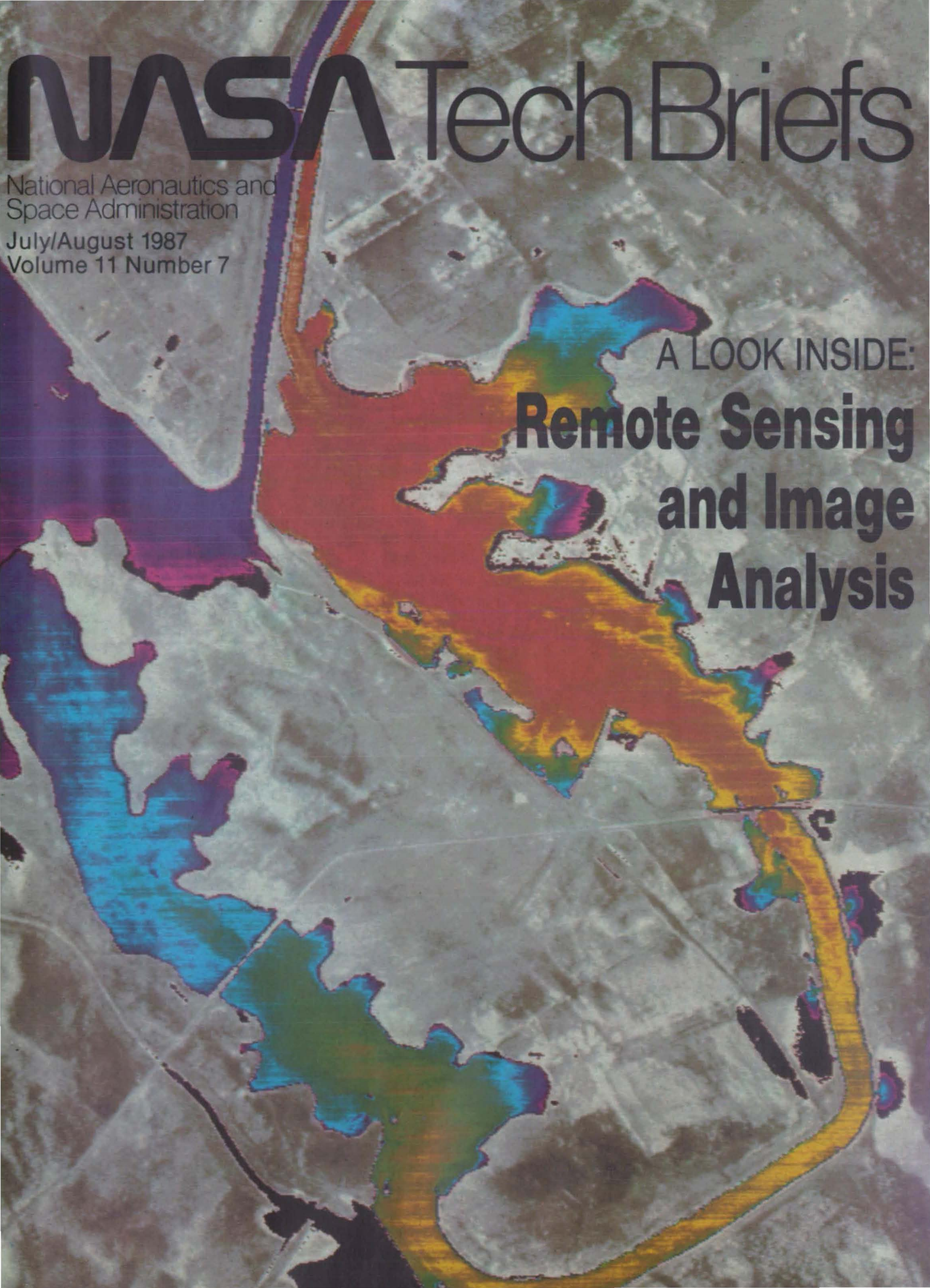
# NASA Tech Briefs

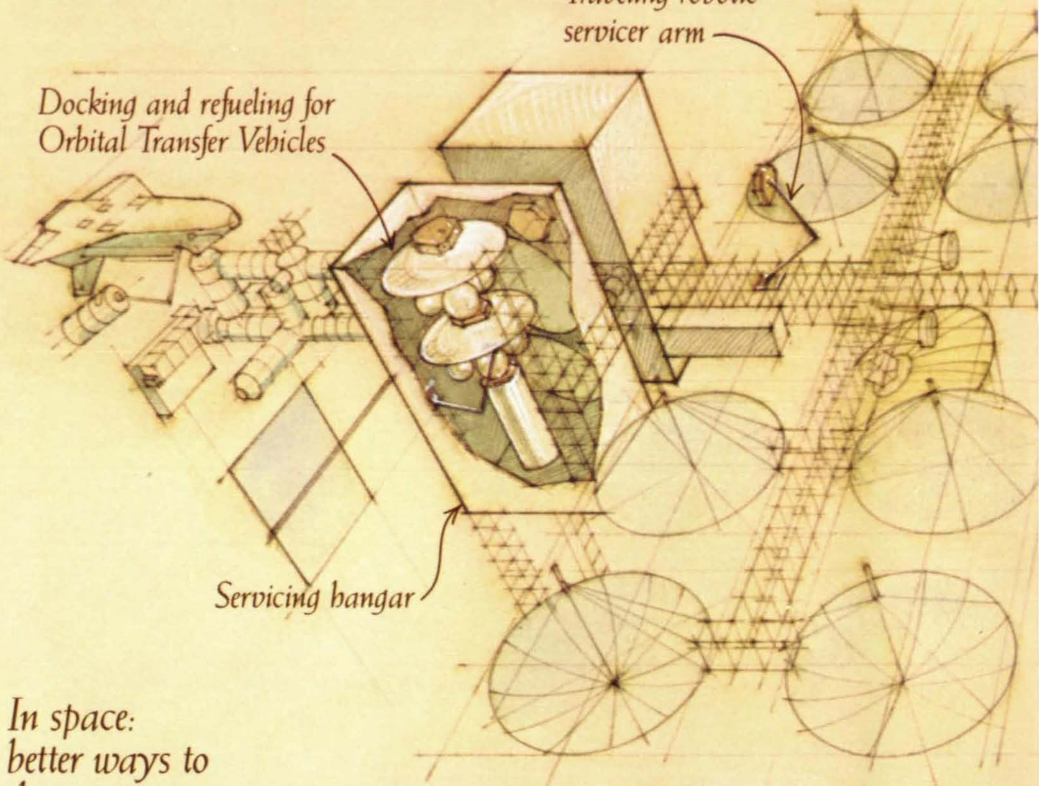
National Aeronautics and
Space Administration
July/August 1987
Volume 11 Number 7

A LOOK INSIDE:
**Remote Sensing and Image Analysis**



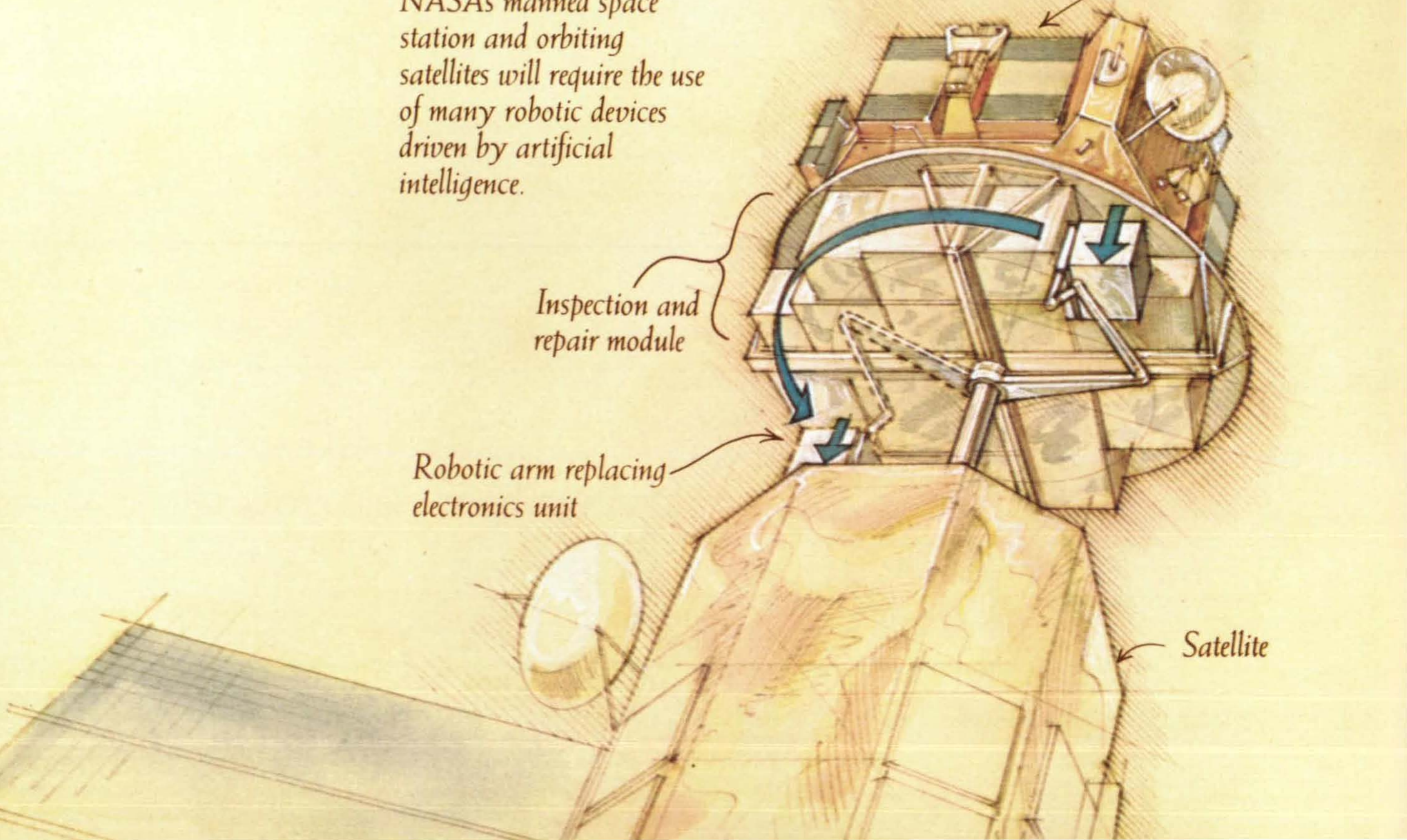
# *Artificial intelligence and robotics: giving machines the ability to sense, reason and act.*

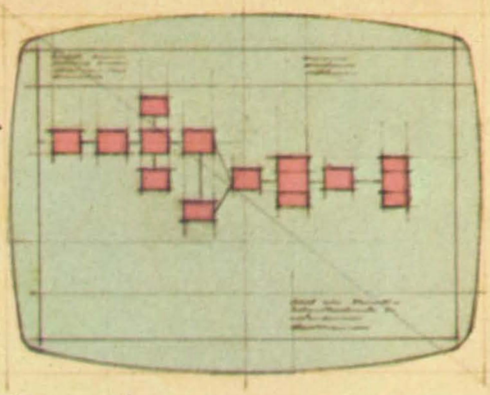
*Much as it may hurt to think so, many things might be done better by independently functioning machines than by humans. Certain tasks may require superhuman precision or speed, or need to be done where humans can't go. Martin Marietta is creating systems that combine the ability to sense, reason and take action—to function autonomously and intelligently. And we are exploring ways to put them to work on a variety of tasks.*

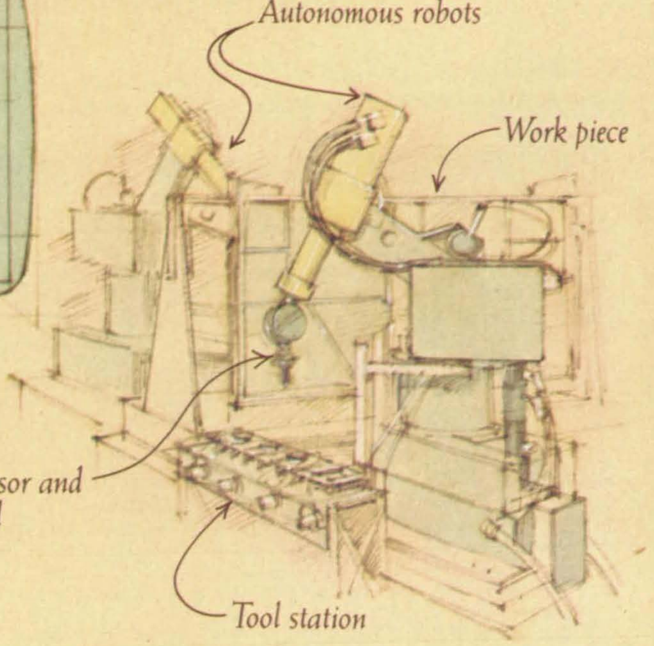


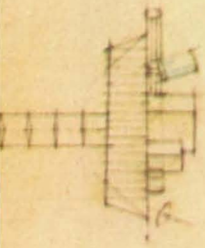

## *In space: better ways to do servicing.*

*NASA's manned space station and orbiting satellites will require the use of many robotic devices driven by artificial intelligence.*



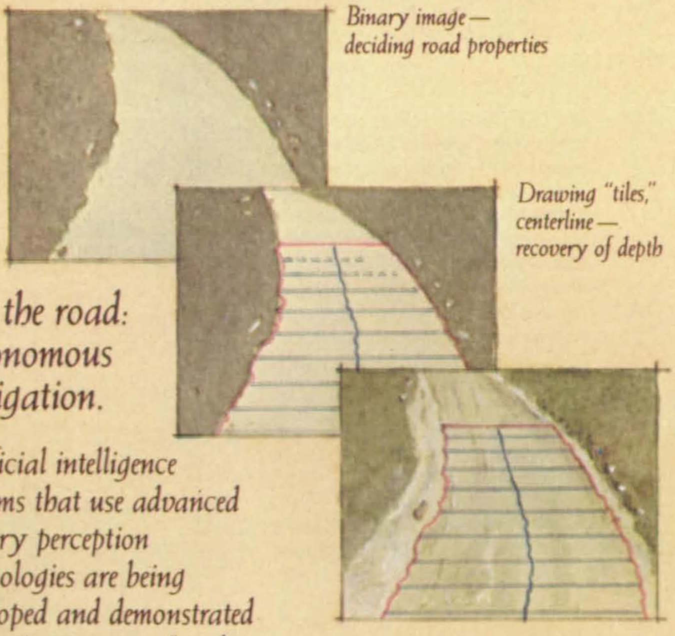


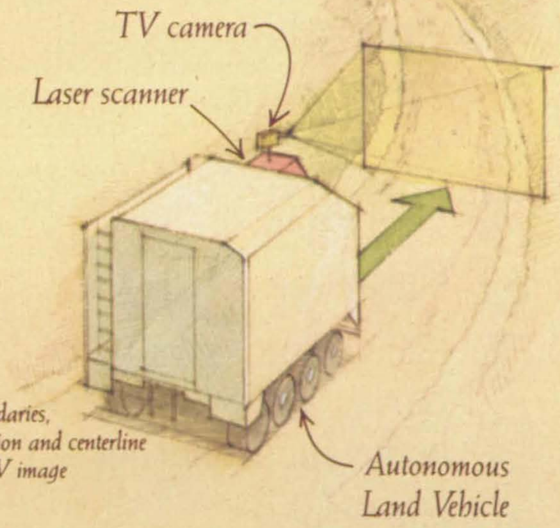



## On earth: faster manufacturing and inspections.

*With creative intelligence stemming from software that we are developing, autonomous robots can quickly and efficiently perform batch manufacturing and precision inspections, even choose their own tools.*




## On the road: autonomous navigation.

*Artificial intelligence systems that use advanced sensory perception technologies are being developed and demonstrated in the Autonomous Land Vehicle. Already able to follow roads, this mobile test bed will eventually be able to plan its route, avoid obstacles and even thread its way across country.*

*Masterminding tomorrow's technologies*

**MARTIN MARIETTA**

Martin Marietta Corporation
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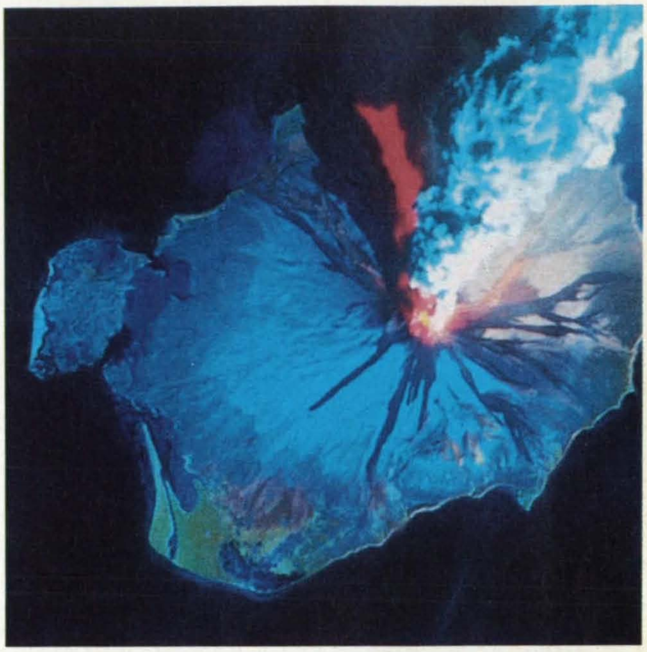
# SPECIAL FEATURES



# TECHNICAL SECTION





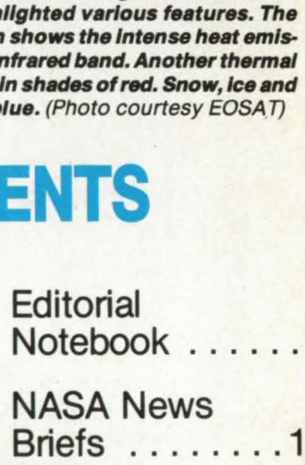
***When the Alaskan Augustine volcano erupted in 1986, the Landsat 5 Thematic Mapper (TM) acquired this image from 438 miles away. Image processing has highlighted various features. The straw color at the volcano's mouth shows the intense heat emission as recorded by the TM's mid-infrared band. Another thermal channel recorded the hot ash flow in shades of red. Snow, ice and water are depicted in shades of blue.*** *(Photo courtesy EOSAT)*

# DEPARTMENTS

***ON THE COVER—With ¼°C resolution, the Thermal Infrared Multispectral scanner photo shows there's more than meets the eye in the cooling recirculation waters for the "Daniel" power plant near Pascagoula, MS. An image analysis program has assigned red and blue hues to warmer and cooler waters. The actual plant is north of the photo. For more information about remote sensing and image processing, turn to our feature story on page 12.*** *(Photo NASA's Earth Resources Laboratory at NSTL)*

***Color-balanced image of Mars from the Viking Lander.*** *(Photo courtesy Comtal/3M)*







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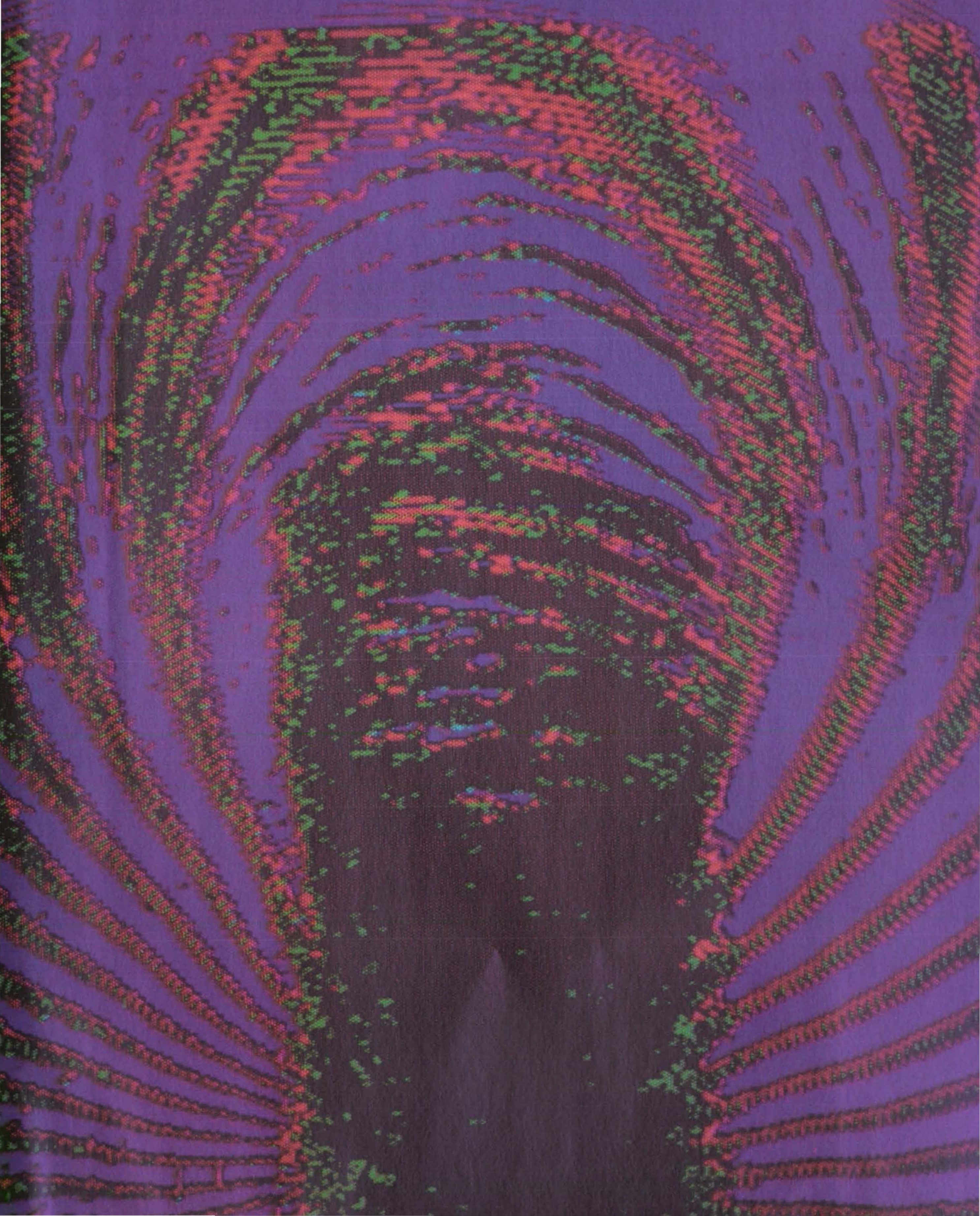
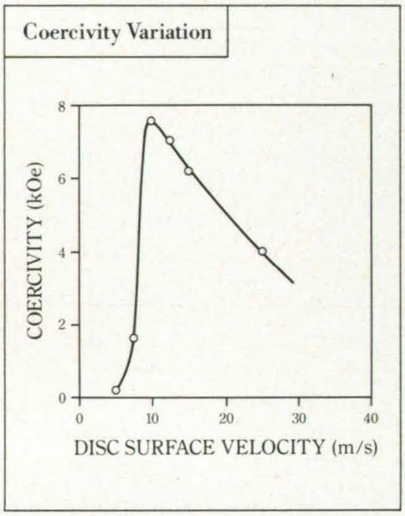
# The Critical Interval



# The Critical Interval

*There has long been a need in the industrial world for low-cost, high-performance permanent magnets. Discoveries at the General Motors Research Laboratories have led the way toward meeting this challenge by the application of new preparation techniques to new rare-earth magnetic materials.*




*Coercivity of $Pr_{0.4}Fe_{0.6}$ plotted as a function of disc surface velocity.*

*Color-enhanced transmission electron micrograph of melt-spun $Nd_{0.4}Fe_{0.6}$ having 7.5 kOe coercivity.*

TWO properties characterize desirable permanent magnets: large coercivity (magnetic hardness or resistance to demagnetization) and high remanence (magnetic strength). Higher-performance magnets are required to reduce further the size and weight of a wide variety of electrical devices, including d.c. motors. Such magnets are available, but the cost of the materials necessary to produce them severely limits their use. The research challenge is to select, synthesize, and magnetically harden economically attractive materials of comparable quality.

Prominent among alternative materials candidates are alloys composed of iron and the abundant light rare earths (lanthanum, cerium, praseodymium, neodymium). Investigations conducted by Drs. John Croat and Jan Herbst at the General Motors Research Laboratories have led to the discovery of a method for magnetically hardening these alloys. By means of a rapid-quench technique, the researchers have achieved coercivities in Pr-Fe and Nd-Fe that are the largest ever reported for any rare earth-iron material.

Drs. Croat and Herbst selected praseodymium-iron and neodymium-iron based upon fundamental considerations which indicate that these alloys would exhibit properties conducive to permanent magnet development. These properties include ferro-magnetic alignment of the rare earth and iron magnetic moments, which would foster high remanence, and significant magnetic anisotropy, a crucial prerequisite for large coercivity.

That these materials do not form suitable crystalline compounds, an essential requirement for magnetic hardening by traditional methods, presents a major obstacle. Drs. Croat and Herbst hypothesized that a metastable phase having the necessary properties could be formed by cooling a molten alloy at a sufficiently rapid rate. They tested this idea by means of the melt-spinning technique, in which a molten alloy is directed onto a cold, rotating disc. The cooling rate, which can be varied by changing the surface velocity of the disc, can easily approach 100,000°C per second. The alloy emerges in the form of a ribbon.

THE researchers found that variations of the cooling rate can dramatically affect the magnetic properties of the solidified alloys. In particular, appreciable coercivity is achieved within a narrow interval of quench rate.

Equally remarkable, synthesis and magnetic hardening, two steps in conventional processing, can be achieved simultaneously.

"X-ray analysis and electron microscopy of the high coercivity alloys reveal an unexpected mixed microstructure," states Dr. Croat. "We observe elongated amorphous regions interspersed with a crystalline rare earth-iron compound."

Understanding the relationship between the coercivity and the microstructure is essential. The two scientists are now studying the extent to which the coercivity is controlled by the shape and composition of the amorphous and crystalline structures.

"The development of significant coercivity is an important and encouraging step," says Dr. Herbst, "but practical application of these materials requires improvement of the remanence. Greater knowledge of the physics governing both properties is the key to meeting the commercial need for permanent magnets."

## TECHNOLOGY UPDATE: 1987

Subsequent to the research reported above, Drs. Croat and Herbst added boron to neodymium-iron as a glassifier to increase the formation of the elongated amorphous regions they had observed in the material. They reasoned that shape anisotropy, and thus coercivity, was related to the presence of these amorphous micro-needles.

They discovered that the addition of boron promoted the formation of a previously unknown ternary compound: $Nd_2Fe_{14}B$. Its atomic magnetic moments are arranged so that this compound has a large magnetization. At the same time, the researchers found that, compared with neodymium-iron, coercivity had risen from 8 to 20 kOe, and that the magnetic energy product had increased by a factor of seven.

On March 31, 1987, General Motors dedicated a new Delco Remy plant in Anderson, Indiana for the production of magnetic material and finished magnets made from $Nd_2Fe_{14}B$ under the commercial name MAGNEQUENCH.



## THE MEN BEHIND THE WORK

Dr. John Croat and Dr. Jan Herbst did their original work on rare-earth magnetic materials when both were Staff Research Scientists in the Physics Department at the General Motors Research Laboratories.

Dr. Croat (right) holds a Ph.D. in metallurgy from Iowa State University. In 1984, he joined GM's Delco Remy Division to stabilize the melt-spinning process for the commercial production of MAGNEQUENCH materials. He is currently Chief Engineer at the Indiana plant.

Dr. Herbst received his Ph.D. in Physics from Cornell University. He is now a Senior Staff Research Scientist and Manager of the Magnetic Materials Section in the Physics Department of the GM Research Laboratories. His research interests also include photo-emission theory, the physics of fluctuating valence compounds, and superconductivity.

Dr. Croat joined General Motors in 1972; Dr. Herbst in 1977.

# NASA Tech Briefs

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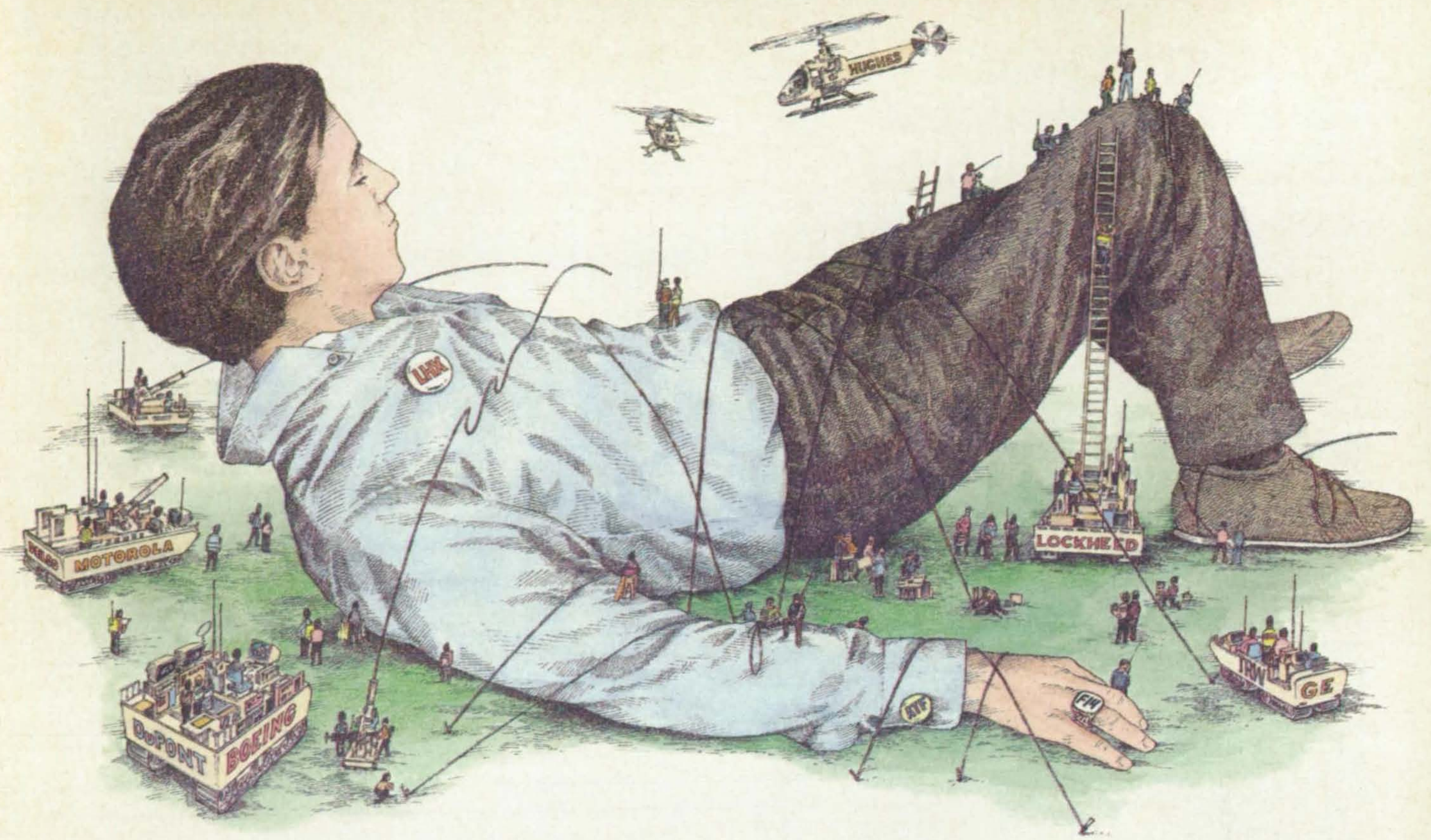


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# Editorial Notebook

Since we began publishing *NASA Tech Briefs* in 1985, I have reviewed thousands of feedback cards; they have been 99+% positive. Even the most common complaint for subscribers new to NTB is a positive: regret at having just discovered the magazine. "What went on before?. . .What are the other briefs that have been published on the subject in which I'm interested?" are questions we frequently receive.

Up until this month there really hasn't been a good answer to those questions. Now there is, and it's called *NASA Tech Briefs'* NTB:BASE. . .a desktop index file of more than 12,000 innovations and technological advances to help engineers, scientists and businessmen find solutions to their technical problems.

NTB:BASE is a collection of floppy disks that contains a description of every tech brief published over the past 25 years. . .by category.

These disks have been set up so that they can be accessed by anyone with an IBM or compatible PC. They have been grouped into 6 categories, and can be searched by year and by category, as well as by key word. The entire history of NASA research that has been published in *NASA Tech Briefs* in any or all of these categories is now available to everyone in American industry through the NTBM Research Center and it's new product NTB:BASE. I am told that there is an ad appearing elsewhere in this issue that more fully explains the program. If you want more information, Project Director Mark Seitman will be delighted to provide it.

## The Civilized Engineer

We've recently been exposed to *The Civilized Engineer**, a book by Samuel Florman that has delighted us. We've received permission to share a few thoughts from the book with NTB readers from time to time, and herewith a first taste:

"I think that engineering is what human beings, deep down, want to do. Not the only thing, but one of the most basic and satisfying things. Engineering is an activity that is fulfilling— existentially.

Both genetically and culturally the engineering instinct has been nurtured within us. To be human is to be technological. When we are being technological we are being human—we are expressing the age-old desire of the tribe to survive and prosper.

Within our hearts, however, we sense that more than biology is involved. Engineering responds to impulses that go beyond mere survival: a craving for variety and new possibilities, a feeling for proportion—for beauty—that we share with the artist. As engineers, we feel an urge to challenge nature— fighting storms, floods, earthquakes, and other life-threatening forces—yet also to work in harmony with nature, seeking understanding of soils, metals, and other basic materials of the earth. We partake of the wonders of the natural sciences and enter the pristine realm of mathematics. Our work contributes to the well-being of our fellow humans. There are religious implications in technology—a little bit of cathedral in everything we build." □

** Published by St. Martin's Press, Inc., New York.*

# NASA NEWS BRIEFS

**Tiltrotor aircraft may have a major worldwide impact on** short and medium range air transportation, according to findings of a study by NASA, FFA, and DOD. With advent of the revolutionary tiltrotor concept, passenger aircraft will take off and land vertically like helicopters- yet fly horizontally for up to 1000 miles at 300-400 mph. A tiltrotor will have twice the speed and range with half the operating cost as compared to helicopters. The study also found that tiltrotors are flexible enough to satisfy emerging aviation markets such as emergency medical services, commuter aviation, and a variety of military requirements.

The first operational tiltrotor, being developed by Bell Helicopter Textron and the Boeing Vertol Company, is scheduled to fly next year, with initial deliveries to the U.S. Marine Corps slated for late 1991.

**NASA has awarded a $384 million contract to Bendix** Field Engineering Corp., a unit of Allied-Signal Inc. The company will provide communications and engineering services for the Goddard Space Flight Center.

**Symbolics, Inc. has been granted a $500,000 contract** from NASA's Ames Research Center for the design of a spaceborne symbolic processor (SSP). The SSP will facilitate artificial intelligence applications and other advanced computing techniques on future space missions.

**NASA has implemented a voluntary, confidential safety** reporting system for its 100,000 employees and contractors to alert NASA management of safety problems. The new system, established as a result of the Challenger accident, will initially focus on safety concerns associated with the Space Shuttle program.

**NASA will seek recommendations** from the National Academy of Sciences (NAS) on ways to improve the quality and reliability of meteorological information for the planning and operation of future space launches. In addition, the NAS will be asked to assess the feasibility of making the Kennedy Space Center a test facility for research on short-term forecasting techniques.

**An Office of Exploration has been** created by NASA to study potential lunar and Mars initiatives. The office is one step in responding to demands for a major initiative that would re-energize America's space program, according to NASA Administrator Dr. James C. Fletcher. Former astronaut Dr. Sally Ride will serve as the office's assistant administrator until mid August, when she is scheduled to leave NASA to assume a post at Stanford University.

**A new division of NASA's Ames Re**search Center will research methods of applying artificial intelligence (AI) technology to space exploration. Ames' Information Sciences Division will work with other NASA centers and private industry to develop automated systems for all phases of space missions, from launch to mission control and on-board operations. A major thrust of the research will be systems integration- establishing methods for two or more AI computer systems to communicate.

# 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 section 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 18). NASA's patent-licensing program to encourage commercial development is described on page 18.**

## Heater for Combustible-Gas Tanks

A proposed heater for pressurizing hydrogen, oxygen, or another combustible liquid or gas would be sealed in an immersion cup in the pressurized tank. The heater would include a coiled rod-type resistance element in the stainless-steel immersion cup. The coiled element would be supported in a bath of low-melting alloy. The molten alloy would carry heat from the heating rod to the cup efficiently and help to prevent hot spots on the rod. **(See page 74).**




## Hot-Gas Nozzle for Desoldering Leadless IC's

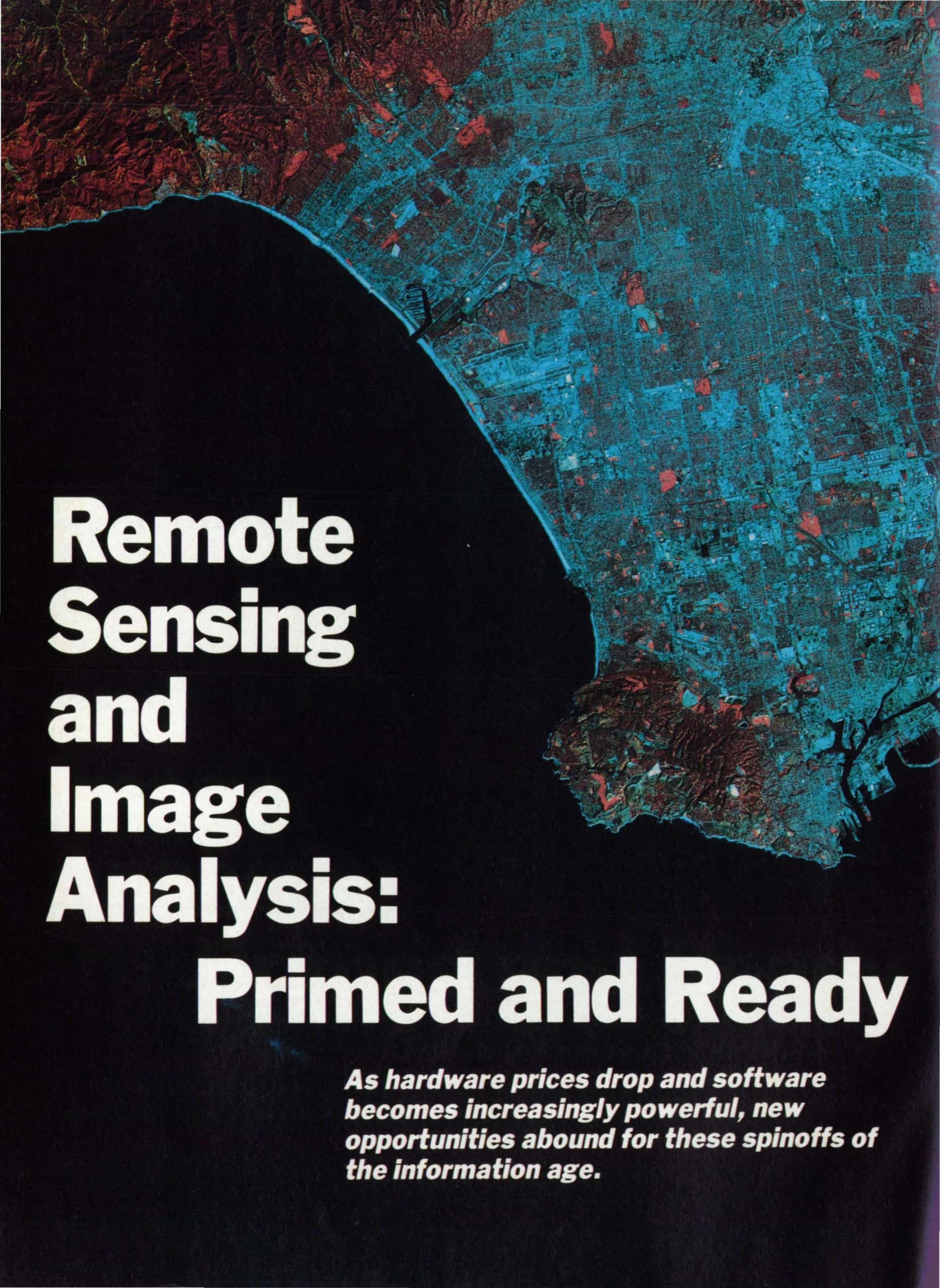
A simple hand-held tool is a specially shaped nozzle that fits on a hot-air gun or other source of hot gas to remove leadless, surface-mounted integrated circuits (IC's) from printed-circuit boards. It can also be used for installation. It takes only 5 to 7 seconds to remove an IC with the new tool, and it is less likely to damage either the IC or the circuit board than are tools of the soldering-iron type. The nozzle includes a deflector that directs the gas flow away from the IC and onto the soldered contacts on the mounting pad at the base of the IC. Deflectors of various sizes could be used to adapt the nozzle to IC's of different sizes. **(See page 90).**

## Prehensile Foot Restraint

A proposed prehensile foot restraint would enable such workers as astronauts and divers to maintain fixed positions in zero gravity or in buoyancy with minimal effort. A claw near the toe of a shoe would grip a rail. The wearer would use the flexible shaft, first to lock the claw tightly on the bar; then, when the work is done, to open the claw. With the foot restraint, a worker could devote attention more fully to the task at hand, with little concern about holding on to a supporting structure. **(See page 94).**

## Mechanism Connects and Disconnects Lines Remotely

A mechanism connects and disconnects electrical, gas, or liquid lines by remote control. The remote-connection mechanism accommodates large displacements and misalignments of the plug and the receptacle. Developed for making (and breaking) electrical connections from the Space Shuttle orbiter to a payload during deployment or retrieval, the mechanism may also be adapted for use in areas inaccessible or hazardous to humans. **(See page 80).**



# Remote Sensing and Image Analysis: Primed and Ready

***As hardware prices drop and software becomes increasingly powerful, new opportunities abound for these spinoffs of the information age.***

# to Go

*At a scale of 1 to 1,000,000, this Landsat Thematic Mapper image shows a 185 Km square view of Los Angeles, CA and Catalina Island. The Thematic Mapper sensor detects energy reflected from the earth's surface as light, including the infrared portion of the spectrum. Sights include San Fernando Valley and the Santa Monica mountain range to the upper left, the San Gabriel Valley to the upper right and Long Beach to the lower right. Blue colors represent urban areas, red and red browns are non-urban vegetation, bright reds are manicured lawns such as parks and golf courses, and green shows the desert scrub brush indigenous to the region. North is up.*

PHOTO COURTESY EOSAT

The search for a better point of view has occupied man for ages. From the first time a boy climbed a tree to the latest orbiting telescope, improved vision has brought with it higher quality information, allowing better decision making. The critical need for facts has driven improvements in gathering and analyzing information, which have led to the burgeoning field of remote sensing and image processing, now branching into such diverse applications as medical imaging, resource management and manufacturing and robotics.

As remote sensing hardware becomes increasingly sophisticated, the levels of sensitivity achieved by the electronics far outstrips the brain's ability to assimilate the information. Image processing software comes to the rescue, using false color techniques to create easy-to-interpret high-contrast pictures. The evening weather reports on television are an everyday example, often displaying thunderstorm activity by using colors to represent the severity of storms.

