NASA Tech Briefs

Official Publication of
National Aeronautics and
Space Administration
Volume 16 Number 1

Transferring Technology
to Industry and
Government
January 1992

Technology 2001:

The Road To The

FUTURE

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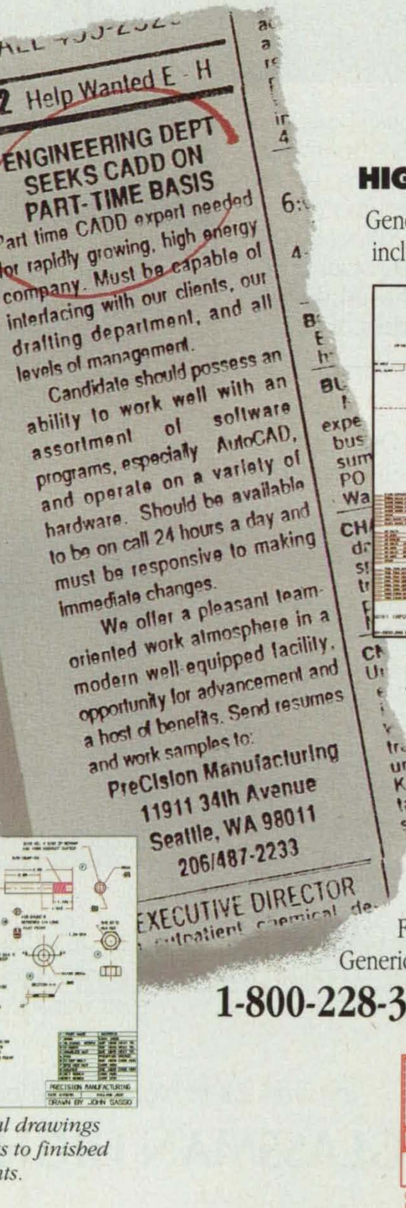
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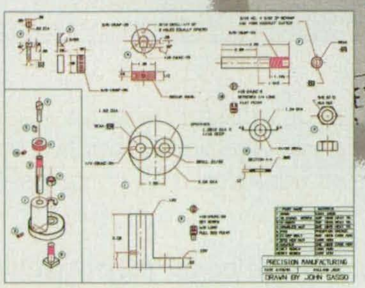

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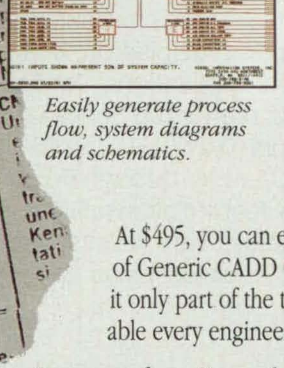

