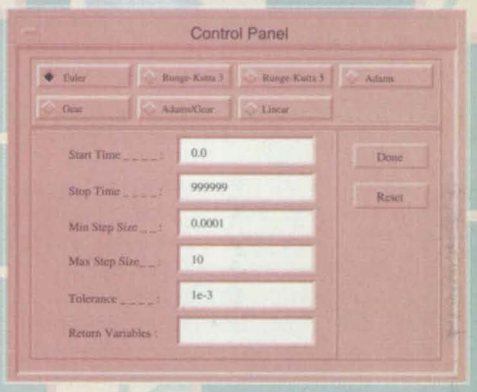

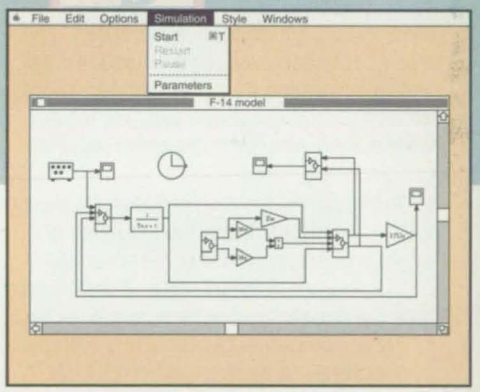

(Top) Use the Scope block to see the "real-time" response of this F-14 model during the simulation; (Center) Specify simulation parameters via dialog boxes or the MATLAB command line; (Bottom) SIMULAB takes full advantage of the X/Motif and Macintosh windowing systems.

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Simplified Learning Scheme for Analog Neural Network

Synaptic connections are adjusted one at a time in small increments.

NASA's Jet Propulsion Laboratory, Pasadena, California

A simplified gradient-descent learning scheme for an electronic neural-network processor is less efficient than the better-known back-propagation scheme is, but offers two advantages: (1) it is easily implemented in circuitry because the data-access circuitry is separated from the learning circuity; (2) the independence of the data-access circuitry makes it possible to implement feedforward as well as feedback networks, including those of the multiple-attractor type. [The output vector of a multiple-attractor network tends to remain at one of a multiplicity of equilibrium points (the attractors) until the input changes enough to push the output to another equilibrium point.] Multiple-attractor networks are important in such applications as the recognition of patterns.

Figure 1 illustrates a simple neural network that includes an input layer, an output layer, and a middle (hidden) layer of neurons. Each neuron is represented as an analog amplifier circuit, the output of which is a nonlinear function (called the "activation function") of its input. The input and output terminals of all the neurons are connected to each other by a matrix of resistors that represent synapses. The matrix includes both feedforward and feedback synapses. The strength of each synaptic connection is adjusted by varying its conductance; where no connection is desired (e.g., no feedforward or feedback along a specific path), the conductance is set to zero.

To initiate the learning process, an input vector of stimuli is fed to the input neurons, and the resulting vector, **o**, of responses of output neurons is measured and compared with the desired response or target vector, **t**. The conductance of one of the synaptic connections is then changed temporarily by a small amount, and the effect on **o** is observed. Thus, the gradient is directly and experimentally determined. If the change causes **o** to move toward (or away from) **t**, then the conductance of that connection is changed in the same (or the opposite, respectively) direction as that of the temporary change, by a small amount related to the error between **o** and **t**. If the temporary change causes no change in the output, then the connection is allowed to remain at its original strength. This procedure is repeated, one synapse at a time, until the entire synaptic matrix has been updated. The procedure for the entire matrix may have to be repeated many times for each stimulus/response pair until the network has learned the entire set of correct responses.

Figure 2 is a simplified schematic diagram of the learning circuitry of a synaptic matrix. Each synapse includes a third terminal for the modification of its connection strength. An electronic programming switch can be closed to connect each synapse to the update line. The learning controller consists of circuitry that updates each synapse in turn by closing its programming switch (via the row- and column-selecting lines), changes the conductance of the synapse slightly, and evaluates the effect of the change.

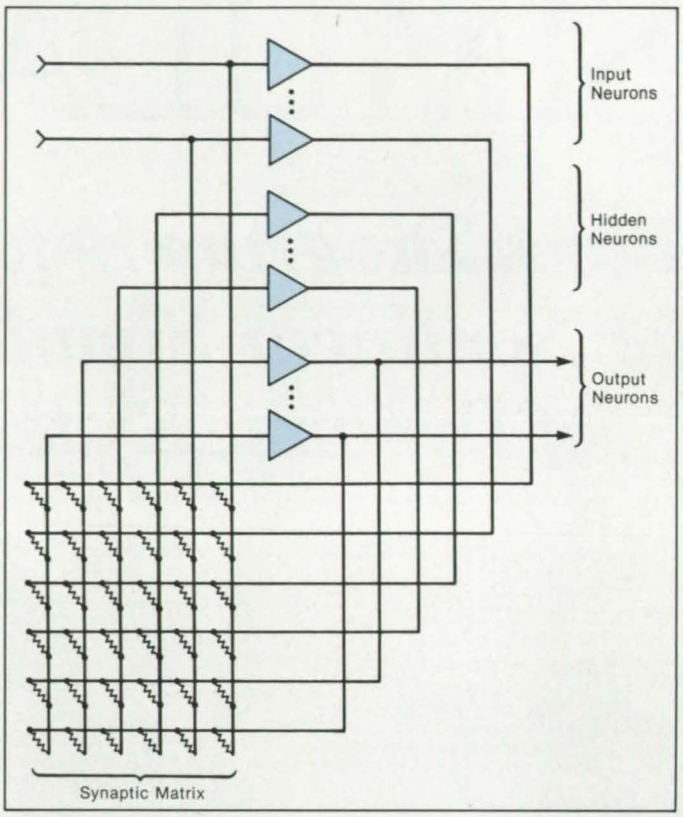
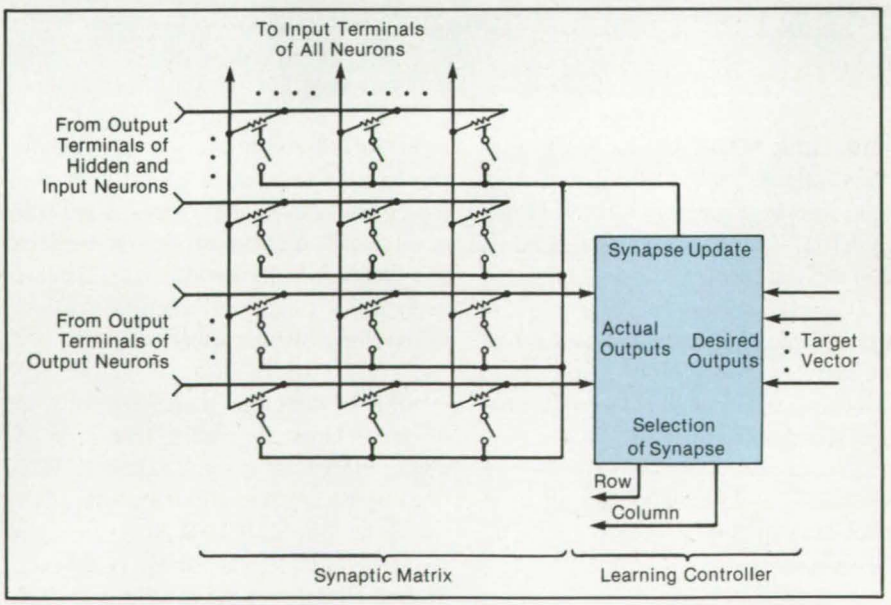


Figure 1. This **Simple Neural Network** includes a synaptic matrix of resistors that are to be updated in a learning process.

Figure 2. This **Learning Subsystem** semipermanently adjusts the resistances of a synaptic matrix like that of Figure 1, in response to changes in the output error of the neural network that occur when those resistances are temporarily changed by small amounts.



This work was done by Silvio P. Eberhardt of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 154 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 14]. Refer to NPO-17664.

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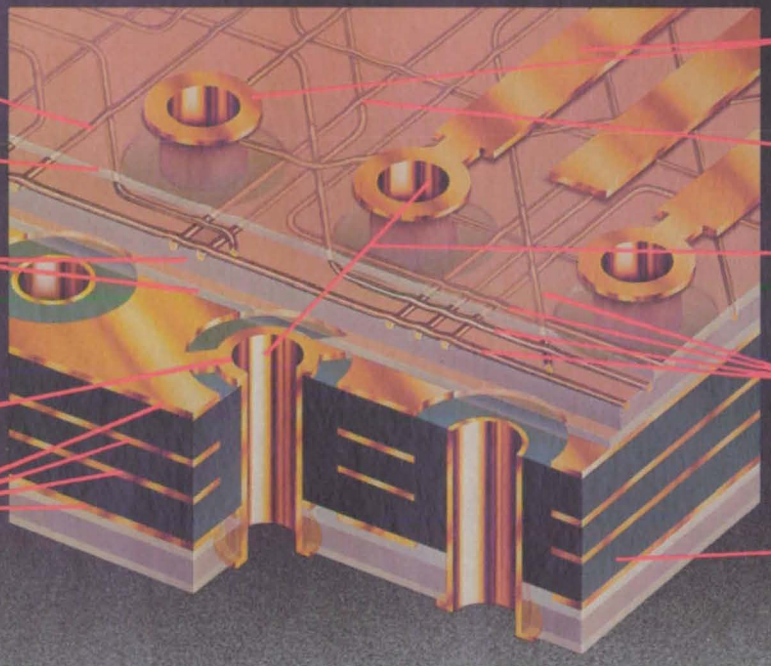

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Quad-Port Transceivers for a Dual-CRR LAN

Redundancy protects against failures.

NASA's Jet Propulsion Laboratory, Pasadena, California

Quad-port fiber-optic transceivers have been demonstrated successfully as the physical-layer interface units in the WhisperNet — a local-area network (LAN) of computers and other devices in communication with each other. The WhisperNet is arranged in a fully redundant configuration in which each quad-port transceiver communicates over four pairs of optical fibers with signals flowing as though in two sets of counterrotating rings (CRR's) (see Figure 1). The WhisperNet meets the interface specifications of the Institute of Electrical and Electronics Engineers (IEEE) Standard 802.3 and Ethernet Version 2.0.

The WhisperNet concept eliminates the need for repeaters (other than the quad-port transceivers), star couplers, and a wiring center. One WhisperNet ring is more versatile than is one segment of Ethernet coaxial cable, to which it corresponds. The quad-port transceiver performs the function of the physical layer according to the Ethernet specification, but by use of optical fiber instead of coaxial cable.

Once a terminal, computer, printer, or other device is connected to the WhisperNet, it can gain access to many other devices on the network at a speed of 10 Mb/s via virtual connections. As used here, "virtual connection" denotes a connection between two devices via the network, in which the network becomes imperceptible in that it functions as a wire between the two devices and in which different speeds, parities, flow controls, and other characteristics of ports are resolved automatically within the network.

Each quad-port transceiver contains two independent dual-port transceivers (see Figure 2), each of which serves one of the CRR's. The quad-port transceivers implement the special dual-CRR features that provide the redundancy that enables the network to tolerate multiple failures. These features are the following:

- Normally, the Ethernet message is transmitted on two CRR's (four fiber-optic rings).
- The network can survive a break in a cable (that is, an optical fiber) in one of the rings without degradation of performance.
- A single failed-node bypass does not isolate the node from the network.
- The network automatically reconfigures itself after breaks in cables on both rings, interconnecting the operating sections of both rings into a larger C-shaped ring.
- A node can be added to, or moved within, the network without causing the network to fail.

Because of its high reliability and availability and its "fail-soft" nature, the network is well suited to military and critical commercial applications.

This work was done by Joseph A. Wiencko, Jr., and Gary R. Mangus of Fiber-Com, Inc., for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 146 on the TSP Request Card. NPO-17541*

Figure 1. **Each Node of the Dual-CRR LAN** contains a quad-port transceiver that serves four pairs of optical fibers.

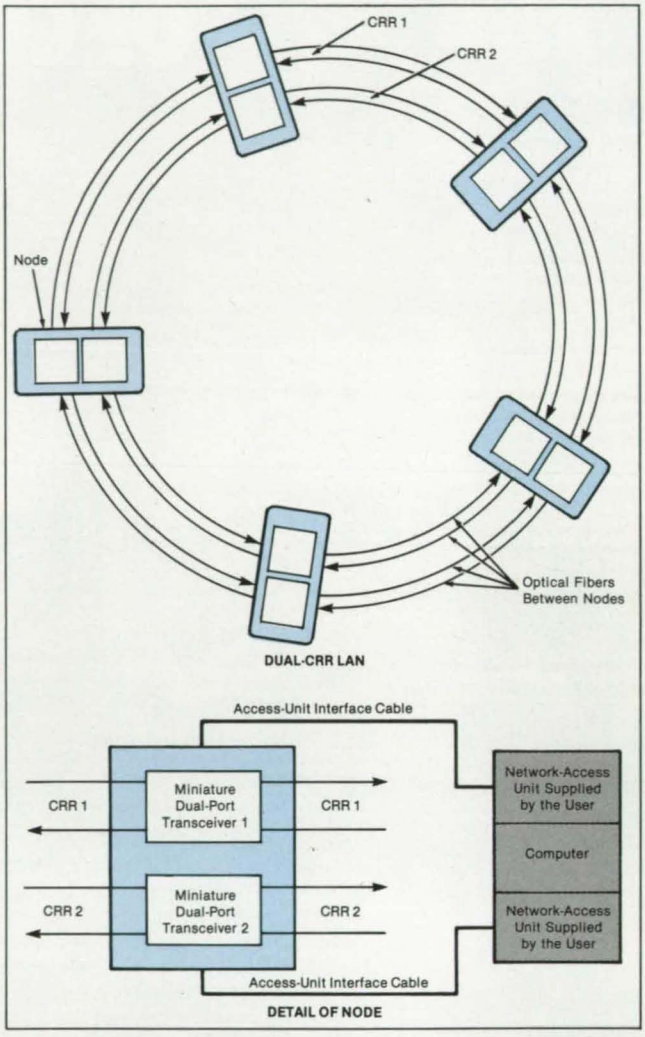
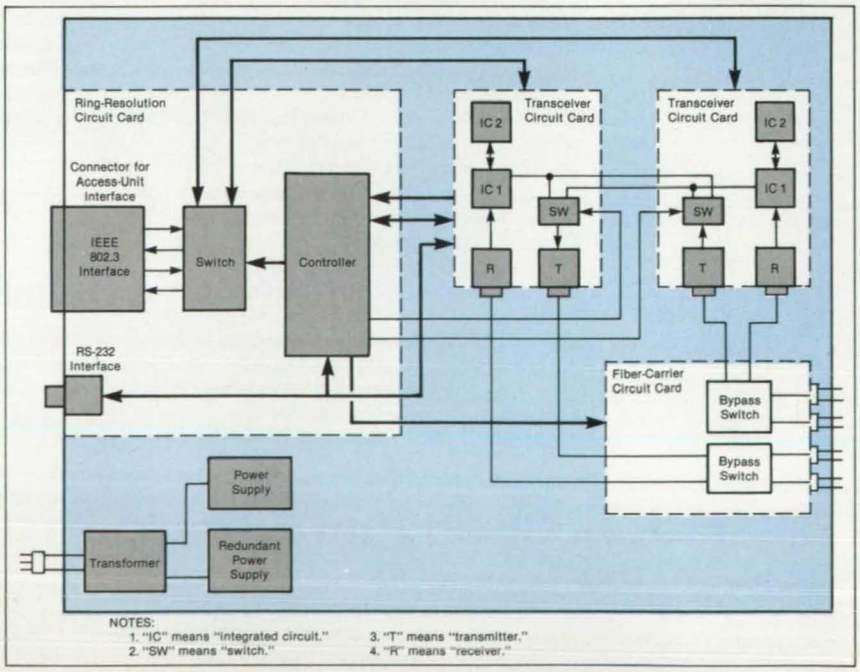


Figure 2. A **Quad-Port Transceiver** consists of two dual-port transceivers and ancillary equipment in a compact package. This transceiver serves as the interface between the optical fibers and the external computing devices.



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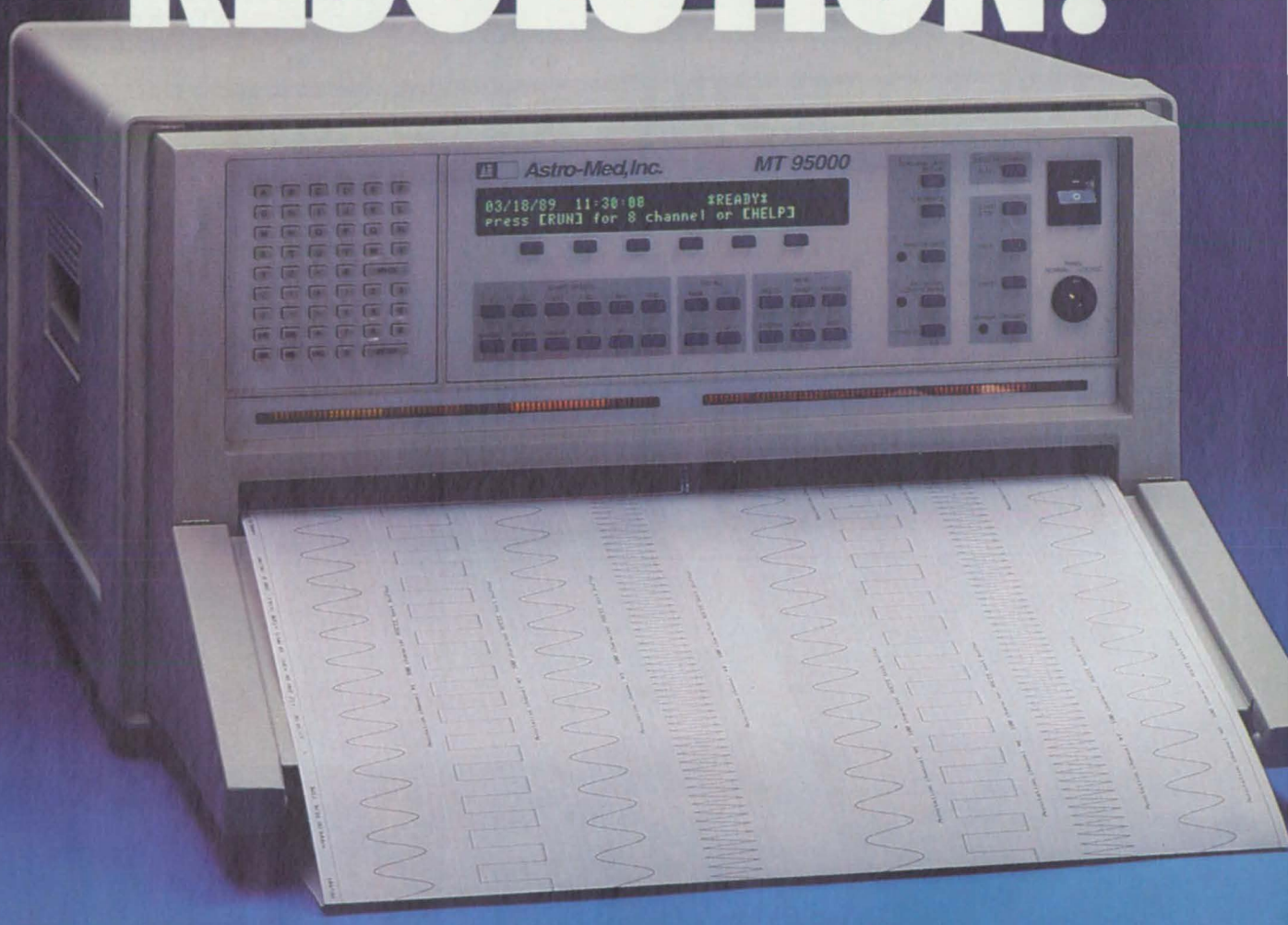

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Circle Reader Action No. 405

Self-Testing Static Random-Access Memory

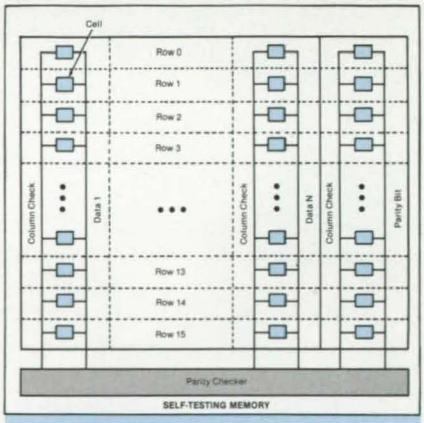
Errors could be detected and corrected during operation.

NASA's Jet Propulsion Laboratory, Pasadena, California

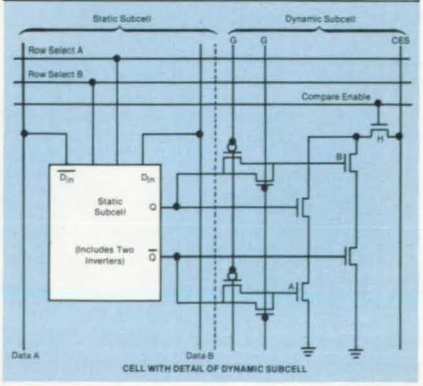
A proposed static random-access memory for a computer would feature improved error-detecting and -correcting capabilities. Unlike schemes that involve the use of Hamming codes to detect and correct errors after data have been read out of a memory, the new self-testing scheme would provide for the detection and correction of errors at any time during normal operation — even while data are being written into the memory. Unlike in prior error-detection and -correction schemes, faults in the equipment (e.g., memory cells stuck at "one" or "zero") that may cause errors in the output data (depending on the input data) could be detected by repeatedly testing every memory cell to determine whether it can still store both "one" and "zero," without destroying the data stored in the memory.

Each cell of the memory would include a static subcell and a dynamic subcell, which would be part of a built-in comparator (see figure). Pass transistors G and G would store the true and complement values of a datum in the static subcell as charge on gates A and B of the comparator. When a datum was written into the cell, it would be stored in both subcells; then the pass transistors would be turned off so that both subcells would be isolated. The static and dynamic subcells would be continuously compared to each other by the built-in comparator. The output of the comparator would be connected to transistor H, which would normally be turned on. The output of transistor H would be connected to a signal line called the "column error signal" (CES) line shared by all memory cells in the same column. A transient fault that flipped either subcell of a memory cell in a column would thus be indicated immediately by a CES.