In the field of medicine, Magnetic Resonance Imaging (MRI) permits doctors to safely "photograph" the human brain for tumors. Such abnormalities stand out when density-coded colors are assigned to an image of the brain. In aerial remote sensing, thermographs and infrared photographs are commonly assigned false colors to accentuate temperature gradients.

In classic remote sensing, satellites take multispectral pictures of the earth and transmit them to ground reception stations. Much of the credit for this goes to NASA, which launched the first of the Landsat series fifteen years ago. Perhaps more importantly, it has sponsored research in the data processing techniques necessary to make sense of the massive amounts of information downloaded from the sky. Though coordination of the Landsat series has passed to EOSAT, a private company run jointly by RCA Corporation and Hughes Aircraft Company, (now owned respectively by GE and GM), NASA still places tremendous emphasis on improving the state of the art in data analysis and image processing.

Much of the Agency's work in remote sensing and image analysis takes place at the National Space Technology Laboratory's (NSTL) Earth Resources Laboratory (ERL). Projects there cover data acquisition, image processing hardware and software, and digital imagery research. The Earth Laboratory Applications Software (ELAS), a primary tool used at ERL, processes and analyzes multispectral digital data. Written by ERL personnel, the transportable software package is used in hundreds of image processing applications around the world.

While the ERL advances the state of the art in remote sensing and image processing, the Institute For Technology Development's (ITD) Space Remote Sensing Center (SRSC), also located at NSTL, seeks to open up new commercial markets in the same fields. The close relationship between the organizations was fostered by the SRSC's 1985 NASA contract as one of five Centers for Commercial Development of Space (CCDS). Designed to make the most of the commercial potential of space, the CCDSs encourage research and development of space-related products and spinoffs, and are usually aligned with universities or federal laboratories.

## Turtles and Fish

Dr. Scott Madry, Support Services Manager at SRSC sees "tremendous potential for remote sensing technologies outside of the traditional realm of land-use management." Much of this potential comes from applying ELAS-type programs to digitized pictures that come from earth-based cameras and sensors rather than from space. ELAS has been used to improve medical images of the human brain and heart. For the latter, MRI data was interpreted with ELAS to noninvasively measure the volume of the heart's cavities to determine blood flow.

Other applications illustrate the software's versatility: ELAS has determined fish and turtle health by analyzing the growth patterns of their body parts. Petrological studies of oil-rich sandstone used ELAS to analyze a micrograph of a thin section of the strata. The program identified the size of the sand grains, the distance between them and the stone's porosity and permeability, thereby determining its oil-bearing capacity. Because of its ability to manipulate data, ELAS has applications in the non-image processing engineering environment. Says Doug Rickman, a research scientist at

ERL, "As long as your data can be expressed in an array, the software doesn't care in the least where the data came from."

## Press Enter

By enhancing and promoting low cost Geographic Information Systems (GIS) software, the SRSC encourages greater use of remote sensing. GIS integrates remotely sensed land use and land cover data with other information, creating layers of different data planes from which users can derive the best answers to land-management questions. GIS's ability to digest dissimilar data is often used in industrial site selection. Companies seeking to build new facilities have specific requirements: The soil must be able to bear the load and drain satisfactorily. Partially cleared land is preferred. The site has to be within defined distances to an interstate highway, a rail spur, an electrical power substation, and within commuting distance to a medium-sized city for a projected workforce of, for example, three thousand. "Think about how difficult it would be on a state-wide or region-wide basis to find a location to fit those requirements," says Madry. "But when you have a GIS system built, one that combines geographic data from a satellite with other databases, it's very simple to say, 'find me everywhere that is 3000 acres of continuous ownership, within all the parameters mentioned above.' Press enter, and you have your answer." Says Mark Bromley, an Applications Analyst with KRS Remote Sensing, a Kodak Company, "With GIS, you can start drawing all sorts of conclusions right out of your database, without leaving your office. In the old days, if you wanted to know what was out there [at a remote site], you had to hop on a plane or walk around on the ground."

One of the more versatile GIS programs is the US Army Corps. of Engineer's Geographic Resource Analysis Support System (GRASS), available from the SRSC for $200. SRSC is currently developing a file interchange between ELAS and GRASS. Once completed, "The GRASS user community will have the image processing abilities of ELAS, and the ELAS user community will be able to use the analytic capability and user friendliness of GRASS," says Madry.

The integration of remote sensing and GIS technologies increases the commercial utility of remote sensing data by orders of magnitude. No longer does remote sensing mean just pretty pictures. The software wrings out embedded details, giving, as Madry sums up, "better information for better decision making."

## Roads To the Top

Another avenue to encourage new remote sensing products and services, the SRSC incubator program, works with entrepreneurs using remote sensing technology in innovative ways. The program provides technical assistance, marketing and other startup help. For further information, contact the Institute for Technology Development, Space Remote Sensing Center, Fred Brumbaugh, Commercial Projects, Building 1100, Suite 308, NSTL Station, MS 39529.

The increasing popularity of remote sensing and image processing could result in a boom similar to that of the microcomputer industry in the early 1980s. Having passed through the necessary hardware and software development cycles, the remaining barrier is price, but even that wall is crumbling—and rapidly. Says Mark Bromley at KRS Remote Sensing, "Before, to do image processing, you needed a mainframe IBM computer that was never optimized to do image processing, or some equivalent series of VAXs. If you didn't have $500,000 in your pocket, you just couldn't do image processing. Now, for $20,000 you can put together a full PC station."

As an official Apple Computer Corporation software developer, the SRSC is porting advanced image processing software to the new MAC-2, which, at about $15,000 with all peripherals, will perform image analysis almost as well as the Center's $200,000 research quality computer system. Depending on the application, the MAC-2 may be all a business needs.

As paper pictures go digital, new efficiencies come to light. Combining the new electronic photography market with image processing allows manipulation and analysis of scenes in the manufacturing cycle: An engineer can transmit his CAE-CAD conception for a widget to an office on the other side of his building. Later, during the manufacture of that same part, the slightly processed original image will be compared against the factory floor reality by a machine-vision quality control (QC) system, which will reject the part if doesn't match. Image analysis can also check for surface fractures, which reflect light differently from the rest of the piece. A well programmed ELAS-type system will be able to detect the flaw, identifying the part for personal inspection.

## The Enhanced Scene

As hardware costs drop, and user-friendly software becomes widely available, remote sensing and image analysis technology are finding increased acceptance in research and business applications. With better raw data from sources such as the Landsat Thematic Mapper and the French SPOT satellite, and with powerful software able to draw the best conclusions from disparate data, the potential for this aspect of the information revolution is tremendous, with a proliferation of innovative applications just around the corner.

Like the advent of the electron microscope, the impact of the combination of image analysis with remote sensing goes far beyond the ability to see finer structures. It lets old questions be asked in a different context, and leads to new ones far beyond anything imagined before. □

***To locate abandoned open-cut mines, major sources of runoff pollution, Dale Quattrochi, a research scientist at NASA's ERL, combined Landsat Multispectral Scanner data with digital elevation data. This Pineville, KY scene assigns blue to forested areas, gold to surface mines, and red to agricultural areas. Clouds appear as white.***

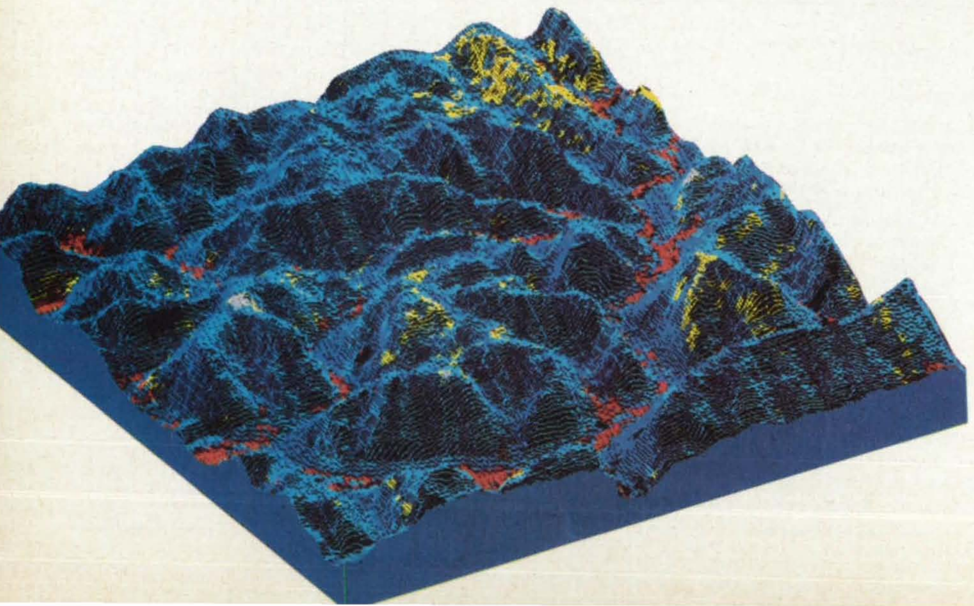


PHOTO COURTESY NSTL/ERL

*To learn more about the ELAS program, or to purchase a copy, contact COSMIC, at 404-542-3265. The complete address is given on page 18 of this issue.*

# HOW YOU CAN BENEFIT FROM NASA's TECHNOLOGY UTILIZATION SERVICES

If you're a regular reader of TECH BRIEFS, then you're already making use of one of the low- and no-cost services provided by NASA's Technology Utilization (TU) Network. But a TECH BRIEFS subscription represents only a fraction of the technical information and applications/engineering services offered by the TU Network as a whole. In fact, when all of the components of NASA's Technology Utilization Network are considered, TECH BRIEFS represents the proverbial tip of the iceberg.

We've outlined below NASA's TU Network—named the participants, described their services, and listed the individuals you can contact for more information relating to your specific needs. We encourage you to make use of the information, access, and applications services offered by NASA's Technology Utilization Network.

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## How You Can Access Technology Transfer Services At NASA Field Centers: **Technology Utilization Officers & Patent Counsels**—Each NASA Field Center has designated a Technology Utilization Officer (TUO) and a Patent Counsel to facilitate technology transfer between NASA and the private sector.

If you need further information about new technologies presented in *NASA Tech Briefs*, request the Technical Support Package (TSP). If a TSP is not available, you can contact the Technology Utilization Officer at the NASA Field Center that sponsored the research. He can arrange for assistance in applying the technology by putting you in touch with the people who developed it. If you want information about the patent status of a technology or are interested in licensing a NASA invention, contact the Patent Counsel at the NASA Field Center that sponsored the research. Refer to the NASA reference number at the end of the Tech Brief.

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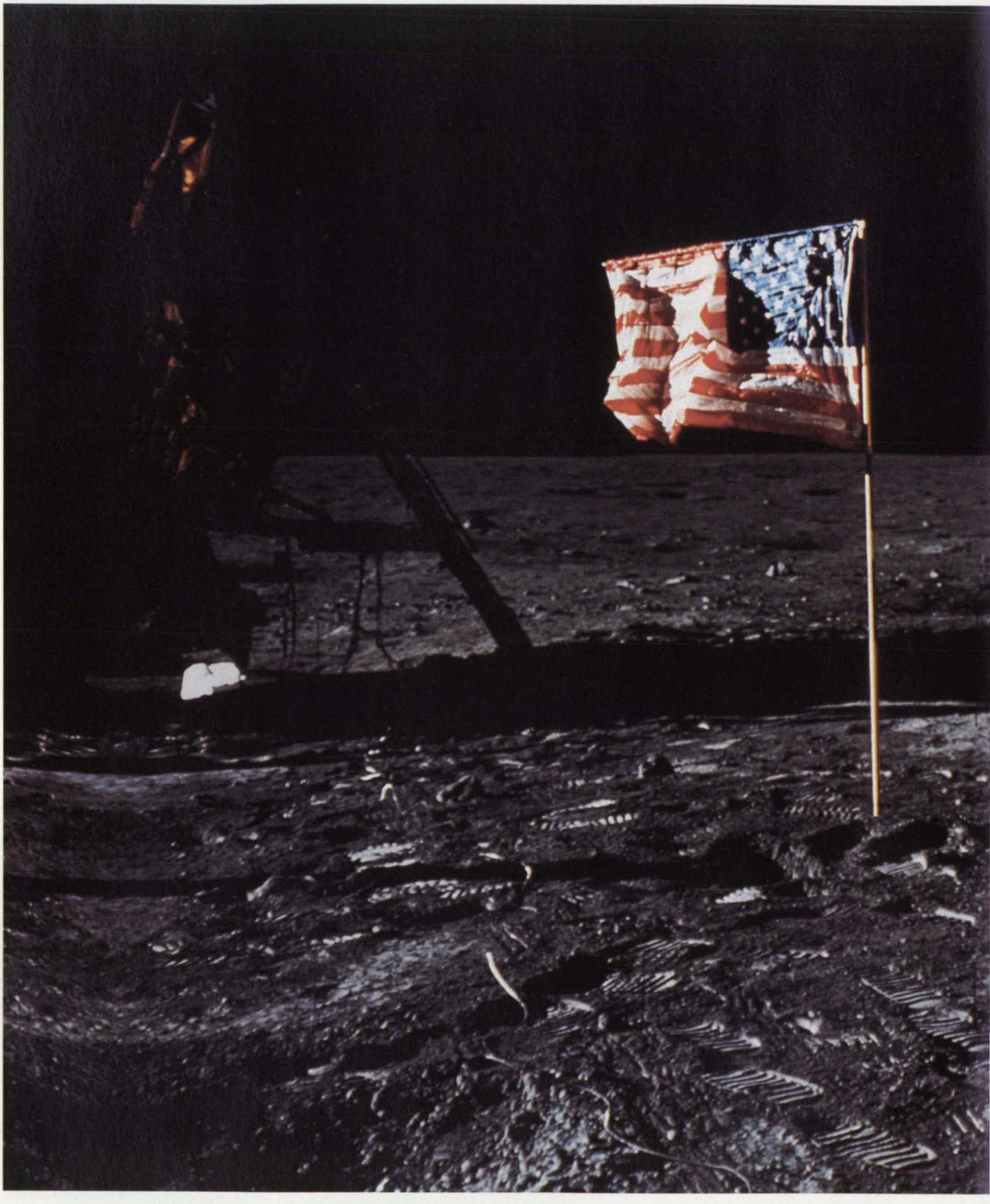

## Measuring Conductor Widths and Spacings Electrically

The split cross-bridge resistor technique helps to verify microcircuit patterns.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

The widths and spacings of conductor lines on integrated circuits are measured electrically by the split cross-bridge resistor technique. Because this technique uses the same test equipment as the one used to characterize test transistors, it speeds the evaluation of integrated-circuit fabrication processes. When the measurement of probe currents and voltages and the reduction of the measurement data are automated, this test structure can be probed and characterized in less than one second. Thus, the structure can be examined quickly to verify adherence to design rules and thereby establish the difference between the linewidth and spacing of the integrated-circuit materials and those specified by the circuit designer.

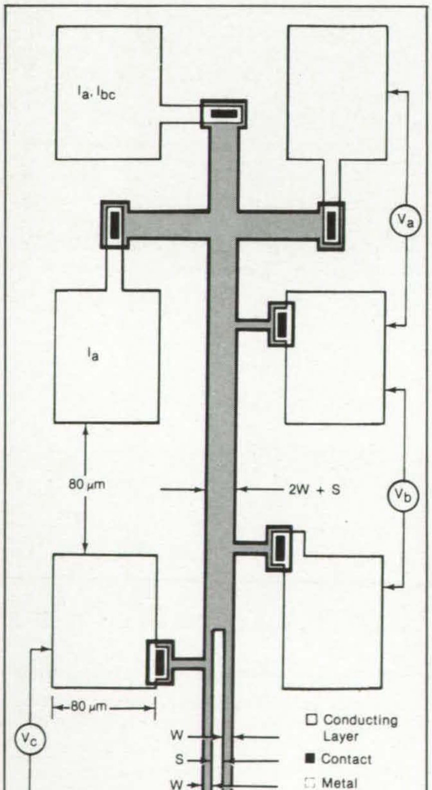


Figure 1. The **Split Cross-Bridge Resistor** is a test structure in a photofabricated single-layer conductor. Electrical measurements via the eight probe pads enable the deduction of critical circuit dimensions.

The split cross-bridge resistor test pattern (see Figure 1) is fabricated by a photolithographic process. The parameters of interest are the sheet resistance, $R_s$, the linewidth, W, the space between the lines, S, and the line pitch, W + S. The structure can be designed so that W and S may have micrometer or submicrometer dimensions. It is also applicable in characterizing the larger lines and spaces found in printed-circuit boards.

The test structure is probed at the eight pads as shown, and the sheet resistance is calculated from the voltage $V_a$ and the current $I_a$ from

$$R_s = \pi V_a/I_a \ln 2$$

The line width and line spacing are calculated from voltage measurements $V_b$ and $V_c$ at taps separated by a distance L along the current-carrying channel. The current for these measurements is $I_{bc}$. The line width is calculated by

$$W = R_s L I_{bc}/(2V_c)$$

and the line spacing is calculated by

$$S = R_s L I_{bc}(V_c - V_b)/(V_b V_c)$$

Finally, the line pitch is calculated from P = W + S.

Figure 2 shows a cross section of the split portion of the structure formed in polycrystalline silicon and covered with silicon dioxide. The dimensions $W_e$ and $S_e$ of the polycrystalline conductor pattern are measured electrically as described above. Also indicated are the widths and spaces, $W_p$ and $S_p$, on the photomask used to make the pattern, and $W_v$ and $S_v$, the visual widths and spacings observed on the circuit. Provided that the features are not

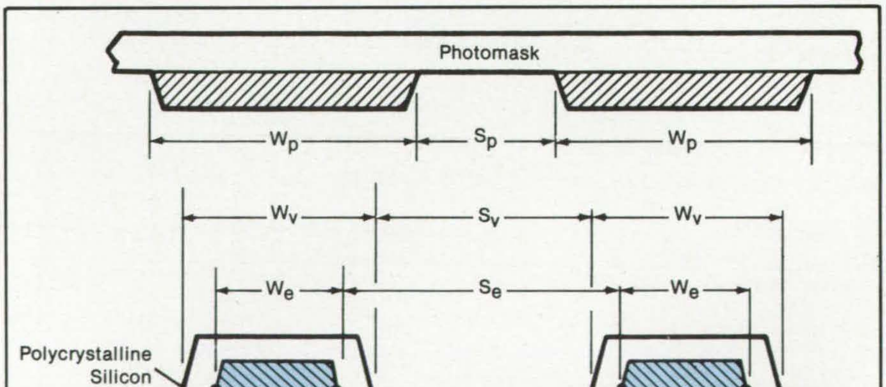


Figure 2. The **Photomask, Polysilicon Conductor, and Oxide Coating** have different line width and line spacings. The subscripts e, v, and p denote the electrical (polysilicon), visual (oxide), and photomask dimensions, respectively.

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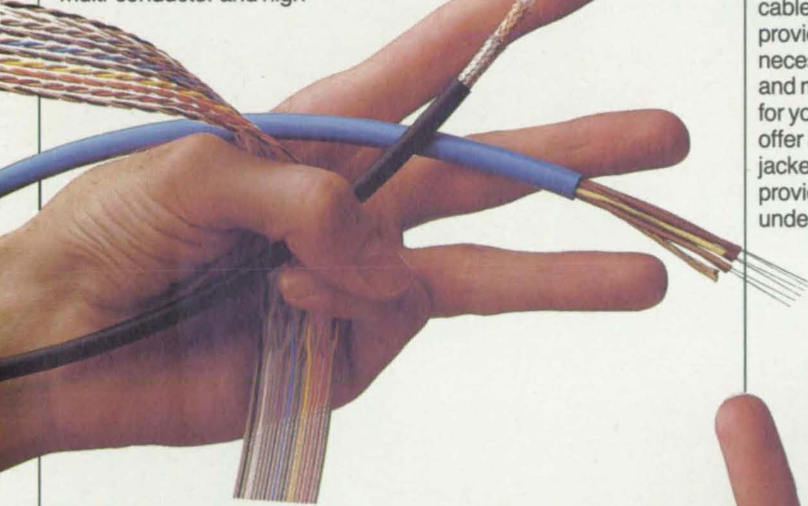

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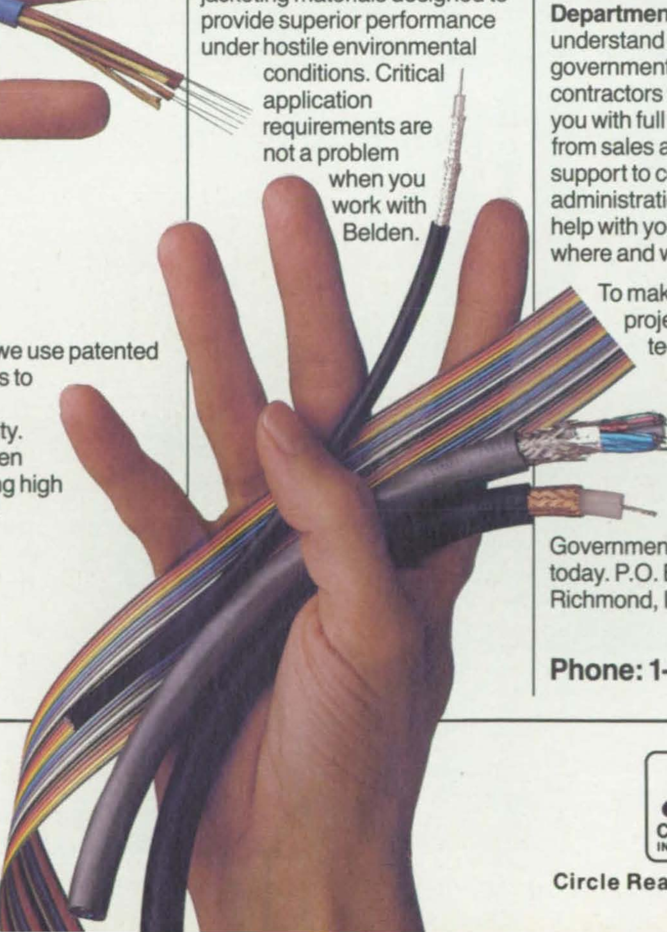

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magnified during photofabrication, the photomask, visual, and electrical pitches must all equal the initial design value. This allows one to double check the electrical pitch value against the design value and thus provides measurement quality assurance. This test structure has been patented under U.S. Patent No. 4,516,071 (May 7, 1985).

*This work was done by Martin G. Buehler of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 68 on the TSP Request Card.*

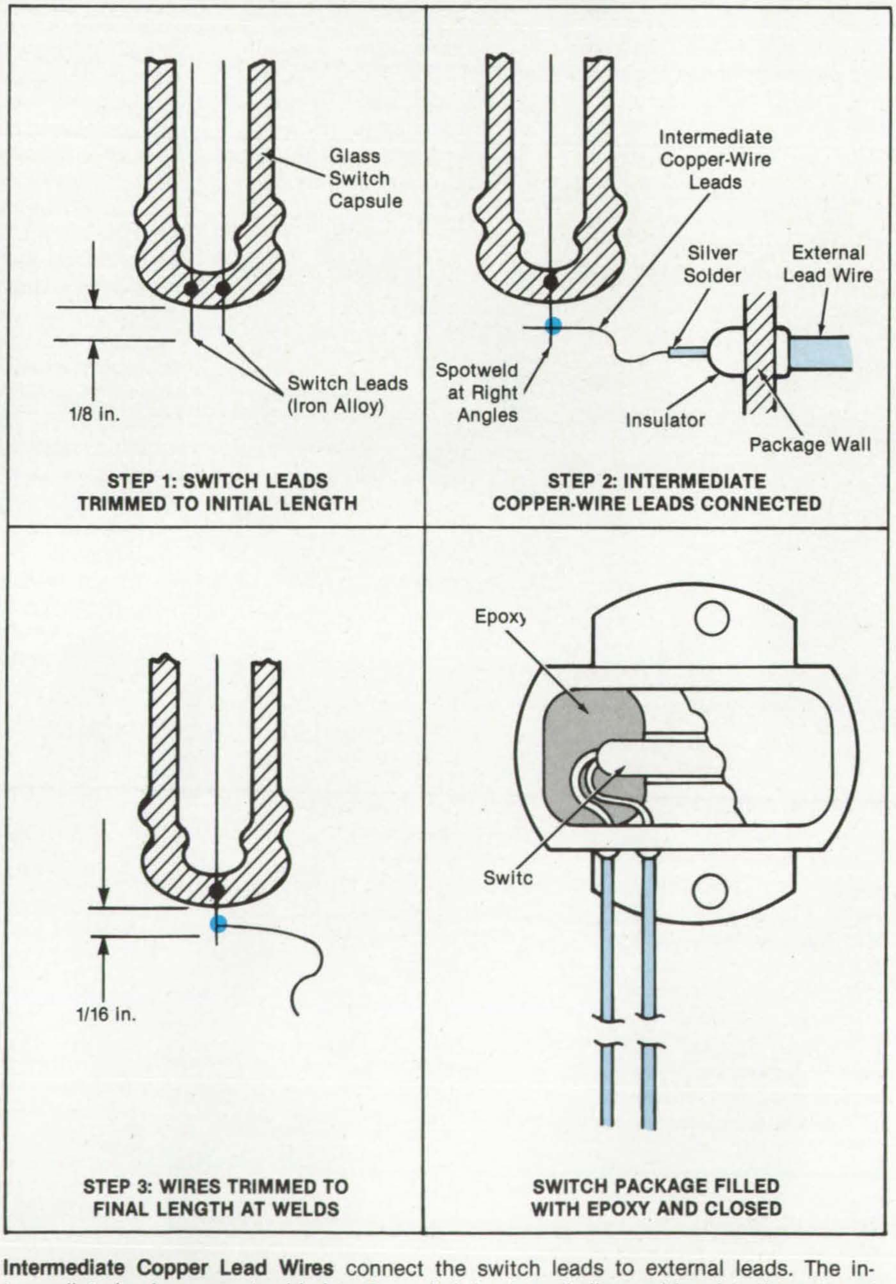
*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 18]. Refer to NPO-16021.*

## Attaching Copper Wires to Magnetic-Reed-Switch Leads

The small, light-weight connections are reliable.

*Lyndon B. Johnson Space Center, Houston, Texas*

A bonding method reliably joins copper wires to short iron-alloy leads from a glass-encased dry magnetic-reed switch without disturbing the integrity of the




**Intermediate Copper Lead Wires** connect the switch leads to external leads. The intermediate leads are spotwelded to the switch leads and silver soldered to the external leads.

glass-to-metal seal. The joint is resistant to high temperatures and has low electrical resistance.

First, the iron-alloy leads that protrude from the glass switch capsule (see figure) are trimmed to a length of 1/8 in. (3.2 mm). Next, one end of each copper wire is silver soldered to one of the external leads at the point where it enters the housing. The other end of each wire is spotwelded at a right angle to one of the iron-alloy switch leads. The switch leads are then trimmed to a final length of 1/16 in. (1.6 mm).

With the bonding method, a reed switch can be installed with a solenoid valve in a small, lightweight package. The switch provides an indication of the open or closed position of the valve.

*This work was done by Rudolf Kamila of Consolidated Controls Corp. for* **Johnson Space Center**. *No further documentation is available.* *MSC-20675*

# Highly Stable Microwave Resonator

Superconducting walls on a sapphire-filled cavity make a low-loss device.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

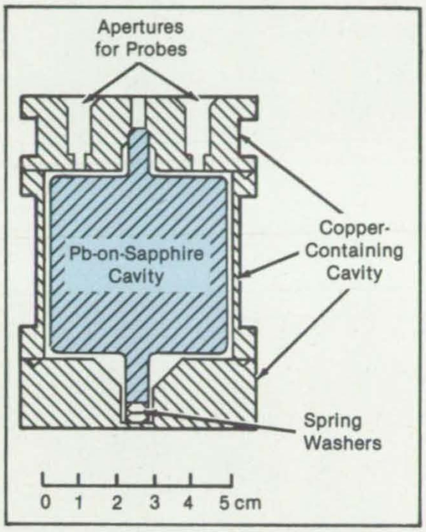



Figure 1. The **Lead-Coated Sapphire Cylinder** is mounted in a lead-plated copper-containing cavity, which is inserted in a bath of liquid helium. Microwave signals are transmitted into and out of the cylinder through the probe ports.

An improved microwave resonant cavity consists of a sapphire cylinder coated with a thin film of superconducting lead (see Figure 1). Operated well below the superconducting transition temperature at 1.5 K, the cavity demonstrated superior frequency stability and quality factor. The quality factor Q (a figure of merit equal to the ratio of reactance to resistance) is more than $2 \times 10^9$ in the $TE_{011}$ mode at the resonant frequency of 2.689 GHz. The cavity frequency is highly stable and therefore this cavity is suitable for use in standard frequency generators and in filters.

The oscillator can be no more stable than the resonant frequency of its cavity.

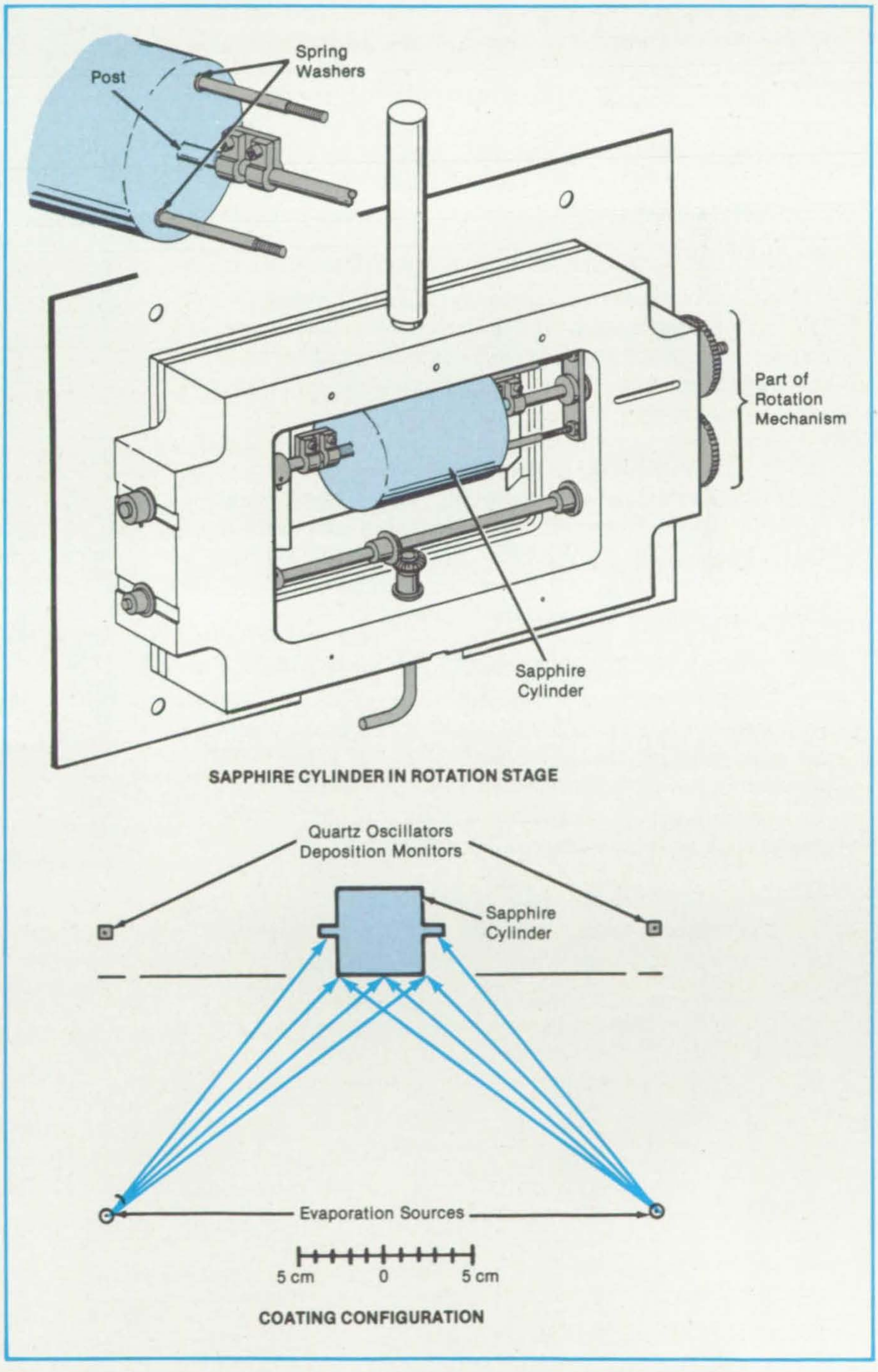



Figure 2. A **Mechanism Turns the Sapphire Cylinder** while lead vapor condenses on it. Two sources of lead and controlled rotational speed ensure the uniform lead film thickness that is essential to the extraordinary performance of the cavity. Spring washers on rods prevent deposition on two circular apertures that will serve as the probe ports.

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Therefore, dimensional stability is crucial to oscillator stability; the dimensional response to changes in temperature and to tilt with respect to gravity should be minimal. In the new cavity, the mechanical and thermal-expansion properties are those of sapphire, and the superconducting film serves as a low-loss cavity wall. The dimensions of the superconductor-on-sapphire cavity are distorted by temperature less than 1/100 as much as those of a bulk niobium cavity, and they respond to tilts less than 1/10 as much.

The sapphire is a right circular cylinder, with equal length and diameter of 4.82 cm. Axial posts extending from each end serve as supports. While the cylinder was rotated on its posts in a vacuum deposition system, a smooth, fault-free film of 99.9999-percent pure lead was evaporated from two molybdenum boats at 45° angles from the central plane of the cylinder (see Figure 2). The boats were connected in series with a power supply. The rates of evaporation were matched by adjustment of a shunt across one of the boats. The rates were monitored individually by deposition on a quartz oscillator directly above each boat. The cylinder was turned at 33 revolutions per minute and a uniform film of sufficient thickness was obtained after 10 minutes of evaporation.

The surface resistance of the lead film closely matches that predicted by theory. The residual resistance is small, indicating that losses at the lead/sapphire interface are quite small. Moreover, since most of the low loss can be accounted for by dissipation in the film, absorption in the sapphire is believed to be exceptionally low.

*This work was done by Donald M. Strayer, Sarita Thakoor, G. John Dick, and James E. Mercereau of Caltech for* **NASA's Jet Propulsion Laboratory.** *For further information, Circle 60 on the TSP Request Card.*
*NPO-16663*

# Electronically Tuned Microwave Oscillator

Features include low phase noise and frequency stability.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

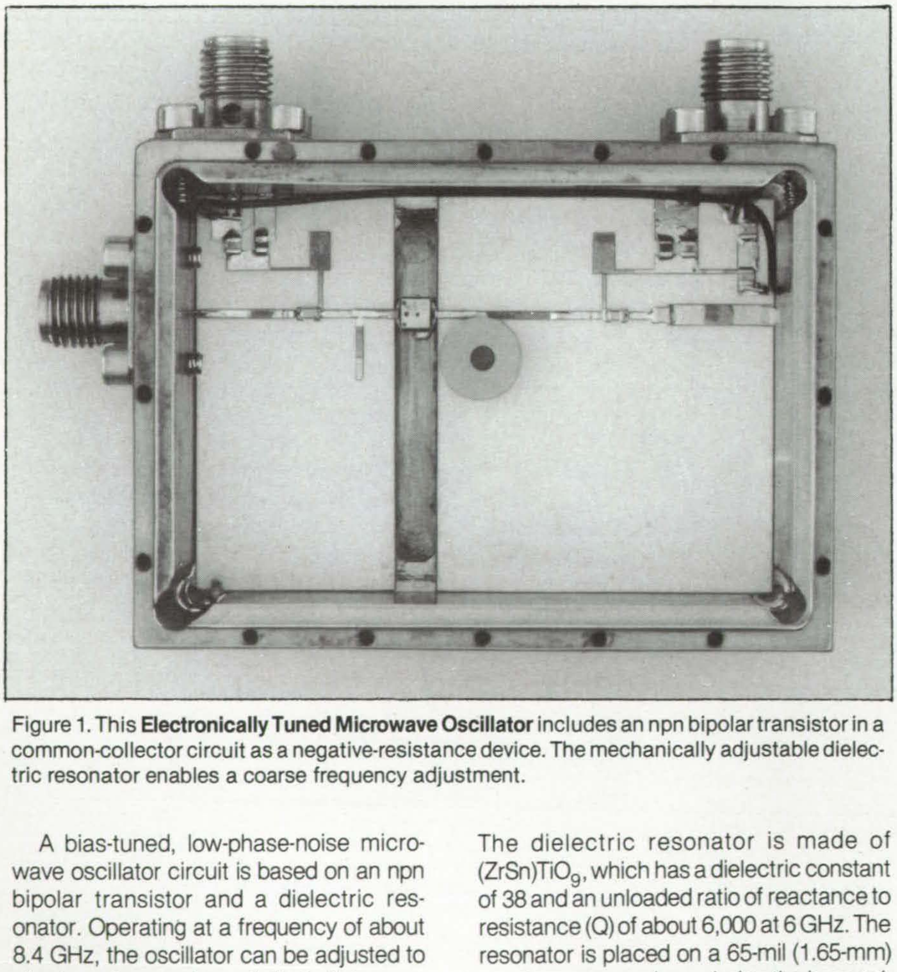


Figure 1. This **Electronically Tuned Microwave Oscillator** includes an npn bipolar transistor in a common-collector circuit as a negative-resistance device. The mechanically adjustable dielectric resonator enables a coarse frequency adjustment.

A bias-tuned, low-phase-noise microwave oscillator circuit is based on an npn bipolar transistor and a dielectric resonator. Operating at a frequency of about 8.4 GHz, the oscillator can be adjusted to give low phase noise, relatively flat power output versus frequency, and nearly linear frequency versus bias voltage.

The oscillator (see Figure 1) is laid out on an alumina substrate in a common-collector configuration to facilitate heat transfer from the transistor to the heat sink. The transistor is conservatively biased at about 60 percent of its rated voltage and current. The dielectric resonator is made of $(ZrSn)TiO_9$, which has a dielectric constant of 38 and an unloaded ratio of reactance to resistance (Q) of about 6,000 at 6 GHz. The resonator is placed on a 65-mil (1.65-mm) quartz spacer and coupled to the base microstrip line by placing it about a quarter wavelength from the transistor base terminal. The exact position has to be adjusted because it is critical in determining the Q under load, electronic tuning range, and the power output.

The resonator includes a mechanically adjustable metal tuning disk that provides a frequency adjustment of about 70 MHz per turn over the range of 8,387 to 8,601 MHz. Electronic tuning (see Figure 2) alters the transistor characteristics to provide a frequency adjustment, the characteristics of which depend on the resonator adjustments. For example, the resonator can be loaded to an estimated Q of 300 to provide about ± 1.75 MHz of nearly linear tuning on either side of a middle frequency of 8,417.75 MHz when $V_{FC}$ is varied between −20 and +8 V. (The frequency sensitivity in this case is −125 kHz/V). The output power over this range varies less than 0.8 dB from a nominal level of −7.5 dBm. Similar results are obtained with a loaded Q of 500.

In the $Q \approx 300$ condition, the single-sideband phase-noise spectral density (relative to the carrier power) at 1 KHz from the carrier was measured at −75.3 dB/Hz,

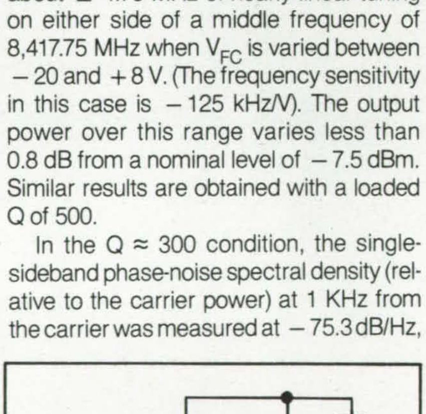



Figure 2. The **dc Component of the Transistor Base Voltage** is determined by the frequency-control voltage, $V_{FC}$, and the network of bias resistors. In combination with the dielectric-resonator adjustments, this bias network enables the oscillator frequency to vary nearly linearly with $V_{FC}$.

−71.5 dB/Hz, and −71.2 dB/Hz at $V_{FC}$ of −20, 0, and +8 V, respectively. Close to the carrier, there is a 30 dB/decade flicker frequency-modulated noise characteristic. The compromises among the dielectric-resonator, electronic-tuning, and phase-noise characteristics can be combined with temperature compensation to meet digital-radio requirements.

*This work was done by Mysore Lakshminarayana of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 160 on the TSP Request Card.*
*NPO-16836*

# Switching Circuit Regulates Solenoid Current

The efficiency is high, yet the ripple current is relatively low.

*Marshall Space Flight Center, Alabama*

By switching current pulses on and off, a circuit regulates the current in a solenoid valve. The regulation is independent of temperature. The switching regulator is much more efficient than the linear regulator it replaces, dissipating 0.075 watt versus 17.7 watts for the linear circuit. The new circuit requires no heat sink and is therefore more compact. Its parts cost no more than those of the linear regulator.

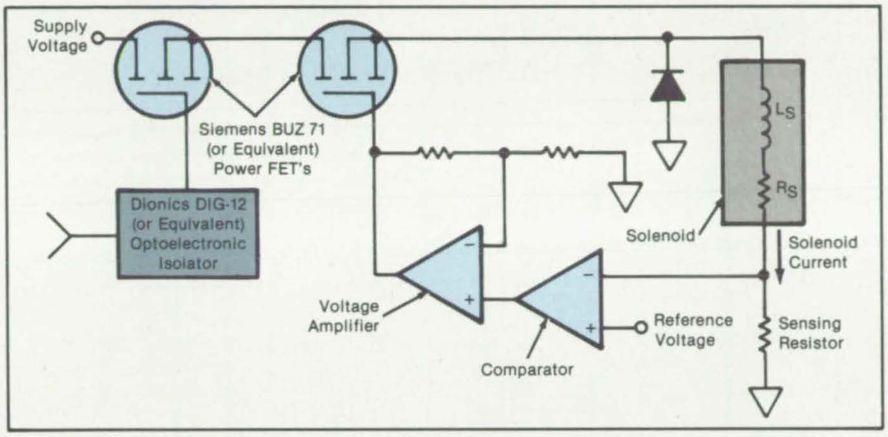



Figure 1. The **Switching Regulator** repeatedly causes the solenoid current to build up to a maximum level, then to decay to a minimum level: thus the current ripples about a commanded intermediate level. The FET's dissipate significant amounts of power only during the brief turn-on and turn-off intervals.