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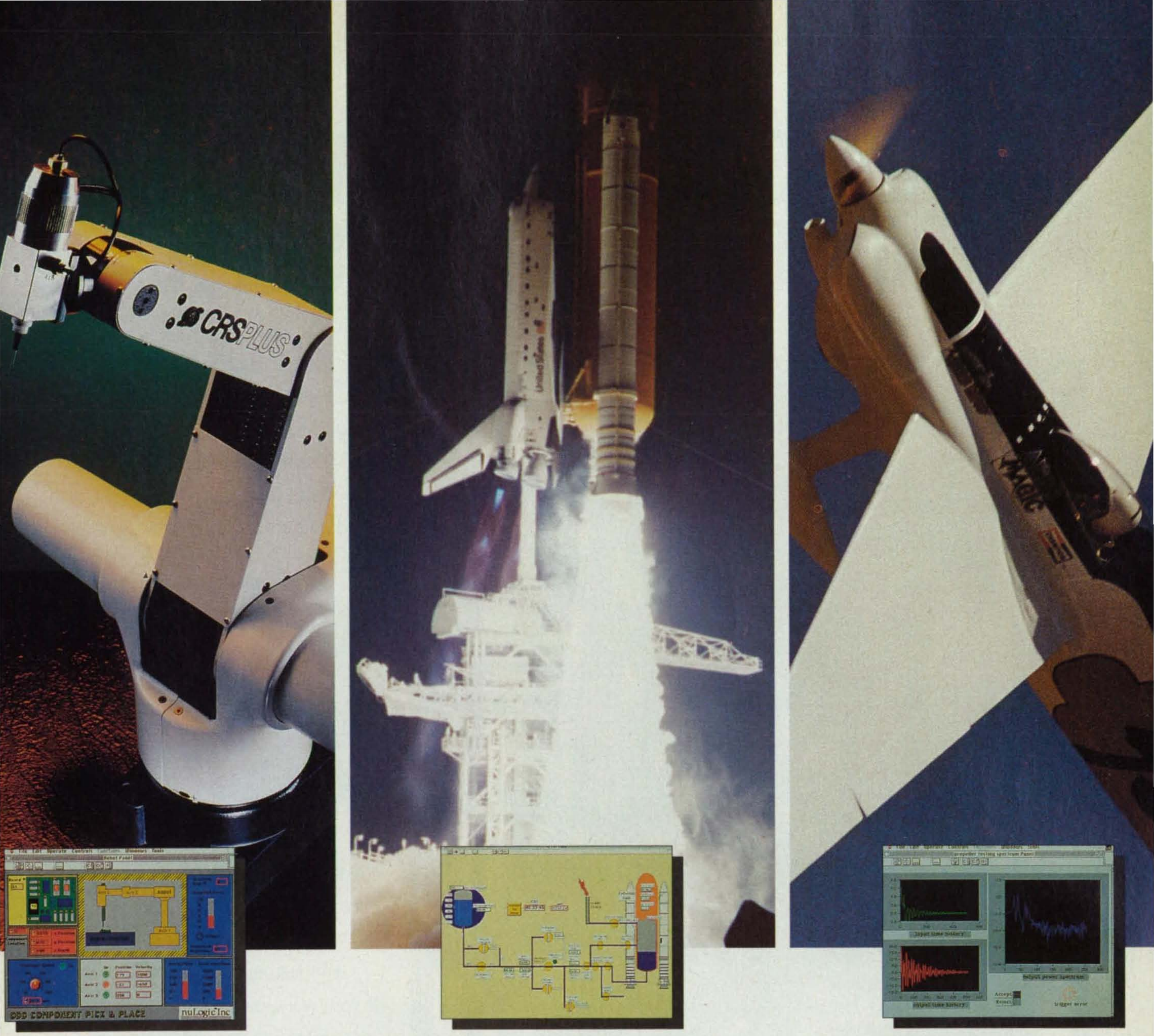
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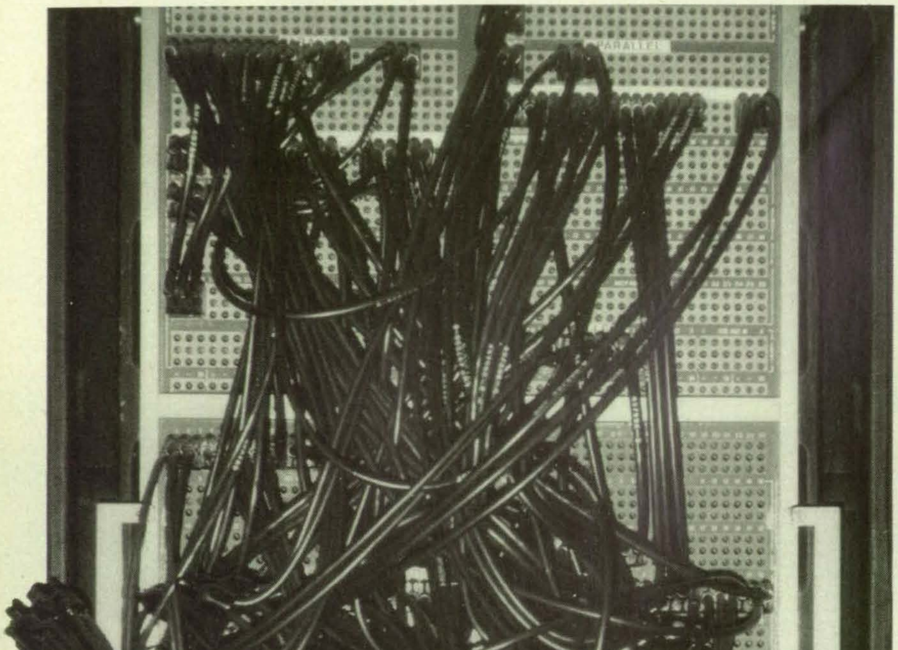