The memory could be made to recover from transient errors by combining the use of a parity bit with a binary search procedure. In this procedure, the H transistors in progressively narrowing groups of rows would be alternately turned on and off until a row giving rise to CES's in each column was identified. A parity check would then be performed on the faulty row to determine whether the error was caused



SELF-TESTING MEMORY



CELL WITH DETAIL OF DYNAMIC SUBCELL

The **Self-Testing Static Random-Access Memory** would detect and correct both "hard" and "soft" errors at any time during normal operation—even while data are being written in or read out.

by the identified static or dynamic subcell. An error could be corrected by either reversing the datum in the faulty static subcell in the case of a parity error or by refreshing the datum in the faulty dynamic subcell where there was no parity error. The binary search would then be backtracked to detect and correct single bit errors in other rows.

This technique could correct single bit errors in any number of words in memory. In the worst case, the time needed to identify a faulty row would be proportional to $\log_2(2N)$, where N is the number of rows. However, backtracking would cause the average identification time to decrease with an increase in the number of faulty rows.

The search of faulty rows could be done during normal memory read/write operations because the CES lines would be independent of the data lines. When a faulty row was isolated, it would be read out, and the faulty bit indicated by the CES would be reversed immediately. This concept also provides for delayed commitment in writing a datum into a cell by temporarily separating the two inverters in the static subcell. The new datum could be loaded dynamically into only one inverter while retaining the previous datum dynamically in the other inverter. If the new datum were to prove faulty, the lower inverter could be used to restore the previous datum.

This work was done by Savio Chau and David Rennels of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 140 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 14]. Refer to NPO-17939.

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Experiments in Multivariable Adaptive Control of a Flexible Structure

A six-input, six-output adaptive control system is successfully demonstrated.

A report describes experiments in the use of a six-input/six-output multivariable adaptive control system to suppress vibrations in a complicated flexible structure. This represents the first time a multivariable adaptive control system of this size has ever been demonstrated experimentally on a physical structure. The structure, 18.5 ft (5.6 m) in diameter, resembles both an antenna and a large spider web. It includes a circular central hub connected to 12 radial ribs, and a large flexible boom that hangs below the hub. The ribs are connected together by two concentric rings of pretensioned wires that couple the circumferential motions of the ribs. This structure is intended to exhibit low modal frequencies and complicated dynamics like those of large structures in outer space. However, the conclusions drawn from this general line of research are also relevant to such applications as the active suppression of wind and earthquake vibrations in tall buildings and other large terrestrial structures.

Collocated sensor-and-actuator pairs were placed at two stations on the hub and near the inner end of each of the ribs 1, 4, 7, and 10. The hub actuators were linear force actuators that applied torque to the hub by pushing on its circumference. The hub sensors were rotary variable-differential transformers that measured the rotary vibrations of the hub. The rib actuators were solenoid-based actuators that provided torque by reacting against mounts on the hub. The rib sensors were linear variable-differential transformers that measured circumferential displacements of the ribs.

In a previous series of experiments on the same structure, only two collocated sensor-and-actuator pairs were installed — both on the hub. In that two-input/two-output system, the dynamics of the system were thus intentionally limited to the "boom-dish" vibrational modes that could be observed and controlled from the hub. In the experiments described in this report, the six-input/six-output system added the pure "dish" vibrational modes to those that are both observable and controllable, thereby enriching the dynamics of the system and extending control authority over a larger domain of the structure.

The adaptive-control algorithm was developed to control the first 4 boom-dish modes and the first 12 dish modes of the structure as defined by a finite-element model of its dynamics. In implementing the control scheme, the researchers encountered some practical difficulties stemming from the use of a Kalman filter to process angular-position measurements into

angular vibrational speeds and from associated problems of limited computational power and sampling rates. Manual adjustment of the filter bandwidths and gain weightings proved to be necessary to provide stable closed-loop adaptive control and to optimize the adaptive performance. Nevertheless, the researchers conclude that the six-input/six-output control system represents a significant upgrade relative to the two-input/two-output system, yielding a significant improvement in spatial controllability and effective damping of a largest set of modes.

This work was done by Che-Hang C. Ih, David S. Bayard, Asif Ahmed, and Shyh J. Wang of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Experiments in Multivariable Adaptive Control of a Large Flexible Structure," Circle 36 on the TSP Request Card.*
NPO-17846

Displaying Computer Simulations of Physical Phenomena

Visual, aural, tactile, and kinesthetic effects can be used to teach such physical sciences as the dynamics of fluids.

A paper discusses computer simulation as a means of experiencing and learning to understand physical phenomena. The paper covers both present simulation capabilities and the major advances expected in the near future.

Today, the flow of air about a complete aircraft can be simulated on a supercomputer, and this dynamic, three-dimensional simulation can be viewed interactively on advanced graphics workstations. The viewer can zoom into a region of the simulation or rotate the viewing position about the region to study the display in more detail. Examples in other fields can also be cited.

But although graphics workstations have improved the interface between the scientist and the computer, they have filled only a small portion of the total bandwidth available for a human to exchange information with the environment. The primary improvements have been in visualization — specifically in the quality of the picture and the speed with which it is rendered.

Research on simulated environments shows that immersion of the human in the simulation environment is much more effective than is simply displaying a picture on the video screen of a workstation. In one series of experiments, the display of the simulated environment filled the subject's entire field of view, and six-degree-of-freedom controls and voice recognition were used. It is now technically feasible to implement many features of this more complete simulated environment.

The paper describes an ideal simulated environment and compares the state of the art with respect to the following features:

- Controls for manipulation,
- Voice input,
- Sensory feedback from the environment (sound, motion, and position),
- Spatial and color resolution,
- Frame-repetition rate,
- Field of view,
- Accuracies of simulation models, and
- Ability to highlight important features and suppress less-important ones.

The paper recommends that classrooms in universities, government, and industry be linked to advanced computing centers so that computer simulations can be integrated into the education process. Large-bandwidth transmission facilities for computer, video, and audio information of the types that will make such links possible are now being installed.

This work was done by Val Watson of **Ames Research Center**. *To obtain a copy of the report, "A Breakthrough for Experiencing and Understanding Simulated Physics," Circle 68 on the TSP Request Card.*
ARC-12502

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Circle Reader Action No. 411

Physical Sciences

Hardware, Techniques, and Processes

Oscillating Thermal Switch

The transferred heat would actuate a device with no moving parts.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed heat switch would transfer heat from a source to a sink in regular cycles. The switch is intended for use in a gas-sorption refrigerator. This type of refrigerator produces heat loads that must be connected and disconnected in precisely timed periods. The proposed heat switch, unlike those now available, would be self-sustaining; it would be actuated by the transferred heat, contain no moving parts, and need no external heaters or electronic circuitry to synchronize heat-transfer periods or control heat-transfer rates.

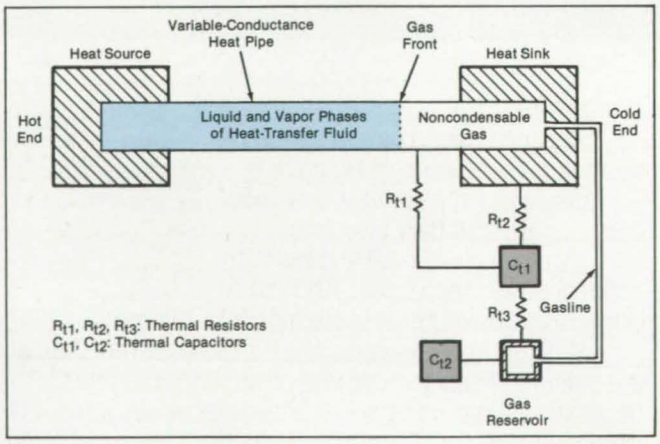
The proposed heat switch would contain a variable-conductance heat pipe. The heat-pipe component of the switch would transfer heat from a heat source to a heat sink when its reservoir of noncondensable gas is cold. The heat pipe would not transfer heat (i.e., would turn off) when the reservoir is hot. The pipe would alternate between on and off at a rate determined by thermal resistance and capacitance elements attached to it, to the heat sink, and to the reservoir. The thermal lags caused by the thermal resistors and capacitors would keep the variations of temperature of the heat pipe out of phase with those of the reservoir, thereby sustaining the temperature oscillations and providing regular on/off thermal switching.

At the beginning of a cycle, a relatively large volume of the noncondensable gas would separate the liquid and vapor in the heat pipe from the heat sink, decoupling the pipe thermally from the sink (see figure). In this state, thermal capacitor 1 and the gas reservoir would be transiting from hot to cold. Then energy from the heat sink would raise the temperature of the heat pipe. The vapor in the pipe would then move into the cold end, forcing the noncondensable gas into the reservoir. Upon making contact with the cold end, the vapor would transfer heat from the source to the sink.

At this time, the thermal path to thermal capacitor 1 would be exposed to the hot liquid and vapor. Heat would flow from the pipe through thermal resistor R_{t1} into thermal capacitor 1 (C_{t1}), raising its temperature. Heat would flow from this thermal capacitor through thermal resistor R_{t3}, raising the temperature of the reservoir and its thermal capacitor C_{t2}. R_{t3} and C_{t2} would be chosen so that the reservoir would start to heat only when the temperature of capacitor 1 approached that of the pipe.

As the reservoir is heated up, it would drive gas into the heat pipe, forcing the gas front away from the cold end. Eventually, the front would push the vapor away from the sink, and the pipe would turn off; that is, heat would no longer flow from the pipe to the sink or to capacitor 1. Capacitor 1 would start to cool down by transferring heat through R_{t2} to the heat sink. Again, R_{t3} and C_{t2} would be large enough so that the reservoir would start to cool only when the temperature of capacitor 1 approached that of the heat sink. The system would then be in the initial condition, and the cycle would repeat. A difference of 50 °C or more between the temperatures of the source and sink should be adequate to sustain the oscillations.

This work was done by S. Walter Petrick of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 31 on the TSP Request Card.*
NPO-17125



When the **Gas Front** is at its far left excursion, no heat would flow from the heat pipe in the heat sink; that is, the switch would be off. When the gas front recedes to the far right, heat would flow from the pipe to the heat sink; that is, the switch would be on. The thermal resistors and thermal capacitors would produce thermal lags in heating and cooling of the gas reservoir, thereby restarting a new on/off cycle as soon as one ends.

Airborne Laser Polarization Sensor

This instrument measures polarization characteristics of the Earth at three wavelengths.

Goddard Space Flight Center, Greenbelt, Maryland

The Airborne Laser Polarization Sensor (ALPS) measures the optical polarization characteristics of the land surface. The ALPS is designed to be flown at altitudes of $\leq$ 300 m to minimize any polarizing or depolarizing effects of the intervening atmosphere and to look along the nadir to minimize any effects that depend on the look angle. The data from the measurements are used in conjunction with data from ground surveys and aircraft-mounted video recorders to refine mathematical models

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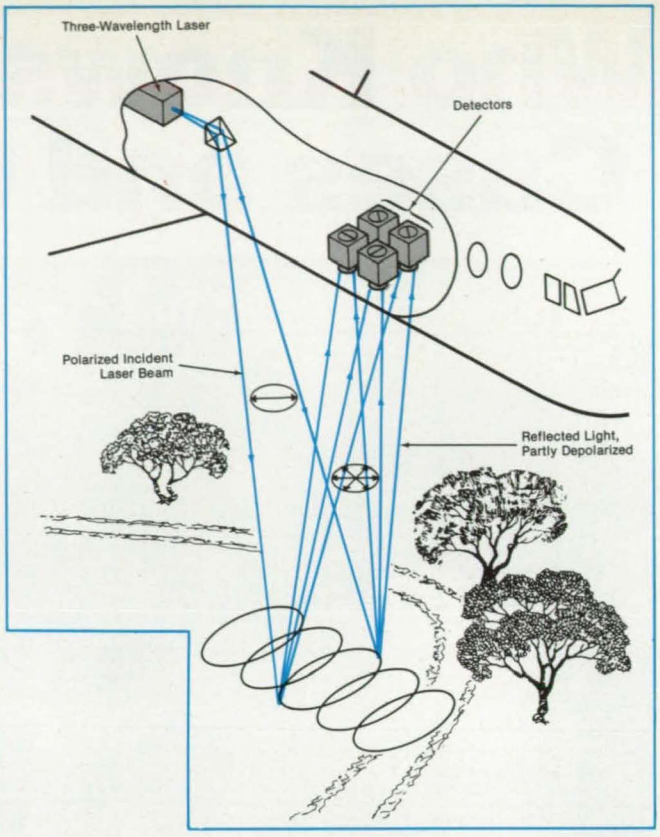
used in the interpretation of higher-altitude polarimetric measurements of reflected sunlight.

The ALPS (see figure) includes a pulsed neodymium:yttrium aluminum garnet laser that emits simultaneously at the fundamental, second-harmonic, and third-harmonic wavelengths of 1,064, 532, and 355 nm, respectively, at rates up to 20 Hz. The output energies per pulse are 100, 300, and 100 mJ, respectively, at the three wavelengths. The laser beam is polarized and transmitted down to the ground.

The portion of laser light that returns from the ground is received by three sets of polarization-sensitive detectors. Each set contains four detectors to obtain data that can be used to calculate the four Stokes parameters for each wavelength. (The Stokes parameters specify the relationship between the polarizations of the incident and the reflected light.) Each detector includes a photomultiplier tube, a linear polarizer, lens, and a 10-nm-band-pass filter. For each wavelength, the polarizer in one detector is oriented at 0° with respect to the polarization of the incident beam, the polarizer in another detector is oriented at 90°, and those in the two other detectors are oriented at 45°. One of the 45° units also includes a quarter-wave plate.

By integrating each return pulse over a period long enough to average together the ground and tree-top returns, one can simulate the effects of a return signal more nearly like that received by a passive solar polarization sensor. To separate the polarization effects of the layers within a tree canopy, a future version of the ALPS will be made to function in a lidar (pulsed ranging) mode, processing the return signals through 200-MHz waveform digitizers.



The **Airborne Laser Polarization Sensor** aims a polarized laser beam at the ground and measures the polarization of the reflected light. Although the simplified version shown here schematically contains only 4 detectors, the actual system contains 12 (4 for each of 3 wavelengths).

The signals from the detectors are fed simultaneously to a 12-channel, 12-bit, charge-integrating analog-to-digital converter mounted in a CAMAC crate (a mounting unit in a standard modular instrumentation-and-digital-interface system). The digitized signals are transferred through the CAMAC crate controller (a communication unit in the CAMAC crate) to a PC-type computer. A time code is superimposed on the "ground-truth" videotape record to enable correlation of the polarization data with data on the type of surface in view. The acquisition and analysis of data are controlled via an easy-to-use menu-driven software system.

This work was done by James Kalshoven, Jr., and Philip Dabney of **Goddard Space Flight Center**. *For further information, Circle 1 on the TSP Request Card.*
GSC-13314

Optical Isolators With Transverse Magnets

Large apertures are obtained in compact isolators that include readily available permanent magnets.

Langley Research Center, Hampton, Virginia

Progress with laser systems has stimulated a demand for an optical isolator of high quality and compact size with a large aperture. An ideal optical isolator is a device that allows total transmission of a beam in the forward direction while totally blocking transmission of the beam in the backward direction, thus preventing backward reflections from disturbing the forward signal. In a high-power laser system, the use of an isolator between an oscillator and an amplifier can protect the oscillator optics from damage by amplified backward reflection.

The commonly used type of isolator consists of a Faraday rotator, a quarter-wave plate, and a pair of polarizers. The most popular Faraday-rotation materials of high optical quality available commercially in large sizes require relatively large magnetic fields. The required magnetic fields can be reduced by using such high-Verdet-constant materials as garnet crystals, which have limitations on transmission range, optical quality, and size, and are not readily available. In addition, electromagnets with water-cooled solenoids are used in typical isolators to produce the large longitudinal magnetic fields required for the proper rotation, making the isolators cumbersome and very expensive.

A new design for an isolator includes a zigzag, forward-and-backward-pass beam path and use of a transverse rather than longitudinal magnetic field (see figure). These design choices produce an isolator with as large an aperture as desired using low-Verdet-constant glass rather than the more expensive crystals. This design also uses commercially available permanent magnets in the Faraday rotator rather than the more expensive and bulky electromagnets. Thus, this isolator is more compact and less expensive than was previously possible in a large-aperture design. This isolator can also be designed to transmit a rectangular beam. The square cross section of the beam can easily be extended to a rectangular shape by increasing one dimension of the glass without having to increase the magnetic field.

A demonstration isolator of the new type, though not of optimum design, was built from available equipment. The isolator had two internal reflections in the forward zigzag pass, two reflections in the backward zigzag pass, and two reflections for the end reflector. The transverse magnet had an average field of 7 kG. Nonoptimum design produced a high transmission loss of 74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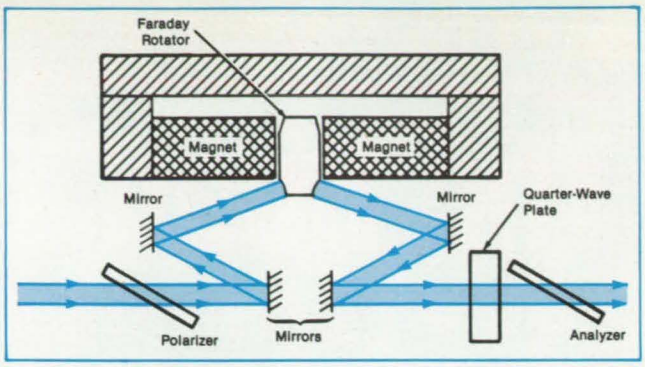
percent. The measured isolation was 36 percent, and the output beam had good quality.

These unique properties make this optical isolator potentially very useful in laser systems involving slab lasers and amplifiers. It could also have application to the study of very-high-power lasers for fusion research.

This work was done by Yuan X. Fan and Robert L. Byer of Stanford University for **Langley Research Center**. *For further information, Circle 23 on the TSP Request Card. LAR-14092*



The **Zigzag Beam-Path Design** results in a smaller, less-expensive optical isolator.

Low-Thermal-Conduction Links for Silicon Sensors

Surface etching reduces conduction and allows sturdier links.

Goddard Space Flight Center, Greenbelt, Maryland

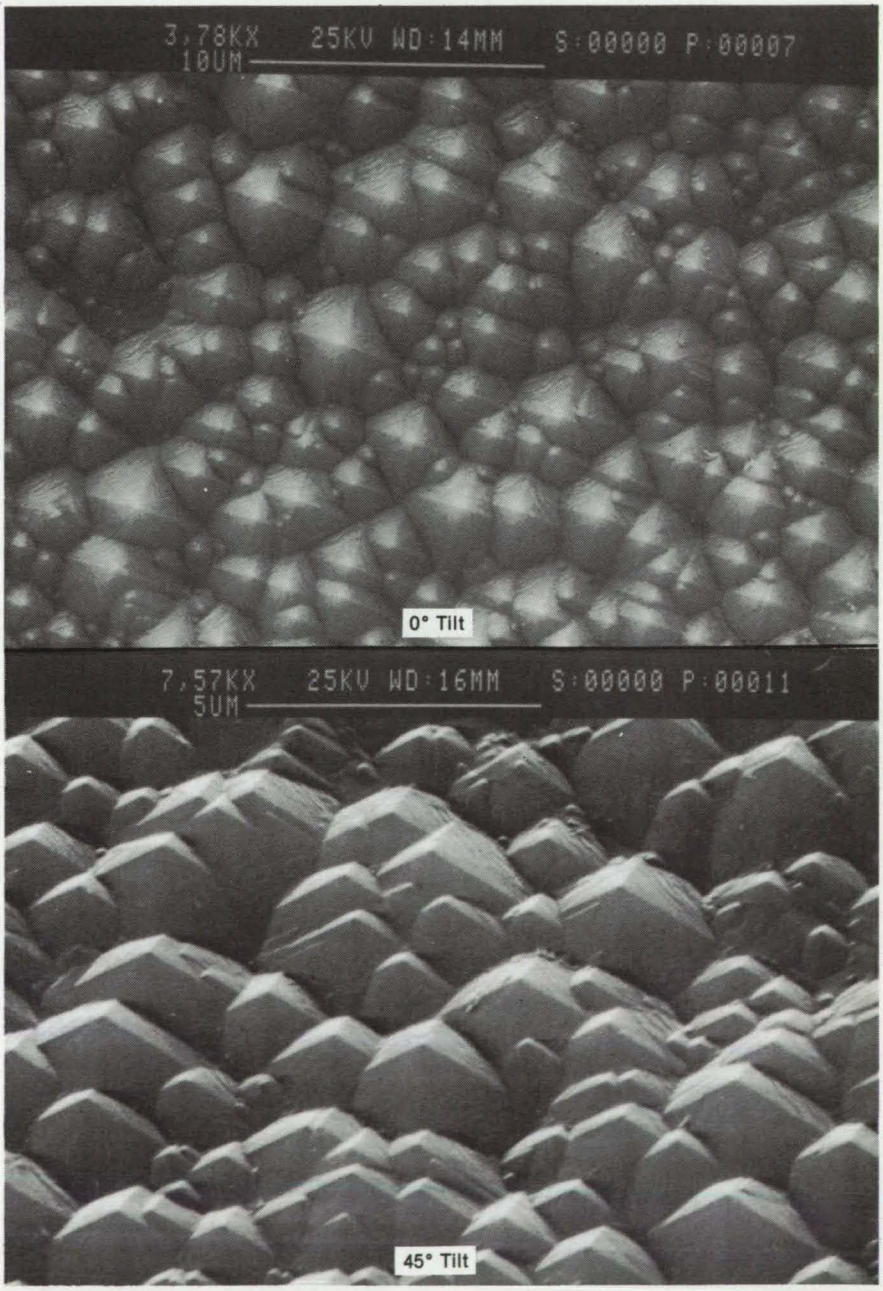
A simple method of texturing the surface of silicon reduces the thermal conductivities of links in silicon x-ray calorimeters and infrared bolometers. In monolithic design, the sensor devices, thermal links, electrical leads, and mechanical supports are all part of the same silicon structure. Until now, the thermal links to the cold bath have been made long and thin or else in complicated shapes to minimize heat transferred through them from the detector to the cold bath. Such links are fragile and have low vibrational frequencies.

Now, however, a textured surface gives the links a high density of phonon scattering sites that reduce the conduction of heat. Therefore, the links can be made shorter and more robust. For 10-μm-thick textured thermal links we measure a thermal conductance of 2×10^{-11} W/K. To obtain this conductance without texturing, the thermal-link thickness must be reduced to 4 μm.