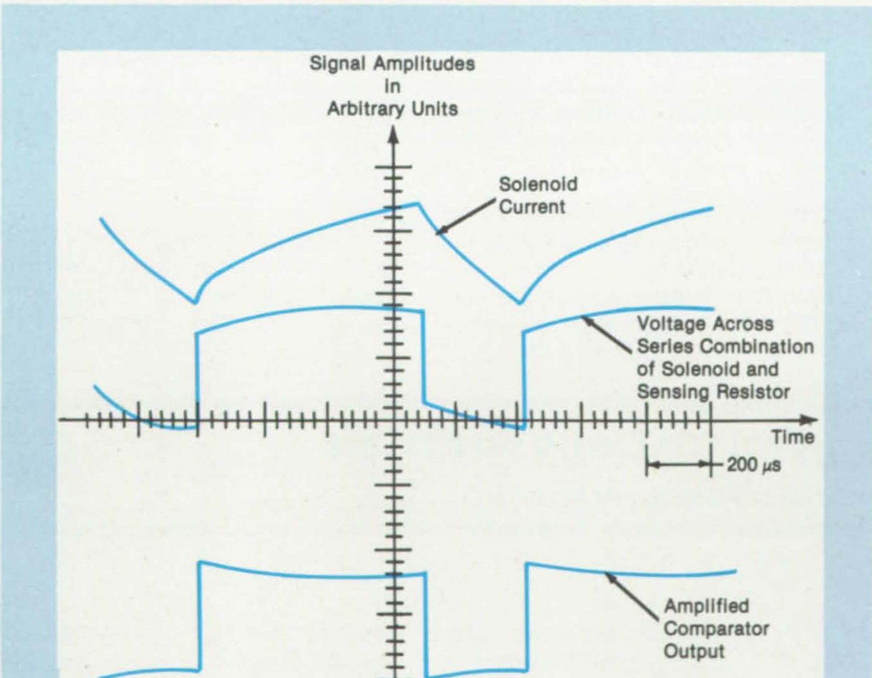



Figure 2. These **Oscilloscope Traces** (redrawn from a photograph for clarity) were taken from the circuit of Figure 1. These traces show the short turn-on and turn-off times that limit the power dissipation of the circuit.

The solenoid current generates a voltage by passing through a sensing resistor (see Figure 1). This voltage is compared with a reference voltage that is proportional to the commanded solenoid current. The comparator produces a high or low voltage at its output terminal, depending on whether the sensed solenoid current is low or high, respectively.

The comparator output is amplified by a direct-coupled voltage amplifier and fed to a power field-effect transistor (FET). The FET accordingly turns the supply voltage to the solenoid on and off so that the solenoid magnetic field repeatedly builds up and collapses at a rate that tends to keep the solenoid current near the commanded value. A power diode clamps the flyback pulse and enables the continuation of the solenoid current during the decay period. In a laboratory version of the circuit, the solenoid current exhibited a 120-mA peak-to-peak ripple about the commanded dc value of 0.75 A, with a buildup time of about 600 μs and a decay time of about 320 μs (see Figure 2).

A remarkable feature of the type of power FET selected for the circuit is that it has an extremely low "on" resistance — no more than 0.1 ohm. This accounts in part for the low power dissipation of the circuit.

Another power FET of the same type is the master switch that connects the supply voltage to the circuit. It is turned on by a light pulse to a photovoltaic optoelectronic isolator. (The isolator acts as a floating voltage source, and the light pulse generates the voltage.) Since the power FET has an ample 8.2-ampere continuous current rating, it can drive additional regulators in parallel. The combination of the power FET and isolator can also be used as an electronic relay.

*This work was done by Richard A. Simon 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 18]**.*
*Refer to MFS-19904.*

# Electronically Controlled Resistor Bank

Resistance is quickly varied in small steps over a wide range.

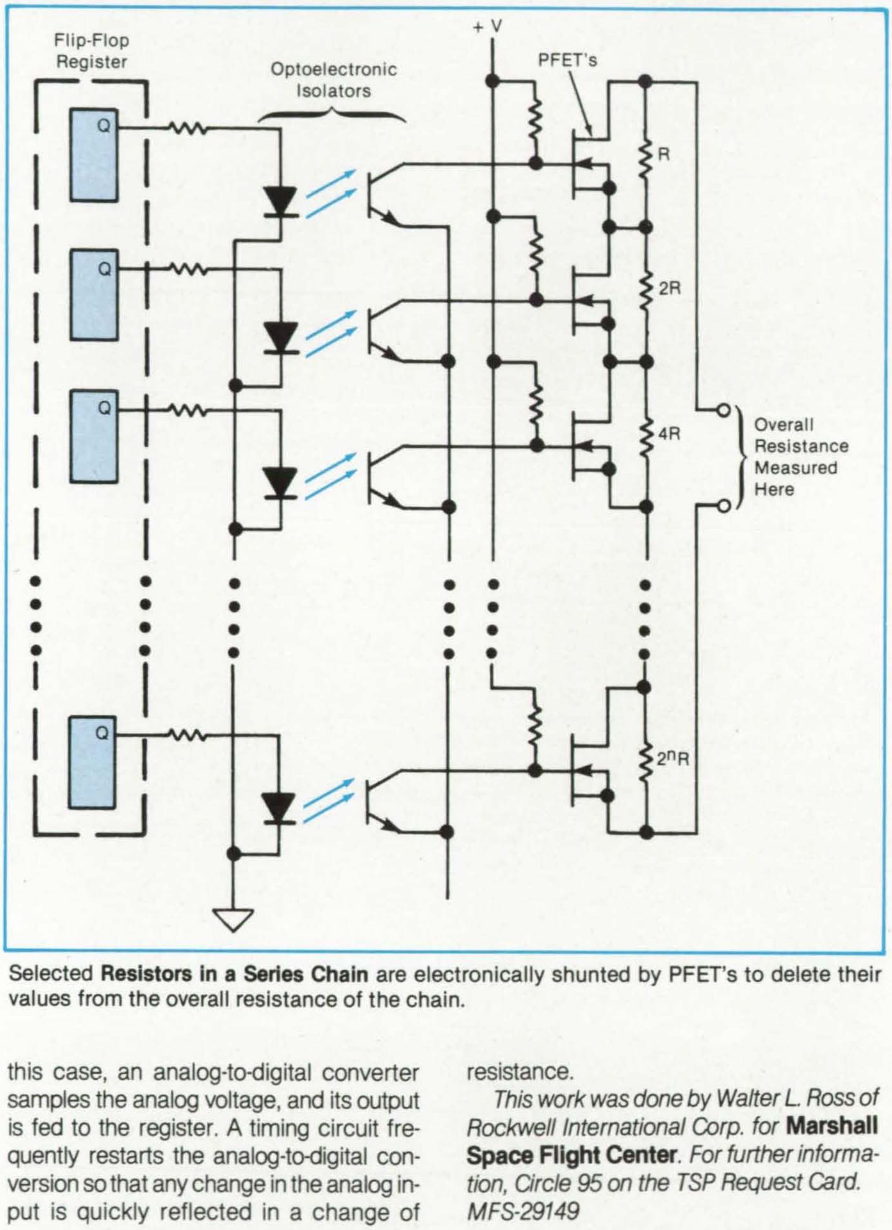
*Marshall Space Flight Center, Alabama*

A device with no moving parts provides a variable electrical resistance. It can be used with analog or digital circuity to provide electronic selection of any of a large number of resistance values for testing, simulation, control, or other purposes. The nearest electromechanical equivalent of the all-electronic device is a potentiometer driven by a servomotor.

The device (see figure) includes n + 1 resistors connected in series, in a binary sequence of resistance values R, 2R, 4R, ... $2^nR$. Each resistor is shunted by a power field-effect transistor (PFET), which has a low "on" resistance. The overall resistance of the chain of resistor/PFET pairs is controlled by using the PFET's to short out selected resistors.

The gate of each PFET is connected through an optoelectronic isolator to the output of one stage of a flip-flop register. When one bit of the register is set (according to its digital input), the register output switches to the state that turns off the associated PFET, thereby turning off the shunt around the corresponding resistor and adding its resistance to the series total.

The bits in the register are arranged in the same order as that of the resistors: the least significant bit controls the resistance R, while the most significant bit controls the resistance $2^nR$. Thus, the overall resistance of the chain is determined by the binary word in the register and can be varied in steps of R from nearly zero — all PFET's on — to $(2^{n+1} - 1)R$ — all PFET's off.




Selected **Resistors in a Series Chain** are electronically shunted by PFET's to delete their values from the overall resistance of the chain.

The overall resistance changes almost instantaneously with a change in register contents. Therefore, the resistance can be varied as a function of time by sending a sequence of binary words to the register. The overall resistance can also be varied in response to a changing analog voltage; in this case, an analog-to-digital converter samples the analog voltage, and its output is fed to the register. A timing circuit frequently restarts the analog-to-digital conversion so that any change in the analog input is quickly reflected in a change of resistance.

*This work was done by Walter L. Ross of Rockwell International Corp. for* **Marshall Space Flight Center.** *For further information, Circle 95 on the TSP Request Card. MFS-29149*

# Computerized Torque Control for Large dc Motors

The speed and torque ranges in the generator mode are extended.

*Marshall Space Flight Center, Alabama*

A system of shunt resistors, electronic switches, and pulse-width modulation controls the torque exerted by a large, three-phase, electronically commutated dc motor. The system is particularly useful for a motor operating in the generator mode because it extends the operating range to low torque and high speed.

In the motor mode, the power-supply switch ($S_4$) is closed, while the shunt-resistor switch ($S_5$) is open (see figure). As the shaft rotates, Hall-effect devices select pairs of switches that determine the current path through the windings. At any instant, one of the lower motor switches ($S_D$, $S_E$, or $S_F$) is closed, while one of the upper motor switches ($S_A$, $S_B$, or $S_C$) is driven on and off by a pulse-width modulation signal with a duty cycle controlled by a computer. When the upper motor switches are all open, the inductively driven, decaying current flows through one of the shunt diodes on one of the lower switches. The inductive/resistive time constant of the motor

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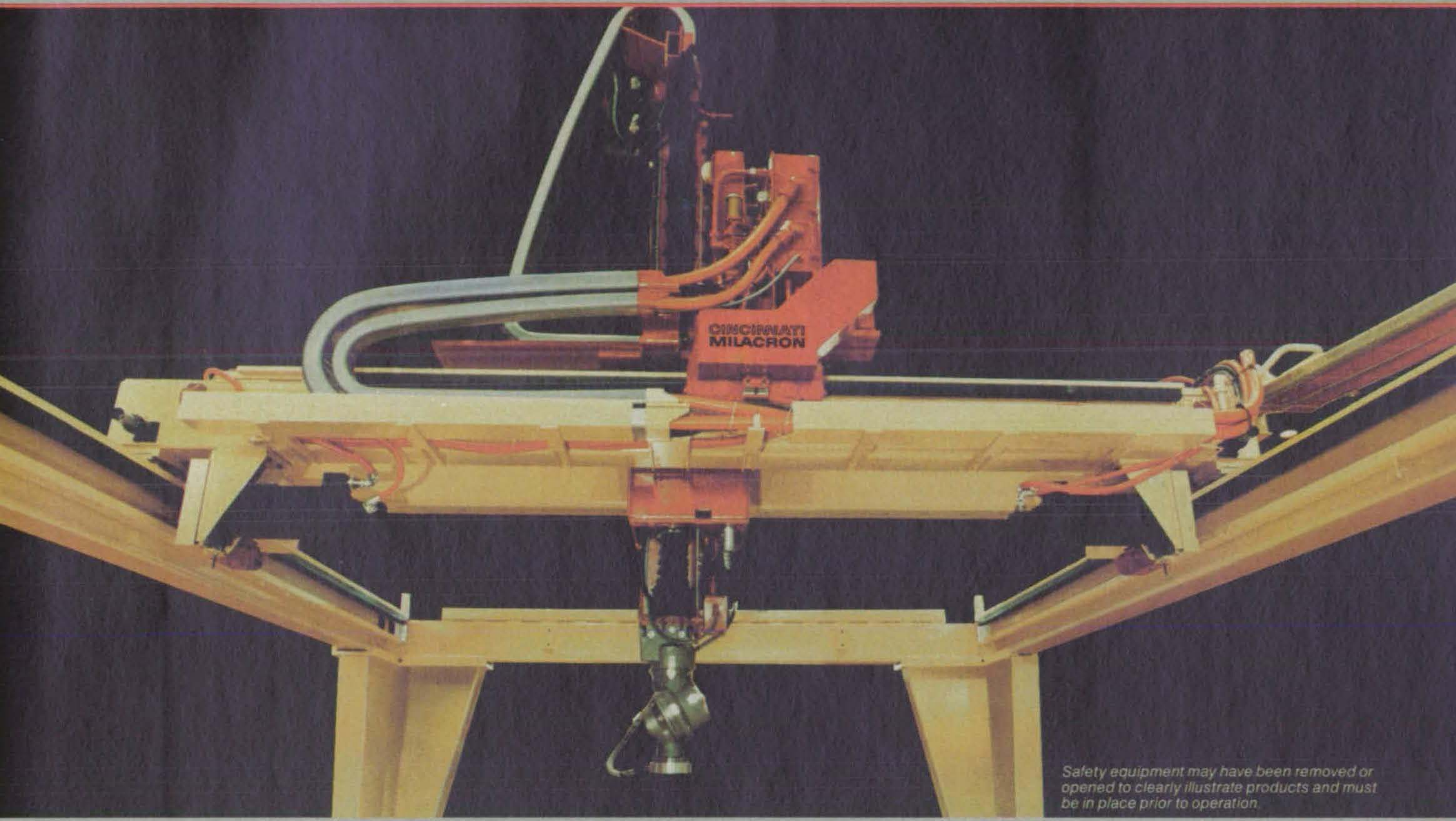


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filters the current fluctuations, thereby smoothing out the torque fluctuations produced by switching.

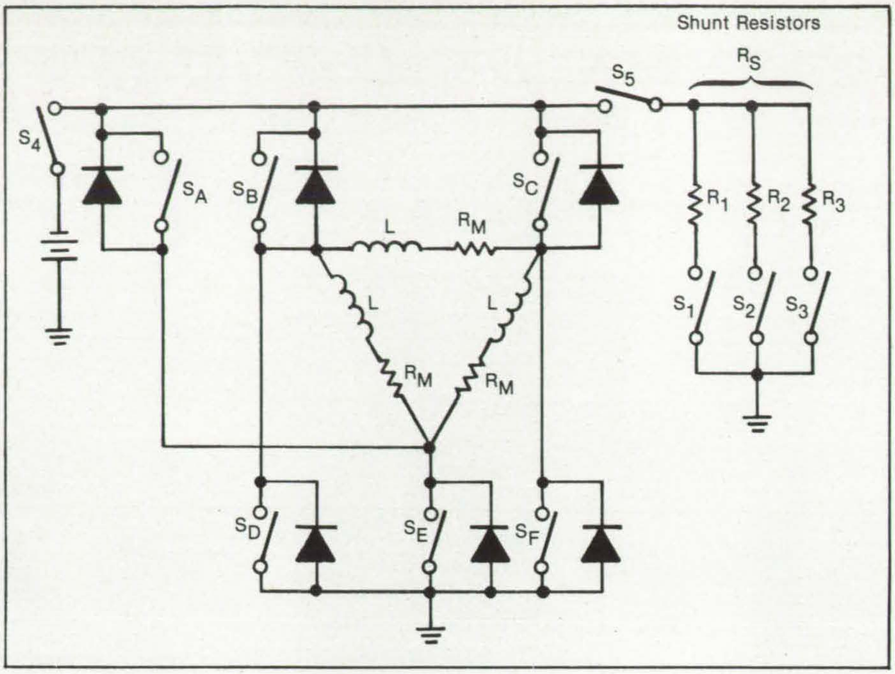
At the transition to the generator mode, the duty cycle of all three upper motor switches goes to zero; that is, they remain open. The three lower switches continue to operate as before, with a duty cycle of 1. As the system goes deeper into the generator mode, the upper switches remain open, and the lower switches are alternately turned off for short periods; that is, they begin to operate at a duty cycle less than 1.

As in the motor mode, this duty cycle can be varied in the generator mode to control the torque. In the generator mode, $S_4$ is opened, and $S_5$ is closed to connect $R_S$, which is one of the shunt resistors $R_1$, $R_2$, or $R_3$. Analysis shows that for a sufficiently large inductive-decay time constant, the torque in the generator mode is given approximately by

$$T = K_T V_B / [R_M + (1 - W) R_S]$$

where $K_T$ = the torque-to-current ratio of the motor, $V_B$ = the back electromotive force of the motor, $R_M$ = the winding resistance, and $W$ = the duty cycle.

Thus, the torque can be decreased by decreasing W or increasing $R_S$. However, one cannot arbitrarily select any combination of W and $R_S$: as the motor speed increases, $V_B$ and the voltage across $R_S$ also increase, and may become too large for the circuit to handle. When this occurs, a lower value of $R_S$ must be selected. That is why $S_1$, $S_2$, and $S_3$ are provided to select different shunt resistances $R_1$, $R_2$, and $R_3$.




The **Shunt Resistor and the Motor-Switch Duty Cycle** are selected by a computer (not shown) to obtain the desired motor torque and a safe voltage across the shunt resistor.

To maintain the continuity of torque while switching shunt resistors, the computer must adjust the duty cycle to maintain the continuity of $(1 - W)R_S$. For example, if the duty cycle is $W_1$ when operating with $R_S = R_1$, then the duty cycle must be changed to $W_2 = 1 + [(W_1 - 1)R_1/R_2]$ when the shunt resistor is changed to $R_2$. Such a calculation is needed only once each time the shunt resistor is changed.

*This work was done by Richard M. Willett, Michael J. Carroll and Ronald V. Geiger of Martin Marietta Corp. for* **Marshall Space Flight Center**. *For further information, Circle 137 on the TSP Request Card.* *MFS-28169*

# FM-to-Digital Converter

## A circuit includes an array of low-cost multivibrators.

*Ames Research Center, Moffett Field, California*

An inexpensive circuit converts a frequency-modulated (FM) signal into a digital signal. The circuit consists of a zero-crossing detector and a series of monostable multivibrators and D-type flip-flops (see Figure 1).

The zero crossings of the FM input are detected and converted to pulses at a voltage compatible with transistor/transistor logic. These pulses are fed to the monostable multivibrators and flip-flops. The positive-going edge of a pulse changes the output of a multivibrator from its normal 1 to a 0. The duration $T_i$ of the 0 output of each multivibrator equals that of its predecessor in the chain minus a small decrement of time: $T_{i+1} = T_i - \Delta T$. In a chain of N monostable/D flip-flop pairs, $T_1$ is half the reciprocal of the lowest frequency to be detected, and $T_N$ is half the reciprocal of the highest frequency to be detected.

When a multivibrator returns to its logic 1 state, it clocks the zero-crossing data from the input to the output of its flip-flop. If the duration of a zero-crossing pulse is shorter than the duration $T_k$ of the logic 0 state of the *k*th multivibrator, a logic 0 will be clocked out of flip-flop $D_k$. If the zero-crossing pulse is longer than $T_k$, a logic 1 is clocked out of flip-flop $D_k$. In the example of Figure 2, the zero-crossing pulse is shorter than $T_2$ but longer than $T_3$, signifying a frequency somewhere between $1/(2T_2)$ and $1/(2T_3)$.

The pattern of 1's and 0's on the flip-flop outputs thus represents the input frequency. As the frequency increases, the zero-crossing pulses grow shorter and the pattern changes, as indicated in the truth table. The more multivibrators there are, the more patterns there will be and the more precisely the input frequency can be resolved.

The circuit might also be used to control a filter. As frequency changes are detected, the binary output could be fed to an attenuator or amplifier to reduce or

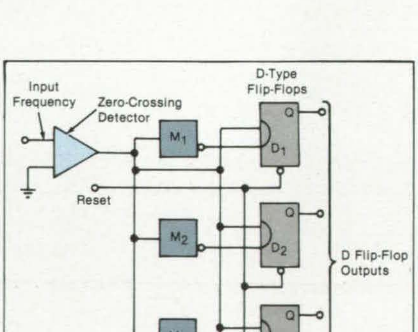



Figure 1. The **Pattern of Ones and Zeros** on the flip-flop outputs represents the input frequency. The truth table shows a pattern for four pairs of multivibrators; many more of these inexpensive chips could be used in a real circuit for greater resolution.

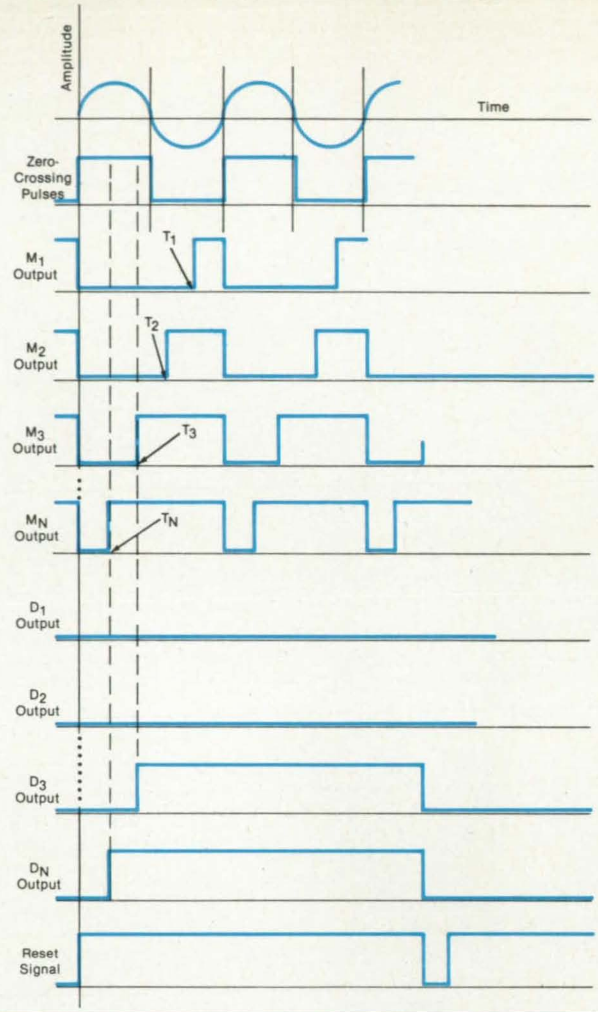



Figure 2. The **Timing Relationships** between the zero-crossing pulses and the logical-zero output intervals of the monostable multivibrators determine the pattern of ones and zeros at the outputs. Here, the frequency lies between $f_2 = 1/(2T_2)$ and $f_3 = 1/(2T_3)$.

increase the gain; unwanted frequencies in a signal would thus be suppressed.

The multivibrator circuit offers important advantages over other ways of converting FM signals to binary signals. Compared with phase-locked loops and constant-energy, pulse averaging circuits, it has fewer components and responds more quickly.

*This work was done by Michael Moniuszko of* ***Ames Research Center****. No further documentation is available.*

*Inquires concerning rights for the commercial use of this invention should be addressed to the Patent Council, Ames Research Center [see page 18]. Refer to ARC-11172.*

# ZnSe Films in GaAs Solar Cells

ZnSe may increase efficiency and conserve material.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Two proposed uses of zinc selenide films promise to boost the performance and reduce the cost of gallium arsenide solar cells. According to the proposal, ZnSe can serve as a surface-passivation layer and as a sacrificial layer that would enable the repeated use of a costly GaAs substrate in fabrication.

Currently, a GaAs cell is passivated by growing a 300-nm film of aluminum gallium arsenide on the front surface. A film of the approximate composition $Al_{0.8}Ga_{0.2}As$ is formed by metalorganic chemical-vapor deposition or by liquid-phase epitaxy at temperatures between 700 and 800 °C. However, the film gradually deteriorates under the influence of moisture and oxygen. It becomes difficult to form a stable, reproducible, low-resistance contact on the surface. In some cases, a thin oxide surface layer caused by prolonged exposure to air may not be optically compatible with various antireflective coating materials. Moreover, etching the oxidized surface may alter the optical properties of the underlying material.

The substitution of ZnSe for $Al_{0.8}Ga_{0.2}As$ would overcome these disadvantages. The lattice structure of ZnSe matches that of the GaAs substrate. The ZnSe is expected to passivate effectively while enabling a low-resistance contact to be formed. The dark saturation current should be reduced and the open-circuit voltage increased, and the cell efficiency should rise as a result. A further benefit is that the refractive index of ZnSe is substantially smaller than that of GaAs — 2.9 versus 3.4. Thus, the ZnSe film would reduce reflection from the cell, and it might not be imperative to apply an antireflective coating in a separate step.

Zinc and selenium are already used as dopants in GaAs solar cells. The same chemical-vapor-deposition apparatus now used to dope the cells with zinc and selenium could be used to form the ZnSe layer as well.

The close match of the crystal structures of ZnSe and GaAs would be further exploited in the other proposed application — using ZnSe as a preparation layer. A thin film of ZnSe would be applied to the GaAs substrate. Layers of n-type and p-type GaAs would be deposited on the ZnSe film, forming the active region of the solar cell.

At this point, the entire cell would be dipped in a 60-percent nitric acid solution. Only the ZnSe layer would dissolve, freeing the active GaAs region from the GaAs substrate. (Alternatively, the ZnSe could be etched away photochemically.)

Consisting only of the active region, the resulting solar cell would be ultrathin and ultralight. A new substrate would not be required for each cell; the same substrate would be used repeatedly as the base for the fabrication of the active regions of many cells. Only about 10 to 15 μm at the surface of the substrate would have to be removed after each use to restore its condition.

*This work was done by Ram H. Kachare of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 115 on the TSP Request Card.* *NPO-16900*

## 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.**

### More on Effects of Radiation on Electronics

A bibliography is expanded.

A third volume in a series of bibliographies on radiation effects on electronics covers the years 1982 and 1983. Previous volumes covered the more recent interval of 1984 and 1985.

The volume summarizes the literature on the effects of total doses of radiation and of test environments. The devices range from simple Zener diodes to complicated integrated circuits. Although the primary focus is on silicon, other semiconductor materials are included — GaAs and HgCdTe, for example.

Abstracts of 273 publications are presented. They are organized in alphabetical order by names of principal authors, in the following four categories:

1. Dose-rate effects,
2. New technology,
3. Post-irradiation effects, and
4. Test environments.

Many abstracts are the authors' originals. However, where the originals are lenghty or vague, they have been edited for use by radiation-test engineers and to fit the standard format of the bibliography. The abstracts are primarily from U.S. sources, some are from British publications, and there are several translations from foreign-language publications.

*This work was done by Frank L. Bouquet of Caltech for* **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Bibliography of Total Dose Radiation Effects on Electronics — Volume III," Circle 24 on the TSP Request Card.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 18]. Refer to NPO-17019.*

## New Products

An 8-channel high speed direct writing recorder has been announced by **Astro-Med, Inc.**, West Warwick, RI. The Model MT-9500 has a real-time frequency response of 5 kHz, and uses low-cost, readily available thermal paper. With transient capture capability, the MT-9500 allows the user to obtain "instant slow-motion replay," with an effective chart speed of 1000 mm/sec. The recorder prints both the waveform data and the chart grid simultaneously. **Circle Reader Service Number 490.**

## Data Bus Adapts to Changing Traffic Level

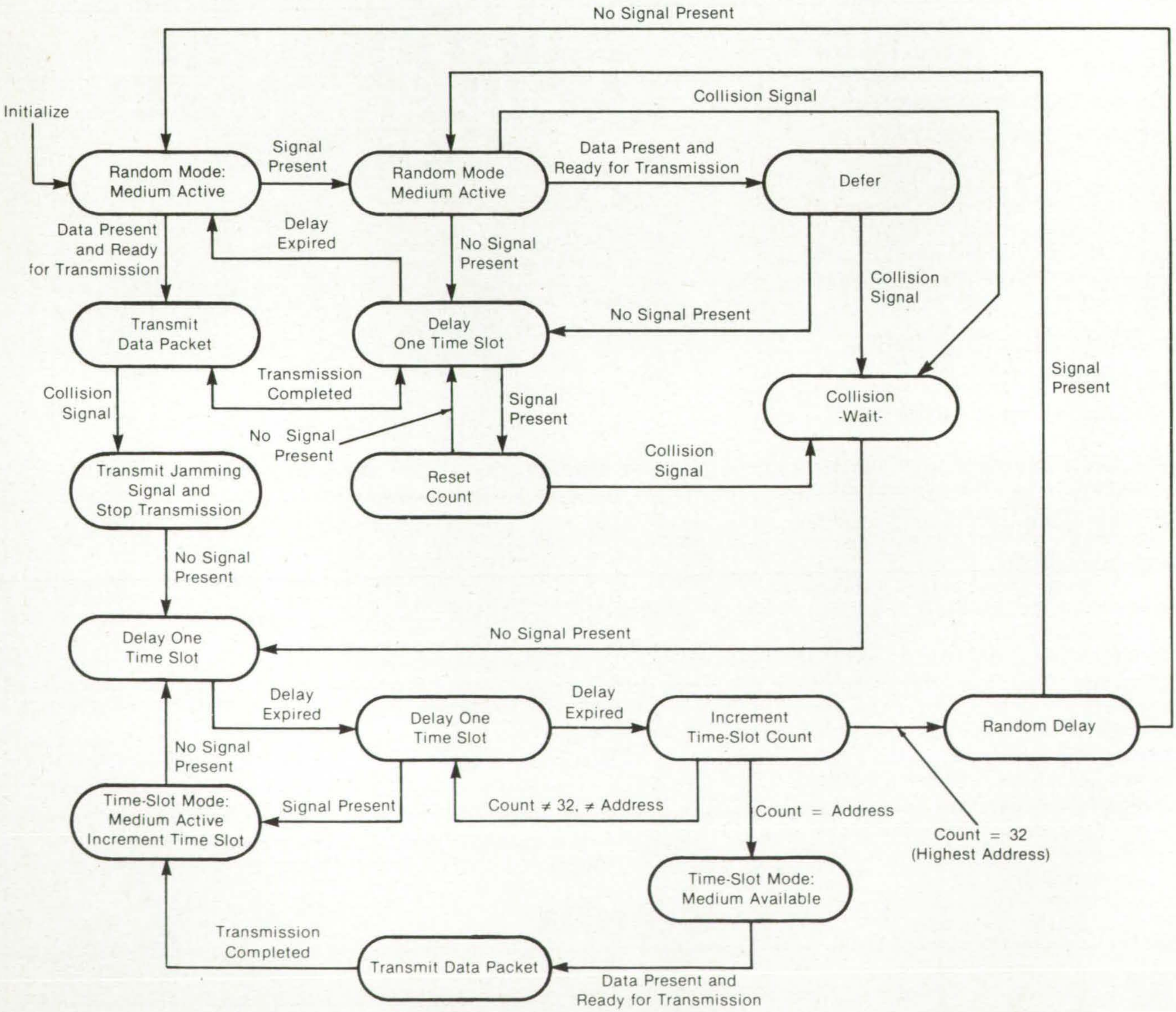
Access becomes timed when collisions threaten.

*Goddard Space Flight Center, Greenbelt, Maryland*

A two-mode scheme is used to grant terminals access to a data bus. The scheme causes the bus to alternate between random accessibility and controlled accessibility to optimize performance and adapt to changing data-traffic conditions. The bus is part of a 100-Mb/s optical-fiber-packet data system.

When traffic on the bus is light, the random-access mode allows the most efficient use of the bus. When traffic increases, the bus changes to the controlled-access mode, which gives all terminals an equal opportunity to send data, even in the heaviest traffic.

The figure is a state diagram of the scheme. In the random-access mode, any terminal can use the bus whenever it




This **State Diagram** illustrates the controlled- and random-access protocols and the transitions between them.

needs to send out a packet of data. If the bus is busy when a terminal requests it, the terminal automatically refrains from transmitting until the bus is free. Of course, two terminals may sometimes gain access to the bus at the same time; in that case, their data packets are said to "collide" and are recorded as not having been sent.

When such a "collision" occurs, all of the terminals in the network cease attempting to transmit data, and the entire network changes to the controlled-access mode. In a preset sequence, each terminal is then allocated its own 1.6-μs timeslot, during which it can gain access to the bus. When a terminal needs to send a message, it must wait until its timeslot comes up to do so. After the terminal has ended its transmission, the sequence of timeslots is resumed. The terminal that recently transmitted may not use the bus again until all the other terminals have been offered their timeslots.

This strict control prevents a few terminals from monopolizing the bus. When all timeslots have been proffered and all pending bus requests have been satisfied, the network reverts to the random-access mode.

*This work was done by Eugene Lew, John DeRuiter and Mike Varga of Sperry Aerospace and Marine for* **Goddard Space Flight Center**. *For further information, Circle 11 on the TSP Request Card.*

*GSC-12967*

## Robot-Arm Dynamic Control by Computer



Feedforward and feedback schemes linearize responses to control inputs.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A method for the control of a robot arm is based on computed nonlinear feedback and state transformations to linearize the system and decouple the robot end-effector motions along each of the cartesian axes in the workspace. The nonlinear feedback is augmented with an optimal scheme for the correction of errors in the workspace.

The mathematical model of the robot arm is stated in homogeneous coordinates together with the Denavit-Hartenberg four-parameter representation of robot-arm kinematics. Using the Lagrangian formulation of mechanics, the dynamic behavior of the robot arm is expressed in matrix/vector form and manipulated to obtain expressions of the types previously found useful in nonlinear-control theory.

The resulting dynamic-control mathematical model satisfies the necessary and sufficient conditions for external (or exact) linearization and simultaneous output decoupling. By using nonlinear feedback and a diffeomorphic transformation, the nonlinear system of dynamical equations is converted into a Brunovsky canonical form and simultaneously output-decoupled.

The linearization accomplished here by nonlinear feedback is an "external linearization" as opposed to the conventional "internal linearization" (Taylor-series expansion). That is, the nonlinear character of the original system is not changed here by any approximation. Therefore, system linearization by nonlinear feedback can be called "exact linearization" in a control sense.

The linearized system is unstable. To stabilize it, a linear feedback loop is added. As long as the feedback matrix is constant and block-diagonal, the system will remain an output-decoupled linear system.

A major new feature of the control method is that the optimal error-correction loop directly operates on the task level and not on the joint-servocontrol level. The task-level errors are then decomposed by the nonlinear-gain matrix into joint-force or joint-torque-drive commands.

The new control method performed well in computer simulations. The augmentation of nonlinear feedback with an optimal error-correcting control provides robust performance and assures acceptable tracking errors even when the dynamical parameters of the mathematical model of the robot arm are in error by as much as 30 percent.

*This work was done by Antal K. Bejczy of* **NASA's Jet Propulsion Laboratory**, *Tzyh J. Tarn of Washington University, and Yilong J. Chen of General Motors Corp. For further information, Circle 42 on the TSP Request Card.* *NPO-16742*

# Portable-Beacon Landing System for Helicopters

## An X-band system brings all-weather landing capability to remote sites.

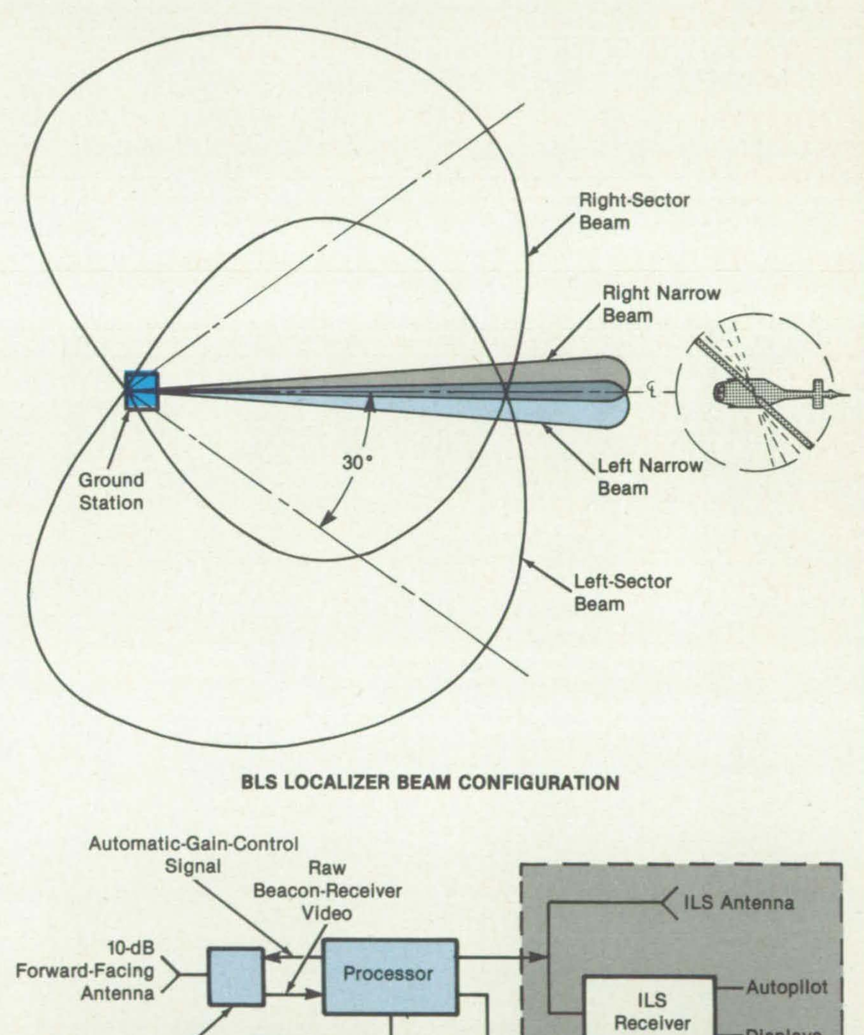
*Ames Research Center, Moffett Field, California*

A prototype beacon landing system (BLS) allows helicopters to make precise landings in all weather. The BLS can easily be added to existing helicopter avionic equipment and can readily be deployed at remote sites. Small and light, the system employs X-band radar and digital processing.

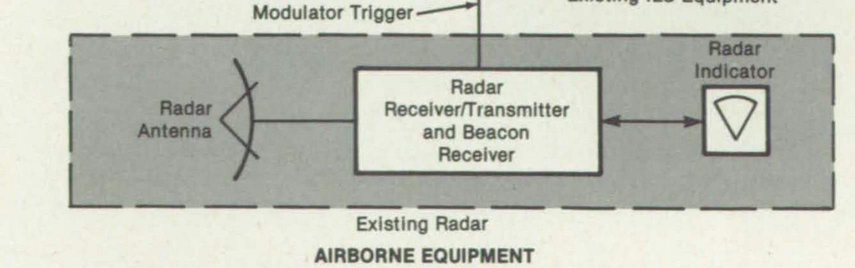
On the helicopter, an X-band receiver and a small microprocessor operate in conjunction with a standard instrument landing system (ILS) and weather radar. On the ground, an inexpensive portable transmitter provides signals for reception by the airborne components. The ground station weighs only 70 pounds (32 kilograms) and consumes only 30 watts of power. It can be set up by one person in 10 minutes.

To begin a BLS landing, a pilot approaches using conventional navigational aids until the helicopter is within range of the BLS ground station. The ground station contains an X-band transponder, two microwave switches and their control circuitry, an antenna array, and a 24-volt battery. Because antennas can be fairly small at X-band frequencies, the ground unit is only 85 cm high. The airborne antenna is even smaller, being 1.25 inches (3.2 centimeters) high. The ground station produces four narrow, overlapping beams oriented above, below, to the left of, and to the right of the desired flight path (see figure). The upper and lower beams indicate the helicopter glide slope. If the helicopter deviates from the desired slope, one signal increases and the other decreases in intensity. When the signals from both beams are of equal intensity, the aircraft is following the proper slope. Similarly, the left and right beams indicate the helicopter course. Deviation to the left or right of the proper course is evident in the relative intensities of the left and right beam signals.

In addition, the station produces two wide sector beams. The BLS airborne processor compares the amplitudes of signals from those of the sector beams with signals from the narrow beams and rejects signals of lower amplitudes than those of the sector beams. This elimi-




**BLS LOCALIZER BEAM CONFIGURATION**




**AIRBORNE EQUIPMENT**

**A Variety of Beams** are pulsed sequentially by the ground station after an initial interrogation by the weather radar of the approaching helicopter. (The upper and lower narrow beams do not appear here.) The airborne microprocessor processes the pulses to determine the glide slope, course deviation, and range.

**"The Ada programming language shall be the single, common, high order programming language for...**

*"...all computers that are integral to, physically a part of, dedicated to, or essential in real time to a performance of the mission of weapon systems...used for specialized training, diagnostic testing and maintenance, simulation, or calibration of weapon systems...used for research and development of weapon systems...Use of validated compilers is required...this directive is effective immediately."*
*—DoD Directive 3405.2, 3/30/87.*

*"...Defense computer resources used in intelligence systems, for the command and control of military forces...all major software upgrades...all other applications (some exceptions) in keeping with the long range goal of establishing Ada as the primary DoD higher order language... waivers to the policy...shall be strictly controlled and closely reviewed...this directive is effective immediately."*
*—DoD Directive 3405.1, 4/2/87.*

AdaNow

nates false course indications that would be generated by side lobes.

Upon interrogation by the airborne weather radar in the approaching helicopter, the ground station sends its first pulses through an omnidirectional antenna, thus providing a wide-coverage reply as to landing-site position and identification. It then sends pulses in sequence through the left-sector antenna, the upper and lower precision antennas, the right-sector antenna, the left-sector antenna again, the left and right precision antennas, and finally the right-sector antenna again. The intervals between succeeding pulses are 6 or 9 μs. The microprocessor counts the pulses and measures the intervals to determine which pulse belongs to which beam.

The airborne BLS antenna and receiver are mounted in the helicopter radome. The 16-bit microprocessor analyzes the received X-band video signal to calculate the range, the course and glide-slope deviation, and the automatic gain control for the receiver. The microprocessor converts its deviation signals to the ILS format, then feeds them to the ILS receiver, which uses them to control the autopilot and to display information to the pilot. The range information is displayed on the weather-radar screen or on a separate digital display.

In the absence of an interrogation signal from an airborne weather radar, the beacon squitters at 100 pulse trains per second. In this asynchronous mode, the airborne unit receives course and glide-slope guidance but no range information. This mode makes it possible for an aircraft without a weather radar to use the BLS.

*This work was done by Thomas J. Davis and George R. Clary of* **Ames Research Center** *and John P. Chisholm and Stanley L. Macdonald of Sierra Nevada Corp. For further information, Circle 152 on the TSP Request Card.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center* *[see page 18].* *Refer to ARC-11674.*

## New Products

**Videk** (Rochester, NY), a division of Eastman Kodak, announces the Megaplus development system, an IBM PC AT-based system that processes images captured by the Videk Megaplus camera. The package includes a Megaplus camera, software, plug-in PC boards and an IBM PC. Capabilities include image enhancement, spacial filtering, zooming, analysis, graphics, measurement and annotation, and image storage and retrieval. **Circle Reader Service Number 336.**

**IFR Systems, Inc.** (Wichita, KS) announces their A-8000 spectrum analyzer. The synthesized RF section covers 10 kHz to 2.6 GHz with a time base accuracy of ±0.5 PPM. Scan widths vary from 1kHz to 200 MHz per division. Resolution bandwidths of 300 Hz to 3 MHz and sweep times of 5mS to 10 sec/division can be selected. A direct entry keyboard facilitates operation. **Circle Reader Service Number 476.**

**Ektron Applied Imaging** (Bedford, MA) announces their EKTRON Laser Image Recorder Model 811. The system, which requires no plumbing or liquid chemicals, writes high-quality continuous tone digital images onto photographic paper or film. It accomodates images of up to 8.5" X 11" and contains 2 Mbytes of image buffer memory. **Circle Reader Service Number 354.**

**Visionics Corporation** (Sunnyvale, CA) released a library module of 200 cross-referenced (CRF) files to enhance their EE Designer and EE Designer II integrated CAE/CAD packages. The package includes an expanded array of TTL logic devices, a variety of ROM, RAM, PROM and EPROM devices, and a series of analog devices. Price is $200. **Circle Reader Service Number 434.**

**Intel Corp.** (Chandler, AZ) announces a Class B version of its static random access memory (SRAM) approved by the VHSIC Program Office. The M51C98 is a 64 K-bit CHMOS SRAM with a 35-nanosecond access time and a maximum power consumption of 100 mA. It is offered in a 22-pin, side-brazed ceramic DIP. **Circle Reader Service Number 386.**

# Physical Sciences



## Glass-to-Metal Seal Against Liquid Helium

Superfluid helium II does not leak through this seal on a transparent container.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A simple compression joint with an indium gasket forms a demountable seal for superfluids. The seal was developed for a metal lid on a glass jar used in experiments on liquid helium. The glass container allows the contents to be viewed for such purposes as calibration of liquid-level detectors and adjustments of displacement plungers. Until now, demountable, leak-tight glass-to-metal joints have not been able to withstand the repeated thermal cycling of cryogenic procedures.