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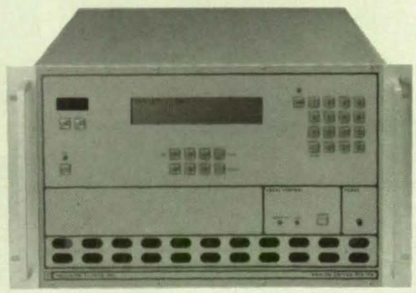

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NASA Tech Briefs

Transferring Technology to Industry and Government

January 1992
Volume 16 Number 1

BPA ABP

Illustration courtesy Ames Research Center

A proposed oblique-flying-wing aircraft would transport passengers and cargo at twice the speed of sound, yet cost the same as current subsonic planes. The tech brief on page 66 explains how the craft would work.

SPECIAL FEATURES

TECHNICAL SECTION

DEPARTMENTS

On The Cover: NASA administrator Richard H. Truly (bottom left photo) gave the keynote address at Technology 2001, the second national technology transfer conference, which featured over 200 exhibitors and 120 technical presentations, and which attracted nearly 4000 attendees to the San Jose convention center. Our show report, including excerpts from Mr. Truly's remarks, begins on page 10.
(Photos courtesy Ames Research Center)

This photo of the ice-covered Kerguelen Island in the South Indian Ocean was captured by the space shuttle's electronic camera from an altitude of 325 miles. The image was processed and color-enhanced using a new software package developed with NASA's help. See Mission Accomplished, page 116.
Photo courtesy Electronic Imagery Inc.

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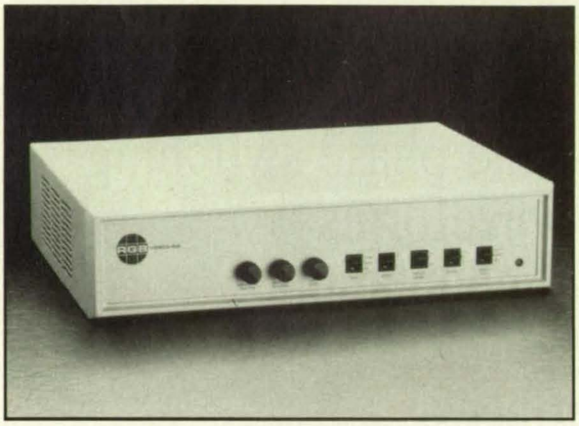