A dilute solution of the anisotropic silicon etchant ethylene diamine pyrocatechol (EDP) is applied to the thermal links to produce small, dense, randomly positioned pyramids ranging in size from about 1 to 5 μm (see figure). The pyramid texture scatters phonons effectively. The texturing process is independent of the design of the monolithic sensor structure.

The texturing technique has been used in making x-ray calorimeters and is expected to be used soon in making infrared bolometers. It should be applicable to any microelectronic device in which a high degree of thermal isolation is needed.

This work was done by D. Brent Mott of **Goddard Space Flight Center**. *No further documentation is available.*
GSC-13321



Irregular Pyramids form a texture on the surface of silicon. These scanning electron micrographs show two such surfaces (at 0° and 45° incidence) that were exposed to a dilute solution of EDP for 5 min at 95 °C. Sizes can be estimated by use of the 5- and 10-μm scale lines near the tops of the photographs.

Two-Wavelength Interferometric Keratometer

Strongly aspherical surfaces could be measured precisely.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed interferometric keratometer would measure the shapes of corneas without touching them. The keratometer might also be used to test strongly aspherical optics. The keratometer, which would resemble present commercial lens-testing interferometers, would generate interferograms representative of the deviation of the surfaces under test from sphericity. Such interferograms can be used to generate contour maps of the surfaces. While existing instruments typically cover corneal diameters no greater than 3 mm, the proposed keratometer would measure corneal topography to diameters as large as 12 mm.

The instrument would employ visible light at two wavelengths; for example, the 0.633-μm red light from an He–Ne laser and the 0.613-μm orange light from another He–Ne laser. The optical train would include three off-axis paraboloidal reflectors. The first reflector would serve as a collimator. The second would form a large-aperture (*f*/1.0) wave front converging on the cornea and partially recollimate the wave front reflected from the surface of the cornea, preserving the optical-path differences. The third reflector would create a quasi-spherical wave front converging onto the obstruction in a Smartt point-diffraction interferometer. (Other interferometic configurations are possible.)

The fringe pattern at the exit pupil of the keratometer would contain the interferograms at each of the two wavelengths superimposed on each other. The superposition would give rise to a beat of spatial variation in the contrast in the fringes between the two interferograms. In effect, this pattern would constitute a third, long-wavelength interferogram of the surface under test. The effective wavelength λ_{eff} (twice the contour depth interval represented by one fringe space) of the third interferogram would be given by

$$\lambda_{eff} = \lambda_1\lambda_2/(\lambda_1 - \lambda_2)$$

where λ_1 and λ_2 are the wavelengths of the illumination. In the case of the He–Ne-laser light mentioned previously, λ_{eff} would be 19.4 μm; thus, one fringe space would represent a depth interval of 19.4/2 = 9.7 μm.

At the price of reduced topographic sensitivity, two-wavelength interferometry enables the measurement of surfaces more aspherical or steeply sloped than could otherwise be measured. When the effective-long-wavelength interferometric information is used to remove the 2π ambiguities in the phases in the shorter-wavelength interferograms, the advantages of both long- and short-wavelength interferometry can be combined to measure strongly aspherical surfaces with high topographic sensitivity.

This work was done by Eric Hochberg and Norman Page of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 85 on the TSP Request Card.*

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

Edward Ansell
Director of Patents and Licensing
Mail Stop 305-6
California Institute of Technology
1201 East California Boulevard
Pasadena, CA 91125

Refer to NPO-17537, volume and number of this NASA Tech Briefs *issue, and the page number.*

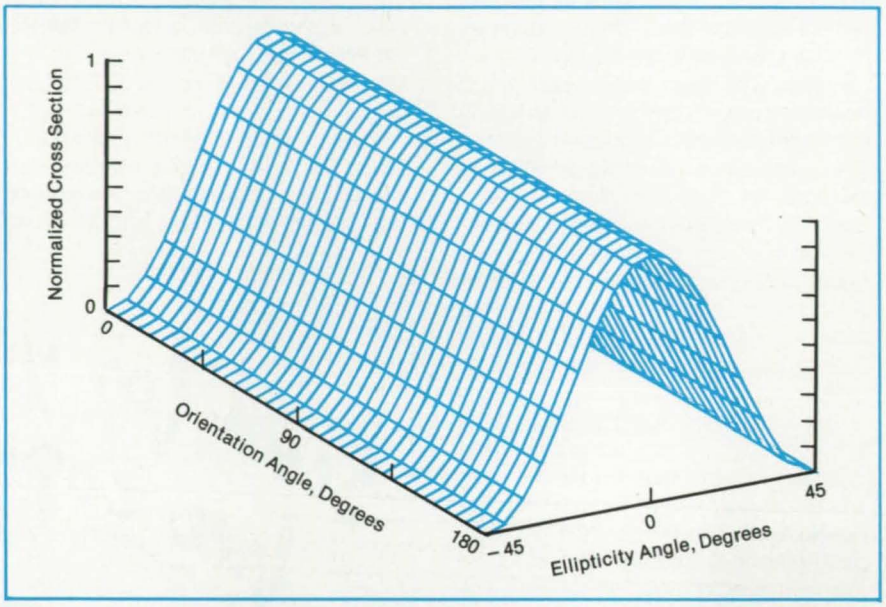
Statistical Partial Calibration of Polarimetric SAR Imagery

Statistical properties of the backscatter can be used to compensate for cross-polarization in the antennas.

NASA's Jet Propulsion Laboratory, Pasadena, California

A mathematical technique for the partial calibration of quadpolarization synthetic-aperture-radar (SAR) image data makes it possible to remove partially those contaminating cross-polarization effects (crosstalk) that arise in the antenna(s) and/or other transmitting and receiving channels. [Quadpolarization data are complex-number representations of the amplitudes and phases of the horizontally and vertically polarized transmitted and received (backscattered) signals and the relationships (including cross-polarization effects) between them]. Therefore, the quadpolarization data processed with the help of this technique better approximate the backscattering properties of the target area. Furthermore, if corner reflectors or other known discrete radar targets are placed in the target area, all of the data channels can be calibrated both relatively to each other and absolutely.

The technique relies on the following two major simplifying assumptions about natural radar targets: (1) the cross-polarized returns from them are reciprocal (the matrices that describe their backscattering properties are symmetrical); (2) for a given polarization of the transmitted signal, the like- and cross-polarized components of the backscatter, integrated over the areas of extended, azimuthally symmetrical targets, are not correlated with each other. The technique also relies on some linearizing approximations that are based on the following additional assumptions: (1) the transmitting and receiving crosstalk parameters are all smaller than –10 dB; (2) the cross-polarized target backscatter parameter is at least 5 dB below the like-polarized target backscatter parameters, but not below the noise level; (3) the cross-correlation between the like-polarized target backscatter parameters is at least 10 dB below the smaller of them.



The Polarization Signature of an Ideal Trihedral Corner Reflector has a simple form, represented by the scattering matrix $\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$ that can be used in the calibration of a polarimetric SAR system.

The equations that result from these assumptions are combined into an iterative algorithm that processes the raw quadpolarization data into approximations of the transmitting and receiving cross-polarization matrices. These matrices can then be inverted to recover an approximation of the target scattering matrix from the crosstalk-contaminated quadpolarization data.

The backscatter from a trihedral corner reflector (see figure) is describable by known equations that can be used in conjunction with the iterative algorithm to obtain a relative polarimetric calibration of the complete transmitting, receiving, and signal-processing system. This calibration is valid at the look angle of the reflector and is nearly complete except for an ambiguity in the relative sign of the like- and cross-polarized components. If, in addition, the cross section of the reflector is known, the calibration can be made absolute in magnitude.

This work was done by Jeffrey D. Klein of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 30 on the TSP Request Card.*
NPO-17888

Measuring Wildfires From Aircraft and Satellites

Remote sensing systems yield a wealth of data.

Ames Research Center, Moffett Field, California

Data about wildfires, collected remotely from satellites and aircraft, provides valuable information both for the management of wildfires and for research on the causes and effects of fires. Aircraft and satellite systems yield wide-area views, providing total coverage of the affected areas. Moreover, they collect data at a variety of wavelengths in the electromagnetic spectrum. The digital transmission of the data makes it easy to enhance images so that the combustion characteristics of biomass can be identified.

A system developed for use aboard the ER-2 aircraft (see figure) includes a digital scanner that records data in 12 channels at wavelengths from 0.42 to 12.5 μm. The data from the system have been used to correlate the characteristics of fires and fuels with reflected and emitted energies. In addition, the system transmits data to a ground station for immediate use in fighting fires.

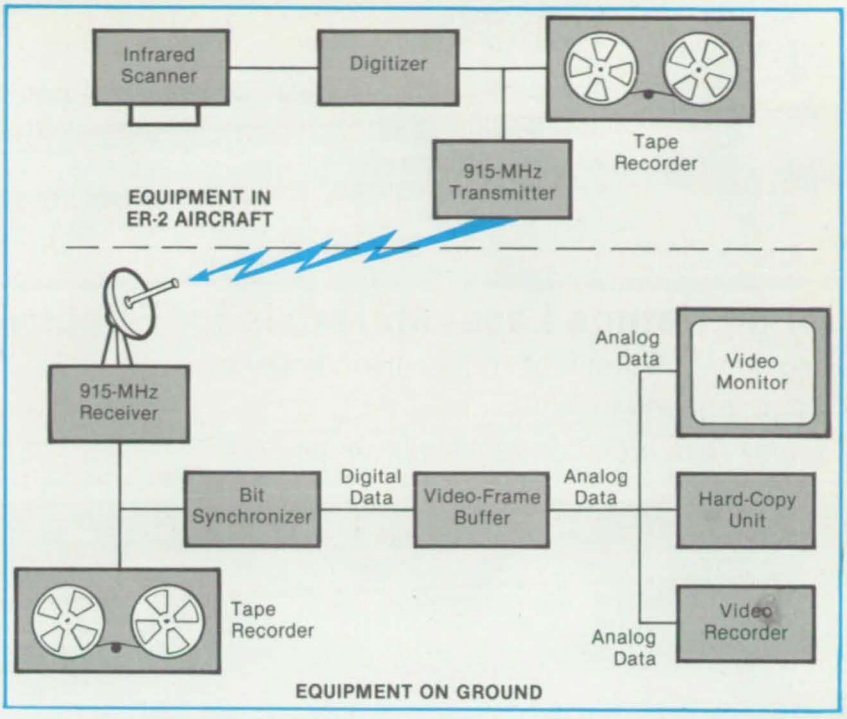
The advanced very-high-resolution radiometer (AVHRR) on the TIROS polar-orbiting satellite provides images and radiance data at 1- and 4-km resolutions. It collects data in five channels at wavelengths from 0.58 to 12.5 μm. It gives synoptic views for regional and global monitoring of fires and for extension of the knowledge of biotic and abiotic responses of ecosystems to larger scales.

The ability to collect digitally encoded information from a multispectral scanner enables researchers to estimate gaseous

and particulate emissions from the fires. The data provide information on the temperatures of flame fronts and soils, the intensities and rates of spread of fires, the characteristics of fuels and smoke plumes, energy-release rates, and concentrations and movements of trace gases. These data can be related to the heating and cooling of soils, the loss of nutrients, and the effects on atmospheric, terrestrial, and aquatic systems.

This work was done by J. A. Brass and J. C. Arvesen of **Ames Research Center**, *V. G. Ambrosia of TGS Technology, Inc., P. J. Riggan of the U.S. Department of Agriculture Forest Service, and J. S. Meyers of ATAC, Inc. Further information may be found in AIAA paper 87-A24933, "Aircraft and Satellite Thermographic Systems for Wildfire Mapping and Assessment."*

Copies may be purchased [prepayment required] from AIAA Technical Information Service Library, 555 West 57th Street, New York, New York 10019, Telephone No. (212) 247-6500.
ARC-12132



The **Airborne Imaging System** records data in 12 wavelength channels and sends digitized data in 2 of these channels to a station on the ground for immediate use in monitoring fires.

Testing Conductive Films for Continuity

A noncontacting, nondestructive apparatus detects discontinuities.

NASA's Jet Propulsion Laboratory, Pasadena, California

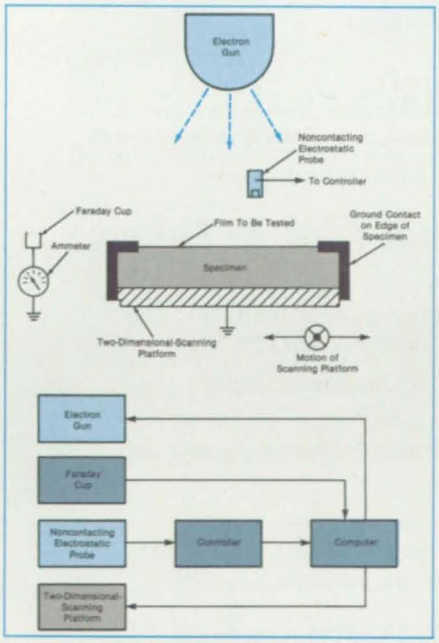
An apparatus tests thin conductive films for continuity without touching them. The apparatus thus avoids the damage to the film and the error from contact resistance that might result from touching the film with a conventional probe.

The apparatus was developed to determine the integrity of conductive coats applied to the surfaces of dielectric materials to inhibit the accumulation of electrostatic charges. During handling, a film can become cracked, and the cracks can reduce its conductance.

A 10-keV diverging electron gun nearly uniformly irradiates the specimen of conductive film on its substrate while the edge of the specimen is connected to ground. Then a scanning platform, on which the specimen is mounted, is moved horizontally to scan a noncontacting electrostatic probe across the surface of the film (see figure).

Where the film is locally in good electrical contact with ground, it readily drains away the incident electrons, and the probe senses ground potential on the film. Where the film is locally surrounded by cracks that disconnect it from ground or where the film contains holes that expose the dielectric, the electron charge builds up, and the probe can sense a potential as great as −8,000 V. The probe can thus readily identify defects.

This work was done by Philip L. Leung of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 126 on the TSP Request Card.*
NPO-17938



The **Specimen is Irradiated** with 10-keV electrons; then the noncontacting electrostatic probe scans the specimen and measures the charge on the spot directly under it.

Materials

Long-Lifetime Laser Materials for Effective Diode Pumping

Long quantum lifetimes reduce the number of diodes required to pump.

Langley Research Center, Hampton, Virginia

While Nd lasers have proved to be quite useful, they would be even more so if they could be pumped by laser diodes. Pumping by laser diodes has been demonstrated with such common Nd laser materials as neodymium:yttrium aluminum garnet (Nd:YAG) and Nd:$YLiF_4$, but such materials as Nd:LaF_3, Nd:$NaF{\cdot}9YF_3$, and possibly Nd:YF_3 could be more useful because of the long lifetimes of their upper laser energy levels.

In the more common Nd:YAG, the lifetime of the upper laser energy level is relatively short. For a pulsed solid-state laser, the number of diodes required is approximately inversely proportional to the lifetime of the upper laser energy level. Thus, if a material with an upper-laser-level lifetime twice as long as that of Nd:YAG were used, about half the number of diodes would be required. For a continuous solid-state laser, the threshold is approximately inversely proportional to the lifetime of the upper laser level. Thus, such a laser could also be improved by the use of one of the proposed materials.

Cost effectiveness is the primary advantage of the solid-state laser materials that have longer upper-laser-level lifetimes. While the costs of the proposed laser materials may be somewhat higher than those of the more common ones, the number of diodes required for pumping may be reduced by factors that range from 2 to 4. Because the cost of the diodes outweighs the cost of the laser material by perhaps two orders of magnitude, the cost would be reduced significantly.

The proposed laser materials have been neglected until now, probably because of the relatively low value of the thermal-shock parameters associated with these fluoride materials. However, benefits of the use of these materials, with their long upper-laser-level lifetimes, may more than offset this disadvantage.

This work was done by Norman P. Barnes of **Langley Research Center**. *No further documentation is available.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 14]. Refer to LAR-13807.

SHIN-ETSU LAUNCHES NEW PRODUCT TO MEET MIL A-46146 TYPE III

New High Strength RTV Silicone Provides Key Properties for Aircraft/Aerospace Market

DATA SHOWS NEW MATERIAL 'RIGHT ON SPECS'

LOS ANGELES—According to Mr. Shibata, President of Shin-Etsu Silicones of America, Inc., "When comparing our new KE 4899 RTV to Dow's 3145 RTV on a property-for-property basis, there is no clear winner. Both materials pass the Mil Spec requirements and both are of equal caliber."

The data shows Shin-Etsu's KE 4899 RTV to meet all of the requirements of MIL A-46146 TYPE III and to compare equally with Dow Corning's 3145 RTV. Both materials are non-corrosive, high strength, low odor, one part adhesives.

THE MATCH-UP

PROPERTY	MIL A-46146 TYPE III	SHIN-ETSU KE 4899*	DOW RTV 3145**
HARDNESS (Shore A)	25 min.	33	33
TENSILE (psi)	500 min.	780	700
ELONGATION %:	500 min.	660	675
TEAR STRENGTH (ppi):	NR	150	125
SPECIFIC GRAVITY:	NR	1.08	1.12
CORROSION ON: Brass, steel, aluminum	None	Passes	Passes
COLORS:	NR	Grey/clear	Grey/clear

*KE4899 data as tested.
**RTV 3145 data as reported — Dow Corning USA Form No. 10-024-82

LOS ANGELES—Shin-Etsu Silicones of America released the above data today, showing the actual published data of both Dow's 3145 RTV and Shin-Etsu's new KE 4899 RTV.

Based upon the direct property-for-property comparison above, it has been determined that the Shin-Etsu material is a direct challenge to Dow's 3145 RTV and should prove an excellent first or second source material. According to Mr. Tomisato, RTV Marketing Manager, "We are accepting requests for samples now."

For more information on the Shin-Etsu Silicones of America KE 4899 RTV, or to receive a sample, contact Doug Bower or John Heitler at:

Shin-Etsu Silicones of America
431 Amapola Avenue
Torrance, California, 90501
(213) 533-1101

A COMMITMENT TO RESEARCH

Shin-Etsu Chemical Co., Ltd., founded in 1926, is a leading world class manufacturer of silicones, offering over 2,800 different products serving a broad spectrum of industrial markets, worldwide. Included in these product lines are many innovative one and two-component RTV silicones, gels, greases, fluoro and fluid silicones with their own revolutionary curing systems.

At the very core of these technological accomplishments is Shin-Etsu's commitment to research. Shin-Etsu's Technical Service Center, located in Torrance, California, provides standard elastomeric testing, including physical and chemical constituents. Its small batch production includes the synthesizing of polymers and compounding them in the latest state-of-the-art mixing equipment. The facility is dedicated to researching all aspects of silicones, including synthesis, property alteration, applications, forming and working, process improvement and complete product evaluation.

Industry Thrilled with New Material for High Performance Bonding and Sealing on Corrosion-Sensitive Electrical/Electronic Parts

LOS ANGELES—According to Doug Bower of Shin-Etsu Silicones of America, Inc., "We've been working on coming up with this product for a very long time. We always knew that Dow's 3145 RTV was the one we had to meet or beat. We also knew that when we introduced this product it had to be right on the money. 'Close' or 'almost' was not about to cut it. As you can see by the comparative data, our RTV KE 4899 was worth the wait."

Mr. Shibata, President of Shin-Etsu Silicones of America, believes that the introduction of their new product will have a dramatic effect on the aircraft/aerospace industry. "Let's face it," said Mr. Shibata, "Dow has an excellent product that has not only been the industry standard for years, but a product without peers. Their 3145 RTV virtually had the market all to itself. As of today, all of that has changed. Now the aircraft/aerospace industry has a choice. Now there is a second one-component RTV silicone available that is every bit as good as Dow's 3145 (RTV) and meets MIL A-46146 Type III to the letter."

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Phase Transformations in Mullite-Precursor Xerogels

Monophasic and diphasic xerogels transform differently under thermal treatment.

A report describes an experimental study of the phase transformations that occur in monophasic and diphasic xerogels of overall stoichiometric mullite composition during thermal treatment. Mullite ($3Al_2O_3 \cdot 2SiO_2$) is valued as a refractory material because it has relatively high mechanical strength, excellent resistance to thermal shock, high resistance to creep, low density, low thermal conductivity, and stability at high temperature. This study is part of a continuing effort to develop precursor materials that can be transformed into mullite and sintered at temperatures low enough to avoid degradation of nonmullite reinforcing fibers in the manufacture of mullite/fiber composites.

By use of the sol-gel process, the monophasic xerogel was synthesized from tetraethyl orthosilicate, and the diphasic xerogel was synthesized from a colloidal suspension of silica and boehmite [AlO(OH)]. The xerogels were subjected to various thermal treatments. The chemical and structural changes that occurred during these treatments were characterized by subjecting specimens before and after to differential thermal analysis, thermogravimetric analysis, x-ray diffraction, scanning electron microscopy, and infrared spectroscopy. Preliminary experiments on sintering behavior were also performed.

The combined results of these experiments show a sequence for the formation of mullite from the two types of xerogel. The monophasic gel crystallizes from an amorphous structure to a silicon-substituted alumina spinel at about 980 °C. The spinel phase is metastable and becomes mullite when held isothermally near the crystallization temperature. The monophasic gel yields a well-crystallized mullite with some residual amorphous phase, the amount of which is reduced by further reaction at higher temperature. The mullite formed initially is deficient in alumina. The composition shifts towards stoichiometry at higher temperatures.

The diphasic material follows a different sequence. This xerogel is intially composed of boehmite and a distinct amorphous silica phase. The boehmite decomposes to a cubic alumina spinel structure at 490 °C. There is little or no reaction between the spinel and amorphous phases. Mullite is formed by solid-state reaction between α-Al_2O_3 and cristobalite, which form from the spinel and amorphous phases, respectively, at 1,360 °C. The mullite is not well-crystallized initially, and residual phases remain even after heating at 1,600 °C for 6 h. Initially, the mullite is also deficient in alumina, but the composition shifts towards stoichiometry at higher temperatures. The diphasic powder can be sintered to high densities, whereas the monophasic powder is much more difficult to densify in spite of its molecular-level homogeneity.

This work was done by Mark J. Hyatt of **Lewis Research Center** *and Narottam P. Bansal of Case Western Reserve University. Further information may be found in NASA TM-101349 [N89-11038], "Phase Transformations in Xerogels of Mullite Composition."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
LEW-14898

Open-Section Composite Structural Elements

Superior mechanical properties of composites may overcome the inherent instabilities of open sections.