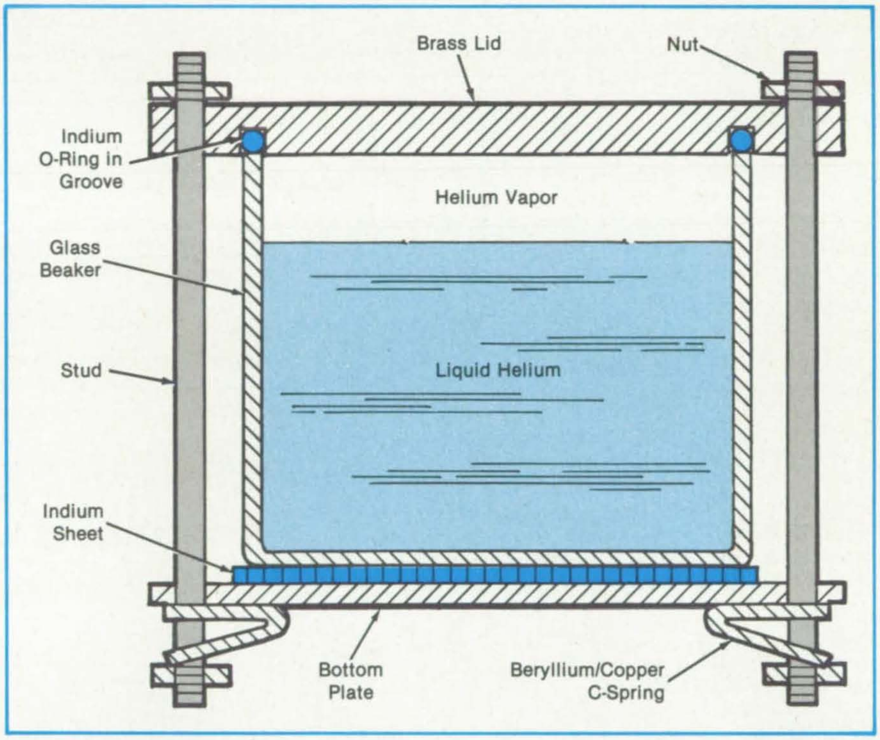
The seal contains liquid helium even when its temperature drops below 2.19 K — the λ point at which the helium becomes helium II, a zero-viscosity fluid that can flow through pores as small as $10^{-6}$ cm. The seal is made from inexpensive, commercially available materials and parts; special metals, special glasses, and skilled glassblowing are unnecessary.

The jar is made from an ordinary Pyrex (or equivalent) glass beaker. The flared top is removed with a glass saw. To remove gross irregularities from the newly exposed edge, the edge is ground on a flat table with 600-grit abrasive paper soaked with alcohol. Grinding continues until the exposed edge appears uniformly gray. The edge is then fire-polished.

The lid is machined from brass 0.125 in. (3.2 mm) thick. A groove is machined in the lid to accommodate an O-ring of indium wire 0.050 in. (1.27 mm) in diameter. Electrical and mechanical connections to the jar pass through the lid.

The jar is pressed tightly against the O-ring by a spring-loaded bottom plate (see figure). Eight studs equally spaced around the lid perimeter hold the plate against the beaker. The beryllium/copper C-shaped springs have enough extra travel to compensate for the cold flow of the indium gasket over time. The O-ring seal should be tightened in stages.

The indium O-ring must be replaced every time the seal is broken. A sheet of indium 0.030 in. (0.76 mm) thick under the jar helps to distribute the compressive load over the irregular glass bottom. Unlike the O-ring, the sheet can be used during many experiments.




**Made From Stock Materials,** a glass experiment cell holds superfluidic helium, even though no special provisions are made to prevent thermal shock in cryogenic experiments. The brass lid and indium O-ring can readily be used on a metal jar when the cell contents do not have to be visible.

In each of a series of 15 experiments, the sealed, helium-filled jar was lowered into a conventional double Dewar flask having window strips in both the inner and outer containers. The outer container was filled with liquid nitrogen at 77 K. After 4 to 6 hours, liquid helium at 4 K was poured into the inner container, and the measurements were taken. There was no noticeable leakage of helium into or out of the jar.

*This work was done by John L. Watkins and John R. Gatewood of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 62 on the TSP Request Card.* *NPO-16308*

# Approximate Analysis of Semiconductor Laser Arrays

A simplified equation yields useful information on gains and output patterns.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A theoretical method based on an approximate waveguide equation enables the prediction of the lateral modes of a gain-guided planar array of parallel semiconductor lasers. The equation for the entire array can be solved directly using a piecewise approximation of the index of refraction by simple functions without the customary approximation based on the coupled waveguide modes of the individual lasers.

The laser array is treated mathematically as though it were uniform along the direction of propagation (the z direction in Figure 1). The electromagnetic modes of the array are therefore taken to be the eigenmodes of the two-dimensional wave-

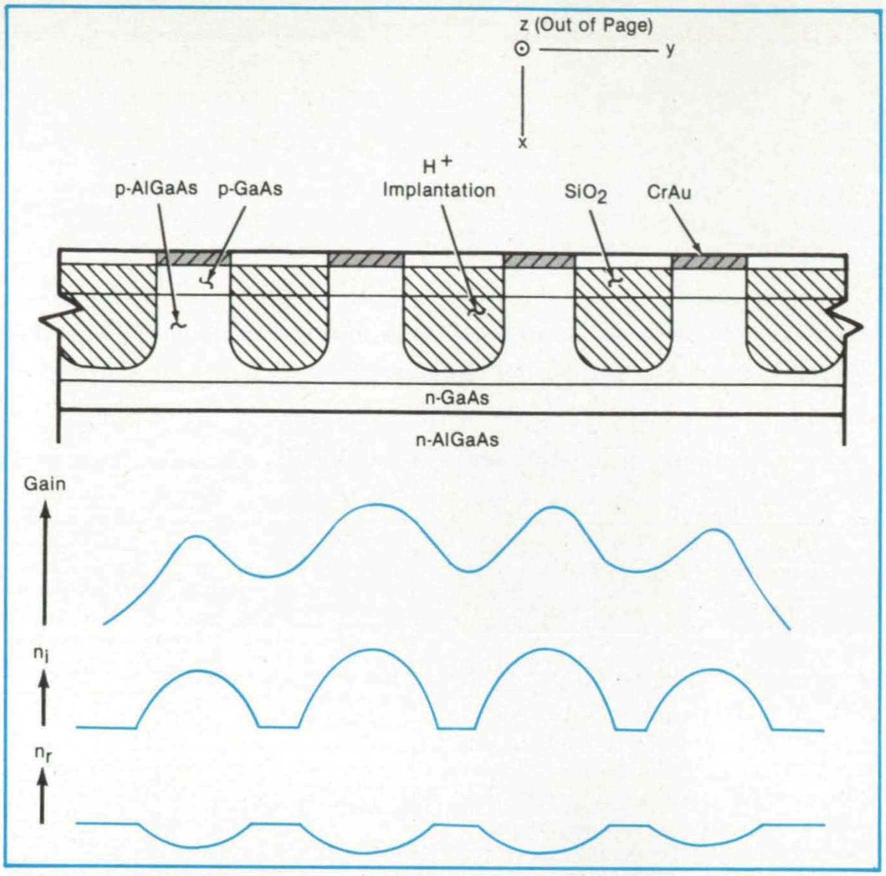



Figure 1. The **Semiconductor Laser Array** is approximated, for the purpose of analysis, by a one-dimensional waveguide with spatially varying gain and real ($n_r$) and imaginary ($n_i$) parts of an effective index of refraction.

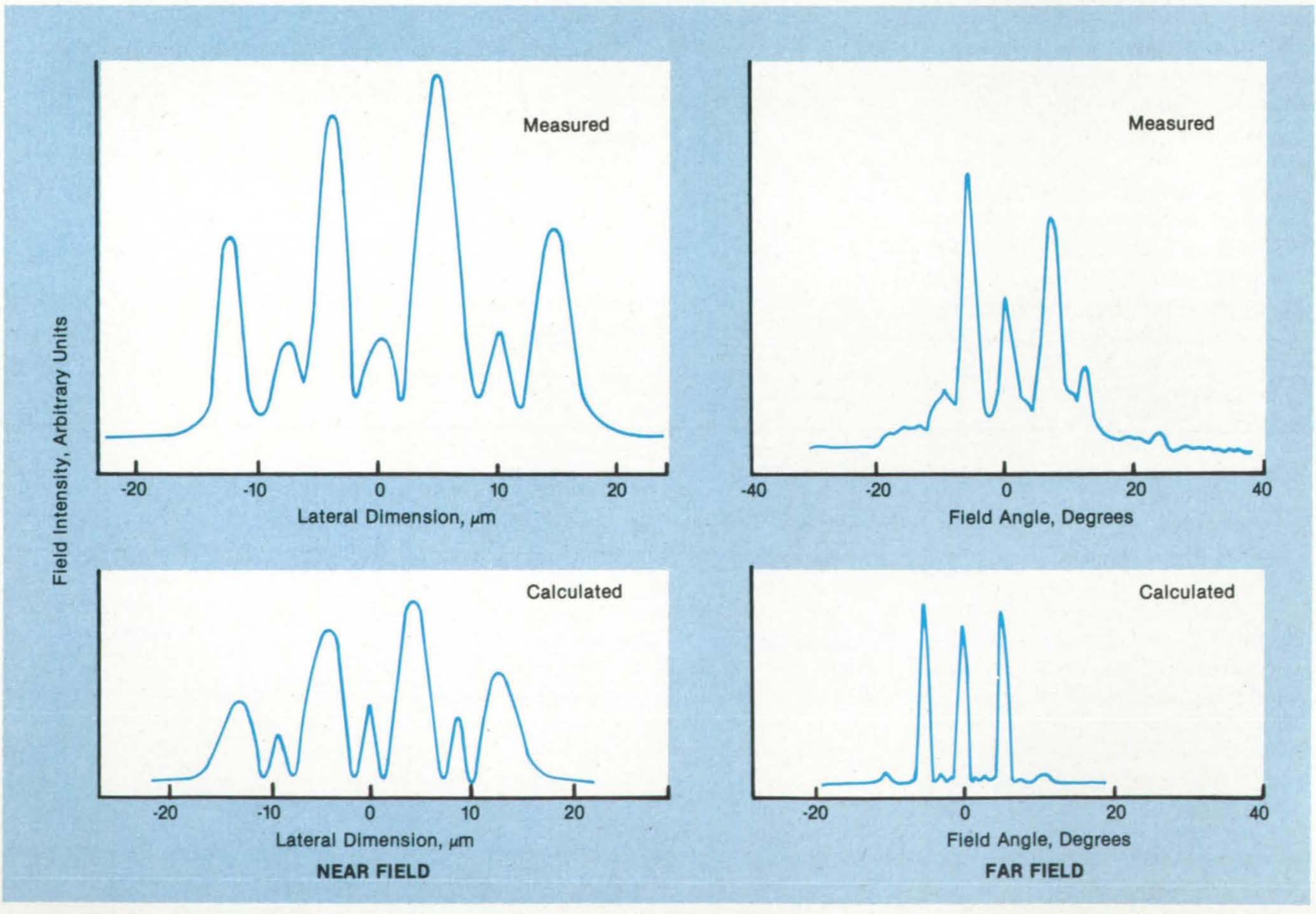



Figure 2. The **Near and Far Fields** of a four-element gain-guided-mode semiconductor laser array were measured and calculated by the new method.

guide formed by the laser heterostructure, gain distribution, and spatially varying index of refraction. However, the eigenmodes are calculated for a simplified one-dimensional version of the structure: an effective index of refraction, n(y), is calculated by a previously known technique and used in place of the actual index, n(x,y).

The resulting approximate waveguide equation for the array is

$$\frac{\partial^2 E_y}{\partial y^2} + [(\omega/c)^2 n^2(y) - \beta^2]E_y = 0$$

where $E_y$ is the electric field in the y direction, $\omega$ is the angular frequency, c is the speed of light, and $\beta$ is the lateral (x-y plane) contribution to the overall propagation constant. The effective index of refraction is represented piecewise by a simple function within each laser stripe and intervening space so that the waveguide equation can be solved in each such region. The separate solutions are then matched at the boundaries between the regions. Subject to the overall boundary condition that the field must decay to zero at $y = \pm\infty$, the combination of matched regional solutions gives the eigenmodes of the array.

Figure 2 illustrates the close agreement between such a calculation and measurements. In general, the new method yields results different from those of the coupled-mode approximation because the coupling is so strong that the modes of the individual lasers lose their identities. The new method also shows differences between gain-guided-mode and real-index-guided-mode laser arrays, which are not evident in prior analyses. The improved results should yield a better understanding of laser-array modes and thereby help in the development of well-behaved high-power semiconductor laser arrays.

*This work was done by William K. Marshall and Joseph Katz of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 109 on the TSP Request Card.* *NPO-16813*

# 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.

## Apodization Control of Line Shape in Spectrometer

### A Kaiser-Bessel apodization function reduces the unwanted sidebands.

A report discusses apodization in a Fourier-transform spectrometer (FTS) for the Advanced Moisture and Temperature Sounder (AMTS). Apodization is the application of spatially varying attenuation over the surface of a lens or mirror to affect the structure of the diffraction pattern that forms the image. For example, when forming an image of a pointlike object like a star, an unapodized circular lens forms a circularly symmetric image consisting of a bright central spot (the Airy disk) surrounded by a series of faint rings. By adjusting the transmission of the lens so that it decreases in just the right way with increasing radius, the rings can be eliminated (or at least greatly reduced), albeit at the expense of enlarging the central spot.

The purpose of apodization in this instrument is to control the shape of the spectrum in wavenumber space to keep radiation at other wavelengths in the passband of the spectrometer out of the AMTS wavenumber channel. The calculation of the apodizing functions involves a general analysis, including an accurate model of the effect of off-axis detectors in FTS instruments. A complete system tradeoff analysis among line-shape control, line-shape degradation, and stability has also been carried out.

The results indicate that the apodizing functions should have the Kaiser-Bessel form as a function of optical path. A Kaiser-Bessel parameter in the range of $K = 6$ to $K = 8$ meets the line-shape control requirements of the AMTS.

*This work was done by Antonio Pires, Edward Niple, and Nathan L. Evans of Perkin Elmer Corp. for* **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Apodization Control of Lineshape in Array Field Widened Interferometer Where Apodizing Functions Have Kais.-Bessel Form," Circle 5 on the TSP Request Card.* *NPO-16389*

## Overview of Fiber-Optical Sensors

### The design, development, and sensitivity of sensors using fiber optics are reviewed.

The state-of-the-art and probable future developments of sensors using fiber optics are described in a 14-page report that includes 35 references to work in the field. The report serves to update previously published surveys. Systems incorporating fiber-optic sensors are used in medical diagnosis, navigation, robotics, sonar, the power industry, and industrial controls.

The report summarizes the operating principles, advantages, and disadvantages of Mach-Zehnder, Michelson, Sagnac, and ring-resonator fiber-optic interferometers, which can be used to form sensors. The two common methods for introducing a transducer into the sensor arm of a Mach-Zender interferometer are discussed: (1) wrapping the fiber around a mandrel that is sensitized to whatever is to be monitored and (2) applying a sensitized coating to the optical fiber. Mandrels and coatings suitable for acoustic, electric, magnetic, and thermal measurements are described. Equations describing the phase-modulation process for coated fibers are also presented.

The report describes two types of rotation sensors (both based on the Sagnac interferometer) that can be used in lieu of mechanical gyroscopes. The lowest reported drifts achieved thus far are 0.005 degree/(hour)$^{1/2}$ for an all-fiber gyroscope and 0.025 degree/(hour)$^{1/2}$ for a hybrid fiber-optic gyroscope.

Ten fiber-optical methods for sensing temperature are listed. The performances of acoustic, magnetic, electric, rotation, and temperature sensors are compared. The authors note the considerable difficulties in eliminating both unwanted sensitivity to temperature in fiber-optic sensors intended to monitor parameters other than temperature and sensitivity to other parameters in devices meant to sense temperature alone.

Existing and potential applications of fiber-optic sensors in medicine and robotics are outlined. The report concludes with an overview of the state of development and unsolved problems for various components (couplers, fibers, integrated optics, modulators, polarizers, and light-source diodes) used in fiber-optic systems.

*This work was done by Ramon P. DePaula and Emery L. Moore of Caltech for* **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Fiber Optic Sensor Overview," Circle 84 on the TSP Request Card.*
*NPO-16817*

# Materials

## Hardware, Techniques, and Processes



## Books and Reports



# Directional Solidification of Nodular Cast Iron

Cerium enhances the formation of graphite nodules.

*Marshall Space Flight Center, Alabama*

Preliminary experiments in the directional solidification of cast iron have shown a quantitative correlation of the graphite microstructure with the growth rate and the thermal gradient, with sufficient spheroidizing element to form spheroidal graphite under the proper thermal conditions. The experimental approach enables the use of directional solidification to study the solidification of spheriodal-graphite cast iron in low gravity. Because directional solidification can often be used to form alloys with regular composite structures, it may be possible to form new structural materials from nodular (spheroidal-graphite) cast iron.

Previous attempts at directional solidification of spheroidal cast iron failed, in part because magnesium was used as the spheroidizing element. In addition, holding the material in the molten state reduced the level of spheroidizing elements below the minimum required to produce spheroidal graphite.

The experiments were performed in a standard Bridgman-type solidification furnace, which includes a cylindrical crucible containing the sample, surrounded by a cylindrical heating element on top of a quenching block. The growth rate and thermal gradient during solidification can be independently controlled by the choice of the speed at which the furnace moves along the longitudinal crucible axis.

Nodular cast iron was directionally solidified under the following conditions:

- Cerium was substituted for magnesium as a spheroidizing element.
- The holding temperature was kept below 1,350 °C.
- Solidification was done under an argon atmosphere.

The study of directionally solidified samples should suffice to establish quantitative relationships between the microstructure of the cast iron, its composition, and the ratio of the temperature gradient to the growth rate during solidification. Previous studies using wedge-chill techniques provided only qualitative information on the effects of cooling rates on structure.

*This work was done by P. A. Curreri of* **Marshall Space Flight Center** *and D. M. Stefanescu and J. C. Hendrix of the University of Alabama. 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 18]. Refer to MFS-28015.*



# Large Deployable Shroud

Deployable masts would extend lightweight fanfolded panels.

*Marshall Space Flight Center, Alabama*

A preliminary design has been proposed for a large, lightweight telescope shroud or light shield (see figure) that could be carried to orbit in a single Space Shuttle cargo load. The shroud concept might be applied

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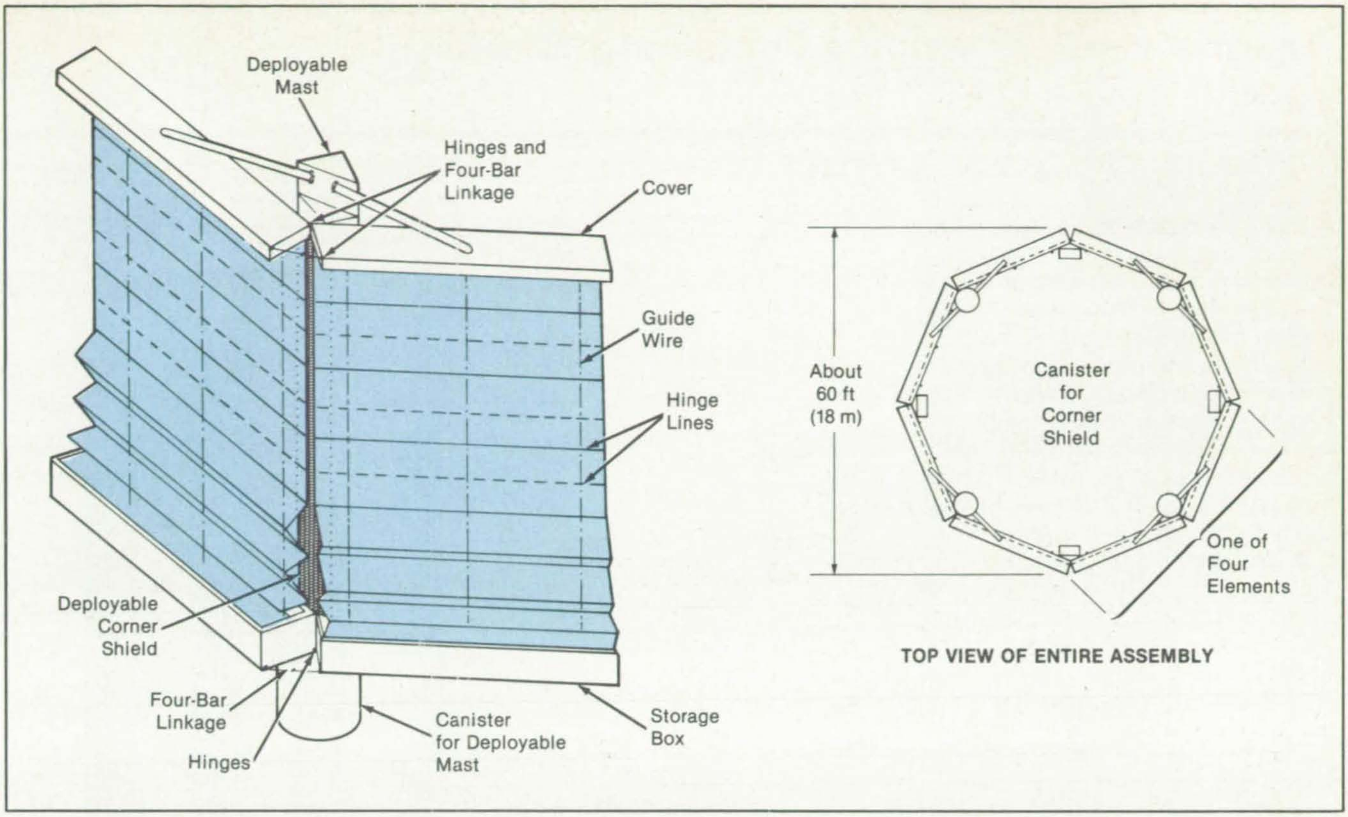



The **Large Telescope Shroud** includes four deployable masts that erect eight walls of hinged panels of polyimide film. The panels are stored fanfolded before deployment and threaded on guide wires that unwind from spools and remain taut during deployment.

on Earth in portable, compactly storable displays or projection screens: indeed, the shroud is based in part on an old portable-projection-screen concept.

The shroud comprises four identical units (see figure), each with one deployable mast and two sets of panels that form two adjacent walls of an octagonal structure. In each shroud unit, the deployable mast fits between the two boxes of panels, which are hinged on the mast canister.

While in storage, the boxes are straightened out; for erection, they are held at the proper angle by a four-bar linkage. Snap locks are used to attach the units to each other and to the structural base so that no tools will be required for assembly.

Once the four shroud units have been attached to the base, the shroud can be deployed by operating a switch to initiate the extension of the masts. A strip is also deployed from a roll canister at each corner to block the lines of sight through the gaps between panels. Anti-flapping straps could then be installed manually to connect adjacent walls of the shroud.

*This work was done by G. G. Jacquemin of* **Marshall Space Flight Center**. *For further information, Circle 32 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 18]. Refer to MFS-28173.*

# Cotton-Fiber-Filled Rubber Insulation

Carbonization of fibers at high temperatures could improve strength and erosion resistance

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Cotton linters (short cotton fibers) are being tested as a replacement for the asbestos filler currently used in rubber insulation in solid rocket motors. The use of asbestos must be discontinued because it poses a serious health hazard to those exposed to it. The cotton-filled rubber insulation may have industrial uses; for example, in some kinds of chemical- or metal-processing equipment, hoses, and protective clothing.

A carbon-fiber-filled version of the insulation has already demonstrated high resistance to erosion in this application, but it is expensive and its physical properties make it difficult to use. It is hoped that satisfactory performance can be achieved more economically by taking advantage of the high-pressure, high-temperature, and relatively reducing atmosphere within the combustion chamber of the rocket motor to carbonize the fibers in the insulation. The question is whether the carbonized cotton fibers will provide the strength and erosion resistance of carbon fibers by forming a strong, thermally protective char layer on the surface of the insulation.

To test the concept, cotton linters are being processed as fillers in various rubber matrices and evaluated as to physical properties, processing properties, and erosion resistance. An alternative fiber, polyacrylonitrile, will also be tested. Test conditions will match the combustion-chamber gas flow and gas-temperature regime of a solid rocket motor burning the solid propellant currently used in the Space Shuttle solid rocket boosters.

*This work was done by Floyd A. Anderson of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 126 on the TSP Request Card. NPO-16868*

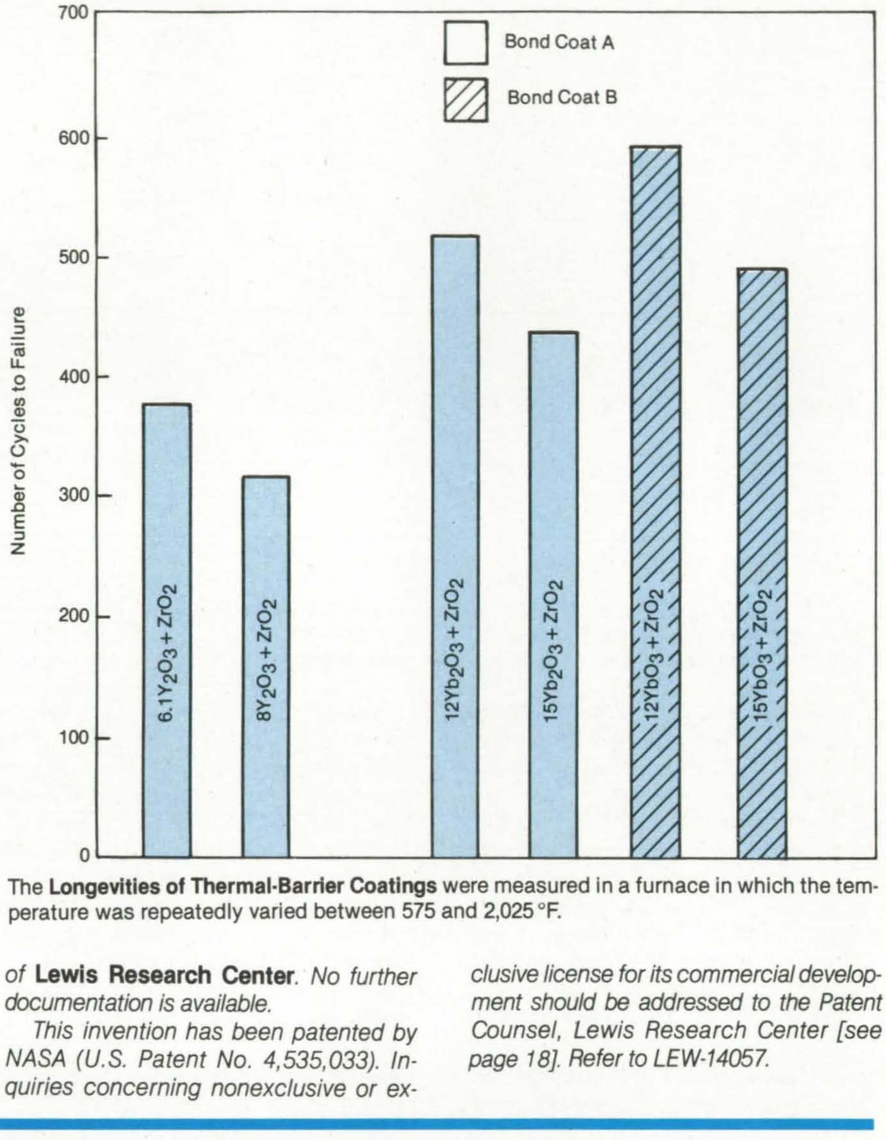
# Thermal-Barrier Coatings Containing Ytterbia

Resistance to thermal cycling is increased.

*Lewis Research Center, Cleveland, Ohio*

High-temperature thermal-barrier coatings are used to protect substrate materials from degradation by high temperatures and by thermal cycling. A thermal-barrier coating generally consists of thin oxide layers that have been plasma- or arc-sprayed on a prepared surface. One of the most effective high-temperature thermal-barrier materials is zirconia ($ZrO_2$) stabilized with yttria ($Y_2O_3$). Yttria concentrations in the range of 6 to 8 percent have demonstrated optimum properties.

A new outer ceramic coating layer for a two-layer (bond coat plus overlay) or graded thermal-barrier coating has been developed. This new ceramic overlay is zirconia stabilized with ytterbia ($ZrO_2 + Yb_2O_3$) and is used in conjunction with NiCrAlY or NiCrAlYb bond coats. This new two-layer system has been evaluated in furnace testing at temperatures cycled between 2,025 °F (1,110 °C) and 575 °F (300 °C). Overlay coats of zirconia ($ZrO_2$) stabilized with 12 and 15 percent ytterbia ($12Yb_2O_3$ and $15Yb_2O_3$) when used over bond coat A (Ni + 16.5Cr + 5.92Al + 0.17Y) and bond coat B (Ni + 17.5Cr + 6.6Al + 0.22Yb) increased the numbers of thermal cycles to failure. An overlay coat $ZrO_2 + 12Yb_2O_3$ on bond coat A increased the life 60 percent over that of the base material ($ZrO_2 + 6.1Y_2O_3$ overlay on bond coat A). With bond coat B, $ZrO_2 + 12Yb_2O_3$ overcoat had a 90-percent greater life than did the base material. The figure shows the longevities of the various coatings in the cyclic tests. Additional work may result in improved bond-coat compositions.




The **Longevities of Thermal-Barrier Coatings** were measured in a furnace in which the temperature was repeatedly varied between 575 and 2,025 °F.

*This work was done by Stephan Stecura of* **Lewis Research Center**. *No further documentation is available.*

*This invention has been patented by NASA (U.S. Patent No. 4,535,033). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Lewis Research Center [see page 18]. Refer to LEW-14057.*

# Acetylene-Terminated Polyimide Siloxanes

Siloxane-containing addition polyimides yield toughened high-temperature adhesives and matrix resins.

*Langley Research Center, Hampton, Virginia*

The need in space research for polymers with enhanced high-temperature capabilities led to the development of linear systems that were impossible to process in high-molecular-weight imide form. More recently, aromatic addition polyimides have been developed as matrix and adhesive resins for applications on future aircraft and spacecraft. Addition polyimides offer distinct advantages over linear polyimides, in that the former can be processed in the form of short-chained oligomers end-capped with latent cross-linking groups. The polymerization of this type of material in place makes it useful as an adhesive. This same processing method can be used for the preparation of fiber-reinforced composites where the polymerization encapsulates the reinforcement and is set.

One particularly attractive addition-type polyimide that is commercially available has the structure shown in Figure 1. It is prepared by the reaction of an aromatic tetracarboxylic acid dianhydride with an aromatic diamine in the presence of an ethynyl-substituted aromatic monoamine to provide a fully imidized, acetylene-terminated thermosetting polyimide resin. Unfortunately, it is insoluble in all solvents except in N-methylpyrrolidone at 100 °C, which leads to the problems associated with removal of this high-boiling-point polar solvent.

Addition polyimides of this type tend to be highly crosslinked, insoluble, and extremely brittle on curing. Efforts made to toughen addition polyimide adhesives (LaRC-13, for example) by physically

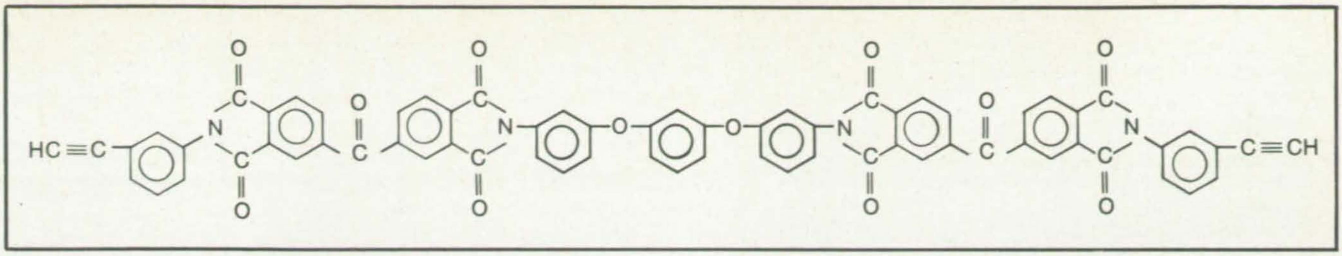


Figure 1. This **Addition Polyimide** is made by the reaction of an aromatic tetracarboxylic acid dianhydride with an aromatic diamine in the presence of an ethynyl-substituted aromatic monoamine.

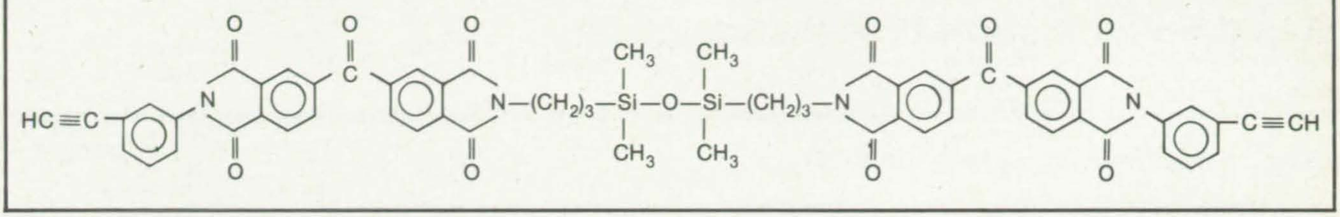


Figure 2. This **Acetylene-Terminated Siloxane Imide** can be cured by heating to yield an acetylene-terminated polyimide siloxane.

blending fluorosilicone and vinyl-terminated silicone rubbers were partially successful. If the siloxane group were chemically incorporated in the polyimide backbone, the effect could be far more pronounced. The resulting siloxane-containing addition oligomer would also have improved solubility by virtue of the flexible —Si—O—Si— linkage.

The process involves the reaction of a diaminosiloxane with acetylene-terminated anhydrides of varying chain lengths. Aminophenyl acetylene (APA) and an aromatic dianhydride are reacted in different molar ratios to develop ethynyl-terminated anhydrides with a range of molecular weights. The anhydride thus formed may be reacted with a diaminosiloxane to yield an acetylene-terminated oligomer, which on curing, yields the acetylene-terminated polyimide siloxane. Figure 2 shows the structure of one of the acetylene-terminated siloxane imides.

The oligomer melts in the temperature range of 125 to 160 °C and undergoes curing between 190 and 270 °C. The oligomer may be extended using different proportions of an aromatic dianhydride and APA. It may be blended further with commercially available resins, like that of Figure 1, with which it is fully compatible.

Scrim cloths can be prepared with these resins by the conventional method of repeatedly coating on glass cloth, allowing to air dry, then imidizing thermally. Scrim cloths can also be prepared by melt-impregnating glass cloth with dry resin powder using localized heating, thus obviating the need for solvents, which are difficult to remove.

Adhesive bonds using these scrim cloths have relatively good lap-shear strengths. Composites prepared from these oligomers can be thermoformed at elevated temperatures after an initial molding in the temperature range of 175 to 200 °C due to the lowered melting temperatures. A range of service temperatures results from blending the oligomers with various acetylene-terminated resins in different proportions.

*This work was done by Terry L. St. Clair of* **Langley Research Center** *and Shubba Maudgal of the Institute for Computer Applications in Science and Engineering. For further information, Circle 65 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, Langley Research Center [see page 18]. Refer to LAR-13318.*

# Carbide/Fluoride/Silver Self-Lubricating Composite

Bearing coatings survive at operating temperatures up to 870°C.

*Lewis Research Center, Cleveland, Ohio*

PS200 is a composite self-lubricating coating for bearing applications that operates at temperatures well above the failure points of such traditional solid lubricants as molybdenum disulfide and graphite. It has shown excellent friction and wear performance in oxidizing atmospheres up to 1,600 °F (870 °C) and reducing atmospheres up to 1,400 °F (760 °C). Such performance is needed for the development of such advanced heat engines as the adiabatic diesel and the Stirling engine, which will have to operate at these elevated temperatures.

PS200 is a plasma-sprayed, ceramic-based coating with solid lubricant additives. Chromium carbide was chosen for the base material because of its excellent wear resistance and thermal stability. However, it exhibits high friction coefficients when used in sliding contacts. The friction coefficient is lowered dramatically by blending in two solid lubricants: silver metal and a barium fluoride/calcium fluoride eutectic.

Because of its low shear strength, silver provides low friction at low temperatures, and the eutectic has been shown to effectively lubricate above 900 °F (480 °C). Like chromium carbide, silver and the fluoride eutectic are thermally and chemically stable to at least 1,650 °F (900 °C). Since silver lubricates from low to moderately high temperatures, and the eutectic lubricates at high temperatures, the resulting composite lubricant does not show any sharp discontinuities in its friction and wear behavior over a wide temperature range. The coating system is designed to lubricate successfully in applications where low-temperature starts and high operating temperatures are encountered.

PS200 has a composition of 80 weight percent metal-bonded chromium carbide, 10 weight percent silver metal, and 10 weight percent barium fluoride/calcium fluoride eutectic. The surface to be coated with the composite is first sandblasted; then a thin bond coat of nickel/chromium powder is plasma-sprayed onto the roughened surface. The PS200 composite, prepared in a blended powder mixture, is plasma-sprayed onto the bond coat, and then diamond ground to the finished bearing surface.

*This work was done by Harold E. Sliney of* **Lewis Research Center**. *Further information may be found in:*

*NASA TM-86943 [N85-20127], "The Role of Silver in Self-Lubricating Coating for Use at Extreme Temperatures,"*

*NASA TM-86895 [N85-14928], "Effects of Silver and Group II Fluoride Additions to Plasma Sprayed Chromium Carbide Coatings for Foil Bearings to 650 °C,"*

*NASA TM-87274 [N86-21682], "A New Chromium Carbide-Based Tribological Coating for Use to 900 °C with Particular Reference to the Stirling Engine," and*

*NASA TM-87261 [N86-20568], "Composition Optimization of Self-Lubricating Chromium Carbide-Based Composite Coatings for Use to 760 °C."*

*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.*

*Inquires concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Lewis Research Center [see page 18]. Refer to LEW-14196*

# Rapid-Solidification Processing Facility

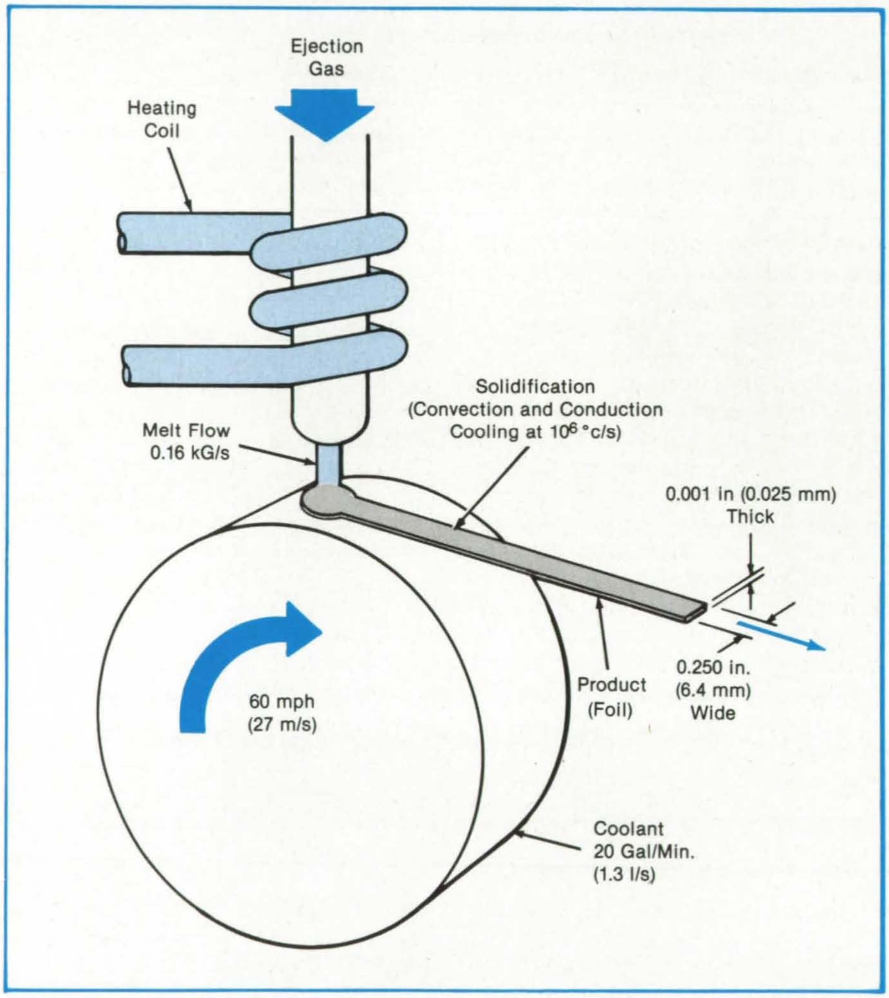
Microstructural changes enhance properties of alloys.

*Lewis Research Center, Cleveland, Ohio*

Rapid-solidification processing in various forms has been of interest for a number of years. A world-class facility that uses the melt-spinning rapid-solidification process is now operating at Lewis Research Center. The essential components of the facility are a source of molten metal, an ejection system, a cooled rotating substrate, a turbo/cryopump vacuum system, and a high-speed data-acquisition system. Currently, the choice of alloys for melting is limited only by the capabilities of dense alumina crucibles.

A major feature of the process is the rapid quenching of alloys or intermetallic compounds from the liquid to the solid state at cooling rates of the order of $10^6$ °C/s (see figure). Such rapid solidification may have a radical impact on the physical and metallurgical natures of materials. Grain sizes are greatly reduced, the segregation of alloying elements or impurities can be minimized, and homogeneity can be greatly improved. These microstructural changes can result in physical and mechanical properties much different from those normally found in alloys quenched at more conventional rates. Preliminary research has resulted in copper alloys with fivefold increases in the solid-solution-alloying content of Cr and a resultant multiplication of strength by a factor of 4.

*This work was done by Thomas K. Glasgow, Robert W. Jech, Thomas J. Moore, and Norman W. Orth of* **Lewis Research Center**. *No further documentation is available. LEW-14510*




A **Jet of Molten Metal** is solidified rapidly when it strikes a liquid-cooled rotating drum.

# Polyimides Containing Carbonyl and Ether Connecting Groups

Semicrystallinity gives rise to tough, solvent-resistant polymers.