NASA Tech Briefs

Official Publication of
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Published by .... **Associated Business Publications**
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Briefs & Supporting Literature:
Provided to National Aeronautics and Space Administration by
International Computers & Telecommunications, Inc.,
NY, NY with assistance from **Logical Technical Services**, NY, NY
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March 26, 1991
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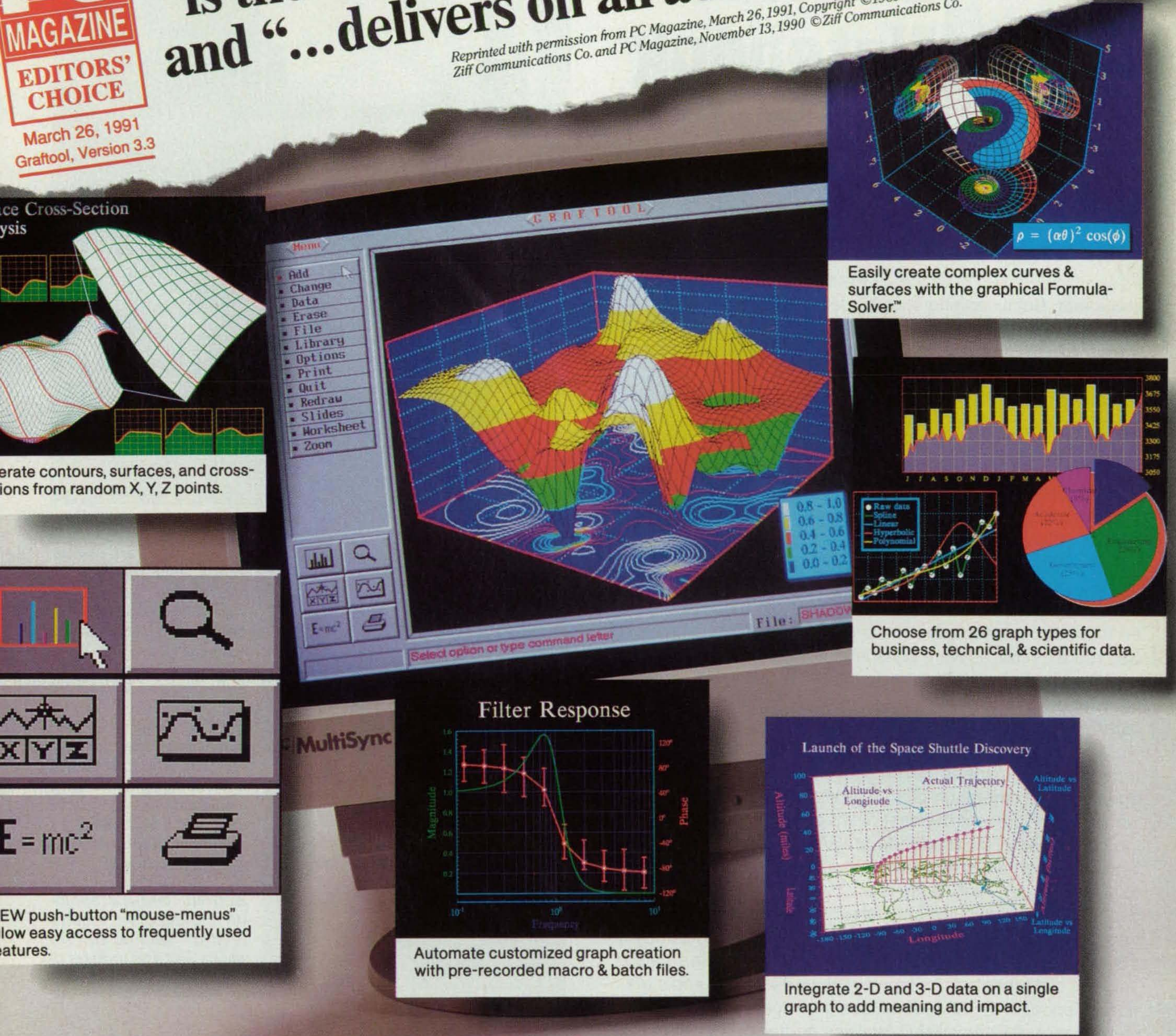

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Editorial Notebook

Technology 2001:

Bigger, Better, And Just The Beginning

Well, it's supposed to be easier the second time. I don't know about that. But it certainly was bigger, better, and even more fun. Perhaps it would have been easier too if we hadn't had twice the exhibit space and 50 percent more attendees than at last year's inaugural event, Technology 2000.

For the record, there were 220 exhibitors occupying 50,000 square feet of exhibit space (4,645 square meters for the metrically-minded) in the San Jose convention center for Technology 2001, the second national technology transfer conference and exposition. Chief scientists, research directors, project leaders, corporate executives...nearly 4000 of the top tier of technology managers in industry and government attended this year's conference, which was expanded from two to three days.