A report describes an investigation of the manufacture and the mechanical properties of graphite-fiber/aluminum-matrix open-section structural elements; e.g., channels and angle bars. The investigation was conducted with a view toward using such elements to build lightweight, thermally stable truss structures in outer space. The same characteristics that make them attractive for that application also make them attractive for such specialized terrestrial applications as transport to, and assembly at, remote or otherwise uninviting locations.

The advantages of open-section structural elements include shapes that permit high packing density during shipment; convenient paths for routing tubes, hoses, and cables; accessibility of both inner and outer surfaces for repair; and ease of attachment of additional hardware. In addition, in comparison with closed-section structural elements (e.g., box beams and tubes), open-section elements are easier and require less equipment to fabricate, and are more amenable to automated fabrication and assembly at the remote site. The primary disadvantage of open-section structural elements is that, in comparison with closed-section structural elements, they are not as resistant to some kinds of deformation under load. In particular, bending and torsional loads tend to change the shapes of the cross sections in such a way as to make open-section elements more vulnerable to buckling.

Accordingly, one of the objectives in this investigation was to exploit the tailorable anisotropy of the composite material to strengthen the open-section elements against buckling. The general approach involves (1) aligning most of the fibers along the longitudinal axis to increase the buckling strength by increasing the longitudinal modulus of elasticity and (2) aligning some of the fibers at off-axis angles to increase the transverse modulus of elasticity, thereby increasing the resistance to changes in the shape of the cross section and further decreasing the susceptibility to buckling.

Another objective was to exploit the tailorable thermal-expansion properties of the composite material to obtain overall thermal stability. High-modulus-of-elasticity, pitch-based graphite fibers have a negative coefficient of thermal expansion along their lengths, while aluminum has a positive coefficient. By combining the two materials in suitable proportions and fiber orientations, one can obtain a composite that has low or zero thermal expansion, at least in some temperature range. Struts made of such a material would be particularly useful in frames that support precise optical instruments.

During the investigation, four structural elements in each of three different configurations were made from unidirectional P100 graphite fibers in a matrix of 6061 aluminum. The graphite occupied about half the volume of the composite. In addition, two truss structures were made of extruded struts of alumium reinforced with boron carbide (B_4C) particles. Several difficulties were encountered in the fabrication of the graphite/aluminum specimens. The major difficulty was the maintenance of the required uniformity of temperature in the region undergoing deformation. The structures made of the Al/B_4C composite were fabricated with little difficulty. This material is relatively inexpensive, and structures can be made from it by conventional manufacturing processes.

This work was done by T. A. Loftin, C. A. Smith, S. J. Raheb, and A. M. Nowitzky of DWA Composite Specialties, Inc. for **Marshall Space Flight Center**. *To obtain a copy of the report, "Composite Structural Elements With Integral End Fittings," Circle 3 on the TSP Request Card.*
MFS-26112

Computer Programs

COSMIC: Transferring NASA Software

COSMIC, NASA's Computer Software Management and Information Center, distributes software developed with NASA funding to industry, other government agencies and academia.

COSMIC's inventory is updated regularly; new programs are reported in Tech Briefs. For additional information on any of the programs described here, circle the appropriate TSP number.

If you don't find a program in this issue that meets your needs, call COSMIC directly for a free review of programs in your area of interest. You can also purchase the annual *COSMIC Software Catalog*, containing descriptions and ordering information for available software.

COSMIC is part of NASA's Technology Utilization Network.

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The University of Georgia
382 East Broad Street
Athens, Georgia 30602

Computer Programs

These programs may be obtained at a very reasonable cost from COSMIC, a facility sponsored by NASA to make computer programs available to the public. For information on program price, size, and availability, circle the reference number on the TSP and COSMIC Request Card in this issue.

Machinery

Computing the Dynamics of Helicopters

CAMRAD calculates the loads on, and the motions of, various rotorcraft.

The Comprehensive Analytical Model of Rotorcraft Aerodynamics (CAMRAD) computer program is designed to calculate the performance of, loads on, and noise generated by, a helicopter rotor; the vibration of the helicopter and its response to gusts; the dynamics and handling qualities of the helicopter in flight; and the aeroelastic stability of the helicopter as a system. The analysis is a consistent combination of structural, inertial, and aerodynamical mathematical models applicable to a wide range of problems and a wide class of vehicles.

The CAMRAD analysis can be applied to articulated, hingeless, gimbaled, and teetering rotors that have arbitrary numbers of blades. The degrees of freedom of a rotor blade included in CAMRAD are blade/flap bending, rigid pitch and elastic torsion, and, optionally, gimbal or teeter motion. General two-rotor aircraft can be modeled. Single-main-rotor, tandem-helicopter, and side-by-side-tilting-prop-rotor aircraft configurations can be considered. The case of a rotor or helicopter in a wind tunnel can also be modeled. The degrees of freedom of aircraft bodies included in CAMRAD are the six rigid-body motions, elastic airframe motions, and the rotor/engine speed perturbations.

CAMRAD calculates the loads on, and motions of, a heli-

copter or airframe in two stages. First, the trim solution is obtained; then the flutter, dynamics of flight, and/or transient behavior can be calculated. The trim operating conditions considered include level flight, steady climb or descent, and steady turns. The analysis of the rotor includes nonlinear inertial and aerodynamic models, applicable to large blade angles and a high inflow ratio. The mathematical model of the aerodynamics of the rotor is based on two-dimensional, steady-flow airfoil characteristics with corrections for the effects of three-dimensional and unsteady flow, including a model of dynamic stall.

In the analysis of flutter, the matrices that describe the linear differential equations of motion are constructed, and the equations are analyzed. In the analysis of the dynamics of flight, the stability derivatives are calculated and the matrices that describe the linear differential equations of motion are constructed. These equations are analyzed. In the analysis of transients, equations of motion of the rigid body are numerically integrated for prescribed transient gust or control input.

The CAMRAD program product is available by license for a period of 10 years to domestic U.S. licensees. The licensed program product includes the CAMRAD source code, command procedures, sample applications, and one set of supporting documentation. Copies of the documentation may be purchased separately. CAMRAD is written in FORTRAN 77 for the DEC VAX computer under VMS 4.6 with a recommended core memory of 4.04 megabytes. The DISSPLA package is necessary for graphical output. CAMRAD was developed in 1980.

This program was written by Wayne Johnson of **Ames Research Center**. *For further information, Circle 55 on the TSP Request Card. ARC-12337*

Mathematics and Information Sciences

YAMM—Yet Another Menu Manager

Alimentary connotations notwithstanding, this is about software for the management of software.

One of the most time-consuming, yet necessary, tasks of writing any piece of interactive software is the development of a software interface with the user. The Yet Another Menu Manager (YAMM) computer program is an application-independent menuing package of software designed to remove much of the difficulty and save much of the time inherent in the implementation of the front ends of large packages of software. Written in C for a UNIX-based operating system, YAMM provides a complete menuing front end for a wide variety of applications, with provisions for independence from specific types of terminals, configurations that meet the specific needs of users, and dynamic creation of menu trees.

An application program running under the menu package consists of two parts: a description of the menu configuration and the body of application code. The menu configuration is used at run time to define the menu structure and any nonstandard keyboard mappings and terminal capabilities. Menu definitions define specific menus within the menu tree. The names used in a definition may be either referenced to application functions or the names of other menus defined within the menu configuration. Application parameters are

entered by use of data-entry screens, which allow for required and optional parameters, tables, and lists of legal values. Both automatic andapplication-specific checking for errors are available. Help is available for both menu operation and specific applications.

The YAMM program was written in C for execution on a Sun Microsystems workstation running SunOS, based on the Berkeley (4.2bsd) version of UNIX. During development, YAMM has been used on both 68020 and SPARC architectures, running SunOS versions 3.5 and 4.0. YAMM should be portable to most other UNIX-based systems. It requires a control memory of approximately 232K bytes. YAMM was developed in 1988.

This program was written by Alan S. Mazer and Richard J. Weidner of Caltech for **NASA's Jet Propulsion Laborator**. *For further information, Circle 137 on the TSP Request Card.*
NPO-17769

Estimating the Cost of Developing Software

The SOFTCOST program combines diverse mathematical models that represent aspects of the development task.

The early estimation of required resources and of a schedule for the development and maintenance of software is usually the least precise aspect of the life cycle of software. However, it is desirable to make some sort of an orderly and rational attempt at estimation in order to plan and organize an implementation effort. The Software Cost Estimation Model program, SOFTCOST, was developed to provide a consistent automated resource-and-schedule mathematical model that is more formalized than the often-used guesswork model based on experience, intuition, and luck.

SOFTCOST was developed after the evaluation of a number of existing cost-estimation programs indicated that there was a need for a cost-estimation program that has a wide range of applicability and adaptability to diverse kinds of software. SOFTCOST combines several software-cost models found in the open literature into one comprehensive set of algorithms that compensate for nearly 50 implementation factors relative to size of the task, inherited baseline, organizational and system environment, and difficulty of the task.

SOFTCOST produces mean and variance estimates of software size, implementation productivity, recommended staff level, probable duration, amount of computer resources required, and amount and cost of software documentation. Since the confidence level for a project using mean estimates is small, the user is given the opportunity to enter risk-biased values for effort, duration, and staffing, to achieve higher confidence levels. SOFTCOST then produces a program evaluation and review technique/critical path method (PERT/CPM) file with subtask efforts, durations, and precedences defined so as to produce the work-breakdown structure (WBS) and schedule that are characterized by the requested overall effort and duration.

The SOFTCOST program operates in an interactive environment, prompting the user for all of the required input. The program builds the supporting PERT data base in a file for later generation or revision of reports. The PERT schedule and the WBS schedule can be printed and stored in a file for later use.

The SOFTCOST program is written in Microsoft BASIC for interactive execution and has been implemented on an IBM PC-XT/AT computer operating under MS-DOS 2.1 or higher with 256K bytes of memory. SOFTCOST was originally developed for the Zylog Z80 system running under CP/M in 1981. It was converted to run on the IBM PC-XT/AT in 1986.

This program was written by Robert C. Tausworthe of **NASA's Jet Propulsion Laboratory**. *For further information, Circle 22 on the TSP Request Card.*
NPO-17936

General-Purpose Ada Software Packages

A collection of subprograms brings to Ada many features from other programming languages.

The General-Purpose Ada Packages computer program contains 10 families of subprograms. The families bring to Ada many features from HAL/S, PL/I, FORTRAN, and other languages. These families are as follows: string subprograms (INDEX, TRIM, LOAD, etc.); scalar subprograms (MAX, MIN, REM, etc.); array subprograms (MAX, MIN, PROD, SUM, GET, and PUT); numerical subprograms (EXP, CUBIC, etc.); service subprograms (DATE_TIME function, etc.); linear-algebra subprograms; Runge–Kutta integrators; and three text input/output families of software packages.

In two cases, a family consists of a single nongeneric package. In all other cases, a family comprises a generic package and its instances for a selected group of scalar types. All generic packages are designed to be easily instantiated for the types declared in the user's facility. Most packages have widespread applicability, although some are oriented for avionics applications. All are designed to facilitate writing new software in Ada.

Several of the packages use conventions introduced by other programming languages. A package of string subprograms is based on HAL/S (a language designed for the avionics software in the Space Shuttle) and PL/I. Packages of scalar and array subprograms are taken from HAL/S or generalized current Ada subprograms. A package of Runge–Kutta integrators is patterned after a built-in MAC (MIT Algebraic Compiler) integrator. Those packages modeled after HAL/S make it easy to translate existing HAL/S software to Ada.

The source code is available as ASCII text files on two 360K, 5.25-in. (13.3-cm) floppy disks written on an IBM/AT personal computer running under PC DOS, v. 3.1. The size of the largest file is 44,032 bytes. The software was developed by use of VAX Ada, v. 1.5 under DEC VMS, v. 4.5. It should be portable to any validated Ada compiler, and it should be executable either interactively or in batch. The software was developed in 1989.

This program was written by Allan R. Klumpp of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 14 on the TSP Request Card.*
NPO-17983

Mechanics

Hardware, Techniques, and Processes

Books and Reports

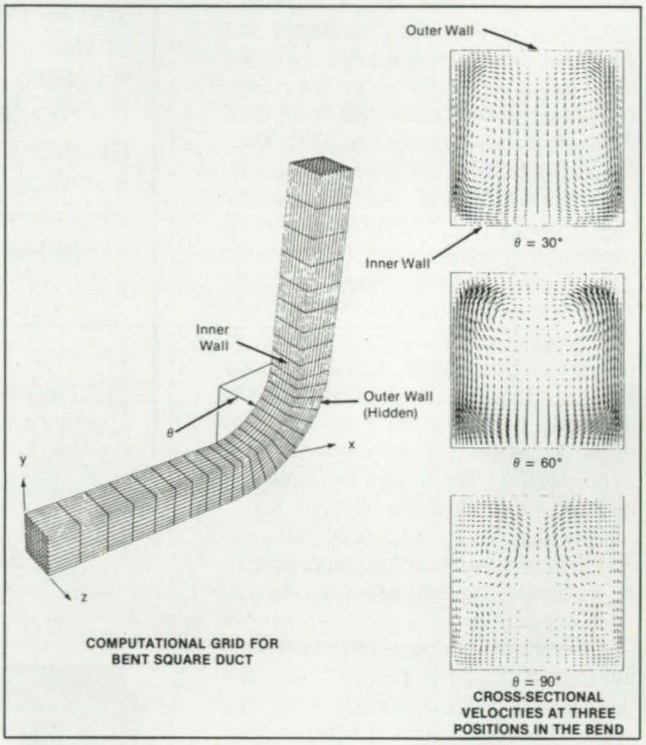
Faster Algorithm for Computation of Incompressible Flow

An artificial-compressibility method and an upwind-differencing scheme are combined.

Ames Research Center, Moffett Field, California

An improved algorithm yields faster numerical solutions of the Navier–Stokes equations of steady or unsteady three-dimensional flow of an incompressible fluid. Like some previous algorithms for incompressible flow, this one is based on the method of artificial compressibility. Unlike in a compressible flow, a disturbance at one point in an incompressible flow affects the flow at every other point simultaneously, making it necessary for any algorithm that simulates the flow to propagate information through the entire flow field during each time step. In the artificial-compressibility method, an unsteady flow is treated as incompressible in advancing from one time step to the next, but at each time step (or in the steady state), the fluid is treated as having a variable compressibility that enables the propagation of the flow field, and subiterations are performed in increments of pseudotime until the effects of compressibility subside. One principal computational advantage of artificial compressibility is that it directly couples the pressure and velocity fields at the same time step and converts the elliptic incompressible Navier–Stokes equations to a hyperbolic form that is more amenable to numerical integration.

The present algorithm incorporates a higher-order flux-difference-splitting numerical-integration scheme for the convective terms and a second-order central-difference numerical-integration scheme for the viscous terms. The use of upwind differencing makes the resulting system of equations diagonally dominant. The equations are solved with a line-relaxation scheme that allows the use of very large increments of pseudotime, leading to fast convergence, both for steady-state problems and for subiterations of time-dependent problems.



Cross-Stream Velocity Vectors computed for the square-cross-section duct show a pair of secondary vortexes generated by large static pressure on the outside wall at the bend. The vortexes move toward the inside wall between the 30° and 60° positions.

The algorithm has been tested by using it to compute steady flows in a duct that has a square cross section and a 90° bend (see figure) and in unsteady flow in an artificial heart.

The steady-state duct computations are in good agreement with experimental data. The artificial-heart computations yield particle traces that resemble those in photographs of the flow in a model of the artificial heart.

This work was done by S. E. Rogers and D. Kwak of **Ames Research Center** *and C. Kiris of Stanford University. Further information may be found in AIAA paper 89A-25378, "Numerical Solution of the Incompressible Navier–Stokes Equations for Steady-State and Time-Dependent Problems."*

Copies may be purchased [prepayment required] from AIAA Technical Information Service Library, 555 West 57th Street, New York, New York 10019, Telephone No. (212) 247-6500.

ARC-12370

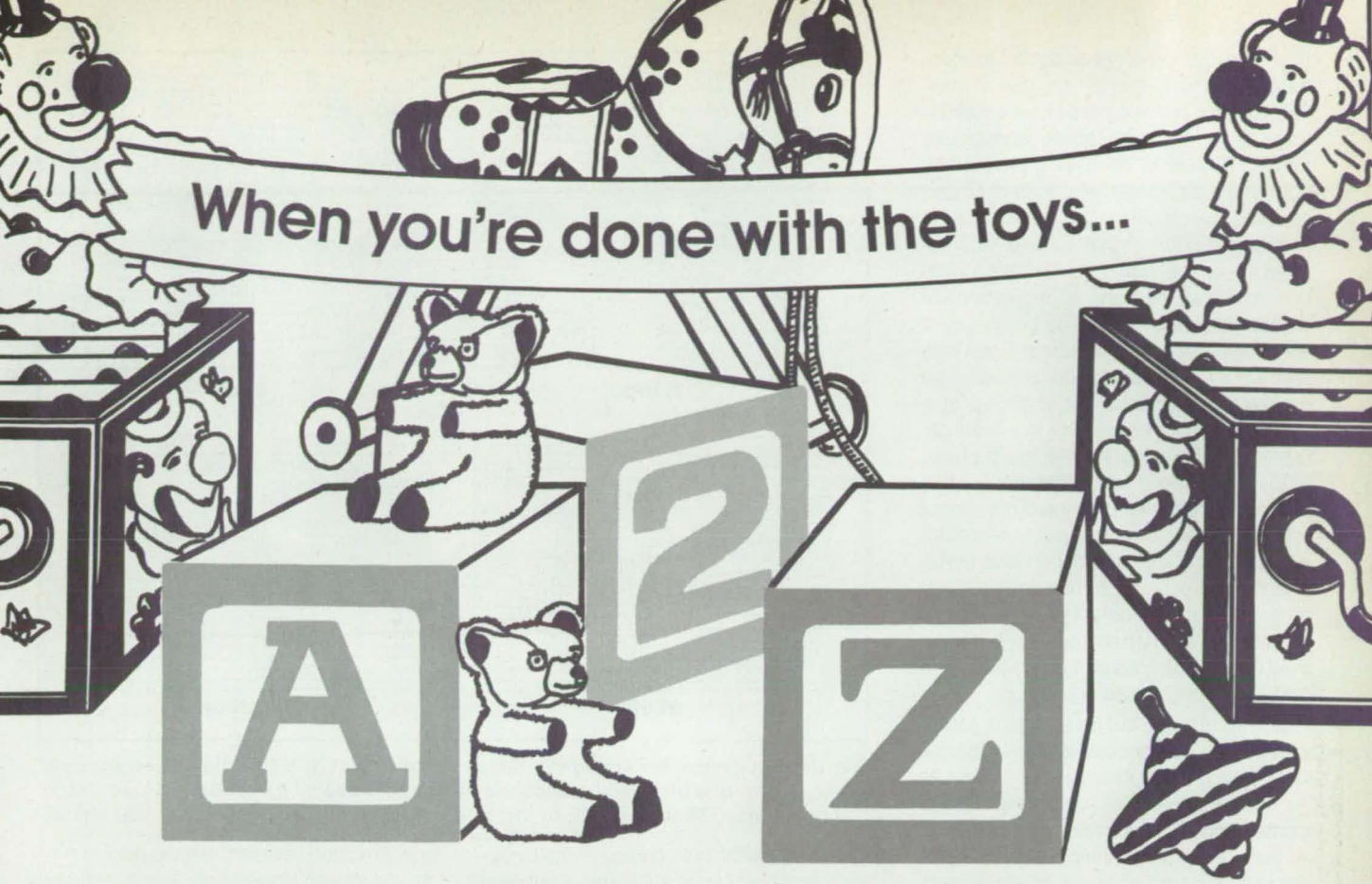
Semiautomatic Design of Zonal Computational Grids

Knowledge-based software helps reduce the complexity of fluid-dynamical computations.

Ames Research Center, Moffett Field, California

EZGrid is a knowledge-based computer program that semiautomatically generates zonal computational grids for use in numerical simulations of two-dimensional flows. Zoning is necessary because of limitations imposed by the size of available computer memory and by the topological complexity of a typical flow field. The complexity and amount of required memory can be reduced by dividing the flow field into zones, within each of which the computational grid is refined only to the extent necessary to resolve local high gradients. EZGrid was developed to speed and systematize zoning, which heretofore has been a tedious manual procedure with a high degree of subjectivity and consequent vulnerability to error.

Because there is usually no consensus among experts as to what constitutes the "ideal" or "correct" zoning of a specific



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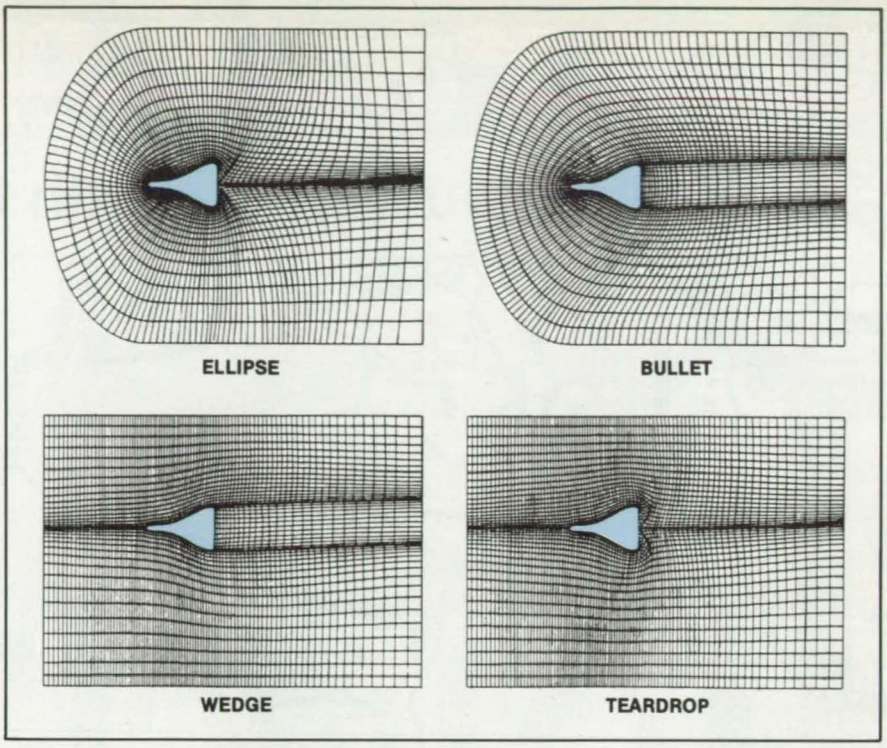
flow field, EZGrid is not designed to eliminate subjectivity entirely. Instead, it codifies portions of zoning expertise on which there is or could be some consensus, thereby speeding the zoning process by narrowing the range of choices among possible zoning plans. One consequence of this approach is that EZGrid incorporates a way of entering qualitative information on the shapes and configurations of objects in a flow field at the beginning of a zoning procedure. The user still provides perceptual information on shapes and groupings of objects, but explicitly, in a consistent manner, only for the input geometry, and only during the setup phase at the beginning of an EZGrid run. For this purpose, EZGrid features interactive input via a language in which objects are regarded as being composed of primitive parts, and the shapes, sizes, orientations, and other attributes of objects are described in standardized terms. The user's choice in describing shapes can affect the zonal grid significantly (see figure).