*Langley Research Center, Hampton, Virginia*

Several new polyimides were prepared from the reaction of aromatic dianhydrides with new diamines containing carbonyl and ether connecting groups between the aromatic rings. The diamines were prepared from the reaction of 4-aminophenol with activated aromatic difluoro compounds in the presence of potassium carbonate. Representative novel diamine monomers synthesized were the following:

- 1,3-bis(4-aminophenoxy-4′-benzoyl)benzene;

# IR, UV and X-RAY...

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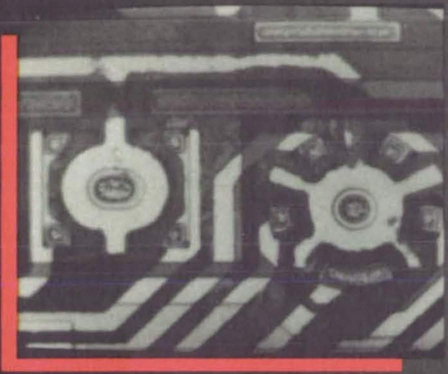
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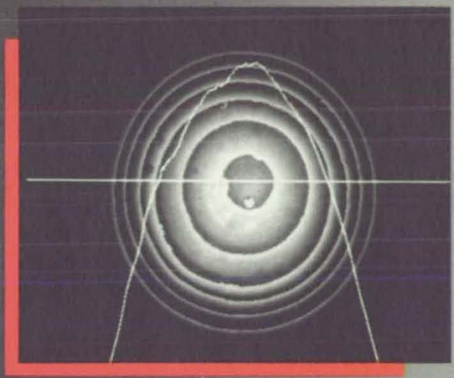
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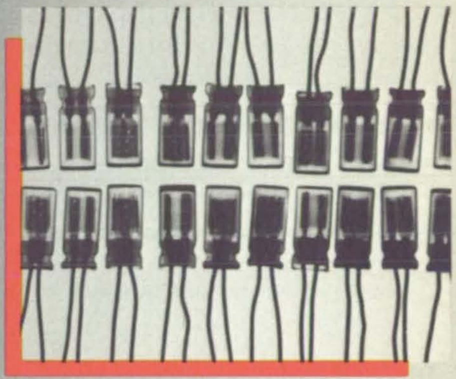
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- 1,4-bis(4-aminophenoxy-4′-benzoyl)benzene;
- 4,4′-bis(4-aminophenoxy-4′-benzoyl)benzophenone;
- 4,4′-bis(4-aminophenoxy-4′-benzoyl)diphenyl ether; and
- 2,6-bis(4-aminophenoxy-4′-benzoyl)naphthalene.

Several of the new polyimides were shown to be semicrystalline as evidenced by wide-angle x-ray diffraction and by differential scanning calorimetry.

Wholly aromatic polyimides are known for their exceptional thermal, thermo-oxidative, and chemical resistances. As a class, they are generally considered to be amorphous with respect to crystalline structure. The introduction of crystallinity into a polymer has long been recognized as an effective way of increasing the elastic modulus and the resistance to solvents. In addition, if the proper degree and type of crystallinity is attained, the material can also display high toughness. Most of the new semicrystalline polyimides formed tough, solvent-resistant films with high tensile properties. One of these materials exhibited very high fracture toughness and can be thermally processed.

Glass-transition temperatures of the polyimides ranged from 192 to 247 °C, and crystalline-melt temperatures were observed between 350 and 442 °C. Some of the films formed by the solution casting of polyamide acids and the subsequent thermal conversion to polyimides were tough and flexible. Tensile strengths, tensile moduli, and elongations at break ranged from 14,500 to 23,000 psi (100 to 160 MPa), 386,000 to 630,000 psi (2.66 to 4.34 GPa); and 3.3 to 39.5 percent, respectively, at 25 °C. Mechanical properties at 177 °C and 232 °C were also good.

One of the polyimides was a solvent-resistant, semicrystalline material that could be molded at 400 °C. Its fracture toughness ($G_{Ic}$) was exceptionally high; namely 37.8 in.-lb/in.$^2$ (6.62 kJ/m$^2$). Its Ti/Ti tensile shear strength at 25 °C was 6,200 psi (41 MPa) and 2,600 psi (17.9 MPa) at 232 °C. In addition, the degree of crystallinity of this polyimide could be altered by either quenching from a temperature above its crystalline-melt temperature (350 °C) or annealing at a temperature slightly below its crystalline-melt temperature. These types of polymers could have potential applications in molded products, films, adhesives, and composites.

*This work was done by Paul M. Hergenrother of* **Langley Research Center** *and Stephen J. Havens of PRC Kentron, Inc. For further information,* ***Circle 2*** *on the TSP Request Card.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Langley Research Center [see page 18]. Refer to LAR-13633.*

# Advanced Thermal-Barrier Bond Coatings for Alloys

New bond coatings increase service lives.

*Lewis Research Center, Cleveland, Ohio*

Over the years, a variety of coatings have been developed to protect substrate metals. Because of their low thermal conductivities, ceramic coatings are used as thermal barriers in the hot sections of turbines in which hostile environments attack the standard nickel- and cobalt-base alloys.

New and improved bond coatings have been developed at Lewis Research Center for use in thermal-barrier systems on Ni-, Co-, and Fe-base alloy substrates. The use of these new bond coatings, containing ytterbium instead of yttrium, has significantly increased the lives of the resultant thermal-barrier systems.

It has been demonstrated that the (Ni/35Cr/6Al/1.1Yb)/($ZrO_2$/6.1$Y_2O_3$) system is at least 40 percent better than the best (Ni/35Cr/6Al/0.95Y)/($ZrO_2$/6.1$Y_2O_3$) system previously reported in the literature. CoCrAlYb and FeCrAlYb bond coatings are significantly better than the CoCrAlY bond coatings. The best nonoptimized Co- and Fe-base coatings were Co/38Cr/10Al/0.07Yb and Fe/37Cr/5Al/0.1Yb.

Although the composition of the FeCrAlYb bond coating was not optimized with respect to Yb concentration, the longest life was attained with (FeCrAlYb)/($ZrO_2$/$Y_2O_3$), followed by optimized (NiCrAlYb)/($ZrO_2$/$Y_2O_3$) and nonoptimized (CoCrAlYb)/($ZrO_2$/$Y_2O_3$). Almost 1,800 1-hour cycles were obtained with (Ni/35Cr/5Al/0.10Yb)/($ZrO_2$/6.1$Y_2O_3$) at 2,050 °F (1,121 °C) as compared to about 1,400 1-hour cycles for (Ni/35Cr/6Al/1.1Yb)/($ZrO_2$/6.1$Y_2O_3$), also at 2,050 °F (1,121 °C).

The bond and thermal-barrier coatings were deposited by plasma spraying in open air onto alumina-blast-cleaned substrates. The cyclic testing of all thermal-barrier systems was done up to 2,150 °F (1,177 °C) in a furnace. Ni-, Co-, and Fe-base bond coatings were evaluated on Ni-, Co-, and Fe-base alloy substrates, respectively. Potential uses include many load-bearing applications in high-temperature, hostile environments.

*This work was done by Stephen Secura of* **Lewis Research Center**. *Further information may be found in NASA TM-87062 [N85-31283/NSP], "Advanced Thermal Barrier System Bond Coatings for Use on Ni-, Co-, and Fe-Base Alloy Substrates."*

*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.*

*This invention has been patented by NASA (U.S. Patent No. 4,485,151). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Lewis Research Center [see page 18]. Refer to LEW-14415.*

# Polyimides From BTDA, m-PDA, and HDA

Aliphatic segments in polyimide backbones help achieve low molding temperatures and resistance to solvents.

*Langley Research Center, Hampton, Virginia*

To develop a solvent- and impact-resistant thermoplastic for use in composites for aerospace applications, linear, flexible, aliphatic segments have been introduced into the backbones of rigid, aromatic, heterocyclic polymers. Polyimides prepared from pyromellitic dianhydride (PMDA) or 3,3′,4,4′-benzophenonetetracarboxylic dianhydride (BTDA) with aromatic diamines are commercially available. Less known are polyimides prepared from PMDA or BTDA with aliphatic diamines. It was found that high-molecular-weight polyimides from PMDA or BTDA with aliphatic diamines can be prepared by con-

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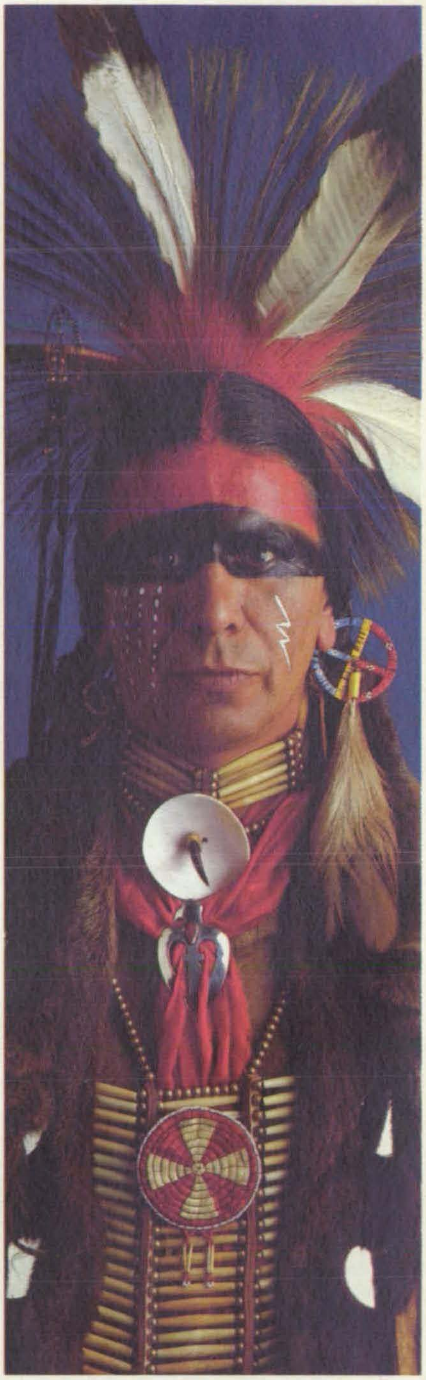

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densation in cresol at 180 °C. Further, high-molecular-weight copolymers containing both aromatic and aliphatic diamines can be similarly prepared.

Preferred reaction times range from 2 to 24 hours and depend on the purities of the monomers and on the monomer concentrations. Reaction temperatures above 200 °C can produce insolubles in the solution. Aliphatic diamines with PMDA produce crystalline polymers and with BTDA produce amorphous polymers. The preferred condensation technique for copolymers containing both aliphatic and aromatic diamines involves the precondensation of the aliphatic diamine with the dianhydride at 180 °C, followed by the addition of the aromatic diamine to produce the high-molecular-weight polyimide.

Moldings of the aliphatic/aromatic polyimides tested for solvent resistance showed that the crystalline polyimides from PMDA with such diamines as 1,6-hexanediamine (HDA) and 1,8-octanediamine had excellent resistance to chloroform, which dissolves many thermoplastic resins. The polyimides from BTDA with aliphatic diamines showed poor resistance to chloroform. However, when 50 mole percent or greater quantity of m-phenylenediamine (m-PDA) was substituted for a corresponding quantity of the aliphatic diamine, the resulting copolymers had excellent resistance to chloroform. The polyimides from PMDA with 1,8-octanediamine and from BTDA with 50/50 weight percents of m-PDA and 1,8-octanediamine showed no evidence of cracking or crazing under stress after exposure to acetone, chloroform, or tricresylphosphate for 500 hours.

The polymer from BTDA with equal weight percents of m-PDA and 1,8-octanediamine exhibited the following neat resin properties of tensile strength, tensile modulus, and elongation at yield: at 25 °C, 114 MPa (16,500 psi), 3,340 MPa (485,000 psi), and 5.6 percent, respectively, and at 82 °C, 89.6 MPa (13,000 psi), 2,550 MPa (370,000 psi), and 4.0 percent, respectively.

The inclusion of aliphatic moieties into the backbones of polyimide polymers lowers their glass-transition temperatures and, consequently, the temperatures required to mold them. The molding temperatures of less than 316 °C that were achieved typically lead to good fusion of such polyimides. Thus, low molding temperatures in combination with good solvent resistance make these polymers potential candidates for use in aerospace applications, particularly as matrices for fibrous composites for structural applications.

*This work was done by Chadwick B. Delano and Charles J. Kiskiras of Acurex Corp. for* **Langley Research Center**. *Further information may be found in NASA CR-172568 [N85-31239/NSP], "Development of an Impact- and Solvent-Resistant Thermoplastic Composite Matrix — Phase III."*

*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.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Langley Research Center [see page 18]. Refer to LAR-13635.*

# Aluminum Alloys for High Temperatures

New Al/Li alloys processed by rapid solidification show greatly improved strength-to-density ratios.

*Langley Research Center, Hampton, Virginia*

Titanium alloys and 2XXX-series aluminum alloys are currently used in aerospace structural applications requiring service in the temperature range of 250 to 500 °F (120 to 260 °C). Although titanium alloys have high strengths, they have densities higher than those of the aluminum alloys. The 2XXX aluminum alloys have low strengths with severe losses of strength at temperatures above 300 °F (150 °C). Aluminum/lithium alloys have very low densities and high strengths at ambient temperature and are thus attractive candidates for improved ratios of strength to density at high temperatures. However, previous work on Al/Li alloys processed by ingot metallurgy and rapid solidification has shown significant degradation of strength following exposures to high temperatures longer than 1 hour. Improved Al/Li alloy compositions are required to produce high strengths for long exposures to high temperatures.

Al/3Cu/2Li/1Mg/0.2Zr, Al/3Cu/2Li/1Mg/1Fe/1Ni/0.2Zr, and Al/3Cu/2Li/1Mg/1.6Cr/0.2Zr alloys processed by rapid solidification were prepared with strength-to-density ratios up to 15 percent greater than those of solution-treated and aged titanium alloys and up to 34 percent greater than those of mill-annealed titanium alloys exposed for more than 100 hours at temperatures of 75 to 300 °F (25 to 150 °C). The new alloys have strength-to-density ratios up to 56 percent greater than those of conventional high-temperature 2XXX alloys at 25 to 150 °C and up to 118 percent greater at 260 °C for exposure times in excess of 100 hours at the stated temperatures. In addition, the new alloys have strength retention (strength at high temperature divided by strength at ambient temperature) superior to that of all competitive titanium- and aluminum-based alloys used at temperatures up to 150 °C.

Powders of the new alloys are produced by inert-gas atomization at solidification rates in excess of $10^3$ K/s. The powders are consolidated by cold pressing, canning, vacuum degassing, vacuum hot pressing, and hot extrusion. This rapid-solidification processing allows segregationless incorporation of the Cu, Li, and Mg, which make precipitates that provide large increments of strength after exposure up to 150 °C for long times. The processing enables the production of incoherent dispersoids, containing either Fe + Ni or Cr, of sufficiently small diameter and homogeneous distribution to increase significantly the strength at high temperatures.

These alloys are promising candidates for use in structural members that must be able to withstand temperatures of at least 150 °C for long times without losses in properties, as in such high-performance aircraft as supersonic fighters, bombers, and transports. The alloys are suitable substitutes for heavier titanium alloys and weaker aluminum alloys in these applications. They are also suitable for use in those high-performance-aircraft structures that are heated by engines and that are normally constructed from titanium alloys. The new alloys can be used in these applications with significant reductions in structural weight.

*This work was done by Peter J. Meschter, Richard J. Lederich, and James E. O'Neal of McDonnell Douglas Corp. for* **Langley Research Center**. *Further information may be found in NASA CR-178145 [N86-31698/NSP], "Study Effects of Powder and Flake Chemistry and Morphology on the Properties of Al-Cu-Mg-X-X-X Powder Metallurgy Advanced Aluminum Alloys — Final Report."*

*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.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Langley Research Center [see page 18]. Refer to LAR-13632.*

# Recycling Silane

This costly gas would be purified after use in a deposition reactor.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A proposed method for recycling silane promises to reduce the cost of producing pure silicon for semiconductor devices. At present, only a small portion of the silane fed to a reactor is consumed in the formation of amorphous silicon films. The unused gas is burned as it leaves the reactor. The proposed method would reduce the waste of this material, which costs about $200 per kilogram (1985 prices).

In the new method, the exhaust gas would pass through a series of permeable membranes. The membranes would remove polymerized silicon hydrides, which are unusable in the reactor. The remaining gas — a mixture of purified silane and hydrogen — would be reconstituted to its original concentration by the addition of more silane. The purified mixture would be stored in a holding tank until needed. Alternatively, the hydrogen and silane could be separated by passing the mixture through another set of membranes.

*This work was done by Ralph Lutwack of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 105 on the TSP Request Card. NPO-16625*

## 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.**

### Extinguishing Fuel-Leak Fires in Jet Engines

Potassium dawsonite and several other chemicals are effective in delaying reignition.

A report describes tests of dry chemicals for extinguishing fires on jet engines. Research in this field continues because fires from in-flight fuel leaks grow more difficult to extinguish as airspeeds, engine case temperatures, and bleed-air temperatures increase. The current practice for extinguishing such fires is to spray the flames with a Halon, such as $CF_3Br$, $CF_2Br_2$, or $CF_2ClBr$. However, more effective extinguishants are still being sought.

In static tests, jet fuel was fed in drops by gravity through a 0.1-centimeter-diameter tube into a trough heated to a temperature between 700 and 900 °C by an underlying electric heater. A thermocouple welded to the trough measured the temperature near where the drop fell.

When the fuel burst into flames, a given weight of dry extinguishant was discharged into the trough near the impinging drops. The dry chemical usually extinguished the fire, but the fuel drops were allowed to continue to fall into the trough and eventually were reignited by the heated trough. The time from the first extinguishment to the second fire — the so-called reignition delay time — was the prime measurement in ranking the effectiveness of the dry-chemical extinguishants.

In dynamic tests, jet fuel was dropped on an electrically heated stainless-steel cylinder, while air flowed over the surface at speeds ranging from 6 to 36 meters per second. After ignition, a given weight of extinguishant was discharged onto the surface, and the reignition delay time was measured.

The report concludes that certain dry chemicals have greater effectiveness per unit weight than do Halons in controlling fuel-leak fires, particularly at high airflow rates. For example, $K_2CO_3$, $KHCO_3$, and $KC_2N_2H_3O_3$ ("monnex") are better than $CF_2ClBr$ in delaying the hot-surface reignition of these fuel-leak fires after initial extinguishment. One of the promising new extinguishants is a mixture of potassium dawsonite [$KAl(OH)_2CO_3$] with KCl or KI. When discharged on a jet fuel fire, this dry powder sticks to hot surfaces. After it puts out the fire, its residue acts as a barrier that delays reignition, even when fuel continues to leak on the surfaces. All conclusions remain tentative, however, and flight tests will be needed to prove the effectiveness of dry extinguishants in nacelle fires.

*This work was done by R. L. Altman of* **Ames Research Center**. *To obtain a copy of the report, "Extinguishing Fuel-Leak Fires With Dry Chemicals," Circle 100 on the TSP Request Card.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 18]. Refer to ARC-11553.*

### Dielectric Monitoring of Curing Composites

Monitoring of dielectric properties may improve the curing process, but additional research is needed.

A report describes preliminary attempts at dielectric monitoring of the curing of graphite/epoxy and carbon/phenolic composites. The objective of such studies is to develop dielectric monitoring for optimizing the curing process and thus reduce the incidence of failures of the produced composite structures.

Such factors as exotherms from polymerization, curing kinetics, cross-linking reactions, the heat-transfer characteristics of the part being formed, and the temperature distribution within the hydroclave, autoclave, or press can make the temperature of the curing composite different from the temperature of the processing or monitoring units.

Preliminary studies have been conducted on two types of dielectric cure-monitoring systems, each applied to both epoxy and phenolic composites. One of the systems included automatic dielectrometers operating at various frequencies from 100 Hz to 100 kHz. This system required two electrodes as parallel plates, with the sample as the dielectric medium of the capacitive cell. The system, however, was unsuitable for highly conductive, heterogeneous composite materials. While successful results were obtained for epoxy resin in an indirect layup configuration, the bare aluminum-foil electrodes in this system were incompatible with the direct layup configuration necessary for routine monitoring and control of manufacturing processes. This system was unsuccessful in monitoring the curing of the highly conductive carbon/phenolic mixture, apparently because the bare foil electrodes were shorted out. Various physical barriers placed between the resin and the electrodes proved to be opaque to the dielectric-monitoring signals.

Some success was achieved with another dielectrometer system. There the dielectric-monitoring signals were measured with a microchip probe in which the electrodes and the thermocouple were part of the same integrated circuit. Initial cure-monitoring data displayed distinct regions that corresponded to portions of the cure cycle. Although further work is necessary to determine the significance of the experimental data, these data appeared to be corroborated by data from dynamic mechanical analysis.

Finally, the theoretical analysis of experimental data indicated the need for a new term to express the contribution of ionic conduction to the dielectric permitivity. This term, hitherto unreported, becomes important when boundary-layer effects and consequent electrode shielding, are taken into account. The initial investigation indicates that the ionic-conduction effect is controlled by diffusion.

*This work was done by Benjamin E. Goldberg and Marie L. Semmel of* **Marshall Space Flight Center**. *Further information may be found in NASA TM-86452 [N84-31378/NSP], "Dielectric Cure Monitoring."*

*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. The report is also available on microfiche at no charge. To obtain a microfiche copy, Circle 161 on the TSP Request Card.*
*MFS-27082*

## Producing Low-Oxygen Samarium/Cobalt Magnet Alloy

### An oxygen content of only 70 parts per million was achieved.

Experiments aimed at producing $SmCo_5$ alloy with low oxygen contamination are described in a report. The lower the oxygen contamination of the alloy, the closer the coercivity of magnets compacted from powdered alloy should approach the theoretical upper limit of 350 kOe ($2.8 \times 10^7$ A/m).

Two methods of alloying by melting without contact with crucible walls were tested. The lowest oxygen contamination (70 parts per million) was achieved by dc arc melting on a water-cooled, tantalum-clad copper hearth in a purified quiescent argon atmosphere. The higher oxygen content obtained with RF levitation and heating in flowing helium (200 parts per million) apparently resulted from oxygen contamination in the helium.

It is expected that the oxygen content of the alloy prepared in zero gravity, where no helium cooling jet would be required, would be similar to, or lower than, that of the arc-melted alloy. Commercial alloys with oxygen contamination as low as 150 parts per million are available.

The report also describes plans and preliminary experimental work on avoiding oxygen contamination during the fabrication of the compacted alloy from the powder. A stainless-steel chamber that can be evacuated and baked out to reach a low pressure of $10^{-6}$ torr (about $10^{-4}$ Pa) is used to provide an oxygen-free argon atmosphere for powder preparation and compaction. After compaction of the powder, the canister is to be sealed by welding. The powder in the sealed canister is to be hot isostatically pressed into solid billets.

The report includes photographs of the equipment, photomicrographs of the alloy samples, detailed descriptions of the procedures tried, and tables of the oxygen contamination and intrinsic coercivities of the samples produced. A paper on $SmCo_5$ magnets produced by hot isostatic pressing is included in an appendix.

*This work was done by Dilip K. Das and Kaplesh Kumar of The Charles Stark Draper Laboratory, Inc. and Robert T. Frost and C. W. Chang of General Electric Co. for* **Marshall Space Flight Center**. *Further information may be found in NASA CR-161823 [N81-75855/NSP], "Ultimate Intrinsic Coercivity Samarium-Cobalt Magnet — on Earth-Based Feasibility Study for Space Shuttle Missions."*

*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. The report is also available on microfiche at no charge. To obtain a microfiche copy, Circle 9 on the TSP Request Card.* *MFS-27011*

## Effects of Hydrogen on Experimental Alloys

### Tensile-strength data are given on candidates for service in a hydrogen atmosphere.

A report presents the results of tensile tests on experimental alloys for use in contact with pressurized hydrogen gas. The tests determined the extent to which tensile strength deteriorated in hydrogen. The specimen materials included Incoloy* 907, various Fe/Ni/Co/Cr alloys, and some Cu/Ni alloys. The report describes the materials, equipment, and procedures. It presents conclusions for the program and for the individual tests. It includes information from 23 previously issued monthly progress reports.

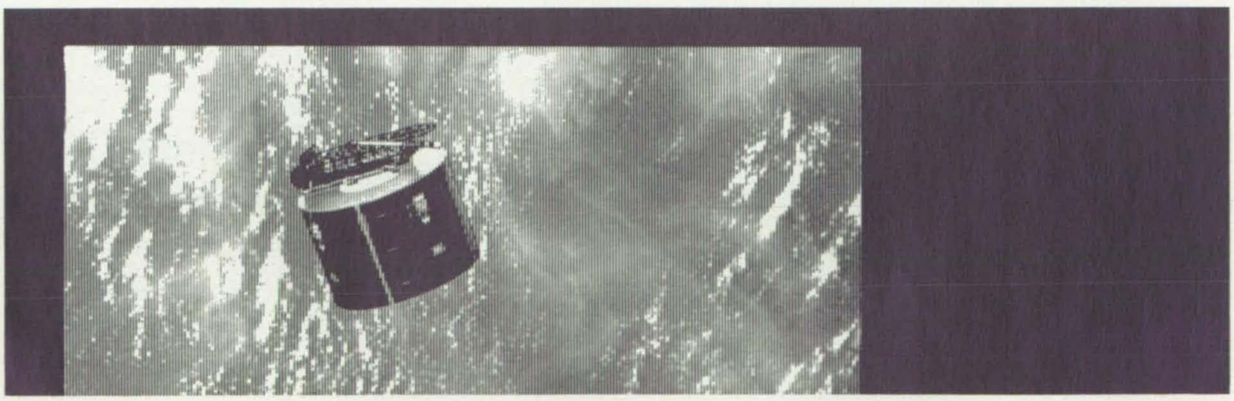
Smooth and notched tensile specimens of Incoloy* 907 were tested in both hydrogen and helium atmospheres at temperatures up to 760 °C and pressures up to 34.5 MPa. Tests were also conducted in air at the ambient temperature and pressure. The deterioration was found by comparing the results for hydrogen with those for helium or air. Except for a small increase over the temperature range of about 430 to 600 °C, the notch tensile strength dropped progressively with increasing temperature; the strength loss in hydrogen was 34 percent at the maximum temperature. The effect was less pronounced on the smooth specimens; strength dropped by 17 percent at the highest temperature.

For the Fe/Ni/Co/Cr alloys, notch specimens were tested at room temperature and a hydrogen pressure of 34.5 MPa. The tensile-strength range varied from 635.7 to 1,390.0 MPa for 19 air-melt alloys. For six vacuum-melt alloys, it ranged from 1,184.5 to 1,394.8 MPa.

For the Cu/Ni specimens, which were notched and from vacuum melts, the range in tensile strength was 308.2 to 1,811.2 MPa for 27 different compositions. These specimens were tested under the same conditions as those for the Fe/Ni/Co/Cr alloys.

*"Incoloy" is a registered trademark of the Inco family of companies.

*This work was done by K.F. Tosi, J. Mucci, J. R. Teel, D. G. Kelly, B. J. Holley, and J. Greenwood of United Technologies Corp. for* **Marshall Space Flight Center**. *To obtain a copy of the report, "Study of Mechanical Properties of Experimental Alloys in Gaseous Hydrogen," Circle 31 on the TSP Request Card.*
*MFS-27060*



# 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 1986 *COSMIC Software Catalog*, containing descriptions and ordering information for available software.

COSMIC is part of NASA's Technology Utilization Network.

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Computer Services Annex, University of Georgia, Athens, GA 30602

## Computer Programs

These programs may be obtained at a very reasonable cost from COSMIC, a facility sponsored by NASA to make raw 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.

## Physical Sciences

### Program for Paraboloidal Solar Concentrators

The optical performances of design alternatives can be estimated.

The Solar-Concentrator Code for Paraboloidal Dishes (SOLCOL) aids in the design and analysis of solar collectors in a space station. SOLCOL calculates the quality of the solar image and the flux distribution on a specified target surface. The receiver target may be the focal plane, a cylinder, a hemisphere, or any arbitrary surface, the normals to which can be supplied. SOLCOL can be used to assess the optical performance of the concentrator. The examples provided in the documentation compare the distribution of flux on receivers of different shapes and investigate the effects of different reflector materials.

The input parameters defining a concentrator system are grouped in the following three categories:

1. The solar-optics variables include the reference flux, the profile of the solar disk, the distance to the sun, the specularity, and the reflectance.
2. The geometrical specifications of the concentrator include the focal length and coordinates of the collector dish and concentrator.
3. The target-position and flux-distribution format parameters include the size and shape of the aperture, the mesh definition, and the surface normals.

The solar radiance is chosen as one of the following models: a uniform solar disk, limb darkening based on either a Kuiper distribution or the Ångstrom approximation, or a Gaussian sun-shape distribution. There are also options for target shading and blocking. Output from SOLCOL consists of the flux intensity in kilowatts per square meter at up to 400 user-specified target points.

SOLCOL is written in FORTRAN 77 for batch execution and has been implemented on a UNIVAC 1100-series computer operating under EXEC 8. This program was developed in 1985.

*This program was written by Liang-Chi Wen, and Philip O'Brien of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 111 on the TSP Request Card.* *NPO-16870*

## Mechanics

### Simulation of Airplane and Rocket Trajectories

Capabilities range from simple ballistics to complicated aerodynamic problems.

The Simulation and Optimization of Rocket Trajectories program (SORT) contains comprehensive mathematical models for simulating aircraft dynamics, freely falling objects, and many types of ballistic trajectories. SORT provides a high-fidelity, three-degrees-of-freedom simulation for atmospheric and exoatmospheric flight. SORT numerically models the vehicle subsystems (aerodynamics, propulsion, steering, and moment balance) and the vehicle environment (gravitational force, atmospheric properties, and winds). SORT has been used for a wide range of simulations, from the unpowered coasting trajectory of a point mass under simple gravity to such complex vehicles as the Space Shuttle.

The aerodynamic model in SORT calculates longitudinal and lateral forces and three-axis moment balances. Contributions from the forebody and power-on base effects are included. The vehicle, if powered, may have fixed or controllable engines fired by a single propellant or a fuel/oxidizer mix. Engine-thrust, throttle, and shutdown effects are modeled. The mass subsystems in SORT include tank slosh and weight changes due to propellant use and vent systems (ice, thermal insulation, etc).

SORT allows the use of phases or timing events; for example, ignition, lift-off, throttle-up, the separation of solid-fuel rocket boosters, and the like. These events are used as control points for the iterations composing the various mathematical models. Each iteration employs one of four techniques for optimization: (1) Newton-Raphson, (2) secant, (3) quadratic curve fit, or (4) carpet plotting.

A table-lookup module to process input data features six standard table types with three interpolation options. Types of output that may be specified include: (a) data echo or input summaries; (b) iteration summaries; (c) detailed print blocks for aerodynamics, engines, equations of motion, orbital elements, and mass properties; and (d) trajectory-plot file generation in either TRWPLOT or MPAD format.

SORT is written in machine-independent FORTRAN 77 for batch execution and has been implemented on a UNIVAC 1100-series computer with a central-memory requirement of approximately 69 K of 36-bit words (40 K if overlaid). This program was developed in 1984.

*This program was written by Magdy M. Wahbah, Michael J. Berning, and Tony S. Choy of McDonnell Douglas Corp. for* **Johnson Space Center**. *For further information, Circle 143 on the TSP Request Card. MSC-20933*

## Fabrication Technology

### Integrated Analysis Capability Program

An interactive program assists in the design of large structures.

The objective of the Integrated Analysis Capability (IAC) software system is to provide a highly effective, interactive analysis tool for the integrated design of large structures. IAC was developed to serve as an interface for programs from the fields of structures, thermodynamics, controls, and system dynamics with an executive system and data base to yield a highly-efficient multidisciplinary system.

Special attention is given to such user requirements as data handling and online assistance with operational features and the ability to add new modules of the user's choice at a future date. IAC contains an executive system, a data base, general utilities, interfaces to various engineering programs, and a framework for building interfaces to other programs. IAC has shown itself to be effective in automating data transfer among analysis programs.

The IAC system architecture is modular in design:

- The executive module contains an input command processor, an extensive data-management system, and a driver code to execute the application modules.
- Technical modules provide stand-alone computational capability as well as support for various solution paths or coupled analyses.
- Interface modules provide for the required data flow between IAC and other modules.
- User modules can be arbitrary executable programs of job-control-language (JCL) procedures with no predefined relationship to the IAC system.
- Special-purpose modules are included; for example, MIMIC (Model Integration via Mesh Interpolation Coefficients), which transforms field values from one model to another; LINK, which simplifies the incorporation of user-specific modules into IAC modules; and DATAPAC, the National Bureau of Standards statistical-analysis package.

The IAC data base contains structured files that provide a common basis for communication between modules and the executive system and can contain such unstructured files as NASTRAN checkpoint files, DISCOS plot files, object code, etc. A full data-manipulation and query system operates with the data base.

The current interface modules comprise the following five groups:

1. Structural analysis — IAC contains a NASTRAN interface for stand-alone analysis or certain structural/control/thermal combinations. IAC provides enhanced structural capabilities for normal modes and static deformation analysis via special DMAP sequences.
2. Thermal analysis — IAC supports finite-element and finite-difference techniques for steady-state or transient analysis. There are interfaces for the NASTRAN thermal analyzer, SINDA/SINFLO, and TRASYS II.
3. System dynamics — A DISCOS interface allows full use of this simulation program for either nonlinear time-domain analysis or linear frequency-domain analysis.
4. Control analysis — Interfaces for the ORACLS, SAMSAN, NBOD, and INCA programs allow a wide range of control-system analyses and synthesis techniques.
5. Graphics — The graphics package PLOT is included in IAC. PLOT generates vector displays of tabular data in the form of curves, charts, correlation tables, and the like. Either DI3000 or PLOT-10 graphics software is required for full graphics capability.

IAC is written in FORTRAN 77 and has been implemented on a DEC VAX-series computer operating under VMS. IAC can be executed by multiple concurrent users in a batch or interactive mode. The basic central-memory requirement for IAC is approximately 750K of 8-bit bytes. The IAC with controls-analysis modules (GSC-12992) includes interfaces and source codes for the control programs (ORACLS, SAMSAN, NBOD, and DISCOS) and full documentation for these programs. The basic IAC (GSC-12994) includes only the interfaces for the control programs. Level 1.5 of IAC was developed in 1985.

*This program was written by Harold P. Frisch and Joan A. Sanborn of* **Goddard Space Flight Center** *and Robert G. Vos, David L. Beste, and Joseph Greg of Boeing Aerospace Corp. For further information, Circle 45 on the TSP Request Card.*

*GSC-12992 and GSC-12994*

## Mathematics and Information Sciences

### FORTRAN Algorithm for Image Processing

Applications might include scientific, industrial, and biomedical imaging.

A FORTRAN computer algorithm that contains various image-processing analysis and enhancement functions has been developed by the Lewis Research Center. The algorithm was developed specifically to process images of developmental heat-engine materials obtained with sophisticated nondestructive evaluation instruments.

Digital image processing has found many applications in scientific, biomedical, and industrial areas. Specific applications include the automatic classification of terrain through pattern-recognition techniques, the formation and enhancement of biomedical imagery, and the enhancement of radiographs and acoustic images of critical components containing possible flaws.

A variety of image-processing systems are available, and the level of software developed for each system varies. In some cases, the image processor is provided by the manufacturer as part of a minicomputer system. Such a system may include "user-friendly" software that requires little if any additional programming effort by the purchaser. In other cases, the image processor is purchased separately from a computer system and must be integrated into the system. Software may be provided and would have to be organized by an experienced computer programmer to develop powerful image-processing capability.

The subject FORTRAN program was developed for a Comtal/Grinnell 274 image processor interfaced with a Digital PDP 11/45 minicomputer. Its task file requires 64 kilobytes (125 blocks) of memory. The program was written using software routines provided by Comtal/Grinnell. Considerable additional FORTRAN programming was required to organize the routines to perform the desired functions. The program is organized into nine subroutines displayed on a main menu. The subroutines are chosen by the use of a computer keyboard. Within the subroutines are other routines, also selected via keyboard.

Some of the functions performed with this program include digitization, storage, and retrieval of images; image enhancement by contrast expansion, addition and subtraction, magnification, inversion, and bit shifting; display and movement of a cursor; display of a plot of the number of image pixels versus the gray level (gray-level histogram of the image); and display of a plot of the variation of the gray level as a function of position within the image. Possible applications of this program include scientific, industrial, and biomedical imaging for studies of flaws in materials, analyses of steel and ores, and pathology, respectively.

*This program was written by Don J. Roth and David R. Hull of* **Lewis Research Center**. *For further information, Circle 46 on the TSP Request Card.* *LEW-14291*

## Expert System for Automated Design Synthesis

### Engineers are assisted in searching for optimum solutions.

The expert-system computer program called EXADS was developed to aid users of the Automated Design Synthesis (ADS) general-purpose optimization program. Because of the general-purpose nature of ADS, it is difficult for a nonexpert to select the best choice of strategy, optimizer, and one-dimensional search options from the 100 or so combinations that are available. EXADS aids an engineer in determining the best combination based on knowledge of a specific problem and the expert knowledge stored in the knowledge base. EXADS is a customized application of the AESOP artificial-intelligence program. (The general version of AESOP is available separately from COSMIC. The ADS program is also available from COSMIC.)

The expert system consists of two main components: the knowledge base contains about 200 rules and is divided into 3 categories: (1) constrained, (2) unconstrained, and (3) constrained treated as unconstrained. The EXADS inference engine is rule based and makes decisions about a particular situation using hypotheses (potential solutions), rules, and answers to questions drawn from the rule base. EXADS is backward chaining; that is, it works from hypotheses to facts. The rule base was compiled from such sources as literature searches, ADS documentation, and surveys of engineers experienced in optimization.

EXADS will accept such answers as "yes," "no," "maybe," "likely," and "don't know" or a certainty factor ranging from 0 to 10. When any hypothesis reaches a confidence level of 90 percent or more, it is deemed the best choice and displayed to the user. If no hypothesis is confirmed, all hypotheses with confidence levels greater than 10 percent are displayed. The user can examine explanations of why the hypotheses failed to reach the 90-percent level.

EXADS is available in two interactive machine versions. The IBM PC version (LAR-13687) is written in IQ-LISP for execution under DOS 2.0 or higher with a central-memory requirement of approximately 512K of 8-bit bytes. The DEC VAX version (LAR-13688) is written in Franz-LISP for operation under VMS. This program was developed in 1986.

*This program was written by James L. Rogers, Jr., of* **Langley Research Center** *and Jean-Francois M. Barthelemy of Virginia Polytechnic Institute and State University. For further information, Circle 155 on the TSP Request Card.*
*LAR-13687*

# New Products

**Alliant Computer Systems Corporation** (Littleton, MA) has introduced the FX/Ada Development System on their high-performance FX/Series minisupercomputer systems. FX/Ada combines Alliant's parallel processing architecture with the parallel constructs inherent in Ada. A single Ada program with multiple tasks will execute in parallel across the FX/Series' computational elements and interactive processors, thereby delivering increasingly faster execution as processors are added to the system. **Circle Reader Service Number 301.**

**Gould Inc., Computer Systems Division** (Ft. Lauderdale, FL) announces a new family of 100-MIP class mini supercomputer systems. The NP1, is the initial offering in a family of compatible systems called the N-Processor Line, or NPL. The NPL family's target applications include compute-intensive, real-time scientific and engineering problems. Because of the machine's large memory, it will be useful for data acquisition, data base systems and large multi-user environments. **Circle Reader Service Number 509.**

**Tartan Laboratories** (Pittsburgh, PA) and **Rational** (Mountain View, CA) announced plans to develop a 1750A Ada cross compiler for the Rational R1000 Development System. This is an extension of a joint development agreement between the two companies to integrate Tartan's optimization and code generation capabilities and Rational's interactive development environment. Under the agreement, Tartan will supply a high quality code generator and runtime support for the 1750A cross compiler. The Tartan Ada code generator and runtime will be fully integrated into the Rational MIL-STD-1750A Cross-Development Facility library and compilation system. **Circle Reader Service Number 437.**

To improve the vector processing abilities of the CYBER 990E, **Control Data Corp.** (Minneapolis, MN) introduces their FORTRAN Version 2 Compiler and the Model 887 Superspeed Disk System, a disk drive that transfers data at up to 12 Mbytes/second. **Circle Reader Service Number 424.**

**Nicolet** (Madison, WI) announces Waveform BASIC for the IBM PC. The program transfers, displays, saves, plots and manipulates data from the 2090, 4094, 3091 and 320 digital oscilloscopes. Pre-programmed routines for integration, FFT, arithmetic functions, RMS, Mean and other functions work on whole or partial waveforms. BASIC commands let users create and run custom programs to quickly get answers from their data. Data outputs include hard copy printing and plotting, sending waveforms to ASCII files and printing data values in tabular form. **Circle Reader Service Number 415.**

**Convex Computer Corporation** (Richardson, TX) announced that the SQL-based ORACLE relational database management system, fourth generation language tools and decision support software will be available on Convex supercomputers. Under the terms of the agreement, Convex has non-exclusive worldwide marketing rights to the Oracle products on the Convex line of air cooled, 64-bit minisupercomputers which include the C1 XL, an entry level system and the high performance multi-processor C1 XP. The ORACLE DBMS provides a high performance relational system across a wide range of computers and operating systems, including Unix. The Convex minisupercomputers run under the industry standard Unix 4.2 BSD operating system. **Circle Reader Service Number 414.**

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# Mechanics



## Measuring the Interlaminar Shear Strengths of Composites

An ultrasonic technique performs nondestructive tests.

*Lewis Research Center, Cleveland, Ohio*

An acousto-ultrasonic technique utilizing a computer and waveform digitizer has been developed for the nondestructive evaluation (NDE) of composite materials. The technique has been employed on filament-wound composite (FWC) specimens cut from sample segments of graphite/epoxy cylinders. The technique is being developed at NASA's Lewis Research Center for use on large composite structures to verify integrity and to assure reusability. Similar applications of the technique are anticipated for a variety of composite structures, such as pipelines and storage tanks.