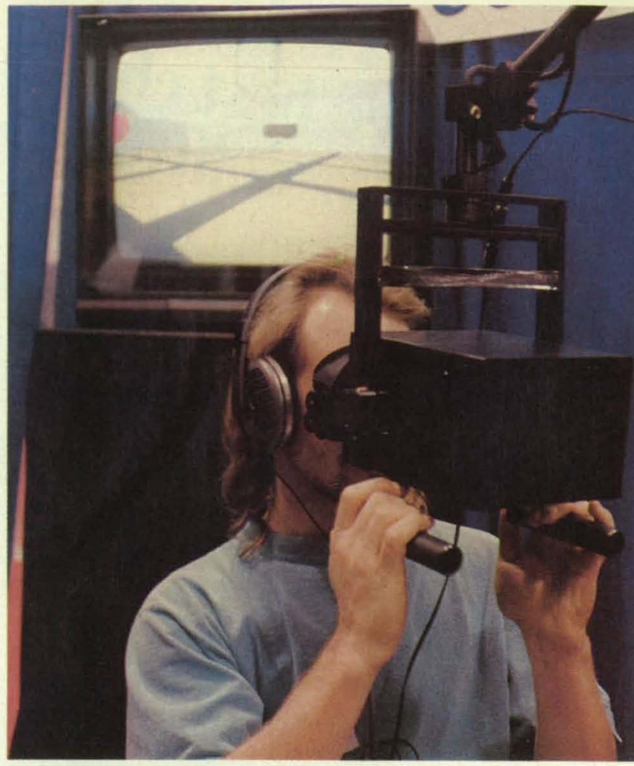
Attendees included over 100 members of the print and electronic media. Virtually every major engineering trade publication was represented, as were consumer magazines such as *Byte* and *Popular Science*. Technology 2001 was covered on ABC, CBS, and a number of cable channels, including CNN. The latter devoted an entire segment of *Future Watch* to the show.

Dr. D. Allan Bromley, science advisor to President Bush, urged NASA to expand Technology 2001 to include its sister agencies and other high-tech organizations, so that the show would truly represent the best of US technology available for industry's use. The result, as NASA administrator Richard Truly commented in his keynote speech (see excerpts on following page), was "impressive." Ten federal agencies joined NASA in exhibiting and presenting papers on their latest inventions available for transfer. Over the course of three days, 120 papers were presented in such diverse, yet interrelated, fields as biotechnology, computing, manufacturing, and materials science. In all, 50 federal labs participated, including 15 Department of Energy R&D facilities and all branches of the Department of Defense.

This, however, was only the beginning. For Technology 2002, to be held December 1-3, 1992 in the Baltimore, MD convention center, we plan to further expand the scope of the exhibits and technical presentations. Look for a "call for papers" in the next issue of *NASA Tech Briefs*, and other exciting details in subsequent editions. If you attended Technology 2001 and have suggestions for this year's event, we would love to hear from you. Call me or Joe Pramberger at (800) 944-NASA.

See you in Baltimore.

For information on obtaining the complete proceedings of Technology 2001, see page 93.



Above: Visitors to the Ames Research Center exhibit were transported to a "virtual" world via a computer system that generates 3D images and sounds.

Left: Pacific Northwest Laboratory, a Department of Energy R&D facility, showcased an array of environmental technologies, including an electro-optic sensor that precisely measures water and liquid contaminant levels in soil.

Bottom: NASA's exhibits included a "theater island" with a 20-foot video wall and models of the space shuttle and National Aero-Space Plane.

Above: Robert M. White, under secretary of the Department of Commerce for technology, addressed audience of 500 at the 1991 Technology Transfer Awards Dinner, held in conjunction with Technology 2001.

Right: Technology 2001 attracted TV, newspaper, and magazine reporters from across the nation.

Truly: Spinoffs Will Spur Economy

Richard H. Truly

Following are excerpts from the Technology 2001 keynote address by NASA administrator Richard H. Truly.

Given the erosion we have seen in America's competitive position, I cannot think of a subject more important to our economy than that being addressed (at Technology 2001): cutting-edge technology.

How valuable to the economy is the transfer of government-developed technology? Is there really a big payoff? The answer is...absolutely.