Any attempt to define standard zoning practice must account for an individual user's bias, which involes such factors as flow-solver capabilities, user's experience, computational objectives, and aesthetics, In generating a flow-field zoning, EZGrid follows standard zoning guidelines, subject to a user's bias as reflected by a "user bias profile" which the user can "tune". This profile is the collection of parameters chosen to represent the factors described above, and it is tuned by the assignment of qualitative weights to each parameter, denoting the importance and/or acceptability of that parameter.



The **User's Opinion Regarding the Shape of an Object** in a flow field is entered via the choice of one of several prescribed names that describe various end/side shape combinations. EZGrid then fits, to the object, a zonal grid appropriate for that shape.

EZGrid constructs zoning plans by assembling predefined subplans. A subplan is a sequence of zoning actions applicable to a specific grouping of objects. The bulk of the zoning design knowledge is contained directly in the subplans. If there is more than one grouping, more than one subplan are selected and assembled together to produce a plan. The rules that determine the way in which the subplans are combined contain the remainder of the zoning design knowledge. The assembly of plans from subplans increases efficiency, and a zoning-design problem is thus transformed into a simpler selection-and-assembly problem.

This work was done by Alison Andrews Vogel of **Ames Research Center**. *For further information, Circle 86 on the TSP Request Card.* ARC-12322

O-Ring-Testing Fixture

Rings can be evaluated under conditions of storage and use.

Marshall Space Flight Center, Alabama

A fixture tests O-rings for sealing ability under dynamic conditions after extended periods of compression. The fixture makes it possible to evaluate the effects of a variety of parameters, including temperature, pressure, rate of pressurization, rate and magnitude of radial gap movement, and pretest compression time.

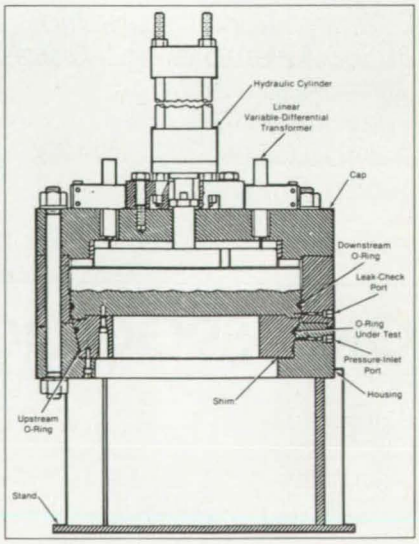
The fixture moves the sealing surface radially away from the O-ring under test and slides the sealing surface axially across the ring. It also stores the O-ring under compression under any of various environmental conditions before it is tested.

A conical plug holds the O-ring under test in a groove in its tapered outer wall (see figure). The plug fits in a similar conical hole in a housing. A shim is placed in the housing so that it lies directly under the plug when the components are bolted together. The thickness of the shim determines the compression applied to the O-ring while it is stored.

When the time comes to test the O-ring dynamically, the assembled plug and housing are placed in a test stand. An upper section is bolted to the plug with a torque wrench, and the bolts joining the plug to the housing are removed. This procedure ensures that the compression on the O-ring is not reduced during the preparation for the dynamic test. A hydraulic cylinder is then attached to the upper section.

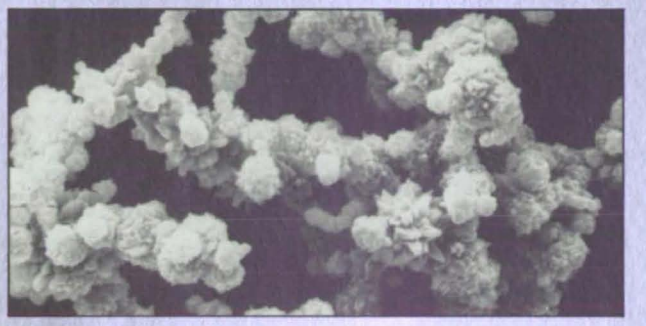
Pressure is applied to the space below the O-ring through ports in the plug. (Auxiliary rings above and below the test ring enable pressurization and measurement of leakage.) The hydraulic cylinder is raised a preset distance at a preset rate, sliding the ring axially on the housing and creating a radial gap between the ring and the housing. Pressure sensors in the housing above and below the O-ring monitor leakage.

This work was done by James E. Turner and D. Scott McCluney of **Marshall Space Flight Center**. *No further documentation is available.*
MFS-28414

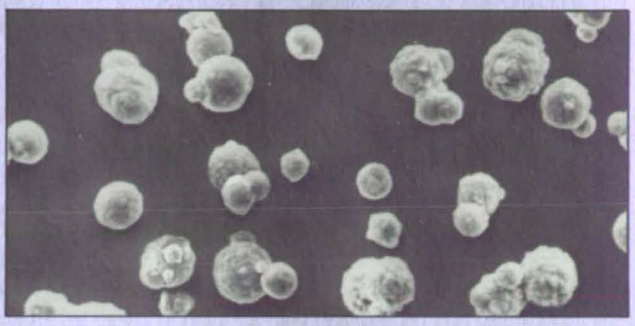


The **Hydraulic Cylinder Moves the Plug** in the housing. The taper of 15° on the plug and the cavity of the housing ensures that a gap is created between the O-ring under test and the wall of the cavity. Secondary O-rings above and below the test ring maintain the pressure applied to the test ring.

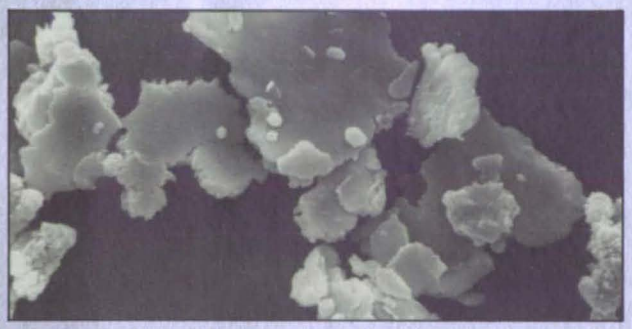
SPECIFY INCO SPECIALTY POWDERS FOR WIDE RANGE OF ELECTRONIC APPLICATIONS



Inco Type T 287 Filamentary Powder, particle size (FSSS) 2.6-3.3 microns, apparent density 0.75-0.95 g/cc, relative surface resistivity 0.30 ohms per square (□).



Novamet Silver Coated Nickel Spheres, 15% Ag, 2.5 g/cc apparent density, particle size 10 microns, screen mesh 99%-250, surface resistivity 0.03 Ω/□.



Novamet HCA-1 Flake, screen mesh 98% minus 400, apparent density 0.90 g/cc, thickness 1.0-1.1 microns, surface resistivity 0.25 Ω/□.

Novamet Nickel Coated Graphite, 60% fully encapsulated Ni, apparent density 1.6 g/cc, particle size (FSSS) 100 microns, screen mesh 63% −150/+250, surface resistivity 0.3 Ω/□.

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Circle Reader Action No. 452

Low-Wear Ball-Bearing Separator

A proposed component would be compatible with liquid oxygen or hydrogen.

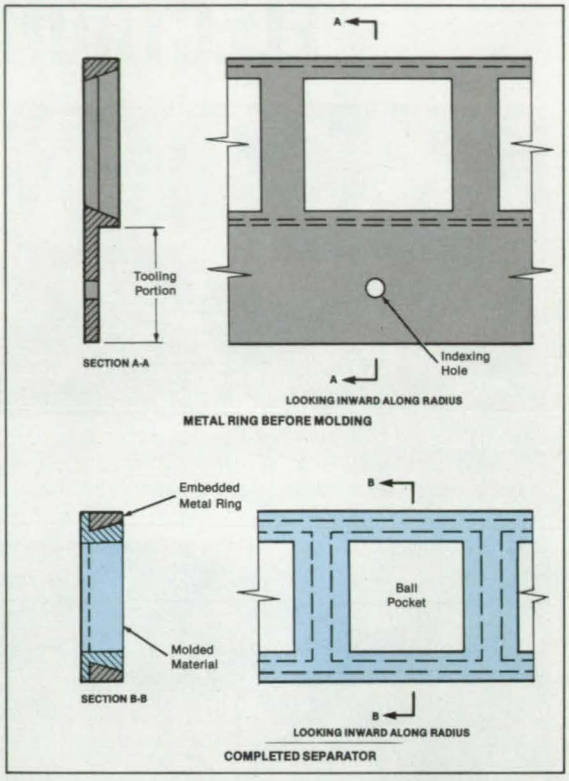
Marshall Space Flight Center, Alabama

A proposed ball-bearing separator for use in a cryogenic pump would be stronger and more resistant to wear than is the present separator made of molded polytetrafluoroethylene (PTFE) reinforced with glass fibers. The fibers contribute to wear, and although these fibers strengthen the part, it is still prone to failure.

The proposed separator would consist of a molded plastic-and-metal composite ring imbued with solid lubricant and containing an embedded metal ring (see figure). The frame would provide strength and rigidity, and the molded wall — without glass fibers — would lubricate the balls.

The fabrication of the separator would begin with the insertion of the metal ring in the cavity of a compression mold. The tooling portion of the ring would be clamped between mating sections of the mold; tooling pins would extend between the sections of the mold through indexing holes in the tooling portion of the metal ring to lock it in position. The cavity would be filled with the molding material, and a compression ram would mold the plastic around the metal ring at a suitable pressure and temperature.

The molded separator would be removed from the mold and placed on a lathe or milling machine (with the aid of the indexing holes in the tooling portion of the metal ring) for machining of the inside and outside wall surfaces and ball pockets. Finally the exposed tooling portion of the ring would be machined away.



The **Metal Ring** would be embedded in the molded wall (top) to obtain a combination of strength and lubricity. Before molding and machining, the ring would include a tooling portion for handling and indexing.

The metal ring would be machined from forgings or plate stock of a material appropriate for the application. For example, Inconel* I-718 alloy might be chosen for use in oxygen, while 440-C corrosion-resistant steel would be a good choice for use in hydrogen.

The molded composite would be a blend of PTFE and fluorinated ethylene/propylene (FEP) filled with brass and bronze powder and molybdenum disulfide powder. The FEP would provide bonding to the metal frame. The PTFE and molybdenum disulfide would give lubricity. The brass and bronze powders would impart mechanical stability and are known from previous experience to be compatible with oxygen.

*"Inconel" is a registered trademark of the INCO family of companies.

This work was done by Elden L. Hawkinson of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information, Circle 109 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 14]. Refer to MFS-29666.

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

High-Resolution Computations of Hypersonic Flows

The enhancement of stability and the rate of convergence is discussed.

A report discusses the extension, to hypersonic flows, of a class of implicit, total-variation-diminishing (TVD) algorithms suitable for the numerical simulation of transonic and supersonic flows that obey the Euler and Navier-Stokes equations. The stabilities and the rates of convergence, relative to those of other algorithms, are discussed. The study is complemented by a variety of computations of steady and unsteady viscous and inviscid hypersonic flows about blunt bodies.

The improved algorithms implement conservative shock-capturing schemes that are accurate to second and third order in space and to first or second order in time. They are fully implicit. Particular emphasis is placed on high-resolution algorithms that are implicit and accurate to second order in time. The algorithms are formulated in finite-volume and pseudo-finite-volume forms, which, for certain physical problems and grid distributions, can enhance stability and the rate of convergence for highly clustered or skewed grids and require only a slight modification from the form in which they were originally presented for generalized geometries.

The report identifies some numerical aspects of TVD-type schemes that affect the rates of convergence for high mach numbers and flows of real gases, but have negligible effects on low-mach-number or perfect-gas flows. The performances of the various linearized implicit forms of the improved schemes similar to the forms of schemes used in some previous studies of transonic flows are re-examined for hypersonic flows.

The behaviors of the improved schemes with various forms of temporal differencing but similar forms of spatial discretization for inviscid and viscous flows is investigated. These studies indicate that the stabilities and rates of convergence of these schemes are different between viscous and inviscid flows. However, with the proper choice of the temporal discretization and suitable implicit linearization, these schemes are fairly efficient and accurate for very complex two-dimensional hypersonic inviscid and viscous shock interactions.

The relative efficiency and accuracy of typical TVD-type schemes for shock-wave computations are examined. A comparative study of steady and unsteady flows reveals that the class of improved TVD-type schemes, in particular, for equilibrium real-gas and nonequilibrium flows produces shock resolutions just as accurate as those of most other TVD schemes and TVD flux-vector-splitting approaches, yet requires fewer operations. Even with the improvements, the rate of convergence is, in general, slower for real gases than for perfect gases. Also, the rate of convergence is, in general, slower for viscous flows than for inviscid, steady flows.

This work was done by H. C. Yee of **Ames Research Center**, *G. H. Klopfer of NEAR, Inc., and J.-L. Montagué of ONERA, France. Further information may be found in NASA TM-100097 [N88-22651], "High-Resolution Shock-Capturing Schemes for Inviscid and Viscous Hypersonic Flows."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
ARC-12254

Lubrication of Nonconformal Contacts

Regimes of minimum-film-thickness lubrication are analyzed.

A report discusses advances in the knowledge of the lubrication of nonconformal contacts in bearings and other machine elements. It reviews previous developments in the theory of lubrication, presents advances in the theory of lubrication to determine minimum film thickness, and describes experiments designed to investigate one of the regimes of lubrication for ball bearings.

The lubrication of nonconformal contacts is characterized by low contact area and high unit loading. The form of lubrication normally found in nonconformal contacts is elastohydrodynamic lubrication (EHL). Depending on the effects of the elastic deformation and the variation of the viscosity with pressure, four regimes of lubrication can be defined: isoviscous/rigid, isoviscous/elastic, piezoviscous/rigid, and piezoviscous/elastic.

The main technical discussion begins with the development of minimum-film-thickness results for the piezoviscous/rigid regime of a compressible Newtonian fluid with Roelands viscosity. These results pro-

vide a basis for the analysis and design of a wide range of machine elements that operate in the piezoviscous/rigid regime.

The second major feature of this study is the development of a numerical method for the calculation of elastic deformations in contact stresses. A biquadratic polynomial is used to approximate the pressure distribution on the whole domain analyzed, and the deformation of every node is expressed as a linear combination of the nodal pressures, the coefficients of which can be combined into an influence-coefficient matrix. This approach has the advantages of higher numerical accuracy, less computing time, and a smaller storage-size requirement for the matrix.

The theory of ideal elastohydrodynamic lubrication is extended to real bearing systems to get a better understanding of failure mechanisms in machine elements. The improved elastic-deformation calculation is incorporated into the EHL numerical scheme. Using this revised numerical technique and the flow-factor model, the effects of surface roughness on the elastohydrodynamic lubrication of point contacts are studied. Conditions typical of an EHL contact in the piezoviscous/elastic regime entrained in pure rolling on rough bearings are investigated. Results are presented to demonstrate the effects of surface roughness on the shape of the film, the distribution of pressure, and rolling friction in a ball bearing.

Experiments to study the transient EHL effects in instrument ball bearings are reported. A parched subregime of elastohydrodynamic lubrication, lying between starved and mixed, is proposed to describe the behavior of instrument ball bearings. The parched regime is characterized by zero flow of lubricant outside the Hertz area, slow crossflow inside the Hertz area, and long-term transients in the thickness of the film. A parched bearing demands the least driving torque and has the best spin-axis definition of any lubrication regime.

This work was done by Yeau-Ren Jeng of **Lewis Research Center**. *Further information may be found in NASA TM-87120 [N86-13679], "Lubrication of Nonconformal Contacts."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
LEW-14882

Simulation of Flow in a Turbine Cascade

A lower–upper implicit scheme and interactive generation of grids are used.

A report discusses the application of a lower–upper (LU) implicit numerical-integration scheme, together with an interactive grid-generation method, to the simulation of inviscid, compressible flow in a two-dimensional model of a turbine cascade. This study is part of the continuing effort to develop techniques for the computation of complicated three-dimensional flows in turbomachinery.

The Euler equations of two-dimensional flow are presented in conservation-law form, then transformed to curvilinear coordinates that conform to the flow boundaries. The LU implicit scheme is then introduced. This scheme, which was developed previously, is an approximate-factorization scheme that requires the inversion of only sparse lower and upper triangular matrices — a procedure that can be performed efficiently without extensive storage of data. As an implicit scheme, it allows the attainment of the steady state via a large time step.

The interactive computer program TURBO, still undergoing development, is used to generate computational grids. This program uses the control-point form of algebraic grid generation, in which the shapes and positions of coordinate curves are adjusted from control points distributed sparsely throughout the flow and the grid conforms precisely to the boundaries. As an algebraic method, the control-point form provides explicit control of the grid structure and requires relatively few computations. One distinct advantage of the TURBO program over other grid-generation programs is that it allows the local grid structure to be changed as necessary (e.g., refined in regions of high curvature or anticipated high gradients) for flows bounded by surfaces with complicated shapes.

The basic interactive process of TURBO is illustrated with examples of grids fitted to turbine stator vanes and cascades of such vanes. The LU implicit scheme is used to simulate the inviscid, compressible flow on one of the cascade grids. The predictions of the implicit scheme are shown to agree closely with laser-anemometer measurements of velocity and measurements of pressure on the surfaces of a vane in an experiment in a cascade that was annular but otherwise had similar geometry.

This work was done by Yung K. Choo of Lewis Research Center, Woo-Yung Soh of Sverdrup Technology, Inc., and Seokkwan Yoon of MCAT Institute for **Ames Research Center**. *To obtain a copy of the report, "Application of a Lower-Upper Implicit Scheme and an Interactive Grid Generation for Turbomachinery Flow Field Simulations," Circle 119 on the TSP Request Card.*
ARC-12551

Meissner-Effect Stepping Motor

Weight, cost, and maintenance would be reduced.

Marshall Space Flight Center, Alabama

A proposed stepping motor would derive torque from the diamagnetic repulsion produced by the Meissner effect — the exclusion of a magnetic field from the interior of a superconductor. The design of the motor would take advantage of silver-doped YB_2Cu_3O and other compounds that have recently been discovered to be superconductive at temperatures as high as that of liquid nitrogen.

The motor (see figure) would include a rotor and a stator in a nonmagnetic housing. The rotor would include a shaft mounted on bearings in the housing and restrained axially by retaining rings. The stator would include electromagnets spaced equally around the circumference and joined at the periphery by a magnetically soft cylinder that would conduct magnetic return flux between them. The rotor body, made of nonmagnetic material, would be mounted on the shaft and would include passages for liquid nitrogen, which would be used to cool it to the temperature required for superconductivity. The outer surface of the rotor body would be a cusped cylinder covered by a superconductive skin.

Figure 2 illustrates the principle of operation. In the top part of this figure, the peaks of the cusps (called "nodes") are positioned between electromagnets C and electromagnets A. Only electromagnets A are energized. Because of the Meissner effect, the magnetic flux of each energized electromagnet is confined to the right of the nearby node. The resulting gradient of magnetic pressure pushes the rotor toward the left.

In the middle part of the Figure 2, the rotor has moved so that the nodes now face the midpoints of unenergized electromagnets C. The fluxes from energized magnets A to unenergized magnets C now pass symmetrically through the bottoms of the valleys between the nodes, and consequently exert no net magnetic force to the right or left. However, because the fluxes from energized magnets A to unenergized magnets C are confined by the Meissner effect to the right of the nodes, there is still a net magnetic force on the rotor toward the left.

If electromagnets A were to remain energized, eventually the rotor would reach the position shown at the bottom of Figure 2. This is a magnetic-equilibrium position because the symmetry of the magnetic fields on all cusps results in zero net magnetic force to the right or left. If it were desired to continue the movement to the left, then electromagnets C would have to be turned on, while electromagnets A would have to be turned off. Similarly, it would be necessary to turn on electromagnets B and turn off electromagnets C to produce motion past the next equilibrium position. Repetition of this cycle would result in continuous motion to the left. Of course, the sequence could be reversed to obtain motion to the right. Modern electronic rotor-position sensors and commutation circuitry would be used to switch the electromagnets on and off at the required positions and times.

The stator of the proposed motor would weigh less and cost less than a conventional stepping motor does because it would not contain the usual heavy metallic, magnetic housing. The rotor would cost less, both to build and to maintain, because it would not contain an arcing commutator. The use of the Meissner effect to produce magnetic force and torque would promote high energy efficiency.

This work was done by Glen A. Robertson of **Marshall Space Flight Center**. *For further information, Circle 9 on the TSP Request Card. MFS-28409*

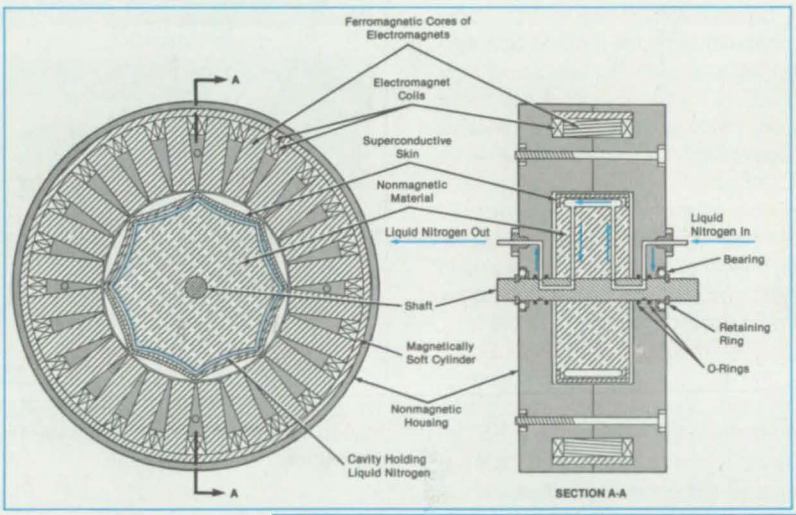


Figure 1. The **Skin of the Rotor** would be cooled below its superconducting-transition temperature by liquid nitrogen. O-Rings would prevent leaks of liquid nitrogen from the rotor.