The sequence of tests carried out on the FWC specimens is shown in Figure 1. The top illustration represents the nondestructive acousto-ultrasonic measurement. In the middle illustration the output pulse is digitized and processed in a computer to generate the stress-wave factor (SWF). The data from the bending tests (bottom il-

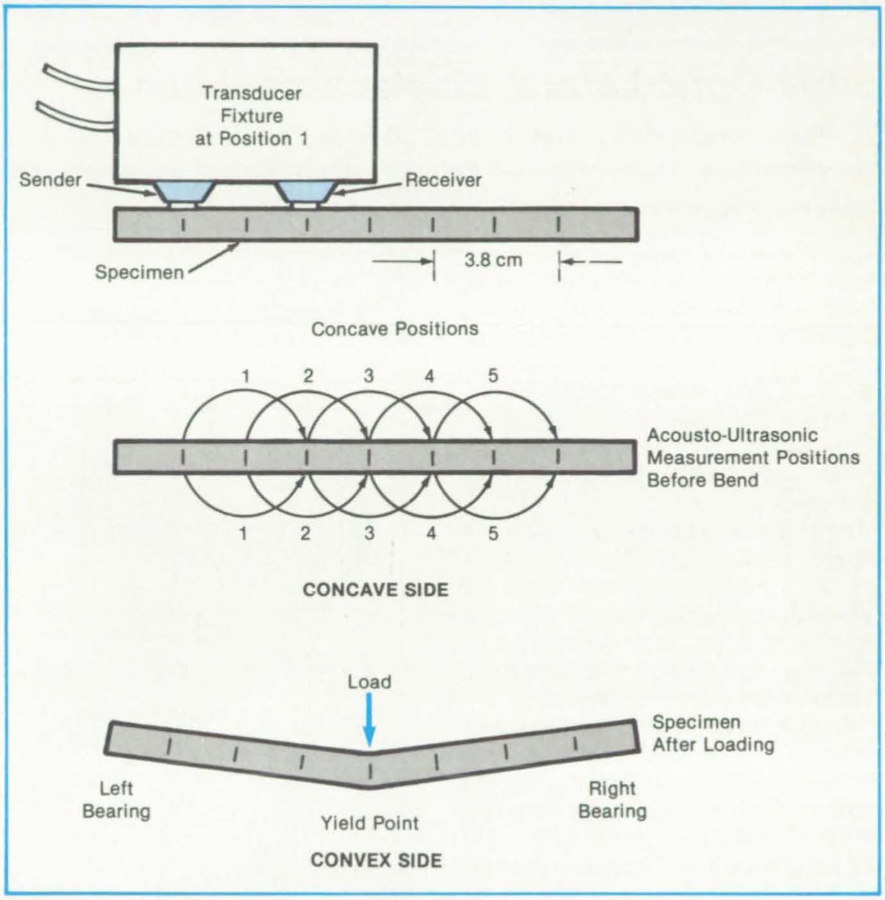
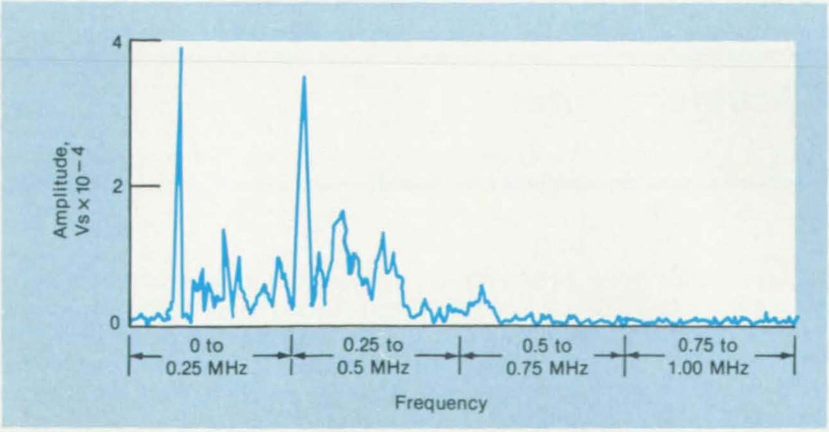



Figure 1. A **Filament-Wound Composite Specimen** is subjected to nondestructive acousto-ultrasonic measurements (top and middle). Then it is subjected to a destructive bending test to determine the interlaminar shear strength.



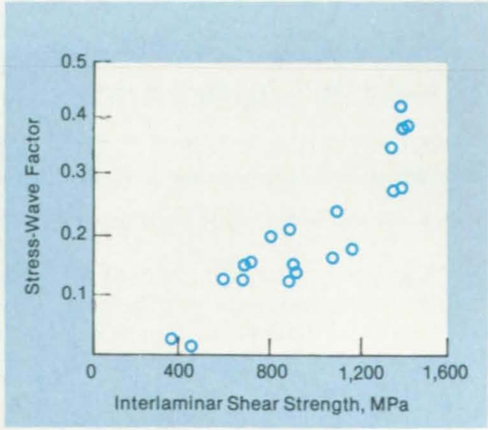




Figure 2. The **Data From the Ultrasonic Tests** illustrated in Figure 1 are processed into two forms. The left plot shows the magnitude of the Fourier spectrum of a typical bend specimen in the four filter bands used in the analysis. The right plot shows the stress-wave factor for the frequency range 0.5 to 0.75 MHz averaged over positions 2 through 4, versus the interlaminar shear strength. Here, $R^2 = 0.806$.

lustration) were used to calculate the interlaminar shear strength.

Frequency spectra of the digitized acousto-ultrasonic output signals were obtained by employing a fast-Fourier-transform algorithm. A typical spectrum is shown at the top of Figure 2. The SWF was calculated for a variety of filter ranges.

The reliability of the SWF as a predictor for interlaminar shear strength in the FWC was tested by performing a regression analysis of the SWF data with the bending-test data. A plot of the data with the highest correlation coefficient R = 0.898 is shown at the bottom of Figure 2. This correlation was obtained with optimum experimental conditions, including the transducer position and frequency. It should be pointed out that the major portion of the spectrum was insensitive to the interlaminar shear strength.

Work is in progress to define more clearly the role of frequency filtering on the value of the SWF as a predictor for mechanical properties in FWC materials and structures. This acousto-ultrasonic-frequency filtering technique may be adoptable to monitoring interlaminar shear strength in a variety of large filament-wound structures.

*This work was done by Harold E. Kautz of* **Lewis Research Center**. *Further information may be found in NASA TM-87088 [N86-10561/NSP], "Ultrasonic Evaluation of Mechanical Properties of Thick, Multilayered, Filament Wound Composites."*

*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-14417

# Fiber-Optic Lateral-Displacement Sensor

A device would determine bearing position and perhaps measure shaft speed.

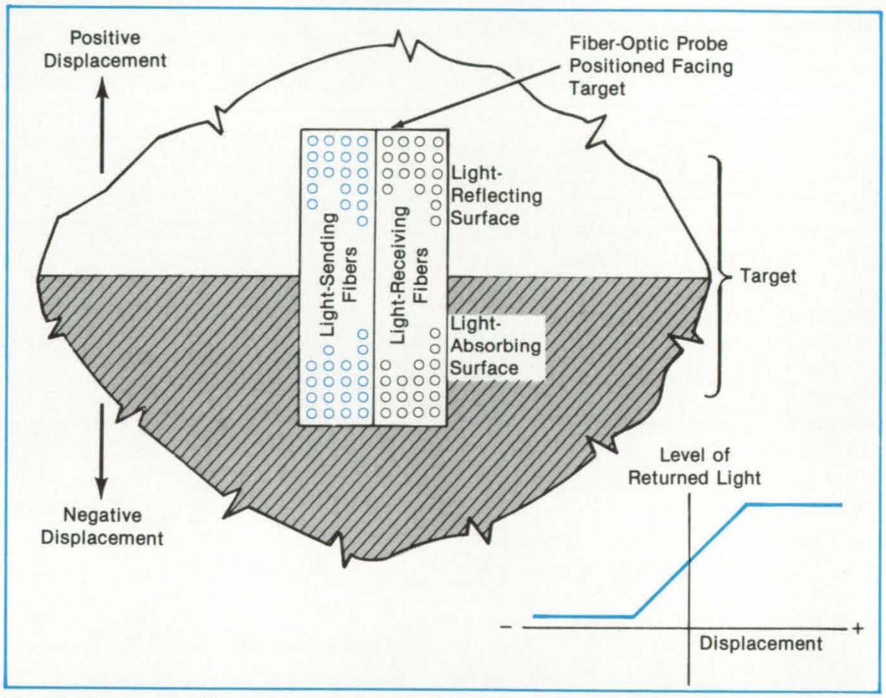
*Marshall Space Flight Center, Alabama*

A proposed fiber-optic sensor would monitor the axial position of a shaft or bearing in a turbomachine. Unlike the magnetic proximity sensors now in use, the fiber-optic device would sense the position of nonmagnetic as well as magnetic material and could be calibrated before assembly in the machine. In addition, it would be more compact.

The tip of a multiple-fiber probe would be shaped into a narrow rectangle, with sending fibers grouped in half the rectangle and receiving fibers grouped in the other half (see figure). The probe tip would be placed facing a target of light and dark zones etched onto the shaft or bearing.

Light from the sending fibers would be reflected from the target into the receiving fibers; the amount reflected would depend on the position of the dark zone. The output of a photodetector at the end of the receiving fibers could thus be correlated with the position of the target.

The concept may also be extended to measure the rotational speed of a shaft. A dark band would be etched in a band halfway around the shaft. The pulses of reflected light would represent the shaft revolutions.




The **Displacement of the Target** changes the area of light-reflecting surface facing the fiber-optic probe and thus changes the light output of the receiving fibers.

*This work was done by Edmund J. Roschak of Rockwell International Corp. for* **Marshall Space Flight Center**. *No further documentation is available.* MFS-29170

# Six-Axis Superconducting Accelerometer

Sensitivity and short-term stability are high.

*Marshall Space Flight Center, Alabama*

An accelerometer design combines superconductivity and magnetic levitation to achieve linear-acceleration sensitivity greater than that of conventional linear accelerometers, and short-term angular stability better than that of conventional gyroscopes. The improved accelerometer could be used to increase precision in inertial navigation and surveying, as a sensitive multiple-axis seismic sensor, as a component of a tensor gravity gradiometer, or to sense the accelerations of stabilized platforms or spacecraft.

A conventional linear accelerometer detects changes of speed along a single axis. Thus, a conventional accelerometer system for inertial navigation requires three linear accelerometers and at least two gyroscopes. The superconducting accelerometer is a single, mechanically simple device that detects all three independent components of linear acceleration and three independent components of angular acceleration simultaneously.

The new accelerometer is housed in a liquid-helium cryostat. A precise, metallic cube (the proof mass) is magnetically levitated. The cubic configuration is compact and facilitates both the magnetic levitation and the simultaneous readout of the signals that contain information on the six independent components of acceleration.

The ac modulation is applied to the levitating coils at six inductance bridges driven at six different frequencies. All six signals are detected by one superconducting quantum interference device, which serves as an amplifier. This arrangement contributes to the compactness and economy of the accelerometer.

The accelerometer operates on the principle of force-rebalance feedback. Negative-feedback force is applied to the proof mass to operate the instrument as a null displacement detector. This feature reduces the cross-coupling of signals, increases the dynamic range, and eliminates the component of noise that originates in the external oscillator.

The linear-acceleration sensitivity of the new accelerometer is better than $10^{-12} g_E Hz^{-1/2}$ (where $g_E = 9.8\ ms^{-2}$, approximately the gravitational acceleration at the surface of the Earth). In contrast, a typical conventional linear accelerometer has a sensitivity of $10^{-6}$ to $10^{-9}$ $g_E Hz^{-1/2}$. The angular-acceleration sensitivity of the new accelerometer is $10^{-9}$ rad $s^{-2} Hz^{-1/2}$.

The major disadvantage of the instrument is the need for the liquid-helium cryostat or supply. Liquid helium could be transferred occasionally from a supply dewar to the cryostat, or else a closed-cycle refrigerator could be used to keep the device at the low operating temperature.

*This work was done by Ho Jung Paik of the University of Maryland for* **Marshall Space Flight Center**. *No further documentation is available.*

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

*Ho Jung Paik*
*Dept. of Physics and Astronomy*
*University of Maryland*
*College Park, MD 20742*

*Refer to MFS-26040, volume and number of this* **NASA Tech Briefs** *issue, and the page number.*

# Measuring Bearing-Cage Rotation

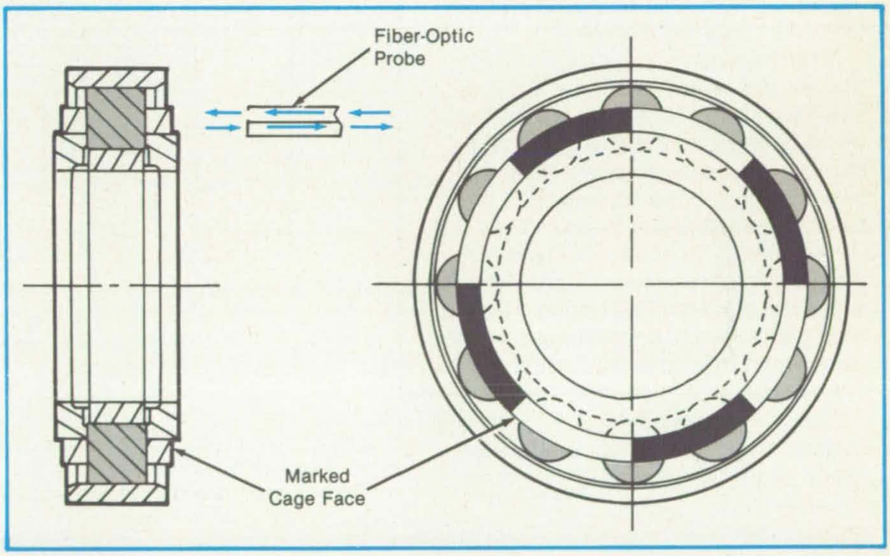
Bearing slip would be measured optically.

*Marshall Space Flight Center, Alabama*

A concept for measuring the rotational speed of a bearing cage promises to be simple and accurate. Based on fiber optics, the concept would require no contact between the measuring device and the bearing, and thus would not introduce wear.

The end face of a ball or roller bearing cage would be marked with light-reflecting and light-absorbing zones (see figure). An optical-fiber probe would view the zones and carry the pulses of reflected light from them to an electronic circuit. From the pulse rate, the circuit would determine the rotational speed of the cage. In combination with the measurement of shaft speed, this measurement would indicate the slip of the balls or rollers in a cage. The principle may also be used to measure the rotations of the inner and outer bearing rings.

*This work was done by E. J. Roschak of Rockwell International Corp. for* **Marshall Space Flight Center**. *No further documentation is available.* *MFS-29182*




**Alternating Bright and Dark** zones on the end face of a bearing cage provide light pulses to an optical fiber. The zones would be etched on the cage.

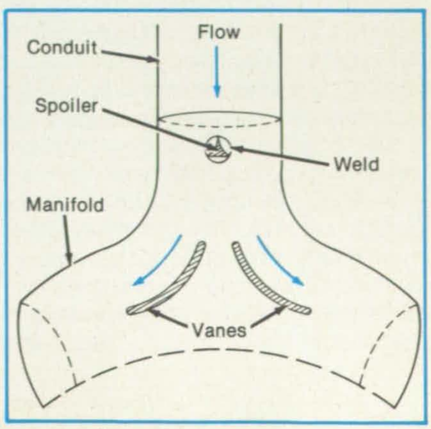
# Vibration-Free Vanes Direct Cryogenic Flow

An upstream fluid-dynamic surface prevents oscillations.

*Marshall Space Flight Center, Alabama*

A simple structural addition to a liquid-oxygen manifold prevents vibration and allows increased flow. A spoiler is placed in the liquid-oxygen conduit, just upstream from the manifold entrance (see figure).

The spoiler reduces the load at the leading edges of the distribution vanes in the manifold by altering the angle at which the




**A T-Shaped Manifold** uses vanes to distribute liquid oxygen. Although far from the vanes, a spoiler suppresses vibrations caused by unstable dynamic coupling between the flow and the elasticity of the vanes.

oxygen stream impinges on the vanes. As a result, the center of pressure on each vane is moved toward its torsional elastic axis.

Without the spoiler, the vanes vibrate strongly at a frequency of about 4 kHz. With the spoiler, vibration is eliminated, even when the liquid-oxygen flow is increased considerably.

The spoiler, a specially shaped bar that spans the liquid-oxygen conduit, is introduced through holes drilled in the conduit and supported in the holes. After the spoiler has been installed, the holes are closed by welding. This mounting is sufficiently rigid that the spoiler itself does not vibrate in the flow.

*This work was done by Gadicherla V. R. Rao of Rockwell International Corp. for* **Marshall Space Flight Center**. *No further information is available. MFS-29180*

# Heater for Combustible-Gas Tanks

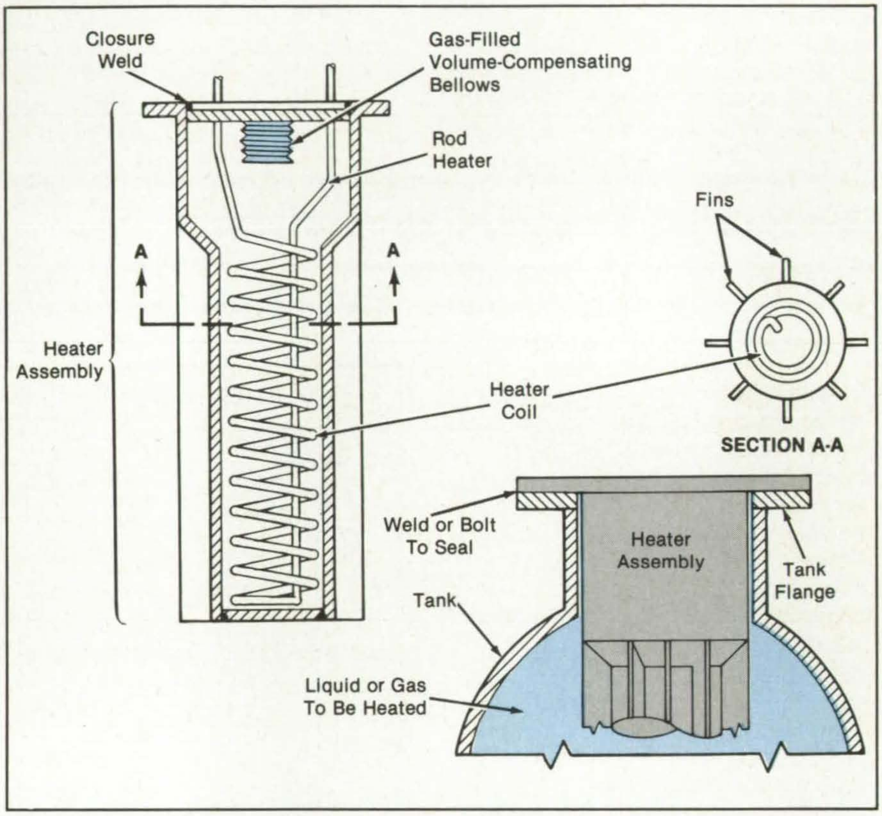
Heat is transferred safely through liquid metal.

*Marshall Space Flight Center, Alabama*

A proposed heater for pressurizing hydrogen, oxygen, or another combustible liquid or gas would be sealed in an immersion cup in the pressurized tank. The heater would be safer than the usual direct-contact heater because it would not be exposed directly to the liquid or gas. Because it can be safely operated at a higher skin temperature than can a conventional, directly exposed internal heater, it can be made smaller and lighter. It can be completely tested as an assembly before installation and can be removed from the tank as an assembly if necessary.

The heater would include a coiled rod-type resistance element in the stainless-steel immersion cup (see figure). The cup would be designed to be as strong as or stronger than the propellant tank. The coiled element would be supported in a bath of low-melting alloy; for example, of Bi with Pb, Sn, Cd, In, and/or Sb. The molten alloy would carry heat from the heating rod to the cup efficiently and help to prevent hot spots on the rod. A gas-filled bellows at the top of the sealed cup would compensate for volume changes in the alloy.

*This work was done by Walter B. Ingle of Rockwell International Corp. for* **Marshall Space Flight Center**. *No further information is available. MFS-29155*




**Firmly Supported in a Finned Cup**, a coiled rod transfers heat through liquid metal to a gas tank. The heater assembly can be welded or bolted to the tank flange.

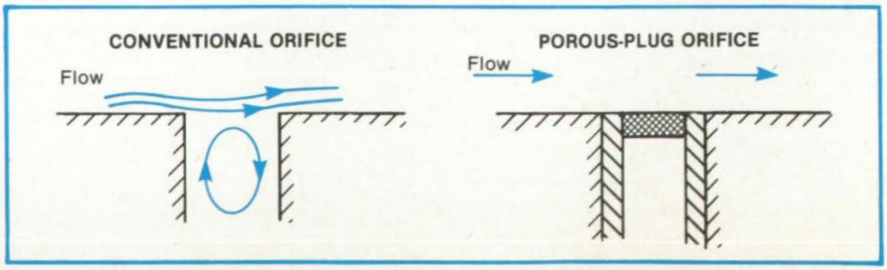
# Reduction of Orifice-Induced Pressure Errors

Porous plugs are placed in the orifices.

*Langley Research Center, Hampton, Virginia*

The use of a porous-plug orifice reduces or eliminates errors, induced by the orifice itself, in measuring static pressure on an airfoil surface in wind-tunnel experiments. A piece of sintered metal is press-fitted into a static-pressure orifice so that it matches the surface contour of the model. The use of the porous material reduces the orifice-induced pressure error associated with a conventional orifice of the same or smaller diameter. The porous-plug orifice also reduces or eliminates any additional errors in the pressure measurement caused by orifice imperfections.

In wind-tunnel experiments, open holes drilled normal to the model surface have been the conventional means used to measure static pressure. To achieve the best result, these orifices must be perfectly round, square edged, and clean. In a high-Reynolds-number facility, the model boun-




The **Flush-Mounted, Sintered-Metal Plug** reduces or eliminates the causes of orifice-induced errors.

dary layer can be an order of magnitude thinner than the boundary layer in a conventional tunnel. For the effects of orifice-induced pressure error to be small under these conditions, the static-pressure orifices need to be very small — 0.010-in. (0.25-mm) diameter is generally used.

The fabrication of such small orifices with no imperfections is difficult. The combined effects of the flow turning into the orifice and a pitot effect, in which the flow stagnates at the downstream edge of the orifice, combine to produce a measured pressure that is inaccurately high. Furthermore, orifice imperfections cause the error in a conventional orfice to be even larger.

The porous-plug orifice (see figure) prevents the flow from turning into the orifice, thereby reducing or eliminating the orifice-induced pressure error. Also, since the flush-mounted, sintered-metal plug smooths the airfoil surface, the error introduced by imperfections in the orifice is eliminated.

This concept was tested on an airfoil in the Langley Research Center 0.3-m Transonic Cryogenic Tunnel at chord Reynolds numbers up to 40 × $10^6$. The pressures obtained using the porous-plug orifices were compared to those obtained using conventional orifices 0.010 in. (0.25 mm) in diameter, and results confirm that the use of the porous-plug orifice provides more accurate measurements in regions with very thin boundary layers.

*This work was done by Elizabeth B. Plentovich, Blair B. Gloss, John W. Eves and John P. Stack of* **Langley Research Center**. *Further information may be found in NASA TP-2537 [N86-20351/NSP].*

*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.*

*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 18]. Refer to LAR-13569.*

## 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.**

### Propellant Tanks for Tethered Orbital Refueling Facility

Thermodynamics, mechanical stability, and mass penalties affect the design.

A pair of reports presents a design study for propellant tanks to be used in low gravity. [See also "Dynamical Considerations for Tethered Orbital Refueling Facility" (MSC-21076), which also appears in this issue of *NASA Tech Briefs*. Each tank, which would most likely contain liquid $H_2$ or $O_2$, would be part of a fuel depot tethered to a station in orbit around the Earth. Some of the engineering concepts in the study could be applied to the design of tanks for use on Earth in the transport and storage of cryogenic liquids and other fluids that require special handling.

The sloshing of the fluid in the tank is of concern because the outlet must remain covered with the fluid. The effects of the tank shape, internal damping devices, gravitation/acceleration, and fluid viscosity on slosh damping were investigated. The criterion for the antislosh effectiveness of a given design was the amount of slosh energy required to uncover the outlet. The analysis showed that a tank consisting of a cylindrical body with one hemispherical and one conical end and a long cylindrical tank with two hemispherical ends require the largest input energy to uncover the outlet and are thus the least sensitive to fluid slosh. When the mass penalty is considered, a short cylindrical tank with a conical base is preferred.

The thermal requirements of the tank system are dominated by the need to prevent the boiloff of the fluid. A representative design includes multilayer insulation and a coupled vapor-cooled-shield/thermodynamic-vent system. The liquid is allowed to evaporate from the tank at the minimal rate needed to maintain the required low temperature, and the resulting vapor is used to cool the shield. In the case of $O_2$, the vented vapor can be refrigerated and recycled. For $H_2$, the additional mass of refrigerating equipment would be excessive, and it is less costly simply to vent the gas overboard.

The tank facility is stabilized partly by the gravity-gradient/orbital-acceleration effect. The length of the tether from the space station to the tank facility must be sufficient to generate the acceleration required to orient the tank and settle the contents. The Bond number, which gives the ratio of gravitational to capillary forces, is particularly useful in analyzing problems like this one. For a conservative design, the Bond number should be about 50. The design must also consider such dynamic problems as maintaining orientation during docking maneuvers and the filling or draining of tanks; for example, in a multiple-tank facility the tanks should be stacked in line along the tether axis to minimize the effects of shifts in the center of mass.

The transfer of fluid from a Space Shuttle at the space station to a tank and from a tank to another space vehicle were investigated. Possible tank-filling methods include venting while filling, evacuation followed by filling, and ullage recompression. Possible methods of transferring the fluid to another vehicle include gravity, pumped, and pressurized flows. For cryogenic fluids, autogenous pressurization can be exploited at a minimal mass penalty.

*This work was done by L. Kevin Rudolph, Erlinda R. Kiefel, and Dale A. Fester of Martin Marietta Corp. for* **Johnson Space Center**. *To obtain copies of the reports, "Tethered Orbital Refueling Study" and "A Space Station Tethered Orbital Refueling Study," Circle 116 on the TSP Request Card.*
*MSC-21074*

### Computer Programs for Spacecraft Maneuvers

Multiple-encounter, multiple maneuver voyages are analyzed in detail.

A report describes the ADAM (ADvanced Analysis of Maneuvers) system, which is an integrated collection of computer programs to aid the design and analysis of maneuvers for deep space voyages involving multiple maneuvers and multiple encounters with planets and moons. The ADAM system is being used in planning the Galileo mission and has been used in both the planning and the operation of the Voyager mission.

The programs in the collection communicate with each other and with other programs in a navigation-software system through computer files. This modular program structure contributes to the robustness and flexibility of the ADAM system. Individual components can be added or enhanced without impact on other components as long as the structure and contents of the files are maintained.

The ADAM simulation program, the major component of the system, is constructed as a discrete-event Monte Carlo simulation program. Its inputs include the prescribed trajectory and maneuvers, the statistical error distribution in measurements of the actual orbit, and parameters that represent the amounts by which the spacecraft deviates from the prescribed maneuvers. Other important inputs include the K-matrices, each of which contains the partial derivatives that specify the sensitivity of the trajectory at a given encounter to trajectory errors at the preceding maneuver. The ADAM outputs are statistics of velocity changes at maneuvers and state errors at the encounters following the maneuvers.

The discrete events are the maneuvers, including the initial orbit injection. One of the major assumptions in the present ADAM formulation is that changes in the orbital state can be represented adequately by linear perturbations about a nominal trajectory. The linear perturbations are calculated with the help of the K-matrices, and the nominal trajectories are obtained from two trajectory-analysis programs called FAST and DPTRAJ. For a large deterministic maneuver that exceeds the linearity assumption, the trajectory is re-linearized about the new nominal trajectory.

Another major assumption is that maneuvers can be treated mathematically as being impulsive; that is, as taking place in zero time. This approximation is usually adequate, but such large trajectory-correction maneuvers as orbit insertion may require special attention.

The ADAM program has been used in preflight applications including the specification of the parameters of control systems, the sizes of propellant tanks, maneuvering strategies, and the prediction of delivery accuracies. In-flight applications include updating the estimated probability of mission success and the remaining margin of the change in velocity that is sought at the next maneuver. If a spacecraft is performing anomalously, ADAM can be used to re-estimate the probability of mission success by updating predictions with measured trajectory parameters. The modularity of ADAM even allows the use of entirely new models, algorithms, trajectories, and maneuvering schedules. This characteristic is a great asset when a spacecraft does not perform as planned.

*This work was done by Clyde Chadwick and Lanny J. Miller of Caltech for* **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "An Overview of the ADAM Maneuver Analysis System," Circle 85 on the TSP Request Card.*
*NPO-16332*

## Dynamical Considerations for Tethered Orbital Refueling Facility

### System concepts are introduced.

A report summarizes a feasibility study for a proposed gravity-gradient-stabilized refueling facility tethered to an orbiting station. It includes the results of a preliminary dynamical analysis of fluid transfer and storage and compares alternative system configurations. The concepts introduced in these documents are applied to design problems in the more detailed study described in "Propellant Tanks for Tethered Orbital Refueling Facility" (MSC-21074), which also appears in this issue of *NASA Tech Briefs*.

The report presents the basic parameters of the fluid-transfer system, including flow rates, transfer times, tank dimensions, tether lengths, and gravity-gradient accelerations required for $O_2$, $H_2$, $N_2H_4$, and $CH_3NHNH_2$. Fluid-transfer concepts and the attendant engineering problems are introduced.

Various configurations for the space station and the refueling facility are described. One includes a combined facility for both the cryogenic (liquid $H_2$ and $O_2$) and the other propellants. Others include separate facilities for the two classes of propellants. Separation may be appropriate because the required accelerations (and therefore tether lengths) and thermal conditions for the two classes of fluids are different. In addition, it may be desirable to retrieve the refueling facility while the Space Shuttle is docked at the space station and to deploy the refueling facility only when transferring fuel to another space vehicle. A table called the "Configuration Comparison Matrix" presents some of the engineering issues involved in each configuration, including its advantages and disadvantages.

Attached to the report is the summary of an evaluation of the tether length required for proper liquid orientation, setting, and outflow. For a system in orbit at 250 nmi (463 km) altitude, typical tether lengths would be 120 ft (36.6 m) for an $O_2$ tank of 13.5-ft (4.1-m) diameter and 3,700 ft (1.1 km) for a $CH_3NHNH_2$ tank of 4.5-ft (1.4-m) diameter. Additional length may be required to maintain orientation during mechanical disturbances of the facility.

*This work was done by Peter W. Abbott, L. Kevin Rudolph, and Dale A. Fester of Martin Marietta Corp. for* **Johnson Space Center**. *To obtain a copy of the report, "Tethered Orbital Refueling Study," Circle 117 on the TSP Request Card.*
*MSC-21076*

## Comparing Test Data on Scale-Model Helicopter Rotors

### Hovering data correlate well, but forward-flight data do not.

A report compares the acoustics and performance of a small-scale helicopter rotor with those of a full-scale rotor in both hovering and forward flight. A 2.1-m-dia, 1/6-scale replica of a main rotor was tested at a hover flight condition in the 40- by 80-ft (12- by 24-m) wind tunnel. Subsequently, the replica was tested in forward flight in a 7- by 10-ft (2- by 3-m) wind tunnel. For comparison, data were taken from previous full-scale tests.

In the hovering test, the performance and acoustic results for the model-scale and full-scale rotors agreed well. The expected influence of the Reynolds number on the profile power was evident. Acoustic low-frequency harmonic levels were found to scale geometrically. At full-scale mid-range frequencies, acoustic spectral levels rolled off more rapidly for the full-scale rotor than for the model. In forward flight, however, acoustics of the small-scale rotor compared poorly with the full-scale data. The acoustic spectra of both the model-and full-scale rotors showed similar trends, but the overall difference in levels was large, ranging from 5 to 10 dB.

*This work was done by Cahit Kitaplioglu and Patrick Shinoda of* **Ames Research Center**. *Further information may be found in NASA TM-86786 [N86-70960/NSP], "Hover and Forward Flight Acoustics and Performance of a Small-Scale Helicopter Rotor System."*

*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.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel. Ames Research Center* *[see page 18].* *Refer to ARC-11722.*

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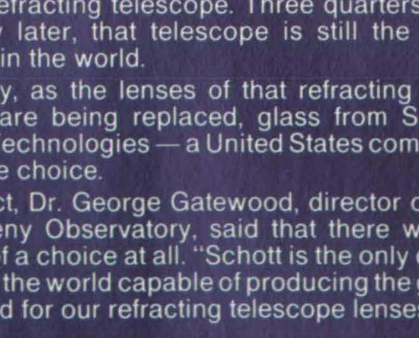

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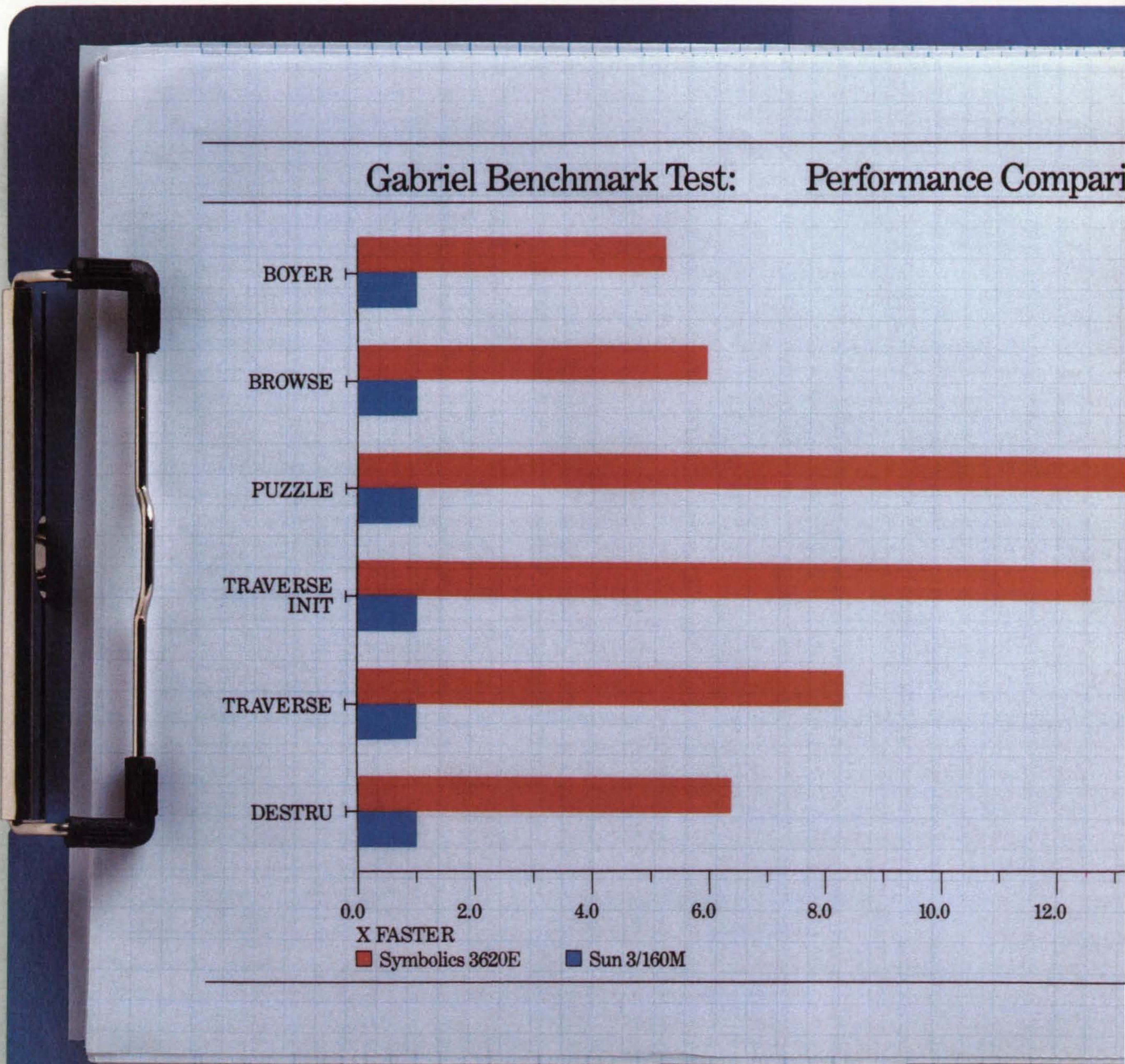

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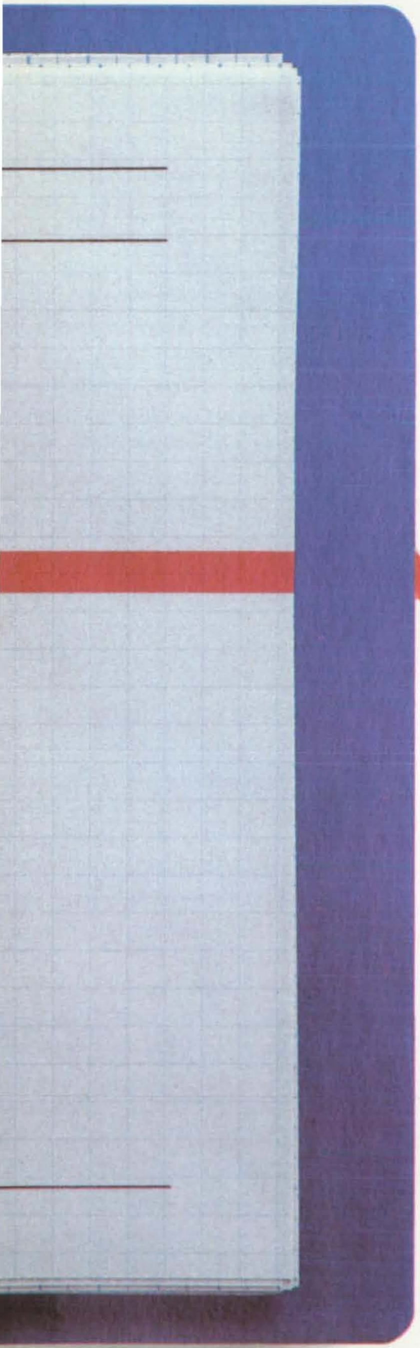

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# Machinery



## Mechanism Connects and Disconnects Lines Remotely

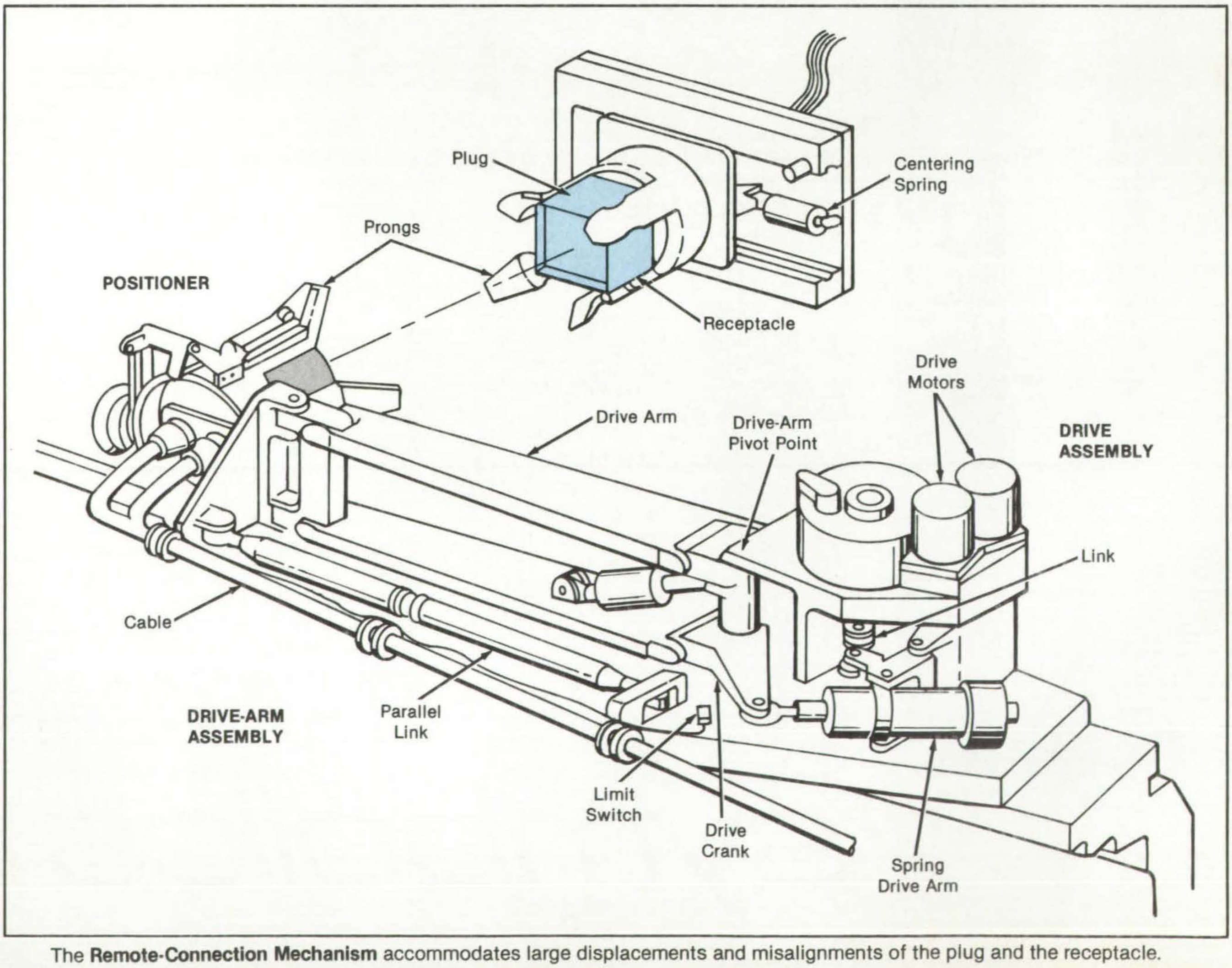
Misaligned, widely separated connector halves can be joined, then separated when necessary, while a human operator remains at a distance.

*Lyndon B. Johnson Space Center, Houston, Texas*

A mechanism connects and disconnects electrical, gas, or liquid lines by remote control. Developed for making (and breaking) electrical connections from the Space Shuttle orbiter to a payload during deployment or retrieval, the mechanism may also be adapted for use in areas inaccessible or hazardous to humans — underwater or in nuclear or chemical plants, for example.

Half of the connector — the plug half in an electrical connector — is mounted on the payload. The other half — the receptacle — is mounted on the positioner at the end of a pivoted drive-arm assembly (see figure). The drive assembly brings the positioner close to the payload connector half. The positioner then provides the adjusting movements necessary to align the connector halves and engage the pins. Meshing prongs on the plug and the receptable help to guide the mating parts.

*This work was done by Victor Strand and Earl V. Holman of Rockwell International Corp. for* **Johnson Space Center**. *For further information, Circle 164 on the TSP Request Card.* *MSC-21086*




The **Remote-Connection Mechanism** accommodates large displacements and misalignments of the plug and the receptacle.

# High-Temperature Vibration Damper

Rotary damper accommodates temperature effects on volume and viscosity.

*Ames Research Center, Moffett Field, California*

A device for damping vibrations functions at temperatures up to 400° F (about 200° C). The device dampens vibrational torque loads as high as 1,000 lb-in. (about 110 N·m) but is compact enough to be part of a helicopter rotor hub.