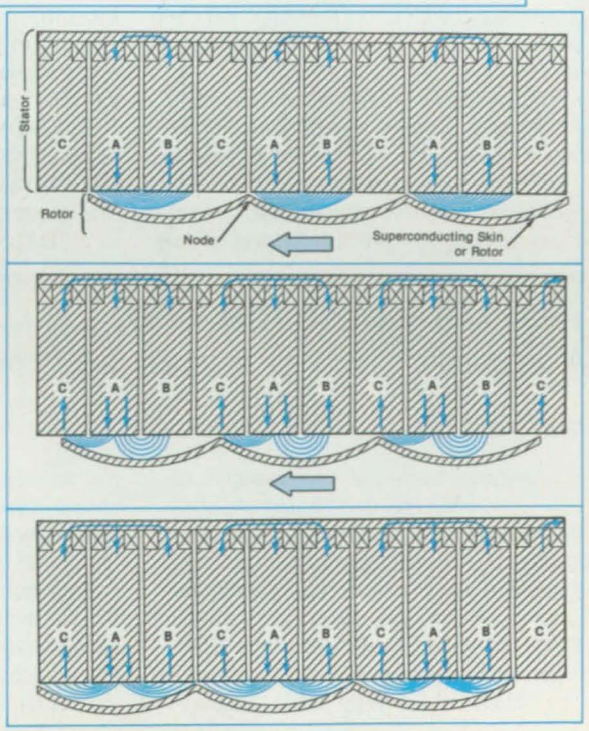


Figure 2. This **Simplified, Flattened View** of the rotor illustrates the principle of operation. One out of every three adjacent magnets is switched on at a given time. The asymmetry of the magnetic field on the superconducting skin of the rotor results in a net magnetic force to the right or left.

Fabrication Technology

Hardware, Techniques, and Processes

Molecular-Beam Epitaxy of $IrSi_3$

In experiments, $IrSi_3$ was formed at the lowest reported temperatures.

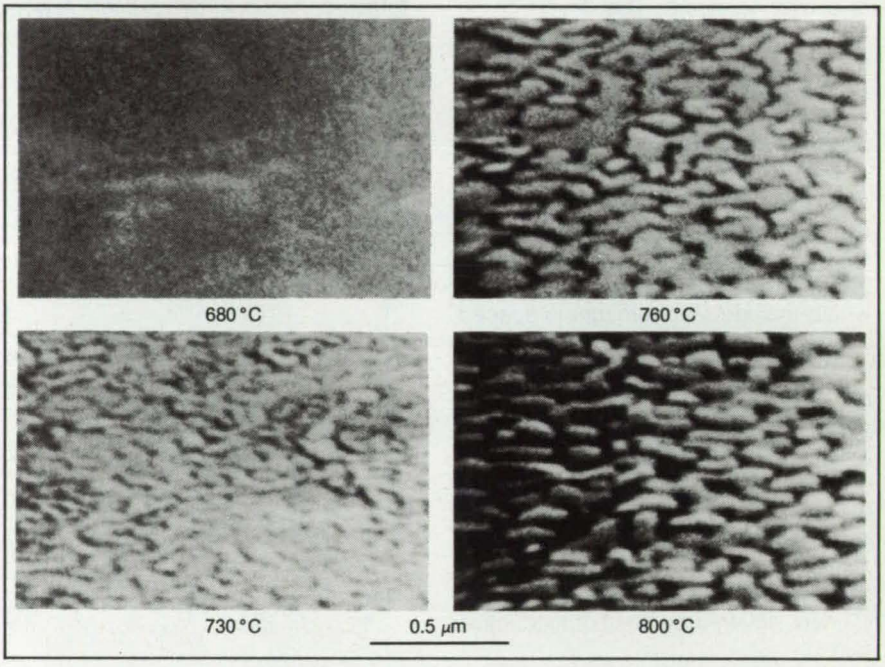
NASA's Jet Propulsion Laboratory, Pasadena, California

Molecular-beam epitaxy grows layers of iridium silicide ($IrSi_3$) on silicon at temperatures of 630 to 800 °C. The formation of $IrSi_3$ by prior techniques required annealing at 1,000 to 1,100 °C. The new, lower formation temperature is expected to enable the growth of arrays of $IrSi_3$/Si infrared detectors on Si wafers without thermally damaging image-processing circuitry integrated on the wafers.

$IrSi_3$ is particularly useful as a photodetector material because it forms Schottky diodes that have potential barriers of only 0.12 to 0.15 eV — the lowest of any metal on silicon. These photodiodes are sensitive to infrared radiation at wavelengths as large as 8 to 10 μm.

Until now, an array of iridium/silicon photodiodes has typically been made by depositing a layer of pure iridium on a silicon substrate by evaporation, then annealing the structure to convert the layer to stable $IrSi_3$. Unfortunately, mixtures of Ir and IrSi, IrSi and $IrSi_{1.75}$, and $IrSi_{1.75}$ and $IrSi_3$ also appear in the layer, producing a high series resistance and variations in the heights of the Schottky barriers. These unwanted materials are eliminated if the annealing temperature is greater than 1,000 °C, but the integrated circuitry in the silicon cannot survive such high temperatures.

With molecular-beam epitaxy, in contrast, iridium and silicon are deposited on the silicon wafer in the stoichiometric ratio of 1 to 3. Stable $IrSi_3$ thus forms on the wafer surface, without unwanted metallic iridium or compounds. The process takes place in vacuum, and the silicon substrate can be cleaned in place, just before deposition starts, to ensure a good starting surface for the $IrSi_3$ layer.



These Scanning Electron Micrographs show the surfaces of films of $IrSi_3$ deposited to a thickness of 77 Å on Si substrates. The temperatures are those of the substrates during deposition.

The deposited layers become epitaxial as the substrate temperature during deposition is raised above 630 °C. A smooth surface morphology of the layer is observed for the substrate temperature below 680 °C (see figure). At higher temperatures, the quality of the surface deteriorates, and islands of $IrSi_3$ form.

This work was done by True-Lon Lin of Caltech for ***NASA's Jet Propulsion Laboratory****. For further information, Circle 78 on the TSP Request Card.*
NPO-17953

Hot Oil Removes Wax

A noncarcinogenic solvent replaces a carcinogenic one.

Marshall Space Flight Center, Alabama

Mineral oil heated to a temperature of 250 °F (121 °C) has been found effective in removing wax from workpieces after fabrication. (For example, one might have to remove wax from a combustion-chamber or heat-exchanger cavity that had been filled with wax in preparation for an electroforming or other fabrication process.) The heated mineral oil serves as a relatively safe alternative to the carcinogenic and environmentally hazardous solvent perchloroethylene, which has commonly been used until now to remove wax.

Depending upon the size and shape of the part to be cleaned of wax, the part can be immersed in a tank of the hot oil, and/or the interior of the part can be flushed with the hot oil. A pump, fittings, and ancillary tooling can be built easily for this purpose. After cleaning, the innocuous oil residue can be washed off the part by an alkaline aqueous degreasing process.

This work was done by James J. Herzstock of Rockwell International Corp. for ***Marshall Space Flight Center****. No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 14].Refer to MFS-29713.

Fast, Nonspattering Inert-Gas Welding

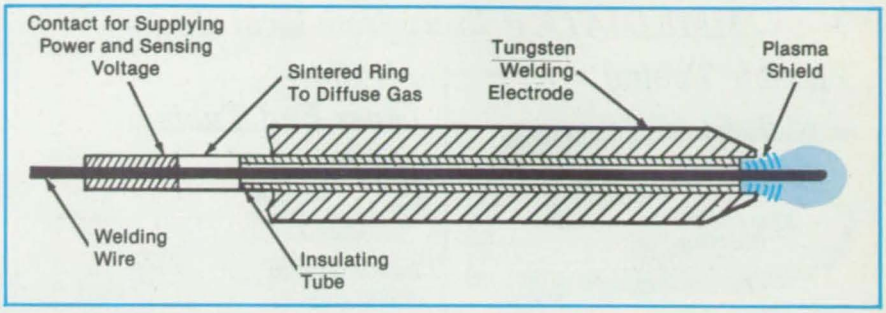
A conceptual technique would combine the best features of three previous arc-welding methods.

Marshall Space Flight Center, Alabama

A proposed welding technique would combine the best features of metal (other than tungsten)/inert-gas welding, plasma arc welding, and tungsten/inert-gas welding. The technique would offer these advantages:

- Wire fed to the weld joint would be preheated; it could therefore be fed at high speed without spattering.
- High-frequency energy would not have to be supplied to the workpiece to initiate welding.
- The size of the arc gap would not be critical; a power-supply control circuit would adjust the voltage across the gap to compensate for changes.
- Only a low gas-flow rate would be needed.
- The welding electrode could be replaced easily as a prefabricated assembly.
- An external wire-feeding manipulator would not be needed.
- The welding process would be relatively forgiving of operator error.

The welding electrode would be a hollow tungsten rod containing a coaxial insulating tube (see figure). A mechanism would feed wire along the inside of the tube. The wire would emerge from the chamfered tip of the rod and enter the weld puddle. An inert gas would enter the insulating tube via a porous sintered diffusing ring and flow along the tube to the welding tip. As it emerged from the tip, the gas would be ionized by a radio-frequency voltage applied across the gap between the wire and the hollow tungsten electrode. The plasma thus created would preheat the wire, provide an ionizing medium for initiation of the welding arc, and protect the wire and the hot welded metal from oxidation.



A Welding Wire Would Pass along the hollow core of a welding-rod assembly. The gas surrounding the wire would become ionized at the tip of the rod. The rod would be about 3/8 in. (9.5 mm) in diameter.

As in plasma welding, two power supplies would be needed. One would furnish the welding power to the wire, and the other would energize the plasma. The welding power would be applied and the welding voltage sensed via a copper contact tube integrated into the electrode structure, as in metal/inert-gas welding.

This work was done by Jeffrey L. Gilbert of Rockwell International Corp. for **Marshall Space Flight Center**. *No further documentation is available.*

MFS-29648

Making Large Suction Panels for Laminar-Flow Control

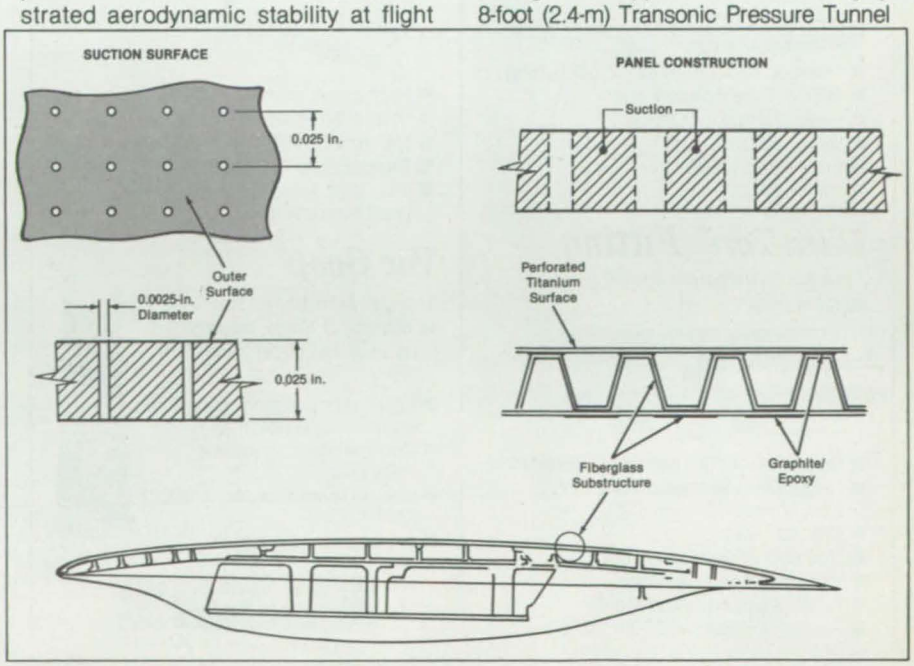
Perforated titanium panels are used to identify and resolve issues related to manufacture.

Langley Research Center, Hampton, Virginia

The attainment of laminar flow on the wings of aircraft has significant potential for reducing drag and increasing fuel efficiency. One way to maintain a large chordwise extent of laminar flow is to suck a small part of the boundary layer through the skin of a wing. This method, called laminar-flow control (LFC), can stabilize the boundary layer against small disturbances and delay the transition to turbulence. The basic theory is well established and has been verified in wind-tunnel tests and demonstrated in flight tests. Continuous suction through a porous surface is an effective means of delaying the boundary-layer transition. Until recently, however, it has been impractical to perforate airplane materials in production with holes of the small sizes required.

Recently, relatively large suction panels with aerodynamically satisfactory surface perforations and with the surface contours and smoothness characteristics necessary for LFC have been designed, fabricated, and tested. The requirements of production lines for commercial transport airplanes were carefully considered in the development of the panels. Much could be learned about the practicality of such panels for aircraft applications, inasmuch as the sizes of the panels are representative of what could be used on the wing of a commercial transport airplane. Tests of the perforated panels in a transonic wind tunnel demonstrated aerodynamic stability at flight mach numbers.

Three titanium suction panels were designed, developed, and manufactured for testing as the upper surface of a Langley 8-foot (2.4-m) Transonic Pressure Tunnel



Large Titanium Suction Panels were fabricated by use of an electron-beam perforation drilling process and sandwich construction.

LFC model. The suction panels represent one of the largest perforated LFC structures ever built, with a chord as large as that of the wing of a general-aviation airplane. The 7- by 7-ft (2.1- by 2.1-m) titanium panels have an 0.8-percent open-area porosity ratio. The perforations are 0.0025-in. (0.064-mm) holes at 0.025-in. (0.064-cm) spacings.

The perforation was done by an electron-beam drilling process that is capable of making 1,000 holes per second. Each panel has a sandwich construction (see figure) with the titanium skin bonded to a corrugated fiberglass core (forming flutes for the subsurface transfer of airflow) and has a graphite inner face sheet. Impervious bond areas divide the surface of the panel such that suction through perforated strips occurs at the surface. Metering holes located in the bottoms of the suction flutes transfer flow to aluminum ducts, from which the flow leaves the tunnel. Ducts are attached to a wing-box support mounted on a wall of the tunnel.

The distribution of pressure in the design of the airfoil incorporates the latest in the technology of supercritical flow and has a drag-divergence mach number comparable to those of modern turbulent airfoils. A significant region of supercritical flow exists on the upper surface. Features of the distribution of static pressure on the upper surface at the airfoil design point (mach number = 0.75, coefficient of lift = 0.55, Reynolds number = 20 million) include a short, steep favorable gradient near the leading edge, caused by the small nose radius, and a slightly adverse gradient over the majority of the chord, with the aft region exhibiting a Stratford-type recovery of pressure. Although the design Reynolds number for the perforated panels was 20 million, the design allows tests at Reynolds numbers as low as 8 million and as high as 40 million. Special development efforts were made to produce panels that meet LFC waviness criteria. The manufacturing tolerances of the test panels are considerably better than those attained in current production-line practice for turbulent aircraft. Critical issues related to the manufacture of large suction panels were identified and largely resolved. The techniques used to make the panels can be adapted to modern aircraft production lines.

This work was done by Dal V. Maddalon of **Langley Research Center**. *Further information may be found in NASA TM-89011 [N86-29815], "Design and Fabrication of Large Suction Panels with Perforated Surfaces for Laminar Flow Control Testing in a Transonic Wind Tunnel."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. LAR-13844

Electrical-Discharge Machining With Additional Axis

Benefits include enhanced flexibility of operation and reduced cost of machining.

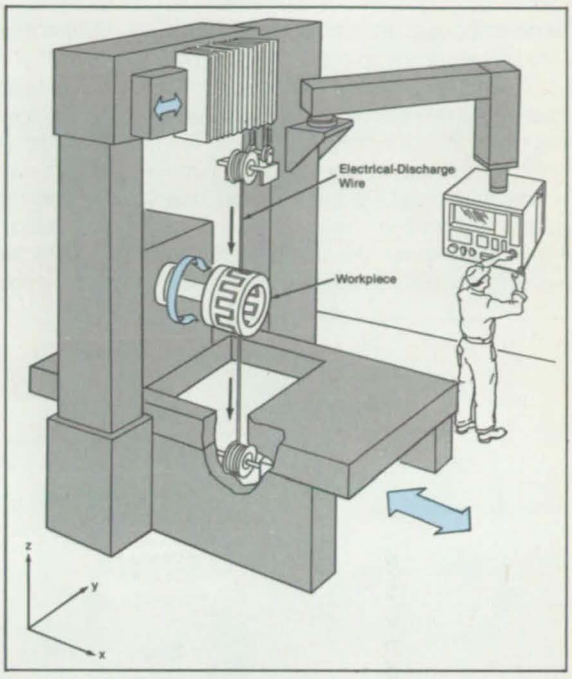
Marshall Space Flight Center, Alabama

A proposed electrical-discharge-machining (EDM) apparatus would use a movable vertical wire as its electrode. The wire would be positionable horizontally along one axis as it slid vertically past the workpiece. The workpiece would be indexed in rotation about a horizontal axis.

The apparatus was proposed to make crenelated cylindrical parts, as shown in the figure. Because of the symmetry of the parts, the wire EDM process can be used to make two such parts at a time by defining the boundary between them. One advantage is that the cost of material is reduced because two such parts can be made from a forging only slightly larger than a forging used to make one such part by conventional machining with a cutting tool.

Another advantage is that wire EDM imparts less residual stress to the workpiece than conventional machining does. Yet another advantage is that less time is spent machining each part when the parts are produced in such symmetrical pairs.

This work was done by Roger M. Malinzak and Gary N. Booth of Rockwell International Corp. for **Marshall Space Flight Center**. *No further documentation is available. MFS-29630*



The **Upper End of the Electrical-Discharge Wire** is moved parallel to the y axis as it unrolls parallel to the z axis. Meanwhile, the workpiece is indexed in rotation about an axis parallel to the x axis and moved linearly back and forth in the x direction. The electrical discharge cuts the crenelated pattern in the workpiece.

Modified Furnace Makes More Silicon Ribbon

A simple change in the lid and heat shields makes faster growth rates possible.

NASA's Jet Propulsion Laboratory, Pasadena, California

The rate of growth of silicon ribbon by the dendritic-web process is increased by a modification in the lid of the growth crucible. The modified furnace produces silicon ribbon at the rate of 8.9 cm^2/min — 44 percent higher than the previous rate.

In the modified furnace, the slots in the shields that make up the lid grow progressively wider from the bottom to the top of the lid (see figure). This allows the ribbon to cool faster by radiation. As a result, the crucible can be maintained at a higher temperature, the 5.8-cm-wide ribbon is thicker, and, therefore, the ribbon can be pulled faster.

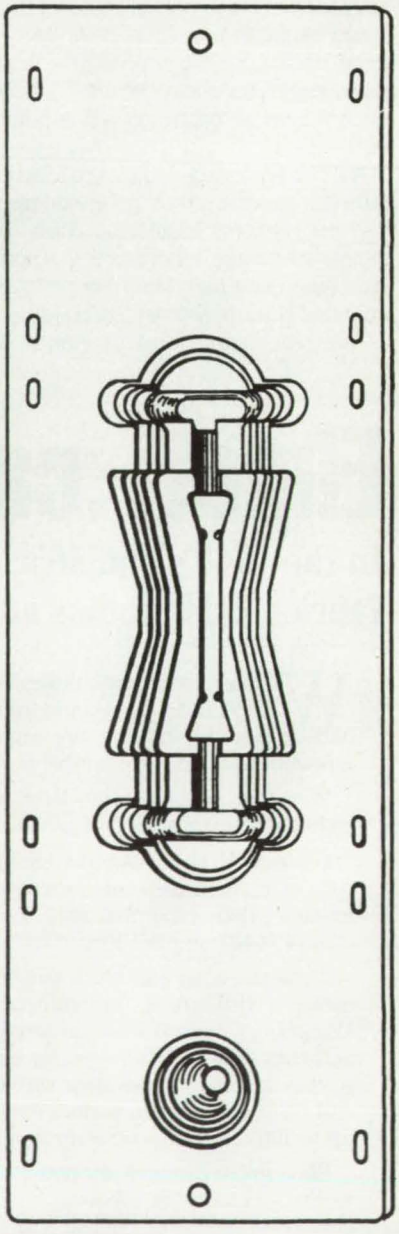
The new lid has made it possible to attain a record high production rate of 54,000 cm^2 per week. It will be used in a pilot production line to demonstrate dendritic-web technology.

This work was done by Paul A. Piotrowski of Westinghouse Electric Corp. for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 73 on the TSP Request Card.*

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

A. P. Iadicicco
Intellectual Property Dept.
Westinghouse Electric Corp.
1310 Beulah Road-Churchill
Pittsburgh, PA 15235

Refer to NPO-17350, volume and number of this NASA Tech Briefs *issue, and the page number.*



The **Stack of Heat Shields** in the lid of the crucible has progressively wider slots. The setbacks allow the silicon ribbon to radiate heat faster as it emerges from the melt through the slots.

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Circle Reader Action No. 640

Mathematics and Information Sciences

Estimating the SNR of AVIRIS Data

Improved estimates of noise are better suited to the needs of investigators.

Ames Research Center, Moffett Field, California

A combination of established statistical and filtering techniques yields improved estimates of the signal-to-noise ratio (SNR) of multispectral imagery produced by the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS). The three methods used heretofore to estimate the SNR have been inadequate: the "laboratory" method inflates the SNR, while the "dark-current" and "image" methods deflate the SNR. The new method yields a more accurate estimate of the random variability in AVIRIS imagery.

The new combination of techniques is called the "geostatistical" method. In the first step of this method, periodic noise is removed by notch filtering in the frequency domain. In the subsequent steps, sensor noise and variability within picture elements are isolated by use of the the semivariance of picture elements. This function is defined as follows:

$$\gamma(h) = (\tfrac{1}{2})E[z(x_i) - z(x_i + h)]^2$$

where $\gamma(h)$ denotes the semivariance for all pairs of picture elements in which the members of each pair are a distance h (called the "lag") apart, x_i is the applicable coordinate of the ith picture element, E denotes the expectation operator, and z denotes the signal at a picture element. The function $\gamma(h)$ or the plot thereof is called the "semivariogram" (see figure).

An unbiased estimate of $\gamma(h)$ is obtained from a transect of m pairs of picture elements separated by the same lag distance, as follows:

$$\bar{S}^2 = (\tfrac{1}{2}m)\sum_{i=1}^{m} [z(x_i) - z(x_i + h)]^2$$

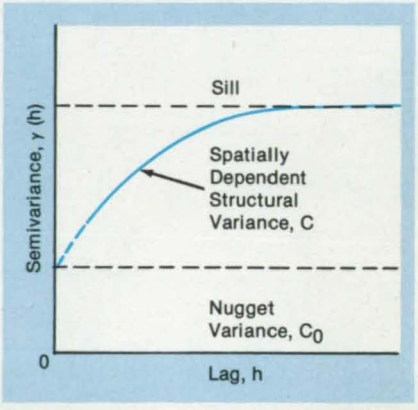
This is a useful measure of the difference between the signals at spatially separate picture elements. The larger $\bar{S}^2$ and, therefore, $\gamma(h)$ is, the less similar the picture elements are.

Three aspects of the semivariogram are of interest here: the sill, which is the asymptotic upper-bound value of $\gamma(h)$; the nugget variance (so named because it is reminiscent of a statistical measure used in prospecting for gold) C_o, which is the limit of $\gamma(h)$ when h approaches 0; and the spatially dependent structural variance, C, which is the sill minus the nugget variance. By definition $\gamma(h)$ equals zero when $h = 0$. In practice, the limit of $\gamma(h)$ when h approaches 0 has a positive value because the nugget variance represents variability at scales smaller than a picture element. This phenomenon is a characteristic of the "regularized" semivariogram calculated for plot rather than point data.

The key argument upon which the geostatistical method is based is that the nugget variance is a sound estimate of the spatially-independent noise variance relevant to the investigator. This argument is intuitively acceptable because at the limit of $\gamma(h)$, when h approaches 0, the nugget variance does not have a spatial component and is composed almost entirely of random sensor noise and variability within picture elements. The statistical justification for this argument requires consideration of a one-dimensional mathematical model in which x is a continuous parameter giving the location along a linear transect. The observed signal $z(x)$, comprises both radiance $r(x)$ (assumed to be stationary) and noise $n(x)$, which is assumed to be stationary, uncorrelated with $r(x)$, and not autocorrelated. It can be shown that the square root of the nugget variance can be used to estimate the standard deviation of the random noise and the variability within picture elements and, thereby, the SNR of AVIRIS data, via the equation

$$\text{SNR} \simeq \bar{z}/\sqrt{C_o}$$

where $\bar{z}$ = the average of the z_i. Because $\bar{z}$ and $\sqrt{C_o}$ depend on wavelength, this calculation should be done for the data in each spectral band sensed by the AVIRIS.



The **semivariogram** of an image gives a measure of the difference between the signals at spatially-separate picture elements.

This work was done by Paul J. Curran of **Ames Research Center** *and Jennifer L. Dungan of TGS Technology, Inc. Further information may be found in NASA TM-101035 [N89-15443], "Estimating the Signal-to-Noise Ratio of AVIRIS Data."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
ARC-12361

Algorithm for Solution of Subset-Regression Problems

Subsets can be selected directly from originally defined regression parameters.

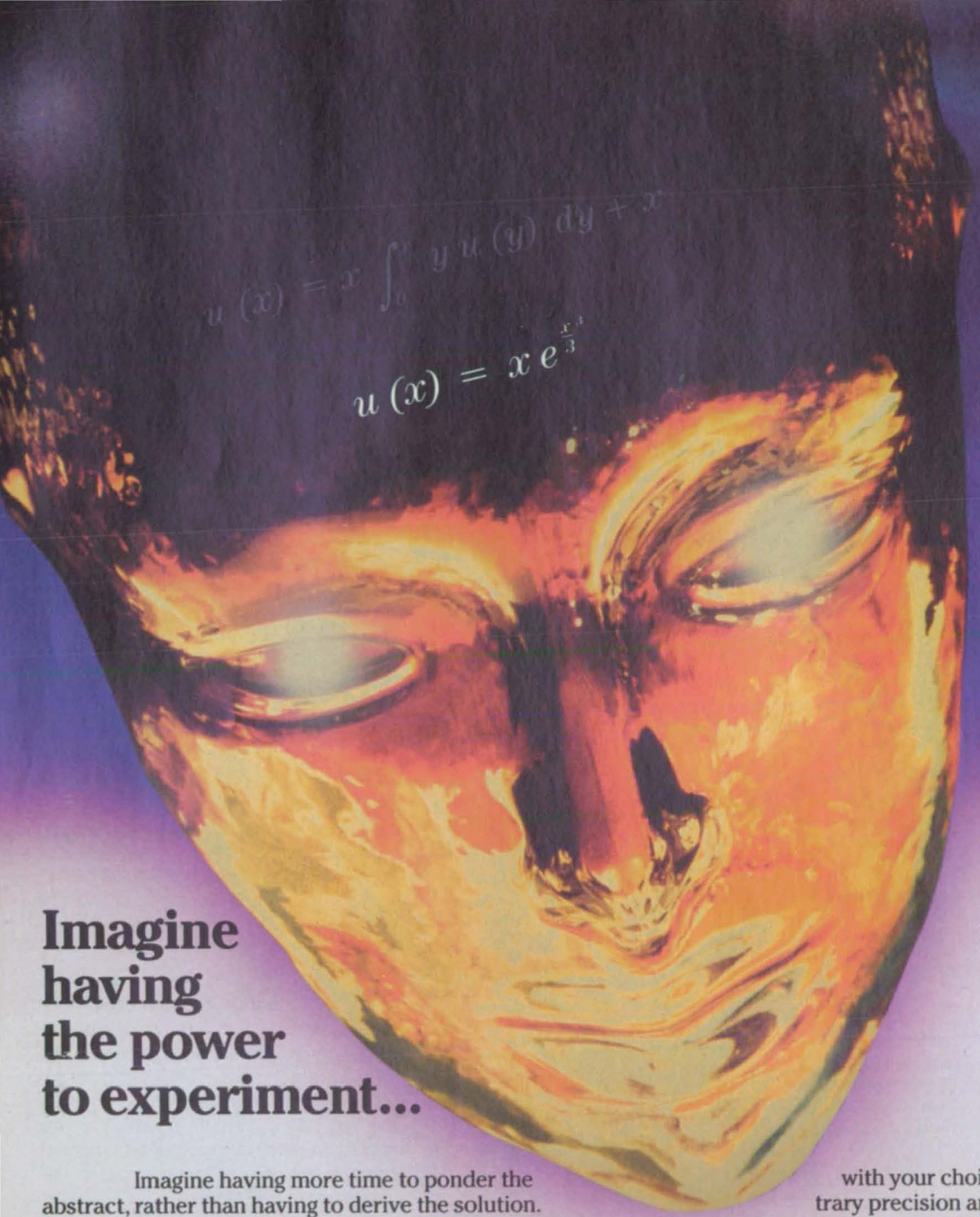
Ames Research Center, Moffett Field, California

A reliable and flexible algorithm for the solution of the subset-regression problem performs a QR decomposition with a new column-pivoting strategy, which enables the selection of the subset directly from the originally defined regression parameters. This feature, in combination with a number of extensions, makes the algorithm very flexible for use in the analysis of subset-regression problems in which the parameters have physical meanings.

The subset-regression problem is the least-squares problem

$$\min_{x} \|Ax - b\|$$

where A is an $m \times n$ ($m \geq n$) system matrix that contains some columns that are nearly linearly dependent on an independent set of columns. As used here, "nearly" means that small perturbations of A that are of the order of the inaccuracies in the entries of A establish the linear dependen-



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Circle Reader Action No. 524

cy. The task is to find the minimal number, k, of columns that constitute the independent set.

One numerically reliable technique used thus far to detect near dependencies is that of singular-value decomposition (SVD), which determines a minimal set of columns. However, the columns selected by SVD are linear combinations of the original columns of A. This is a major disadvantage in such practical subset-regression problems as the identification of the parameters of an aerodynamic model.

The QR decomposition of A is denoted as

$$Q_o^T A = \begin{bmatrix} R \\ 0 \end{bmatrix}$$

where R is an $n \times n$ upper triangular matrix and

$$Q_o^T Q_o = I_m$$

In contrast with the SVD, this decomposition does not involve a right orthogonal transformation of A that would obscure the selection of k individual columns of A. The only right transformation of A allowed in this technique is a permutation of columns.

The idea of column pivoting is to exploit the freedom introduced by this column permutation to solve the rank-deficient least-squares problem. Furthermore, it is not necessary to compute the full SVD of A to determine k because accurate estimates of the singular values, which enable such a determination, are also obtained.

The algorithm rearranges the columns of A as $[\mathbf{a}_{c_1} \ldots \mathbf{a}_{c_k}\ \mathbf{a}_{c_{k+1}} \ldots \mathbf{a}_{c_n}]$, where the vectors $[\mathbf{a}_{c_1} \ldots \mathbf{a}_{c_k}]$ correspond to the so-called identifiable or independent components $\mathbf{x}_b$ of $\mathbf{x}$, and $[\mathbf{a}_{c_{k+1}} \ldots \mathbf{a}_{c_n}]$ correspond to the dependent ones. When a component of $\mathbf{x}$ is deemed not identifiable, because its corresponding estimated variance becomes unacceptably large, then another procedure for determining the dependencies more precisely corresponds to determining whether an unacceptable increase in the variances of the components of $\mathbf{x}_b$ occurs.

In physical applications, information is often available about which components of $\mathbf{x}$ have to be in $\mathbf{x}_b$, and a priori estimates of individual components of $\mathbf{x}$ with corresponding variances are available. This information, inserted after a modified QR decomposition, enables one to interchange columns of $[\mathbf{a}_{c_1} \ldots \mathbf{a}_{c_k}]$ with columns of $[\mathbf{a}_{c_{k+1}} \ldots \mathbf{a}_{c_n}]$.

The algorithm can also be extended to enable the joint processing of columns that are contaminated by noise with those that are free of noise, without using scaling techniques. This involves a two- or three-stage procedure in which one investigates the dependencies after a modified QR decomposition in which A is partitioned into noisy and noise-free parts.

This work was done by Michel Verhaegen of **Ames Research Center**. *For further information, Circle 8 on the TSP Request Card. ARC-12145*

Life Sciences Hardware, Techniques, and Processes

Prosthetic Hand Lifts Heavy Loads

Features include ruggedness, simplicity, and relatively low cost.

Marshall Space Flight Center, Alabama

A prosthetic hand is designed to enable an amputee to lift diverse heavy objects like rocks and logs. The device is both simple and rugged. In addition, it costs less than do many other prosthetic hands, which are often awkward, bulky, heavy, and otherwise not well suited to strenuous lifting.

The new prosthetic hand (see figure) has no moving parts other than flexible straps that hold it in place. It includes a simple L-shaped metal end effector that is serrated to help prevent the lifted object from slipping off. The end effector is bolted into the end of a reinforced fiberglass cuff, which is fitted onto the remaining part of the forearm. A sock of cotton or similar material is placed over the remaining part of the forearm before inserting it in the cuff.

Hook-and-pile straps hold a flexible band on the upper arm. An inner strap and an outer strap extend downward from this flexible band to hold the cuff on the forearm. A loop strap, a front shoulder strap, and a back strap (hidden in the figure) keep the flexible band and, therefore, the prosthetic hand from being pulled off by heavy loads. The back strap and the front shoulder strap are anchored by a ring to a front strap, which anchors the system of straps under the shoulder opposite that of the amputated hand.

A steel strip on the side of the cuff that faces the body protects the cuff against damage by the lifted object. A rubber sheath could be placed over the cuff for additional protection.

This work was done by James R. Carden, William Norton, and Jewell G. Belcher of **Marshall Space Flight Center** *and Thomas W. Vest of Management Services, Inc. For further information, Circle 133 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 14]. Refer to MFS-28465.

The **Prosthetic Hand** has a simple serrated end effector with no moving parts. The prosthesis is held on the forearm by a system of flexible straps.

Rotationally Actuated Prosthetic Hand

A simple mechanism is powered by rotation of the forearm.

Marshall Space Flight Center, Alabama

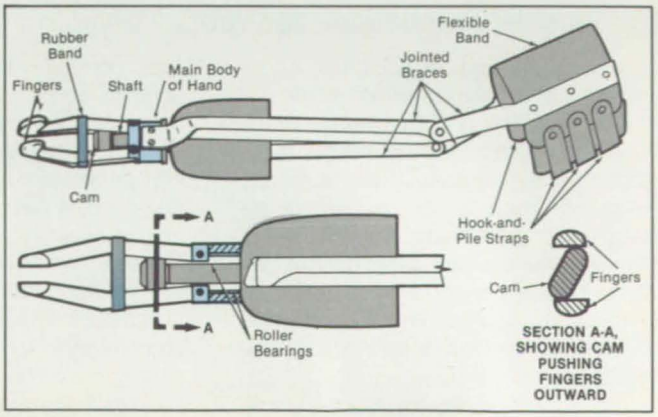
A prosthetic hand includes two pincerlike fingers that are actuated by rotation of the forearm. In comparison with "bionic" devices and body-powered artificial limbs that include cable controls, the prosthetic hand is simpler in design, is simpler to operate, weighs less, and takes up less space.

The prosthetic hand (see figure) is attached to the affected arm of an amputee at two places: (1) a plastic cuff slips over the end of the remaining part of the forearm, and (2) a flexible band with hook-and-pile (Velcro™ or equivalent) straps is wrapped around the upper arm just above the elbow. A pair of braces jointed at the elbow restrain the main body of the hand against rotation about the axis of the forearm. However, the forearm is free to rotate about its own axis, and as it does so it rotates the cuff, which is mounted at one end of a shaft supported by roller bearings in the main body.

An oval cam is mounted at the other end of the shaft; it rotates with the cuff and shaft. Two fingers attached to the main body are pressed toward each other and onto the cam by a rubber band. The cam pushes the fingers apart by an amount that depends on its rotational position. When the forearm and cuff are rotated to a position at which the long dimension of the oval lies along the gap between the fingers, the fingers are spread apart to the maximum extent; when the forearm and cuff are rotated 90° from the foregoing position, the ends of the fingers are pressed together. Intermediate separations are obtained at intermediate rotational positions.

This work was done by William E. Norton, Jewell G. Belcher, Jr., and James R. Carden of **Marshall Space Flight Center** *and Thomas W. Vest of Management Services, Inc. For further information, Circle 148 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 14]. Refer to MFS-28426.



The **Prosthetic Hand** is attached to the end of the remaining part of the forearm and to the upper arm just above the elbow. The pincerlike fingers are pushed apart to a degree that depends on the rotation of the forearm.

Treating Wastewater With Immobilized Enzymes

Urea and other contaminants are removed.

Marshall Space Flight Center, Alabama

Experiments have shown that enzymes can be immobilized on supporting materials to make biocatalyst beds for the treatment of wastewater. With a suitable combination of enzymes, the concentrations of various inorganic and organic contaminants, including ammonia and urea, can be reduced significantly.

The enzyme urease can be used to catalyze the decomposition of urea according to

$$\underbrace{NH_2CONH_2}_{\text{Urea}} + H_2O \xrightarrow{\underbrace{\text{Immobilized Urease}}} 2NH_3 + CO_2$$

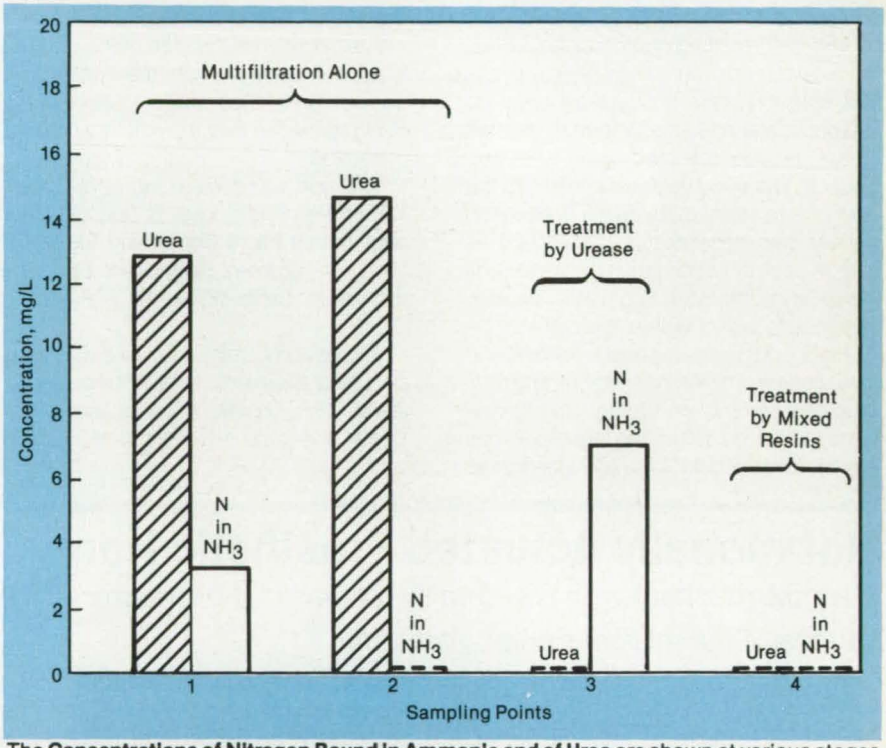
In an experiment, urease was immobilized on a 1,6-hexanediamine derivative of silica that had been activated by Ti(IV) ions. The immobilized-enzyme material was packed in a 7.1-cm^3 column. A solution of 30 mg/L urea was passed through the column at a flow of 2.5 cm^3/min, yielding a contact time of 2.8 min. Analysis of the first 29 liters of effluent showed that the column had catalyzed the reaction of nearly all measurable urea to NH_3 and CO_2.

The enzyme alcohol oxidase can be used to catalyze the decomposition of alcohols and formaldehyde. In an experiment, alcohol oxidase was immobilized on derivatized silica, and the immobilized-enzyme material was packed in a 35-cm^3 column. A solution of 50 mg/L methanol saturated with oxygen was pumped through the column at a flow of 5 cm^3/min, yielding a contact time of 7.1 min. Initially, the column removed all measurable methanol; it then began to lose activity because of degradation by H_2O_2.

To protect the alcohol oxidase, it is necessary to add enzymes that catalyze the decomposition of H_2O_2 in situ. One proposed way to do this is to coimmobilize the alcohol oxidase with catalase and superoxide dismutase on derivatized silica. When such a mixture was tested in a 30 cm^3 column at a flow of 3.4 cm^3/min (contact time 5 min), it removed 24 mg/L of ethanol from 3.2 L of 80 mg/L ethanol solution.

In a third experiment, a bed of immobilized urease and a bed of mixed resins were used to post-treat shower water that contained 15 mg/L urea and had been treated conventionally by multifiltration. As the figure shows, multifiltration did not remove urea from the water, but treatment by the column reduced the concentration of urea to below measurable levels. After further treatment by the bed of mixed resins, the concentrations of all of the carbon bound in inorganic compounds (principally CO_2) and of the ammonia from the decomposition of the urea were reduced below measurable levels. The total concentration of carbon bound in organic compounds in the effluent was 3.3 mg/L.

This work was done by Clifford D. Jolly of Umpqua Research Co. for **Marshall Space Flight Center**. *For further information, Circle 164 on the TSP Request Card. MFS-26090*



The **Concentrations of Nitrogen Bound in Ammonia and of Urea** are shown at various stages in the treatment of shower water. The limits of detection are 1.0 mg/L for urea and 0.1 mg/L for N in NH_3.

Optical Computation of Matrices From Vectors

Four-wave mixing yields a two-dimensional pattern of light and dark.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed optical apparatus would generate a rectangular pattern of light and dark areas, the brightnesses of which would represent the elements of the matrix product of two vectors. Optical multipliers of this type might be used as real-time analog tensor generators, components of neural networks, and generators of patterns to steer electromagnetic beams by diffraction or to effect temporary interconnections in very-large-scale integrated circuits.

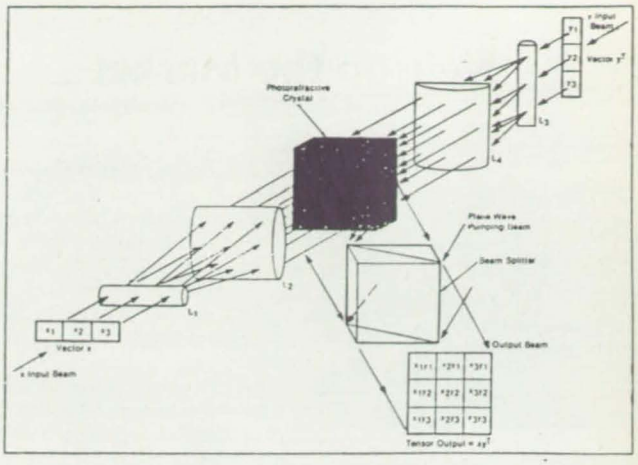
The apparatus (see figure) would, in effect, compute the tensor product $\mathbf{x}\mathbf{y}^T$ (where T denotes the matrix transpose) of the vectors **x** and **y**, which would be represented by linear arrays of small areas of various degrees of transparency. A laser beam would pass through the horizontal strip transparency representing vector **x**. The beam would be expanded by horizontal cylindrical lens L_1, then collimated by horizontal cylindrical lens L_2, forming columns of uniformly collimated light representing the components of **x**. In a similar manner, a second laser beam coherent with the first would pass through the vertical strip transparency representing $\mathbf{y}^T$, then through vertical cylindrical lenses L_3 and L_4 to form rows of uniformly collimated light representing the components of $\mathbf{y}^T$.

The row and column patterns of laser light would be applied to opposite faces of a photorefractive crystal. A plane-wave pumping laser beam coherent with the first two beams would be applied to the photorefractive crystal (e.g., $LiNbO_3$) from a third direction through a beam splitter. An output beam representing the matrix product

would be generated by four-wave mixing. The intensity in the output beam would be distributed spatially in proportion to the product of the three input waves. The output beam would propagate in the direction opposite that of the pumping beam, out through the beam splitter to the output plane, where it would be fed to sensors, a projection screen, or possibly another optical computing apparatus.