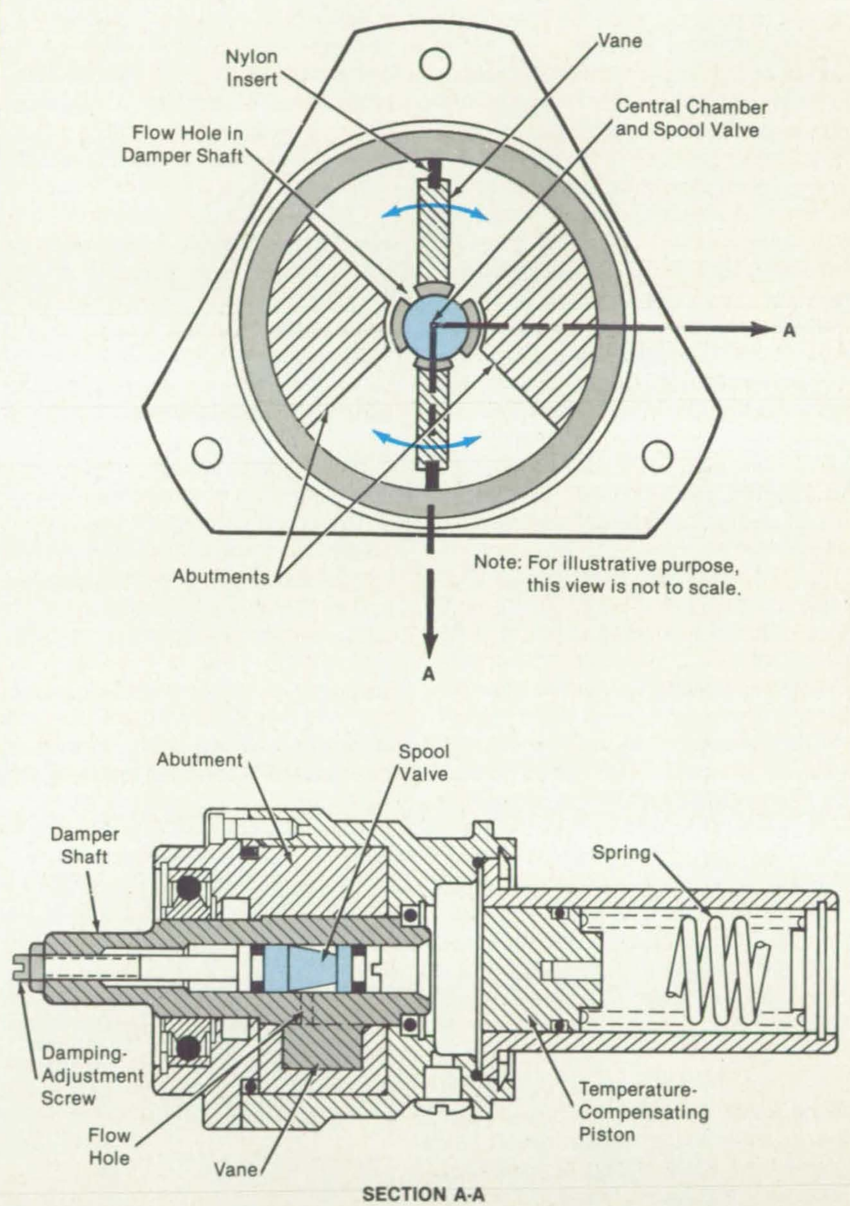
Vibration is applied via a connecting rod to an arm on the damper shaft. The oscillating torque thus imposed on the shaft is carried to a pair of vanes in separate chambers (see figure). As a vane turns in its chamber, it forces hydraulic fluid out of the chamber through small holes into a chamber in the center of the damper, then back into the chamber on the low-pressure side of the vane. The direction of vane rotation alternates repeatedly as the shaft oscillates. The inertial and viscous resistance to the shuttling of hydraulic fluid back and forth through the orifices dampens the vibrations.

A spool valve in the central chamber is positioned by a damping-adjustment screw to control the back pressure on the fluid shooting through the orifices. The resistance to fluid flow can therefore be increased or decreased to provide more or less damping.

A temperature-compensating piston allows for the expansion of the fluid as its temperature increases. A spring on the piston ensures that the fluid is always under pressure. This prevents gases from coming out of solution in the fluid or from entering from the outside. Either occurrence would introduce a compressible fluid into the damper and thus degrade its damping ability. This feature also serves as a reservoir to allow for compensation for minor leakage.

Originally, the temperature-compensating piston was connected to the spool valve so that it automatically adjusted the valve for the change in fluid viscosity with temperature. This was found to be an unnecessary complication, however. It made the damping rate overly sensitive to small temperature changes, and the damper became hard to stabilize. Since the normal damper operating temperature is fairly constant and since viscosity varies but little with small temperature changes, the piston and the valve were separated. The spool valve is adjusted independently for viscosity.

To prevent rapid wear, the chamber walls are coated with an abrasion-resistant film. Similarly, the vane tips hold nylon inserts that prevent the rapid wear caused by metal-to-metal contact.




The **Rotary Damper** absorbs energy from a vibrating rod, dissipating it in the turbulent motion of a viscous hydraulic fluid forced by moving vanes through small orifices. Only one of the two vanes appears in the side cross section; the other is at an angle to the plane of the page.

*This work was done by Alan Clarke, Joel Litwin, and Harold Krauss of United Technologies Corp. for* **Ames Research Center.** *For further information, Circle 162 on the TSP Request Card.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 18]. Refer to ARC-11604.*

# Electromagnetic Repulsive Deicer for Aircraft

A proposed lightweight device would eject ice with minimal power drain.

*Ames Research Center, Moffett Field, California*

A scheme for removing ice from airfoils in flight would add little weight and demand a relatively small amount of energy. Employing the electromagnetic repulsion of conductors embedded in a rubber covering on an airfoil, the scheme breaks up a layer of ice by snapping it in the manner of snapping a rug to remove dust.

The electrorepulsion principle promises to make deicing more practical for helicopter rotors as well as for wings on fixed-wing aircraft. It avoids the disadvantages of conventional deicing methods. For example, melting ice by resistance heaters adds substantially to the electrical power demand in an aircraft and therefore to the power-equipment weight. Cracking ice by inflating boots on an airfoil is slow and is ineffective for thin but nonetheless troublesome ice layers, and the inflation of the boot can seriously degrade rotor performance.

In the proposed electromagnetic-repulsion deicer, a sheet of elastomer is bonded to the supporting structure of the airfoil (see figure). An embedded layer of electrically conductive ribbons near the airfoil is separated from an upper layer of similar ribbons by slits in the elastomer. When a capacitor is discharged through the ribbons, the discharge current passes in opposite directions through the upper and lower ribbons. The opposing currents and their magnetic fields create a repulsive force between the upper and lower ribbons. The force distends the elastomer layer around the slits so that a series of ridges on the upper (airfoil) surface is formed.

The capacitor discharges quickly, and the motion of the elastomer is abrupt, exerting a very powerful impulse; the sudden change in the surface profile also cracks any ice that has accumulated, even very thin layers, and the ice fragments are blown away in the airstream. The distortion of the surface is small and brief, since elasticity and the vacuum in the slits draws the slits back to their original shape as soon as the capacitor has discharged; consequently, the aerodynamic properties of the airfoil are only slightly affected.

For upper and lower deicer ribbons each 2 mm wide and placed 7.6 mm apart, carrying a peak discharge current of 3,000 amperes, the total distorting force would be high indeed — about 2,400 pounds per foot of ribbon length (35,000 newtons per meter). This force would be concentrated at the ridges of the distended elastomer; the force in the valleys would be lower. Thus there would be large moments on the brittle ice sheet that would twist it apart. The stresses exerted on the supporting structure inside the airfoil when the deicer acts are compressive stresses, which the structure can readily absorb.

The elastomeric material should be selected for elasticity, fatigue resistance, tear strength, and dielectric strength. Neoprene, silicone, or polyurethane are possible choices. When the deicer will be subjected to severe erosion from sand or rain — as it will be on a helicopter rotor — commercial polyether or polyester versions of polyurethane can be used as a durable surface coating or even as the bulk material.

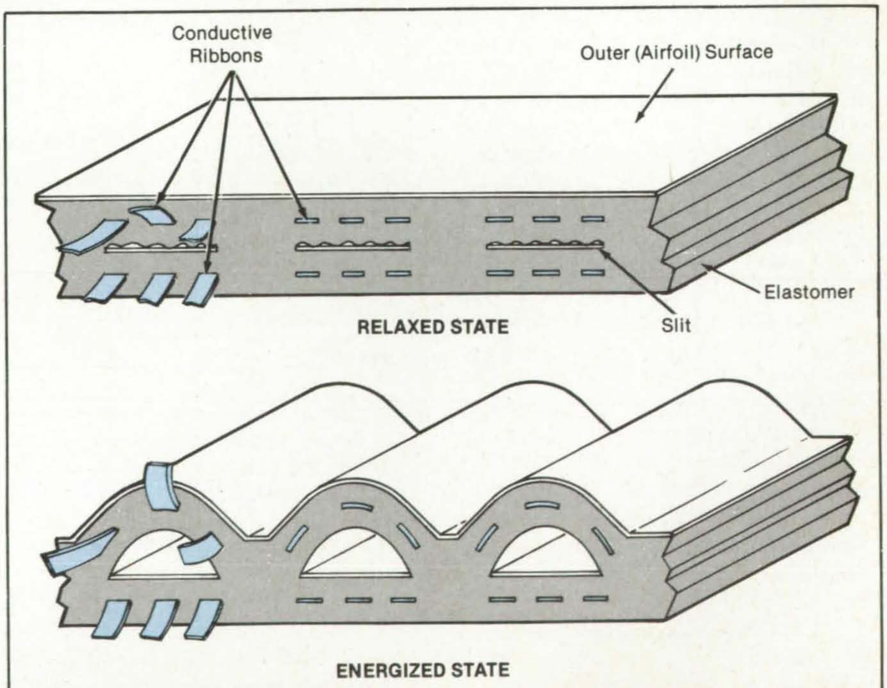
The ribbon conductor material should be selected for high conductivity, flexibility, fatigue resistance, corrosion resistance, and tensile strength. Copper, unless it is costly oxygen-free copper, is not especially suitable because it tends to work harden. A better material would be tantalum. The ribbon can be made from many strips attached end to end. Braided wire can be used instead of solid metal strips.

A side-by-side array at pairs of ribbon conductors would be pulsed sequentially. The deicer ridges would then ripple across the airfoil, sweeping the ice away. The electrical energy stored in the capacitors would be transferred to the ribbons by heavy-duty relays such as that in an automobile starter. A timing circuit in the power supply would control pulsing. A pulse sequence would be repeated many times to ensure complete ice removal.

The deicer can be installed on an aircraft while it is being assembled in the factory or can be retrofit. Since a deicer can readily be attached to a wing or rotor with adhesive, installation in the field will be easy. Deicers can be used on engine inlet ducts that are subject to icing as well as on wings and rotors.

*This work was done by Leonard A. Haslim and Robert D. Lee of* **Ames Research Center**. *For further information, Circle 108 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, Ames Research Center [see page 18]. Refer to ARC-11613.*




**Layer of Elastomer Conforms** to the shape of an airfoil in the relaxed state. When carrying large electrical currents, conductive ribbons in the elastomer repel each other, creating a ridged surface on the airfoil. A sheet of ice on the airfoil would be broken up in the sudden transition from the relaxed state to the energized state.

# Shaft Coupler With Friction and Spline Clutches

Dual clutches ensure smooth acceleration and efficient power transfer from engine to rotor at full aircraft speed.

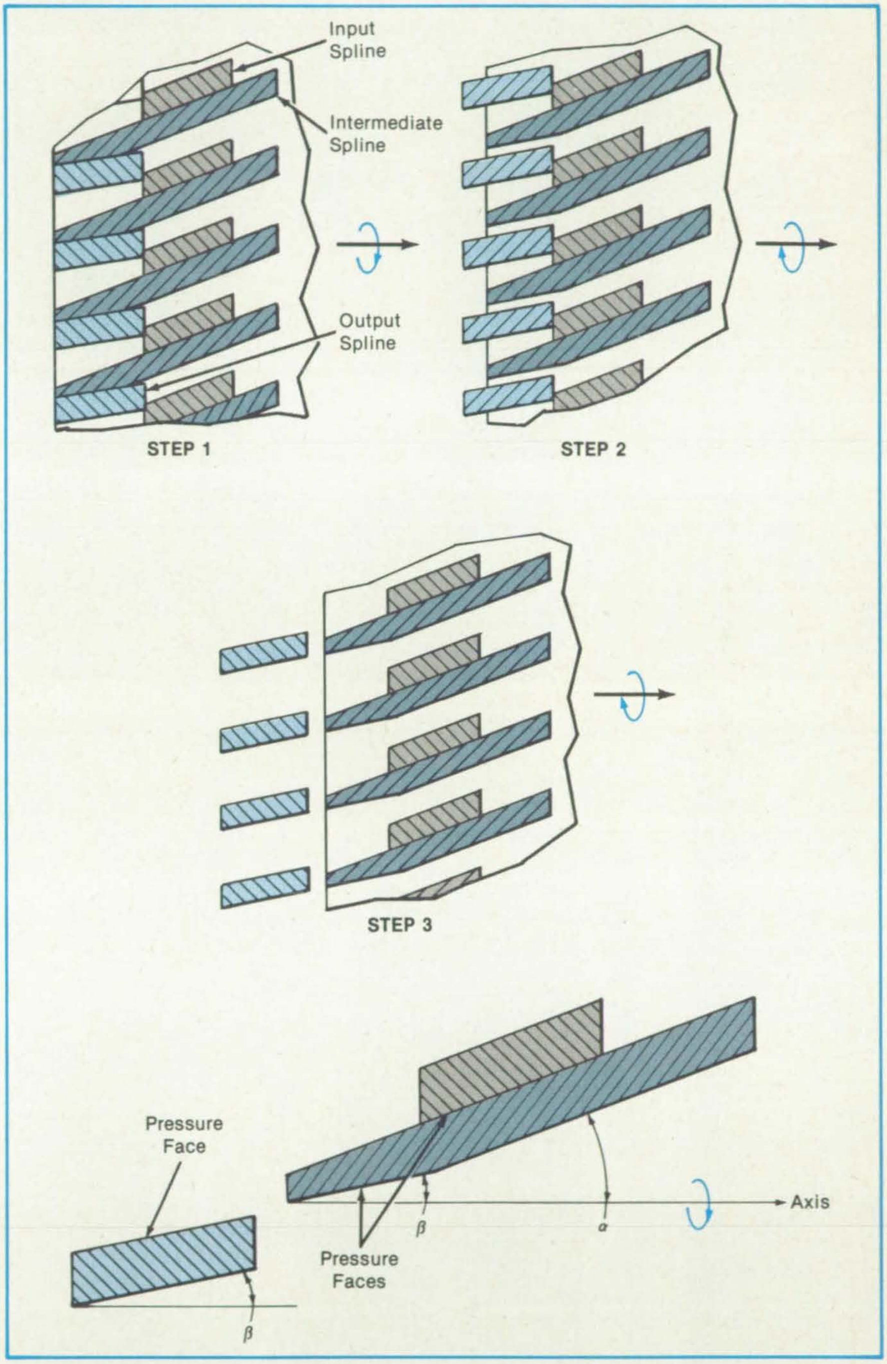
*Ames Research Center, Moffett Field, California*

A coupling, developed for the rotor of a lift/cruise aircraft, employs two clutches for a smooth transmission of power from a gas-turbine engine to the rotor. Prior to ascent, the coupling applies a friction-type transition clutch that accelerates the rotor shaft to speeds matching those of the engine shaft. Once the shafts are synchronized, the spline coupling is engaged and the friction clutch released to provide positive mechanical drive.

Deceleration of the rotor for horizontal flight is accomplished by engaging the friction clutch to assume the shaft torque load. The splined coupling is then disengaged. Now the friction clutch can be released, which allows the rotor to decelerate and be stopped and locked by its break mechanism.

The spline clutch is designed so that it withdraws, separating the pressure faces of the splines circumferentially as the splines separate longitudinally. Each of the splines on the input shaft has a pressure face oriented at a helix angle $\alpha$ relative to the shaft axis (see figure). An intermediate lock member also contains splines, at the same pitch as that of the input splines. Each of the lock-member splines has two pressure faces: one, at a helix angle $\alpha$, that contacts the input splines, the other, at a helix angle $\beta$, that contacts the output splines. The pressure faces of the output splines are oriented at helix angle $\beta$, like the mating faces on the lock-member splines.

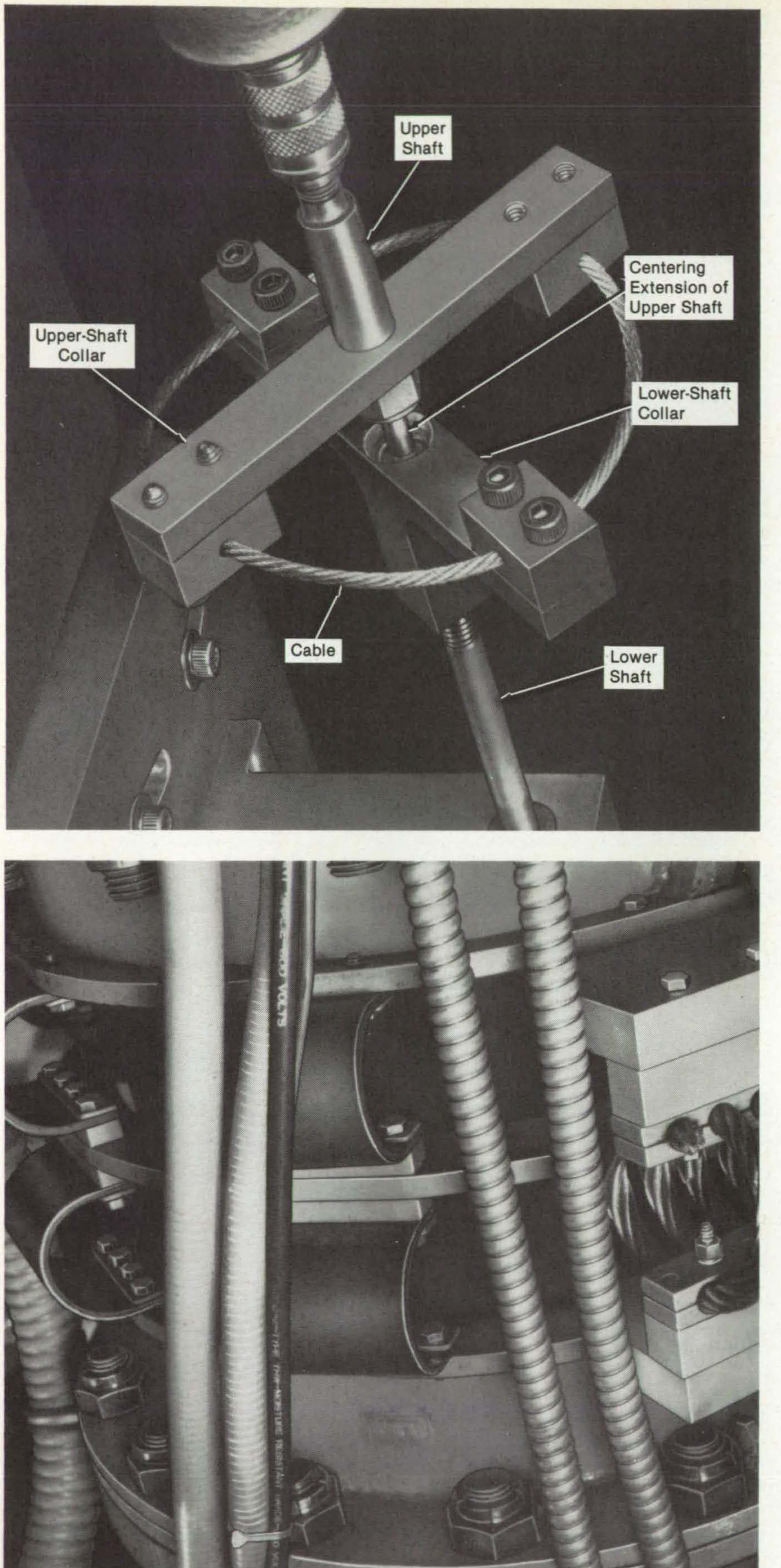
When the rotor is turning synchronously with the input shaft, the input, intermediate, and output splines turn in unison, with no relative motion between them. To start the transition from active rotor to inactive rotor, the transition clutch is energized and the lock member is retracted from its locked axial position. The axial force exerted by the actuating piston pushes the splines on the intermediate lock member axially away from the output splines. Because the helical angle $\beta$ is less than $\alpha$, this motion also disengages the intermediate lock and output splines circumferentially. When the intermediate lock and output splines are fully disengaged, the transition clutch assumes the full load. The transition clutch is then gradually disengaged, and the rotor is stopped by an external brake.




**Three Stages in the Transition** from engagement to disengagement are illustrated. In step 1, the pressure faces of the input splines, the intermediate splines, and the output splines are in contact. In step 2, the intermediate splines have pulled away circumferentially and axially from the output splines so that power is no longer transmitted to the output along this path. In step 3, the input and intermediate splines are withdrawn further along the axis to complete the disengagement. Representative values for the angles $\alpha$ and $\beta$ are 14° and 12°, respectively.

*This work was done by Glenn W. Thebert of General Motors Corp. for* **Ames Research Center**. *For further information, Circle 59 on the TSP Request Card.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 18]. Refer to ARC-11627.*




The **Flexible Coupling** can be made in a variety of sizes and configurations. The one at the top functions as a universal joint. The one at the bottom is a large, relatively stiff spring coupling between wide shafts.

## Flexible Coupling With Centering Device

A bending cable accommodates misalignments.

*Goddard Space Flight Center, Greenbelt, Maryland*

Misaligned machine shafts operating at low speeds can be coupled with a cheap, simple mechanism made in part from wire rope. The wire rope, which can be ordinary steel cable, bends to accommodate angular and lateral misalignments and dampens vibrations that accompany, or are caused by, the rotation of the shafts.

In the version shown in the upper part of the figure, the cable transmits the torque between the shafts. An extension of the upper shaft turns loosely in a hole in the collar attached to the lower shaft. This simple centering device assures that the two shafts intersect at the coupling, even when subjected to eccentric loads.

The coupling mechanism can be made in a wide range of sizes and for a wide range of torques. The version at the bottom of the figure is longer and stiffer than the one shown above and includes U-shaped leaf springs as well as cable springs.

*This work was done by James Kerley of* **Goddard Space Flight Center**. *No further documentation is available. GSC-12976*

# 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.**

## Coal-Fired Rocket Engine

A proposed hybrid engine would combine solid fuel with liquid oxidizer.

A brief report describes a concept for a coal-burning hybrid rocket engine. The proposed engine would carry a larger payload, burn more cleanly, and be safer to manufacture and handle than are conventional solid-propellant rockets. Its thrust would be changeable in flight, and it could be stopped and started on demand.

The coal-burning rocket engine could be used in boosters, upper stages, and intermittent thrusters (for station-keeping and course correction, for example). It could also be used as a gas generator or electrical-power generator. It could supply energy for high-intensity lasers on spacecraft, for instance.

Unlike ordinary solid-propellant engines, the coal-burning engine would not release large amounts of hydrogen chloride into the atmosphere during a launch. At the same time, it would offer higher performance at lower cost.

The fuel would consist of powdered coal and aluminum powder in a high-molecular-weight, rubbery polymer matrix. This solid fuel would be burned with liquid oxygen in the rocket motor. The solid fuel would be processed as a case-bonded unit. In the processing, shipping, and assembly stages, the fuel units could be handled as inert units from a safety standpoint.

*This work was done by Floyd A. Anderson of Caltech for* **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "High Performance, Clean Burning Propulsion System," Circle 23 on the TSP Request Card.*
*NPO-16902*

## Lightweight Monorail Transport System

### Tubular rails have a high strength-to-weight ratio.

A report proposes a monorail transportation system for a zero-gravity environment. The system would carry materials and parts between locations on a space station.

The system would include tubular rails instead of the open channels usually found in overhead conveyor systems. Since the resistance to torque of a closed tube is greater than that of an open channel for the same amount of material, the tubular monorail can be designed for higher loads or for greater spacing between support points.

A vehicle on one fixed and one swivel truck would ride the monorail. The rails would incorporate supports and switch mechanisms within a 90° quadrant, allowing three-fourths of the rail surface to be used by the truck drive mechanism. The truck drive wheels would be powered by a gearmotor through a drivebelt. Rollers on opposite sides of the truck would ride in grooves on the sides of the monorail; they would hold the truck on the rail and minimize sidesway.

The torque loads induced by the truck motion would be transmitted by a pin at one end of a rail segment and by a sliding tongue within a fixed groove at the other end of the rail segment. Where a rail connects to the space-station structure, the torque loads would be transmitted by pin connections. Each rail segment would be longitudinally independent of the space-station structure so that thermal expansion and contraction stresses would not be transmitted.

*This work was done by Harold F. Weir, Kenneth E. Wood, and Myron T. Strecker of Rockwell International Corp. for* **Johnson Space Center**. *To obtain a copy of the report, "Monorail Transport for Zero-G Environment," Circle 127 on the TSP Request Card. MSC-21119*

## Recursive Robot-Arm Dynamics via Filtering and Smoothing

### Forward and inverse dynamics are solved using Kalman filtering and Bryson-Frazier smoothing.

The dynamics of a serial-link robot arm are solved by using recursive techniques from linear filtering and smoothing theory. The solutions of the dynamical equations give the forces, moments, and accelerations at the joints between the links, and the multilink inertia matrix and its inverse. The theoretical developments lay the foundation for the use of filtering and smoothing techniques in the design of robot controls.

The dynamical equations are written for a robot arm that has rotational joints. The innermost joint attaches the innermost link to an immobile base. The notions of spatial force, acceleration, and inertia are used to simplify the dynamical equations. A spatial force acting on a link is defined as a six-dimensional vector, the first three components of which represent a moment and the last three components of which represent a force. Similarly, a spatial acceleration is defined to be a six-dimensional vector formed by an angular acceleration and a linear acceleration. The spatial inertia of a link is a 6-by-6 matrix that expresses the mass and inertia properties of the link about its inner joint.

The equations of motion for each link can be cast as a linear difference equation that establishes a means to "propagate" the spatial force inwardly within a link from the outer to the inner joint. In addition, the continuity of the spatial force at the joints makes it possible to propagate the spatial force across a joint at the interface between two adjacent links. The recursive use of these two propagation mechanisms allows a complete link-to-link sequential propagation of the spatial force from the tip of the manipulator to its base. The difference equation generates the joint moments as an output.

The difference equation is very similar to those describing the evolution of the state of a discrete-time state-space system. The spatial force plays the role of the state. The link spatial interval, defined as the vector from the inner to the outer joint of a link, plays the role of the time interval between discrete time samples. However, it should be stressed that the equation for the spatial forces is a difference equation in space and not in time. There is no time discretization involved, and a fully continuous time evolution is retained.

Similarly, using the joint accelerations as inputs, a complementary difference equation produces a set of spatial accelerations. The spatial accelerations play the role of the costates (or adjoint variables) that are typical in optimal-control and estimation problems. This costate equation reflects the kinematic relationship between the spatial accelerations at the outer and inner joints of a link.

When combined, the state and costate difference equations define a two-point boundary-value problem. The boundary conditions are that the state (forces and moments) vanishes at the tip because the tip is unconstrained, and the costate (accelerations) vanishes at the base because the base is immobile.

The solution of this is based on filtering and smoothing techniques identical to the equations of Kalman filtering and Bryson-Frazier fixed-time-interval smoothing. The solutions prescribe an inward filtering recursion that starts from the tip of the manipulator and proceeds sequentially from link to link to the base, to compute a sequence of constraint forces and moments. Similarly, an outward iteration from the base to the tip is used to determine a corresponding sequence of link/joint linear and angular accelerations. The number of required computations grows linearly with the number of links.

*This work was done by Guillermo Rodriguez of Caltech for* **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Kalman Filtering, Smoothing, and Recursive Robot Arm Forward and Inverse Dynamics," Circle 148 on the TSP Request Card. NPO-17040*

# Optical Monitor for Rotating Welding Turret

Built-in optics enable coaxial viewing through a torch in any orientation.

*Marshall Space Flight Center, Alabama*

A set of internal mirrors in a welding-torch turret allows a weld seam to be monitored regardless of the angle between the turret and the torch. The turret can thus be rotated as necessary to reach various positions on the workpiece.

Mirrors are placed at the elbow between the supporting tube and the turret and within the turret, each at 45° to its respective optical axis (see Figure 1). A third mirror in the turret has a central hole, through which the welding electrode passes.

The optical system is simple and compact. It can be placed in a commercially available 90° welding torch. An additional mirror/elbow can be added to rotate the view to the desired orientation with respect to the portion of the view blocked by the

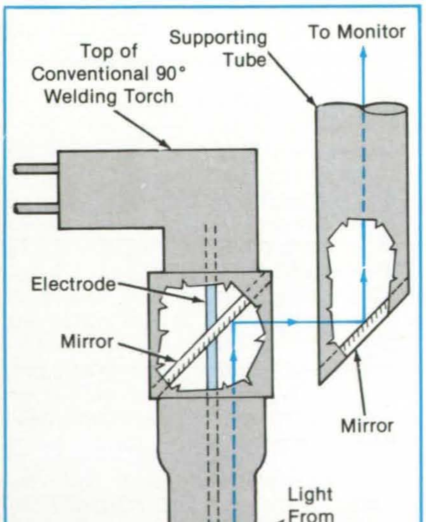



Figure 1. The **Workpiece Is Viewed** along the welding-torch axis with the help of a periscopelike arrangement of mirrors.

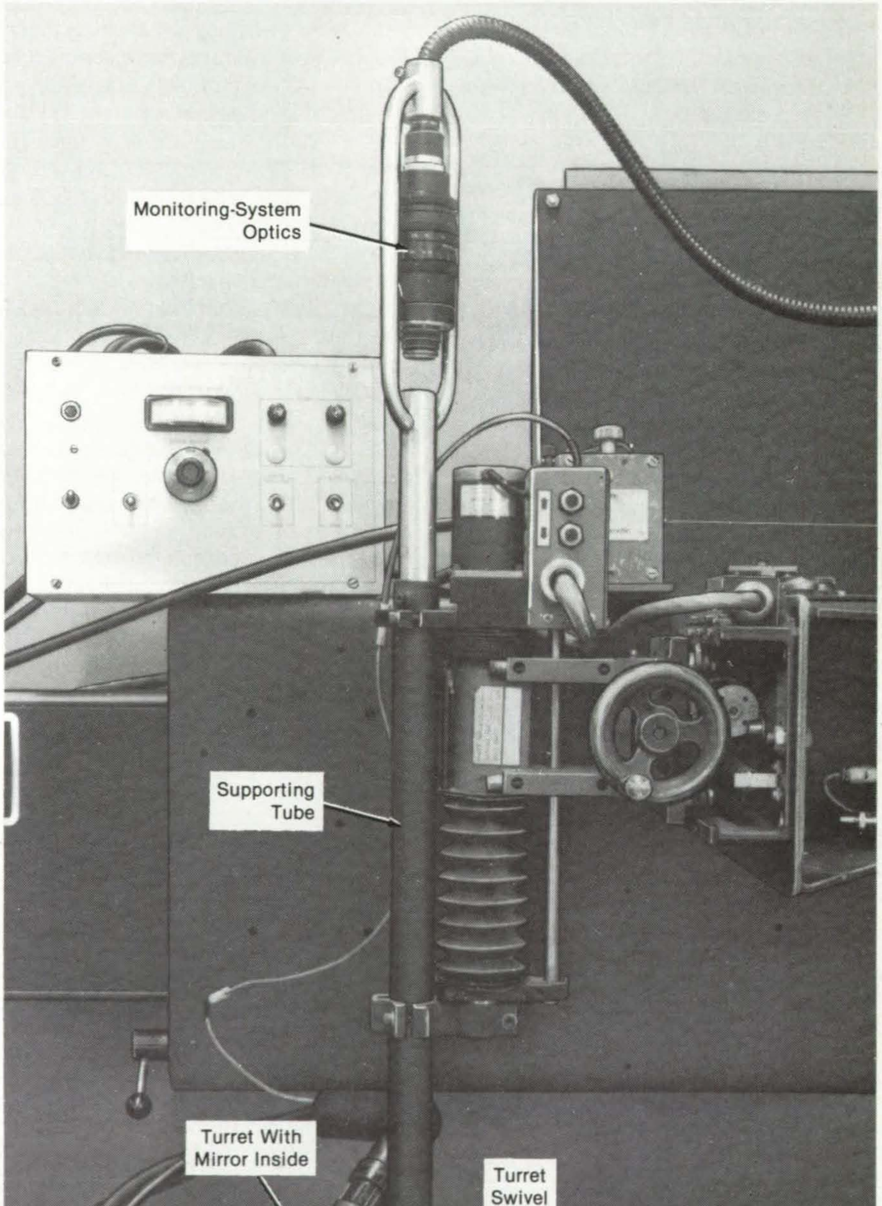



Figure 2. **Tilted at Any Angle**, an arc-welding torch still gives a clear view, through a pair of mirrors, of a weld in progress. The turret can be swiveled while the support tube remains fixed.

electrode, as in the apparatus shown in Figure 2.

*This work was done by Stephen G. Babcock, Gerald E. Dyer, and Stephen S. Gordon 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 18]. Refer to MFS-29177*

# Making Double-Bevel End Cuts on Tubes

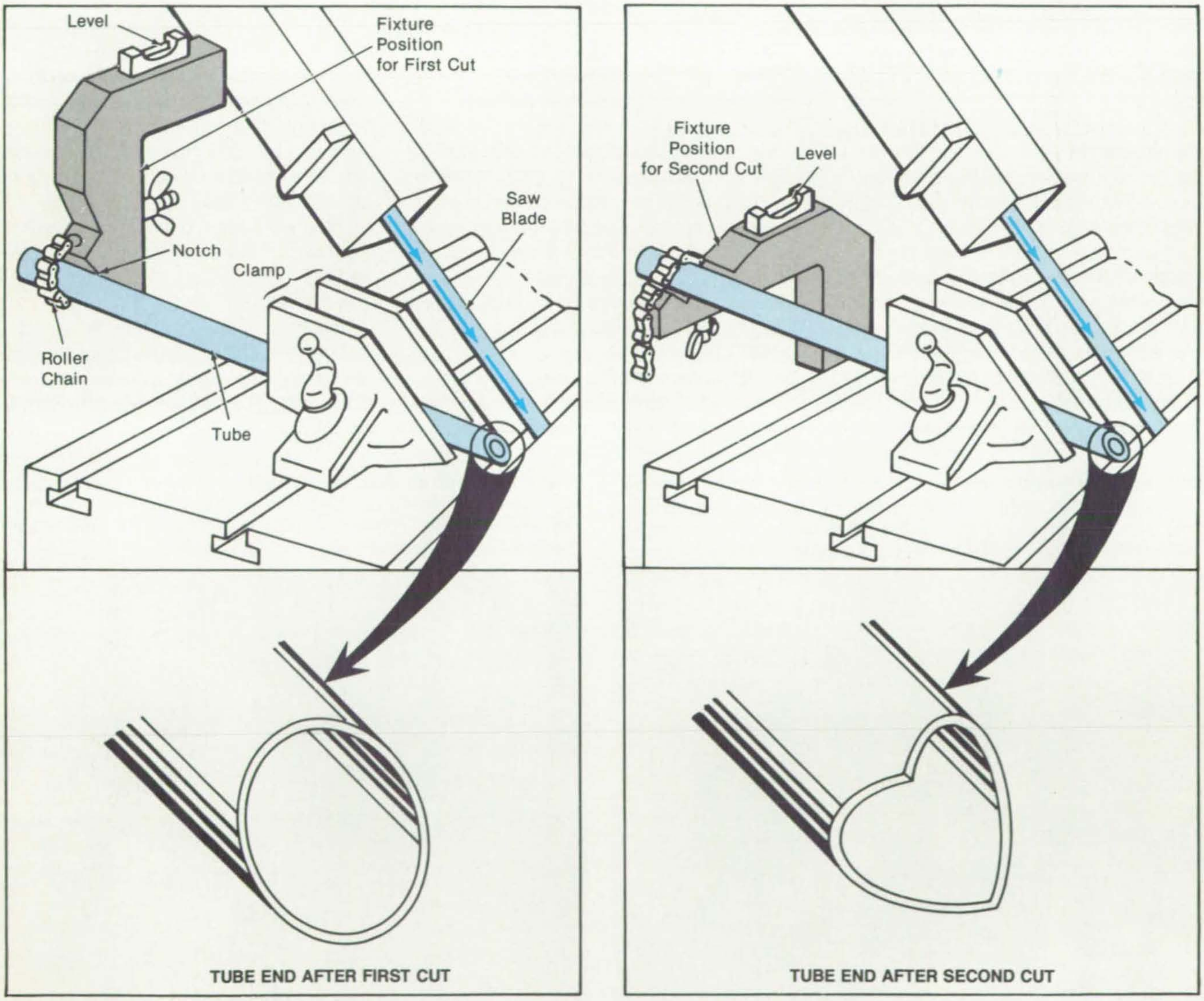
A fixture for a power saw saves time, eliminates waste, and ensures precision.

*Lyndon B. Johnson Space Center, Houston, Texas*

With the aid of a new fixture, tubing sections can be cut so that they mate precisely at orthogonal joints, such as those at the corners of protective railings, for example. The fixture orients the end of a section at the correct angle for two sequential cuts by a power hacksaw or bandsaw. It eliminates cut-and-try methods, thereby saving time and labor and reducing waste.

The fixture is made from a notched, generally L-shaped plate. A tube rests in a notch in one leg of the fixture, secured by a roller chain that is pulled tightly around the tube section by a thumb screw (see figure). With one end of the tube in the fixture and the other end in a clamp on the power saw, the tube is leveled, and the first cut is made. The tube and fixture are rotated 90° and releveled, and the second cut is made. The tube end is then beveled so that it will mate precisely for welding with two mutually perpendicular tubes cut similarly.

*This work was done by Joseph R. Cardenas and Harvey L. Berg of Rockwell International Corp. for* **Johnson Space Center**. *For further information, Circle 118 on the TSP Request Card.* MSC-21135




A **Simple Fixture** positions a tube for a 45° end cut, then repositions it for a cut at 90° to the first cut. A roller chain holds the tube in place for both cuts.

# Fast Melting and Freezing for Microgravity Experiments

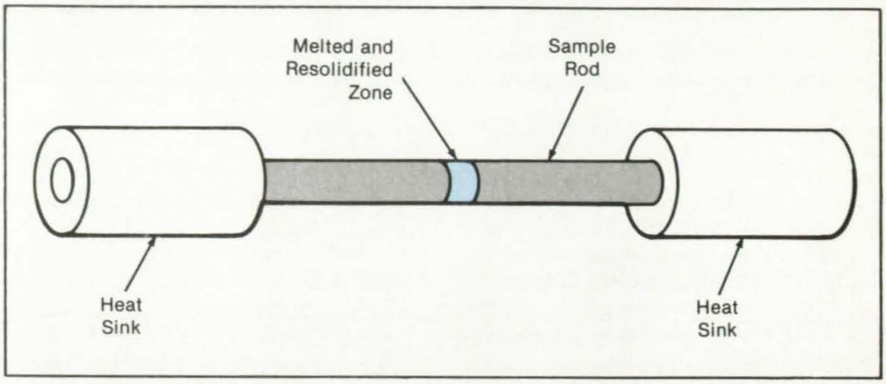
Commercial tube welders are adapted to metallurgical research.

*Marshall Space Flight Center, Alabama*

A proposed furnace would melt and resolidify small metal samples during brief periods. In the furnace, a sample would be surrounded by large heat sinks and rapidly heated near its midlength by an intense source of heat. The furnace is intended for use in experiments in microgravity: the entire melting-and-freezing process would require less than the 20 s of near weightlessness that can be experienced in the parabolic climb and dive of a KC-135 airplane.

In a demonstration of feasibility, the heat source was a commercial automatic gas/tungsten-arc tube welder. In the automatic welder the arc moves around the sample at programmed speeds up to 60 r/min. The welding current is timed and programmed for up to four different current levels. The length and position of the arc are adjustable.

A variety of resolidification patterns can be provided by controlling the flow of heat to and from the samples. In the demonstration, the samples were aluminum, copper, and tungsten rods 90 mm long, with various diameters of 3 mm or more. Aluminum masses 13 mm in diameter and 25 mm long were attached to both ends of each rod to serve as heat sinks (see figure) to conduct heat axially from the heated region at the middle, thus producing directional solidification along the axis. (If the heat flow along the sample rod were reduced, the molten metal could be made to freeze from the circumference toward the middle, yielding radial solidification.)




**Large Aluminum Heat Sinks** are placed on the ends of a sample rod. The welding arc or other intense source of heat is applied at the middle of the exposed portion of the rod and melts a short section that resolidifies quickly as heat flows to the heat sinks.

The automatic tube welder can readily be adapted to operate on a KC-135 airplane. The 110-V, 60-Hz, 20-A power on board would be ample for the requisite welding current. The 90-lb (41-kg) welding power supply, the tube-welding head, and the operator's remote controller are easy to use. Samples can be changed readily during flight between low-gravity trajectories.

For a microgravity experiment, the furnace would be fitted with a variety of sensors. Optical and thermocouple measurements would be made of temperature, for example, and a Peltier pulser would be used to mark solidification fronts and dimensional changes. Alternative sources of heat can be used instead of the tungsten arc — a laser, an electron beam, or focused thermal radiation, for instance.

*This work was done by Richard M. Poorman of* **Marshall Space Flight Center**. *For further information, Circle 142 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 18]. Refer to MFS-27181.*

**Microgravity researchers** measure the duration of their experiments in tens of seconds, when they can find research opportunities at all. Current sources of low gravity include drop tubes, drop towers and aircraft such as the KC-135 shown here, during a parabolic flight path.

**Weightless in an aircraft**, Marshall Space Flight Center scientists melt and freeze metal within 20 seconds. Using a 100-Ampere furnace, 3mm and greater diameter aluminum, stainless steel and tungsten samples are monitored as they change phase in low gravity fields.

# Shaping Component Leads for Small-Scale Production

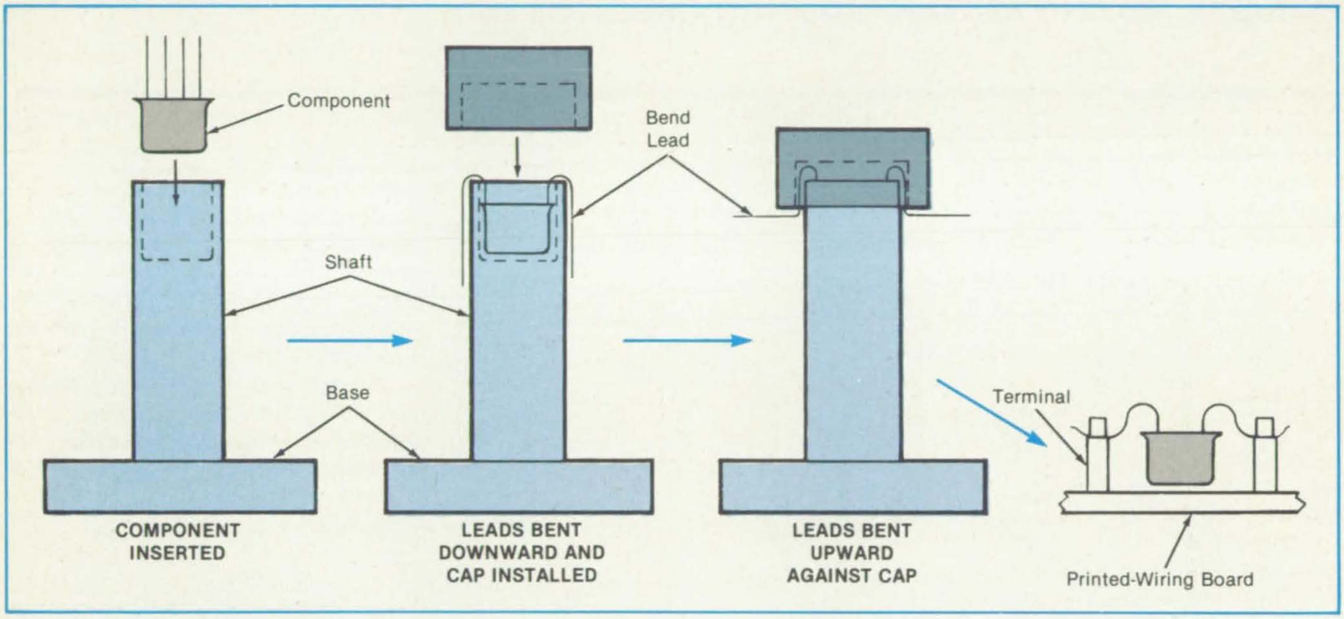
Tedious individual shaping of leads is avoided.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A simple tool makes it easy to bend the leads of electronic components quickly and uniformly for assembly on a circuit board. The tool is useful in the small-scale production of electronic circuits; it saves labor but avoids the cost of complicated machinery. The tool can be made in a range of sizes to accommodate components in a variety of dimensions.