This work was done by Hua-Kuang Liu of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 114 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 14]. Refer to NPO-17512

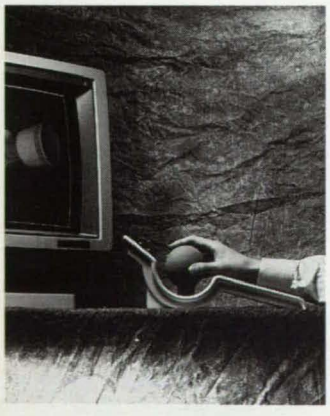


The **Photorefractive Effect** would give rise to four-wave mixing, which would generate an output beam modulated spatially by the matrix product xy^T

New on the Market

The XS-420 **thermal imaging camera** from Xedar Corp., Boulder, CO, features an image resolution of 270 x 270 elements and provides approximately 0.2° C thermal resolution. The battery-powered camera—including 50 mm f/.7 Germanium optic and 1.5" viewfinder—weighs 8.5 lbs., and is TV-compatible.
Circle Reader Action Number 772.

Adhesives Research Inc., Glen Rock, PA, has introduced a line of **electrically-conductive pressure-sensitive tapes**. The technology can be incorporated into a variety of adhesives and coated onto conductive or nonconductive materials such as copper foil and pressure-sensitive foam and film tapes. Applications include foils and tapes in EMI/RFI shielding, replacements for low-voltage wires, bonding layers, and antistatic uses in computers and integrated circuits.
Circle Reader Action Number 770.



The Spaceball™, from Spatial Systems Inc., Billerica, MA, is a **force-sensing input control device** which enables a computer user to manipulate screen images using simple hand movements. Users can move from axis to axis instantly by changing the direction of the force applied to the ball. Spaceball is supported on major graphics platforms including Silicon Graphics, Apollo, Sun, Intergraph, and Hewlett-Packard.
Circle Reader Action Number 776.

The Boardmaster **digital diagnostic system** from United Electronic Industries, Watertown, MA, tests digital devices with up to 40 pins, including surface mount packages. The stand-alone system can test digital ICs in- or out-of-circuit. TTL, CMOS, LSI, static and dynamic memory and interface devices are among the test programs included in the system library. All results and pin conditions are displayed on the unit's integral VDU.
Circle Reader Action Number 766.

The ECR904 **ion beam source** from Microscience Inc., Norwell, MA, combines ECR plasma technology with ion beam extraction optics. As the ECR process does not require a filament, 904GR can work with reactive gases for extended periods of time. Applications include RIBE, CAIBE for GaAs technology, precision milling for semiconductor laser fabrication, and optical structures.
Circle Reader Action Number 768.

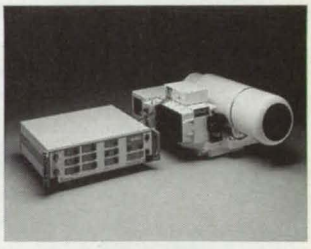
A demonstration kit from EG&G Electro-Optics, Salem, MA, shows how **pulsed xenon lighting and silicon photodiodes** can be used as a UV-visible light system for analytical equipment. The kit includes a pulsed xenon lamp with LITE-PAC® power supply, focusing optics, an integrated reference and signal channel with cuvette, and a channel for direct viewing of the light pulse.
Circle Reader Action Number 774.

The Model 891 ruggedized miniature **CCD video camera** from Videospection, Salt Lake City, UT, features a compact, lightweight aluminum modular housing. The CCD image sensor incorporates an X1000 anti-blooming capability, zero percent geometric distortion, over 70 dB dynamic range, and low image retention. The camera complies with Mil-E-5400 airborne electronic equipment requirements and is available in US RS-170 or European CCIR sync standards.
Circle Reader Action Number 792.

CubiCalc™, from HyperLogic Corp., Escondido, CA, is a **fuzzy logic decision system shell** that allows users to design, prototype, and test a complete fuzzy system on a PC without external equipment or programming. The shell contains a text editor for entry of the English-like rules which form the basis of the decision procedure and another editor for entry of spreadsheet-like expressions used to define data pre-processing and post-processing steps. Available for $495, CubiCalc is based on IBM AT computers running Microsoft Windows.
Circle Reader Action Number 798.

Designed to report **real-time dimensional measurement and data accumulation** for instant inspection of machined parts, the Computer-Aided Gaging (CAG) system from Edmunds Gages, Farmington, CT, monitors complex gaging operations through full cycle. Using 16 to 32 multiple and expandable inputs, the microprocessor-based system can be linked in any combination to produce automatic mastering, user-programmable master size and part tolerances, and statistical, histogram, and XR displays.
Circle Reader Action Number 740.

Cotronics Corp., Brooklyn, NY, has developed a **ceramic putty** with a melting point above 3200° F. Made from asbestos-free aluminum-oxide-based ceramics, THERMEEZ™ is resistant to oxidizing and reducing atmospheres, molten nonferrous metals, steam, and most chemicals and solvents. Applications include molded ceramic fiber components, high-temperature insulation, and liquid metal handling.
Circle Reader Action Number 794.



The LRY-1000 **laser rangefinder** from the Electro-Optics Division of Holometrix, Cambridge, MA, measures distances up to 30 km to an accuracy of ±10 cm. The system features a 90 millijoule Nd:YAG laser transceiver operating at 20 pulses per second, a control console, and a laser power supply. Its adjustable laser beam width enables the LRY-1000 to be used in a variety of rangefinding, tracking, surveying, mapping, and photogrammetric applications.
Circle Reader Action Number 800.

A new **digital audio multiplexer**, the NV2000 High-Definition Audio System from NVision, Nevada City, CA, supports and simplifies multichannel audio interconnection requirements, including HDTV, D-1/D-2, and Type C videotape recorders. It provides 20 bit encoding and distribution capability for multiple channels of program audio with 100 dB S/N in a studio environment. Program audio channels and ancillary signals are multiplexed together into one data stream, allowing one deck of a video routing switch to carry all program audio, time code, and cue information.
Circle Reader Action Number 796.

New on the Market

RepliCAD, a **computer-aided design system which automates the design and simulation of replacement parts**, has been introduced by Honeywell Inc., Minneapolis, MN. The system can distribute Simulation Program for Integrated Circuit Emulation (SPICE) simulations across an Apollo computer network. Once the simulations have been defined using the "click and point" menu-driven software, the system task manager automatically distributes the SPICE simulations to idle Apollo nodes based on user selections.
Circle Reader Action Number 788.

The D4C series **fiber optic connector** from OFTI, Billerica, MA, incorporates an internal spring-loaded ferrule designed to eliminate the risk of signal interruption when the cable is pulled. The one-piece connectors are available for single-mode fibers and both 125 and 140 μm clad, multimode fibers. They perform over a temperature range from -40° to +80°C.
Circle Reader Action Number 778.

PSSI/BIMA **ergonomic chairs** from Plug-In Storage® Systems Inc., Orange, CT, are suitable for use in ESD and class 10 clean room environments. Static charges are dissipated through the chairs to a conductive floor. Electrically-conductive upholstery prevents static generation. Available in desk and bench heights, all models have been independently tested to below the class 10 limits of Federal Standard 209D, Table 1, for all particle sizes.
Circle Reader Action Number 790.

The MDL series of **miniature collimated diode lasers** from LaserMax Inc., Rochester, NY, can be TTL-modulated up to 1 KHz or modulated at 10 Hz with a built-in flash circuit. The 11 mm diameter by 28 mm lasers function on unregulated DC power and are suitable for optical disc interferometry, holography, and alignment.
Circle Reader Action Number 786.

The first real-time **3D graphics board** for Intel-based PCs has been introduced by Silicon Graphics Inc., Mountain View, CA. IRISVISION™ supports 8- and 24-bit color on MicroChannel and AT PCs. The two-board set uses the IRIS Graphics Library™ (GL™) software interface, which facilitates the development of high-performance visual processing applications.
Circle Reader Action Number 784.

New **miniature CCD cameras** from PULNiX, Sunnyvale, CA, measure two inches square and operate without support electronics. The TM-7 cameras feature a high-resolution (768H x 493V) 1/2" format interline CCD. Any C-mount lens may be used with the TM-7.
Circle Reader Action Number 782.

Optical Coating Laboratory Inc., Santa Rosa, CA, has developed MetaMode™, a **fully-automated, high-rate coating process** which produces sputtered thin films. A relatively "cold" process, MetaMode allows flat or irregularly shaped substrates such as glass or plastic to be coated at or near room temperature, usually eliminating the need for heating or cooling cycles.
Circle Reader Action Number 780.

New Literature

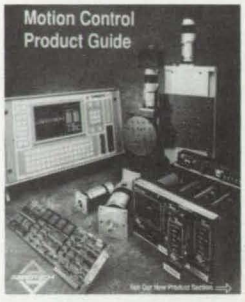
More than 1700 **controls and gages** are featured in a free catalog from Dwyer Instruments, Inc., Michigan City, IN. Included are pressure and differential pressure gages and switches, manometers, air filter gages, flowmeters, Pitot tubes, air velocity gages, and pressure transmitters for air and fluids. All provide 4-20 mA output signals for spans from 0-0.1" wc up to 0-2000 psi.
Circle Reader Action Number 720.

A brochure describing TECPLOT™, an **interactive plotting program** for visualizing engineering and scientific data, is available from Amtec Engineering Inc., Bellevue, WA. TECPLOT integrates X-Y, 2D, and 3D plotting capabilities, and allows the display of multiple plots on the screen using windows.
Circle Reader Action Number 728.

A four-color brochure from Technetics Corp., Deland, FL, describes **fiber metal products** including abradable seals, acoustic products, and thermal barrier systems produced with and without plasma flame sprayed ceramic coatings. The brochure also covers the company's quality control procedures, engineering laboratory, and design and manufacturing capabilities.
Circle Reader Action Number 722.

Kurta Corp., Phoenix, AZ, has produced a four-color brochure highlighting its line of **digitizers, pointing devices, and software solutions**. The centerfold spotlights the Kurta Studio, a Macintosh-based system for PageMaker, FreeHand, and Persuasion software which features a color-coordinated template.
Circle Reader Action Number 726.

J.W. Lemmens Inc., St. Louis, MO, is offering two free technical papers on its equipment and procedure used in **nondestructive testing of refractory products**. The system measures a material's modulus of elasticity through impulse excitation and provides a reading of strength, porosity, wear rate, and thermal shock resistance. Because the system can be set up to test automatically, it makes total batch testing and grading practical.
Circle Reader Action Number 716.



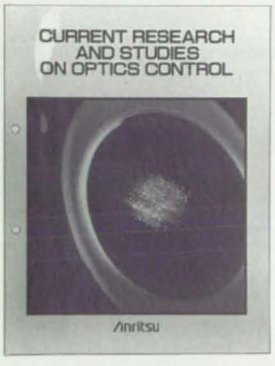
A free 216-page guide describes **motion control products** developed by Aerotech Inc., Pittsburgh, PA. The publication features motor-driven linear and rotary positioning stages, microstepping translators, stepping motors and drives, servo motors, amplifiers, and brushless drives. Also described is the UNIDEX™ motion controller line ranging from single-axis point-to-point microstepping controllers to the eight-axis UNIDEX 21 contouring motion controller.
Circle Reader Action Number 724.

Penny & Giles Data Systems Inc., Rosewell, GA, has published an eight-page brochure on the **Multiband Data Recorder**, which features a wide range of direct, FM, and high-density digital recording (HDDR) formats, and track configurations up to 42 channels. The free brochure describes ECAL, a unique Electronic Channel Alignment that permits up to four user-programmable equalizer settings per channel for optimum performance in IRIG, non-IRIG, and HDDR operations.
Circle Reader Action Number 718.

New Literature

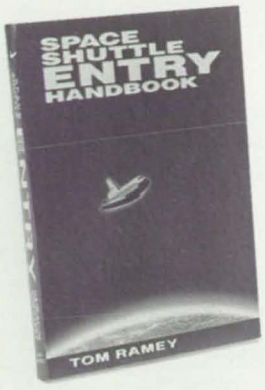
A Practical Guide to Neural Nets, from Addison-Wesley Publishing Co., Reading, MA, explores the state of the art in research, system development, and deployed applications. It explains how **neural networks** function and how to move from theory to application for development of a neural net to be embedded in an expert system. An IBM-compatible diskette is included which demonstrates a neural net in the process of learning.
Circle Reader Action Number 702.

A 38-page booklet from Anritsu America Inc., Oakland, NJ, describes five **optics control techniques**: high-speed modulation of lightwaves, control of optical waves via nonlinear optical effects, development of a hyper-coherent optical sweep generator using semiconductor lasers, phase conjugate optics using dye-doped films, and semiconductor quantum effect devices. The booklet includes technical data and diagrams.
Circle Reader Action Number 710.



Virtual Reality: The Next Revolution in Computer/Human Interface, from Matrix Information Services, Lathrup Village, MI, reports on **virtual reality R&D efforts** worldwide, identifying key players and likely future competition. It previews commercial systems, discusses current and future legal issues, and includes a bibliography and conference schedule.
Circle Reader Action Number 704.

Lambda/Ten Optics, Westford, MA, has published a catalog featuring its **optical instruments** and components, including laser beam expanders, Newtonian collimators, parabolic mirrors off-axis, front surface flat mirrors, and coatings. It describes each product's function, applications, design benefits, specifications, and optional features.
Circle Reader Action Number 714.



Ramey Aerospace, Carmel Valley, CA, has published the *Space Shuttle Entry Handbook*, a comprehensive **course in deorbit and entry, guidance, navigation and control, and flight procedures**. Based on NASA astronaut training materials, the 300-page softcover book includes data on aerodynamics and thermodynamics.
Circle Reader Action Number 706.

Vacuum pumps and accessories are described in a 16-page catalog from Vaccon Co. Inc., Medfield, MA. The catalog includes performance data, physical dimensions, factors to consider when selecting a vacuum pump, and pricing information. A comparison chart of Vaccon J-Series air-powered vacuum pumps to equivalent electrical pumps is also provided.
Circle Reader Action Number 712.

A free catalog spotlights axial leaded conformal coated **monolithic ceramic capacitors** from Murata Erie, Smyrna, GA. It contains specifications such as temperature characteristics, capacitance tolerance, and mechanical and environmental details. Tape and reel dimensions are also included.
Circle Reader Action Number 708.

Subject Index

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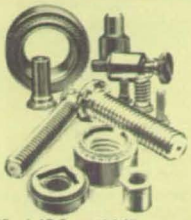

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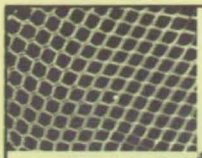

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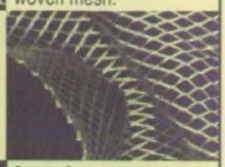

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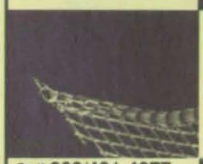

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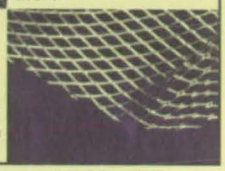

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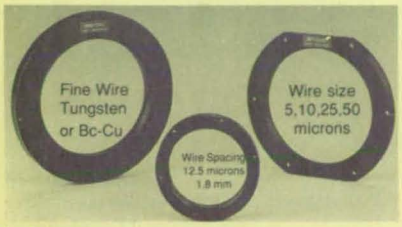

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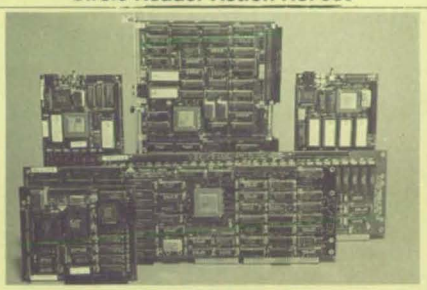

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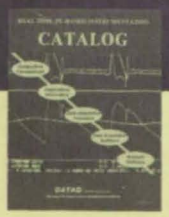

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NASA PATENTS

Over the past three decades, NASA has granted more than 1000 patent licenses in virtually every area of technology. Sales of licensed inventions exceed $10 million, and royalties paid to NASA approach $1 million. The Space Agency has a portfolio of 3000 domestic and foreign patents and pending applications available now for license by small and large businesses, and by individuals. Recently patented inventions include:

Carbide/Fluoride/Silver Self-Lubricating Composite

(U.S. Patent No. 4,728,448)
Inventor: **Harold E. Sliney**
Mr. Sliney, NASA's 1989 Inventor of the Year, has created a self-lubricating, friction- and wear-reducing composite material for use over a wide temperature spectrum from cryogenic to about 900°C in a chemically-reactive environment comprising silver, barium fluoride/calcium fluoride eutectic, and metal-bonded chromium carbide.

Polyimides Containing Carbonyl and Ether Connecting Groups

(U.S. Patent No. 4,820,791)
Inventors: **Paul M. Hergenrother** and **Stephen J. Havens**
This invention relates to structural resins and, in particular, to new polyimides formed from the reaction of aromatic dianhydrides with novel aromatic diamines containing carbonyl and ether connecting groups between the aromatic rings, whereby processible, solvent-chemical-, and impact-resistant polyimides are obtained.

Human Serum Albumin Crystals and Method of Preparation

(U.S. Patent No. 4,833,233)
Inventor: **Daniel C. Carter**
NASA's 1990 Inventor of the Year, Carter has developed a methodology for preparing crystals of human serum albumin in a form suitable for x-ray analysis of crystal structure. The size and quality of the resulting crystals enable drug binding and genetic engineering studies.

Airplane Takeoff and Landing Performance Monitoring System

(U.S. Patent No. 4,843,554)
Inventors: **David B. Middleton**, **Raghavachari Srivatsan**, and **Lee H. Person**
This invention provides the pilot with graphic and metric information to assist in decisions related to achieving rotation speed within the safe zone of the runway or stopping the aircraft on the runway after landing or takeoff abort. The real-time monitoring system displays the aircraft's position on the runway, summarizes the critical information into a situation advisory flag, flags engine failures and off-nominal acceleration performance, and indicates where on the runway events such as decision speed and expected stop points will occur based on actual or predicted performance.

Methods of Using Fluoroepoxy Compounds as Adhesives for Fluoroplastic Adherends and Products Made Therefrom

(U.S. Patent No. 4,902,574)
Inventor: **Sheng Y. Lee**
Fluoroepoxy compounds are made by reacting a fluoroepoxy resin with an effective curing agent such as an adduct amine. While the compound is sufficiently liquid to wet a fluoroplastic surface, it can be applied to a fluoroplastic adherend such as Teflon and employed as an adhesive to form various fluoroplastic products, without requiring any surface treatment of the adherend. The compounds are formulated with high fluorine contents, normally above 46 percent by weight, preferably for bonding fluoroplastics with a high F-content, above 55 percent by weight.

Multi-Fingered Robotic Hand

(U.S. Patent No. 4,921,293)
Inventors: **Carl F. Ruoff** and **J. Kenneth Salisbury, Jr.**
The invention is a robotic hand having a plurality of fingers, each with multiple joints pivotally connected to one another, with actuators attached at one end to an actuating and control mechanism mounted remotely from the hand and at the other end to the joints of the fingers for manipulating the digits and passing the robot arm in between the hand and the actuating and control mechanism. Pulleys route the actuators within the fingers.

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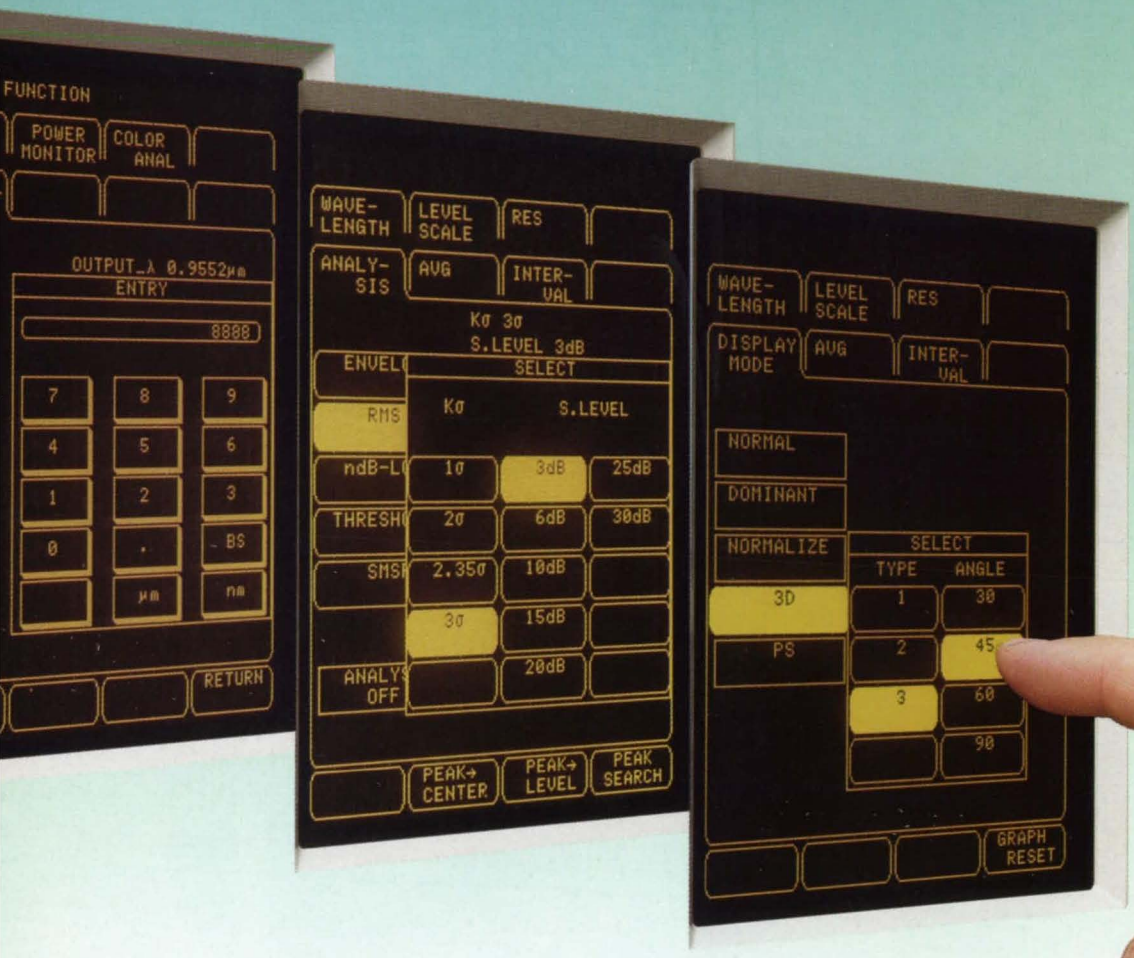

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