The tool includes a shaft, hollow at one end, mounted on a baseplate (see figure). The component is inserted in the tool cavity with its leads upward. The assembler bends the leads over the rim of the shaft, creating the first of two bends on each lead. A cap is then placed over the shaft, creating a base for a second bend in each lead so that they can be bonded to terminals with minimal stress.

*This work was done by Lawrence Jan of Loral Electro Optical Systems, Inc. for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 7 on the TSP Request Card.* NPO-16863




**Lead-Shaping Proceeds Straightforwardly** after insertion of an inverted component into the hollow of the tool. The assembler bends the leads downward over the edge of the tool shaft, then places a cap over the shaft. The assembler then bends the leads upward against the cap, giving them a form that can readily be mounted on a printed-wiring board.

# Alternating-Polarity Arc Welding

Briefly reversing the polarity of welding current greatly improves the quality of welds.

*Marshall Space Flight Center, Alabama*

A NASA technical memorandum recounts progress in the art of variable-polarity plasma-arc (VPPA) welding, with emphasis on the welding of aluminum-alloy tanks. VPPA welders offer the following important advantages over conventional single-polarity gas/tungsten arc welders:

- Stray air currents and external magnetic fields, which ordinarily make the arc wander, have little effect.
- The alternating polarity keeps the electrodes clean, making it possible to weld most aluminum alloys without special scraping or cleaning.
- The alternating arc current sets up Lorentz (electromagnetic) forces and swirling in the weld puddle that help to remove contaminants.
- Welding can be done in the keyhole mode, in which the plasma punches completely through the workpiece. Contaminants are swept away, and complete weld penetration is ensured.
- Porosity is nearly eliminated.
- Because of the high weld quality, radiographic inspection is often unnecessary.

The arc voltage typically follows a rectangular waveform. For about 19 milliseconds, the electrode is negative with respect to the workpiece; then for 4 milliseconds, the electrode is positive. This cycle yields an alternation frequency of about 43.5 hertz. The current is 130 amperes in the negative polarity and 180 amperes in the positive polarity.

A computer controls the VPPA manipulator, weld-wire feed, torch, and power supply. The computer regulates a variety of measured parameters so that they coincide with the set points established by the welding engineer. The computer makes it possible to form tapered longitudinal and circumferential welds on materials of varying thicknesses.

Argon gas is forced through the torch orifice at a high velocity so that the hole melted in the workpiece opens up ahead of the plasma jet in the direction of travel. The molten puddle material is washed backward and solidifies behind the plasma jet. Because moisture in the gas would distrupt the formation of the weld bead and produce a rough contour, the argon is first passed through a titanium getter furnace and filters, which absorb moisture.

The torch was redesigned to align the electrode precisely, to eliminate double arcing (in which the arc jumps from the electrode to the nozzle to the workpiece), and to provide a steady, fast, concentrated argon flow. An electrical filter was developed to reduce electromagnetic interference from the polarity reversals, thereby ensuring a constant arc voltage. Other measures to reduce electromagnetic interference included separating signal and power leads, using twisted pairs in the power cables, providing noise-bypass capacitors, and increasing the distance between power and control cabinets.

The VPPA process has been used to weld over 190,000 in. (4.8 km) of type 2219 aluminum alloy in thicknesses up to 1 in. (2.5 cm) without a single internal defect. Tensile properties were better than those for conventional gas/tungsten arc welding. There has been no reduction of fracture toughness or fatigue life. Similar benefits result from the VPPA welding of other aluminum alloys.

*This work was done by R. J. Schwinghamer of* **Marshall Space Flight Center**. *Further information may be found in NASA TM-86536 [N86-19617/NSP], "Unique Variable Polarity Plasma Arc Welding for Space Shuttle."*

*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. The report is also available on microfiche at no charge. To obtain a microfiche copy, Circle 73 on the TSP Request Card.*

*MFS-27147*

# Hot-Gas Nozzle for Desoldering Leadless IC's

An economical tool fits on a hot-air gun.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

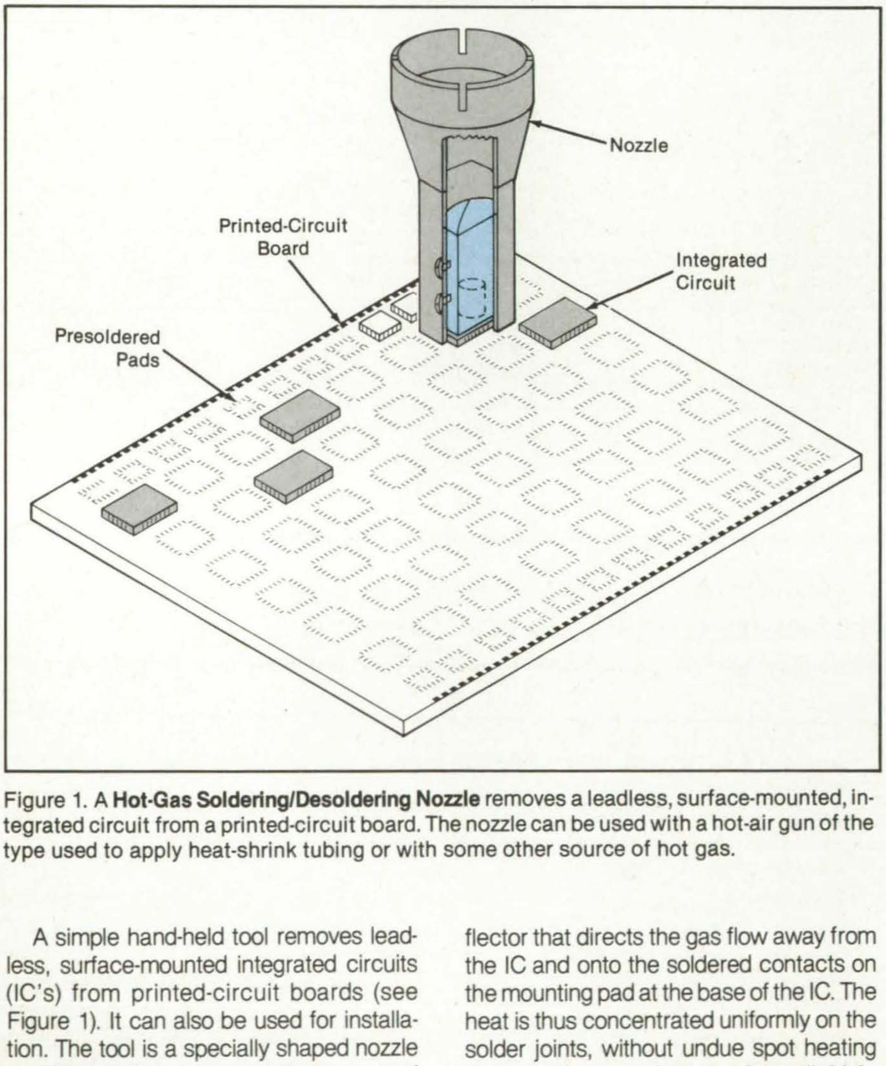



Figure 1. A **Hot-Gas Soldering/Desoldering Nozzle** removes a leadless, surface-mounted, integrated circuit from a printed-circuit board. The nozzle can be used with a hot-air gun of the type used to apply heat-shrink tubing or with some other source of hot gas.

A simple hand-held tool removes leadless, surface-mounted integrated circuits (IC's) from printed-circuit boards (see Figure 1). It can also be used for installation. The tool is a specially shaped nozzle that fits on a hot-air gun or other source of hot gas (see figure). It takes only 5 to 7 seconds to remove an IC with the new tool. The new tool is easier to use and less likely to damage either the IC or the circuit board than are tools of the soldering-iron type.

The nozzle (see Figure 2) includes a deflector that directs the gas flow away from the IC and onto the soldered contacts on the mounting pad at the base of the IC. The heat is thus concentrated uniformly on the solder joints, without undue spot heating that would cause damage. A small, high-energy (rare-earth) magnet in the deflector applies a lifting force to the IC via magnetic material in the IC. Thus, the IC is pulled away from the board as soon as the solder is melted.

Deflectors of various sizes could be used to adapt the nozzle to IC's of different sizes. Alternatively, a series of nozzles of different sizes with permanently mounted deflectors could be used. Nozzles with other types of mechanical or vacuum grips could also be devised.

*This work was done by Mark T. Hanlon and Robert M. Deering of Caltech for* **NASA's Jet Propulsion Laboratory**. *For further information, Circle 165 on the TSP Request Card.*

*NPO-16897*

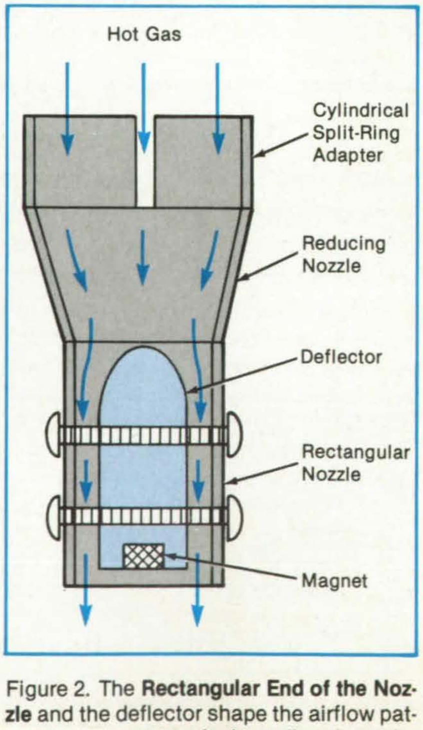



Figure 2. The **Rectangular End of the Nozzle** and the deflector shape the airflow pattern to concentrate the heat directly on the soldering pads located around the edge of the IC's to heat them quickly and uniformly.

# Applying Tape in Vacuum or Air

Cost and complexity may be reduced.

*Marshall Space Flight Center, Alabama*

A device applies adhesive second-surface-mirror tape to flat surfaces. The use of the device replaces the previous application of tape by a time-consuming and labor-intensive procedure of autoclaving in vacuum bags.

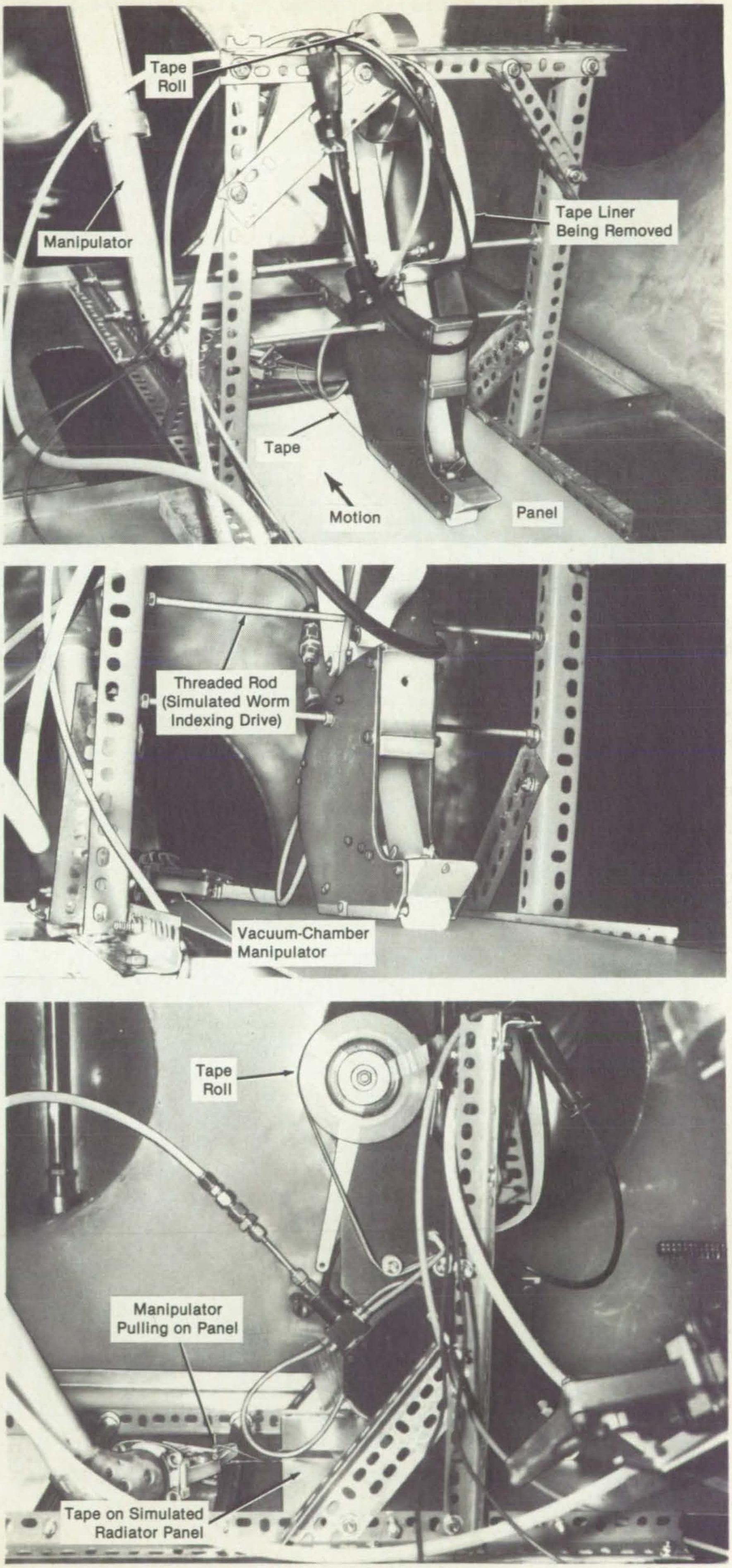
The device was developed to test the feasibility of applying thermal-control tape to radiator panels in the Space Station. Repairs could then be made in orbit; it would be unnecessary to return radiators to Earth for refurbishment. The device can be used in air, possibly as part of a terrestrial fabrication process. However, if the taped item is to be exposed subsequently to a vacuum, the possibility of the formation of bubbles of trapped air must be taken into account.

Housed in a vacuum chamber, the device presses a tape dispenser against a panel (see figure). As a manipulator pulls the panel under the dispenser, tape from a roll adheres to the panel and forms a long strip. The tape liner is separated from the tape as the tape is dispensed. When a strip has been laid down, a threaded rod can be rotated to index the device to a new position for application of an adjacent strip.

*This work was done by Karyn S. Downs and Kenneth A. Karki of Martin Marietta 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 18]. Refer to MFS-28187.*






The **Taping Device** lays down a strip of tape as the panel moves underneath.

**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.**

### Minimum Joint Gap for Robotic Welder

A vision system requires a minimum gap at a joint to be welded.

A report describes an evaluation of the factors influencing the minimum-gap requirement for a robot-welded joint. The evaluation is part of a series on a vision-based welding-control system.

In the robotic system, trajectory control is based on optoelectronic detection of the joint and, optionally, of the edges of the weld pool. The joint center and joint edges are extracted from the second derivative of the light-intensity profile with respect to position across the joint. The maximum positive second derivative defines the joint center, and the maximum negative second derivative defines the edges. Each feature is given a confidence level based on the number of times the feature is detected within a window column.

When the system calculates a response to a tracking error, it uses the detected joint features on a priority basis. The first priority is to use the detected joint-edge locations to calculate the joint center, which is then used to determine the tracking error. This method is the most accurate. However, if the confidence levels of the joint edges are below a preset threshold, the detected joint center is used in the error calculation. If the confidence level of the detected joint center is also below the threshold, the system makes no control response, but maintains its current path.

In the evaluation of the joint-tracking system, plates 0.125 in. (3.2 mm) thick, to be butt-welded, were beveled to obtain the desired gaps on the surfaces opposite those of the butted edges. Joints with included angles of 0°, 5°, and 10° were studied, corresponding to gap widths of 0, 0.01, and 0.02 in. (0, 0.25, and 0.5 mm, respectively). The butted plates were clamped in a fixture. A welding-torch manipulator was programmed to follow the joint closely.

The experiments showed that a minimum gap width less than 0.01 in. (0.25 mm) is adequate under controlled conditions. This means that the edges of the plates 0.125 in. (3 mm) thick to be joined have to be beveled to an angle of only 2.5°. However, the gap is a function of the workpiece restraint, the heat input, and the heat flow, all of which affect the thermal distortion of the gap. For practical purposes, therefore, a minimum gap of about 0.02 in. (0.5 mm) is needed, corresponding to a 5° edge bevel or 10° included angle at the joint.

*This work was done by K. J. Gangel and J. L. Weeks of Rockwell International Corp. for* **Marshall Space Flight Center**. *Further information may be found in NASA CR-178537 [N86-16586/NSP], "Investigation of Weld Joint Detection Capabilities of a Coaxial Weld Vision System."*

*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. The report is also available on microfiche at no charge. To obtain a microfiche copy, Circle 16 on the TSP Request Card.*

*MFS-27144*

# Mathematics and Information Sciences



## 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.

### The Diffusion of Innovation

New ideas encounter obstacles on the way to becoming products.

A report examines the process by which new ideas become products, processes, or accepted standards — a sequence of events that has been called "the diffusion of innovation." The report focuses on the development of material processing in low gravity as a case study in the diffusion of innovation.

The report considers the origins of the diffusion process in consumer and nonconsumer industries. It analyzes incentives for innovation and the roles of market "pull" and technology "push."

The learning process is discussed as it pertains to innovation, from the purely personal and psychological level to the communal level. The ways that ideas spread are reviewed — word of mouth, journals, and advertising media, for example.

Details of the diffusion process are examined. In particular, the product-development process in a high-technology industrial firm is found to evolve naturally through assessment, development, and execution. Special attention is given to the barriers that impede the diffusion of innovation. Among these are schisms between designers and materials specialists, between materials scientists and materials processors, and between theoreticians and empiricists. Ways of bridging the schisms are evaluated. Notably the MIT Materials Processing Center was founded to work with industry and government on broad problems in the production and forming of materials.

Finally, the industrial marketplace is scrutinized. The influence of risk and uncertainty on diffusion is discussed, as is the effect on company attitudes of such factors as company size, resources, management structure, available capital, and competitive status. Attitudes are summarized for large companies, middle-size companies, small companies, and entrepreneurs.

*This work was done by Gerard J. Earabino, G. Christopher Heyl, and Thomas J. Percorini of Worcester Polytechnic Institute for* **Marshall Space Flight Center**. *To obtain a copy of the report, "The Diffusion of Innovation: From Concept to Product," Circle 132 on the TSP Request Card. MFS-26010*

### Partitioned Matrices for Combined Linear Systems

Multiple-input, multiple-output mathematical models are combined.

A report presents the mathematical background for the combination of linear multiple-input, multiple-output equations of subsystems into overall matrix equations for a whole system. The development of such system mathematical models is essential for the design of complicated control systems.

The theory applies to subsystems that behave according to

$$\dot{\mathbf{x}} = A\mathbf{x} + B\mathbf{u}$$
$$\mathbf{y} = C\mathbf{x} + D\mathbf{u}$$

where **x** and **y** are state and observation vectors, respectively, and where A, B, C, and D are the state, control, observation, and feedforward matrices, respectively.

The equations of a subsystem can include an input-selection matrix F that operates on generalized input vector **w** to produce selected input $\mathbf{u} = F\mathbf{w}$. There can also be an output-selection matrix H that operates on the observation vector to produce selected output $\mathbf{z} = H\mathbf{y}$. An output-selection matrix that is not an identity matrix could be used as a feedback-controller model independent of the model of the plant to be controlled.

The system models can be produced from the models of six different kinds of combinations of subsystems: (1) separate subsystems with parallel inputs, (2) separate subsystems with parallel inputs and summed outputs, (3) concatenated subsystems, (4) separate subsystems with a common input, (5) separate systems with a common input and summed outputs, and (6) a feedback system composed of two subsystems.

The system matrix equation is formed from and can be partitioned into submatrices. Just as a matrix equation is formed from scalar equations, a matrix equation representing a system can be formed with submatrix elements derived from the subsystem matrix equations. The overall matrix and the submatrices can be manipulated in the same manner as that of normal matrices and their elements, provided that the matrices are conformable for the given mathematical operation. The author develops the partitioned system matrix representing each of the six subsystem combinations.

The report includes a description of a MATRIX$_x$* computer-program-command file to aid in the combination of subsystem models. This file uses subsystem matrices that have names consistent with those in the mathematical derivation. The options provided by the command file are the six subsystem combinations. The command file produces A, B, C, and D submatrices and the full matrix for the total system.

*MATRIX$_x$ is a proprietary product of Integrated Systems, Inc., Palo Alto, California.

*This work was done by Eugene L. Duke of Dryden Flight Research Facility for* **Ames Research Center**. *Further information may be found in NASA TM-85912 [N86-25166/NSP], "Combining and Connecting Linear, Multi-Input, Multi-Output Subsystem Models."*

*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.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center* *[see page 18]*. *Refer to ARC-11727.*

## New Products

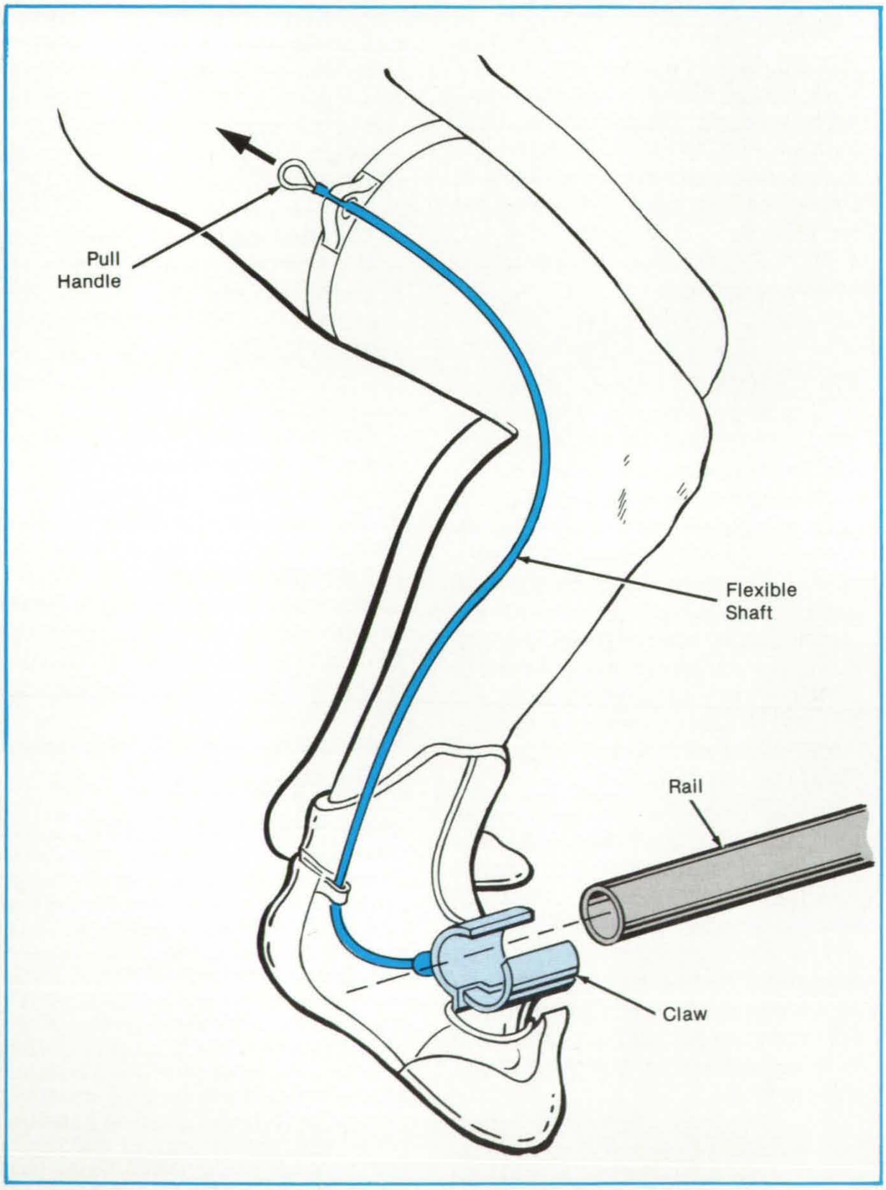
**A base station that improves the commercially available accuracy of the Navstar Global Positioning System (GPS) from 25 meters to within 10 meters has been introduced by Rockwell's Collins Air Transport Division. The Collins Differential GPS Base Station receives the GPS satellite signals, compares the position data with the position of a presurveyed point, and provides correction data to other GPS users observing the same satellites. Correction data includes the pseudo-range correction, delta-range correction, satellite ID and figure-of-merit, base station ID and health, and the age of the correction. Corrections can be sent in real-time through a radio link to the remote users. Circle Reader Service Number 367.**

## Prehensile Foot Restraint

Underwater or in space, this device would boost productivity.

*Lyndon B. Johnson Space Center, Houston, Texas*

A proposed prehensile foot restraint would enable such workers as astronauts and divers to maintain fixed positions in zero gravity or in buoyancy with minimal effort. With the foot restraint, a worker could devote attention more fully to the task at hand, with little concern about holding on to a supporting structure.




A **Claw Near the Toe of a Shoe** would grip a rail. The wearer would use the flexible shaft, first to lock the claw tightly on the bar; then, when the work is done, to open the claw.

The concept calls for a clawlike fixture on each of the worker's feet (see figure). The claw would grip a rail in the work area, fixing the worker's position without awkward belts or torso clamps.

Positioned on the top of the foot between the toes and arch, the claw would be easily seen by the wearer. To lock onto a rail, the wearer would bring the top of the foot under the rail. The act of bringing a claw in contact with the rail would activate a mechanism to close the claw loosely. Later, when the wearer is in the desired orientation and position on the rail, the wearer can activate a locking mechanism to make the claw grip the rail tightly. With both feet thus engaged, the wearer will be securely perched on the rail, much like a bird on a branch.

The locking mechanism would be operated through a flexible shaft extending from the claw along the leg to midthigh, where the shaft handle could be easily reached. The same shaft would be used to release the claw when the worker is ready to move. The shaft would not interfere with joint movement at the ankle, knee, or hip.

Two shafts — one on each leg — could be extended and joined on a girdle at the abdomen. The wearer could then lock or release both claws simultaneously with a single motion.

Two other methods of activating the locking/unlocking mechanism are also proposed. In a system based on over-center latching and releasing, the wearer could simply pull the shaft; the first pull would latch, and the second would unlatch. Alternatively, to lock the claw, the wearer could turn a spin-wheel- or water-faucet-type double-acting helix drive to pressurize a hydraulic gel in the shaft against a piston that is spring loaded in the "open" position. To unlock and open the claw, the wearer would turn the wheel to relieve the hydraulic pressure.

*This work was done by Charles A. Willits of Rockwell International Corp. for* **Johnson Space Center**. *No further documentation is available.* *MSC-21071*

Special Report:

# HIGH TECH CAREERS


## An overview of today's engineering job market

"Despite up-turns and downturns as market conditions change, skilled engineers continue to be in great demand," says Joseph Gendron, Managing Director for Source Engineering, a nationwide recruiting firm targeting engineers. "But," he points out, "despite this demand, needs for specific engineering skills will rise or wane as technology evolves."

Which high tech specialties are on the rise? Here are key areas experts advise watching:

• **Electronics**—The electronics market is experiencing a period of rapid growth, with more than 100,000 jobs having been created since 1983, reports the U.S. Bureau of Labor Statistics. "The demand is greatest for senior level engineers with software design expertise and a working knowledge of hardware," says Thomas Thrailkill, President of Independent Personnel Consultants, an Alabama-based recruiting firm.

Defense electronics will remain a booming market in upcoming years, according to Mr. Gendron. "An order backlog on projects such as SDI (Strategic Defense Initiative) and ELINT (electronic intelligence) will create opportunities for military engineers into the next decade and beyond," he explains.

• **Artificial Intelligence (AI)**—"The most lucrative high tech field today is artificial intelligence," states Janet Dierker, a recruitment specialist for Booz Allen & Hamilton, a leading technology consulting firm. "A shortage of qualified engineers has turned AI into a seller's market."

Mr. Gendron predicts AI will be a $5 billion industry by 1990. As CAD/CAM/CIM expands, he says, "the entire arena of AI will grow. Fields of specialization such as knowledge representation, machine vision, and image processing will come into their own."

• **Aerospace**—Mr. Thrailkill foresees increased opportunities within the space program. "Things are starting to turn around now that we have a reasonably firm schedule for the next few Space Shuttle launches," he states. "And there's also a great deal of anticipation for Space Station."

"The advent of Space Station will dramatically increase the engineering job market," according to James Furilla, Personnel Director for Ford Aerospace. Mr. Furilla estimates that within the next five years the project will create 2000 additional positions for design engineers alone.

"(Space Station) will open up a whole new world of opportunities in areas such as waste management, chemistry, thermal analysis, and electronics for communications," adds Lee Holcomb, a professional recruiter for Grey-Kimball Associates, a New York search firm.

• **Communications**—The communications field will expand at least fourfold over the next decade, Mr. Gendron predicts. "This surge," he explains, "is due in part to improved price/performance of new communications technologies, and in part to the divestiture of Bell Systems." Gendron stresses the need for communications engineers to broaden their skills. Engineers who can combine multiple skills of mechanical, electromechanical, chemical, electronics, acoustics, and communications theory and application will be in top demand by communications companies, he says.

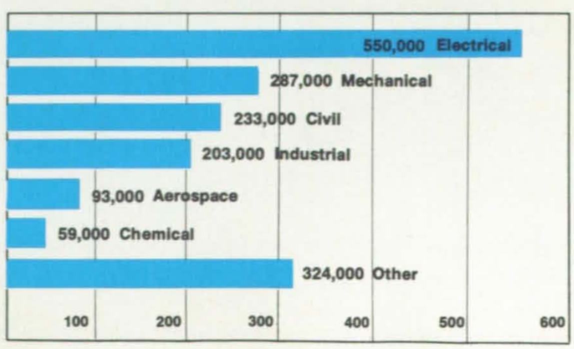
• **Semiconductors**—The semiconductor industry is "just beginning to make a crack in the cement wall," according to Mr. Gendron. "Newer technologies are now gaining industry acceptance that will help revitalize the industry." Gendron looks for manufacturers to initiate the evolution of new, less costly IC's in the near future.

Ms. Dierker, however, foresees continued stagnation. "It may be awhile before there's any real job growth in the semiconductor industry," she says. "We've simply reached the saturation point in that market."

Chemical engineering is another area in which Ms. Dierker sees little growth potential."The chemical and petrochemical industries are on a downswing right now," she says. Adds Mr. Gendron, "Chemical engineers are the hardest for us to place. The demand just isn't there."

Of the high technology market on a whole, however, the experts agree there is little danger of oversaturation. "There are still more jobs than bodies to fill them," comments Mr. Furilla. "I don't foresee that changing anytime soon." □

***Approximate Number of Engineers Employed in the U.S.:***




Employment, 1986 (000's)
Source:
Bureau of Labor Statistics

# Feedback

### Changing Formats

I would like to see an easier "scanning" format summary, such as an article list on the front cover.

John Dunlop
Development Engineer
Cominco Electronics
Spokane, WA

*Editor's note: Though we didn't use Mr. Dunlop's suggestion, we have redesigned the journal, commencing with this issue. Let us know how you like it.*

### White Hot

I am interested in flame retardants for polyolefins. The articles "Fire-and Heat-Resistant Laminating Resins" (May, 1987) and "Catalytic Layer Makes Aircraft Seats More Fire Retardant" (May, 1987) were very thought-provoking and helped me generate ideas for my research.

Dr. Marifaith Hackett
Chemist
Amoco Chemical Company
Naperville, IL

We were considering using Halon 1301 in Space Station fire suppression, but were worried about toxic compounds produced when Halon 1301 is used to extinguish fires. I noticed an article in *Tech Briefs* in which Johnson Space Center had eliminated this problem by addition of ammonium compounds to the Halon prior to using it as a fire suppressant. While we are a NASA center, the agency is too large for us to know about programs conducted at other centers, and *Tech Briefs* helps in this area. (We need more chemical or hazardous waste articles.)

Dinah Higgins
Aerospace Technologist - Materials
NASA/Marshall Space Flight Center
MSFC, AL

### Problem Solving

Two recent articles—one regarding the "wet winding" of coils, and the second regarding conductive silver epoxy, were applied with good results to our production methods. The first article helped us with a cost/time problem regarding encapsulation of site-built coils, and the second solved a reliability problem with its advice to abrade surfaces to help the adhesion of the silver-filled epoxy.

Bruce E. Baldwin
QA Manager
Microwave Application Group
Santa Maria, CA

*Tech Briefs* has provided solutions in the design and control of self-regulating systems, and has provided insights and solutions in problems of material selection.

Dr. Hugo E. Mayer
Operations Research Analyst
TRADOC Analysis Command
Ft. Leavenworth, KS

I enjoy the articles on services to small technical firms such as low-cost patent searches and information retrieval/search services. Knowing about these resources is fully as important as the technology items you report.

S. B. Prellwitz
Principal
Prellwitz/Pittsburgh Co.
Pittsburgh, PA

### Budget Booster

A very convincing tool in persuading management as to the importance of certain technological developments and their impact on our requirements. Thank you for this very informative and impressive service.

M.F. Aschenberg
Senior Manufacturing Engineer
McDonnell Douglas
Long Beach, CA

# Subject Index

# Classifieds

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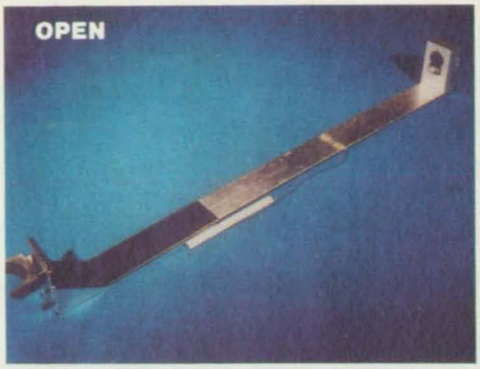
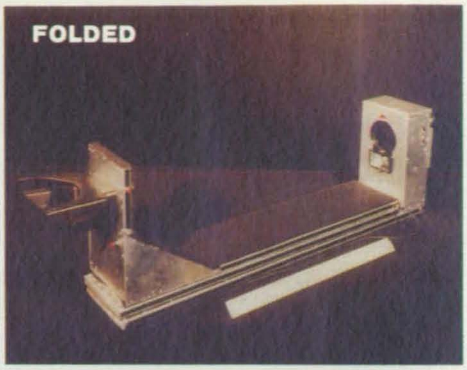
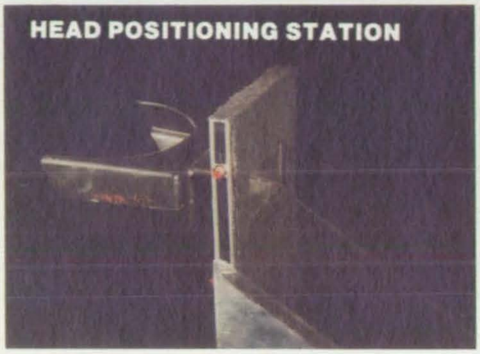
**Through the technology transfer process, many of the systems, methods and products pioneered by NASA are reapplied in the private sector, obviating duplicate research and making a broad range of new products and services available to the public.**





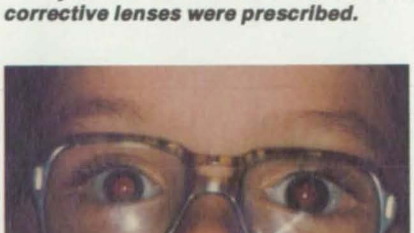
# Mission Accomplished

In the United States today thousands of young children have eye defects which, if not detected and treated in the early stages, could result in permanent blindness. Until recently, however, there was no nationwide ocular screening program for the young, due to the lack of a fast, reliable, and economical method. But now a NASA-patented screening system called Visiscreen-100 provides the means for wide scale detection of vision problems.

Visiscreen was jointly developed by NASA's Marshall Space Flight Center and Dr. Howard Kerr, President of Medical Sciences Corporation (MSC), exclusive manufacturer of the system. The portable 2.4 meter apparatus contains at one end a hood to hold the subject's head, and at the other a photorefractor consisting of a 35-mm camera and electronic flash unit. The flash causes light to reflect from the subject's retina back to the camera lens. The photorefractor then produces a color photograph of the subject's eyes, which MSC technicians analyze using a set of computerized algorithms. Each eye is examined for refractive error and obstruction in the cornea or lens, while alignment defects are detected by photographing both eyes simultaneously. If problems are discovered, they are verified by ophthalmological follow-up.

"The tremendous advantage of this system is that it requires minimal cooperation from the child," said John Richardson, New Technology Director at Marshall. "Communication isn't necessary, which makes Visiscreen especially useful for infants and other non-communicative children."

***Above: Amblyopia (commonly called "lazy eye") first detected with the Visiscreen-100 system. Below: The same child after corrective lenses were prescribed.***



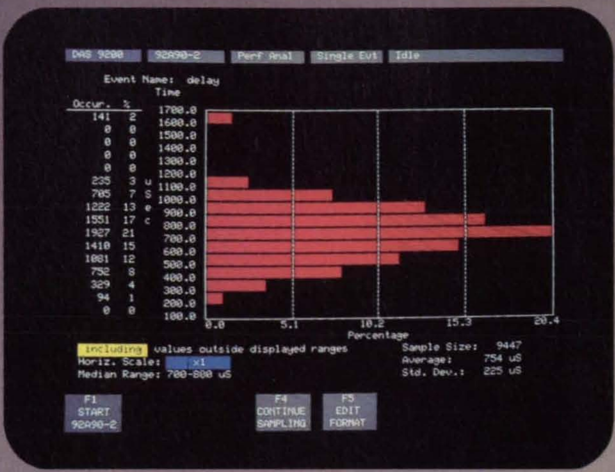
Added Dr. Kerr, "Pediatric ophthalmologists have told us how they sometimes spend two hours chasing a child around the office with a retinoscope, trying to get some cooperation. With the photorefractor we can screen 100 children in one hour without any fuss. And we do it at a very reasonable cost." (MSC currently charges $11.00 per screening.)

Visiscreen offers greater sensitivity than the traditional eye chart. In a test of 1,657 Alabama children, only 111 failed the chart test, but the Visiscreen system found 507 abnormalities that were later verified by ophthalmologists. Another test of more than 700 kindergarten and first grade students proved Visiscreen 95% accurate in detecting refractive error. Overall, the invention has been used on more than 20,000 children in 23 states.

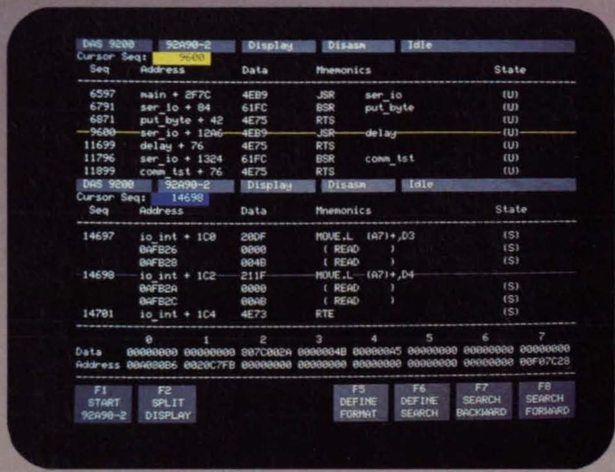
MSC provides screening at 1,025 Kinder-Care Learing Centers in the United States and Canada. The company has also established programs with the Illinois Department of Health and the CIGNA Healthplan of Georgia. According to Dr. Kerr, within five years MSC will have regional offices in 29 states covering an area containing 90% of the U.S. population.

Although Visiscreen looks to be a commercial success, its value transcends mere dollars and cents. "What's really important," said Dr. Kerr, "is that we've found a very significant number of children to be candidates for defects like amblyopia (progressive dimness of vision) and caught them in time to be treated. We get a lot of nice letters from grateful parents. That makes it all worthwhile." □

# DAS9200 DIGITAL ANALYSIS: NOW TEK MAKES THE IMPOSSIBLE LOOK EASY.




Software Performance Analysis, like this distribution of a subroutine's execution times, helps you easily understand the activity of your code.




Step backwards through acquired data, including subroutines, stack and register models, using time-correlated split-screen displays to pinpoint problems.

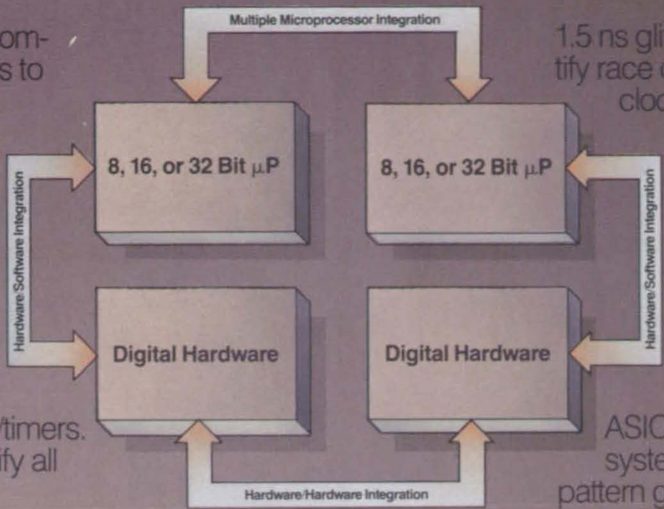
**In every dimension— speed, channel width, memory depth, trigger capability, modularity and ease of use—the DAS9200 dwarfs what's been possible before.**

The DAS9200 features a tightly coupled, high-speed architecture in which multiple card modules can act as a single unit. Large color-coded displays, pop-up menus, performance analysis graphs,

multi-tasking and more combine to take logic analysis to levels like these:

**1 State-driven triggering at 200 MHz.** You can use up to 384 channels of sync and async data acquisition. You can assurance-test high-speed logic at full speed, using 4-level state tracking and high-speed counter/timers. You can monitor and verify all timing measurements in a circuit.

**2 Symbolic, real-time software debugging.** Register deduction and stack simulation let you pinpoint problems like stack overflow or incorrectly restored pointers—without breakpoints or manual notation.




**3 Simultaneous integration of up to six microprocessors.** Use the dual timebases and real-time handshaking between system modules to set up split-screens displays that scroll in precise time alignment.

**4 160 channels of acquisition at 2 GHz.** Use up to 500 ps sample interval and 1.5 ns glitch detection to identify race conditions, spurious clocks and setup/hold violations in any logic family. System probes feature input capacitance of <1 pf.

**5 Easy ASIC verification at up to 50 MHz.** The DAS9200 is available as a low-cost turnkey ASIC device verification system. Featuring 50 MHz pattern generation, 8K bit vector depth, and 1 ns edge placement, it offers the power, precision and simplicity to be an attractive alternative to centralized systems.

**6 Stop wishing for the impossible in digital analysis:** Compare your wish list against the complete list of DAS9200 capabilities. Contact your Tek sales engineer, or call toll-free for more information.
**Call 1-800-245-2036.**
In Oregon, 1-213-1220.

Available in desktop and rack-mount versions, the DAS9200 mainframe can be augmented with up to three expansion mainframes for a total of 28 card slots.

**Tektronix**
COMMITTED TO EXCELLENCE

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