NASA's experience is a prime example. Our programs have spurred a revolution in new products and processes—more than 30,000 of them—to improve the quality of living and boost American competitiveness in the world marketplace. Just in the past decade, the bottom line on quantifiable benefits has been exceptional. Combined sales and savings amounted to almost $22 billion. Some 259 spinoff applications led to the creation or retention of 352,000 jobs over that decade. In 67 instances, the products or processes—and, in some cases, entire companies—would not have come into existence without NASA technology. These cases alone resulted in sales or savings totaling more than $5 billion.

The challenge ahead is for our space program to continue to drive spinoff technologies, and for American industry to more effectively bring derived products to a profitable marketplace.

Space technology spinoffs will receive a powerful new boost from space station Freedom. Freedom will allow us to pursue materials and life sciences research on an uninterrupted basis in a totally new environment: the world of microgravity.

On Earth, industry alters natural materials like iron ore by employing the physical phenomena you find here—heat, electricity, pressure, gravity, vacuum, magnetism, and so on. The outcome is a tremendous range of alloys, crystals, ceramics, electronic materials, pharmaceuticals, and more.

The new environment of microgravity and ultra-vacuum gives us additional control. Now we can eliminate the disturbing effects of convection, buoyance, and hydrostatic pressure. The result: great improvements in existing materials and creation of new materials.

We are talking about materials that will be stronger, lighter, and more heat-resistant than anything known on Earth. We are talking about super-quality semiconductors, resulting in super-fast computers. We are talking about pharmaceuticals, perhaps even to attack diabetes, cancer, and AIDS.

Once we get continuous access to micrograivty, access the station provides, we can engage in continuous experimentation to build up sound statistical bases. This will enable industry to establish the processes and controls required for quality commercial production, including production in space.

Another key area for technology development and transfer is life sciences. Life sciences research on the space shuttle and space station Freedom will have a big payoff on Earth. We will use our new knowledge to combat cardiovascular diseases, hypertension, and osteoporosis. It will give us new insights into aging, anemia, diabetes, muscle atrophy, and the basic immune function. Biomaterial will be developed to use for artificial skin, tendons, blood vessels, and the cornea.

NASA's aeronautics research has been providing tremendous technologies to industry for years. Today, we do a great deal of aeronautics research focused on the traditional goals of better performance, greater economy, and improved safety. One of our largest efforts is the resumption of research on a high-speed civil transport and the development of the National Aero-Space Plane, which is highlighted in an impressive exhibit at this conference. A substantial market is developing for a fleet of supersonic transports to serve the Pacific rim and transatlantic routes. Our research will help keep America at the forefront of this rapidly expanding opportunity.

Virtually all of this is setting the stage for the next great adventure in space: sustained human exploration of the solar system. Today, we possess the basic technical skills required to begin the expansion of the human race off the mother planet; to take another step in the evolution of the human race.

When we can muster the financial resources, human beings can return to the moon—this time to stay. Enormous opportunities await us there. It is rich in mineral resources. Telescopes on its dark side would be far more powerful than any on Earth or in space. And it is the perfect nearby classroom and laboratory to prepare for Mars.

Mars gives us the opportunity to explore for the first time in human history another planet, much like our own in many respects, but radically different in others.

(continued on page 114)

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 14). NASA's patent-licensing program to encourage commercial development is described on page 14.

Tissue-Simulating Gel for Medical Research

A new gel features thermal stability, which should make it useful for studying hypothermia as a treatment for cancer. The gel retains its shape without a supporting shell for simpler ultrasonic analysis. Liquids can be injected into it by hypodermic needle as into real tissue and can be viewed from outside.
(See page 80)

Stall-Departure-Resistance Enhancer

This enhancer improves the stall departure resistance of aircraft operating at or near angle of attack of a wing. The enhancer imposes a lesser drag penalty than do conventional vortex generators. It increases lift by as much as 30 percent.
(See page 61)

Improved Warm-Working Process for an Iron-Base Alloy

This process produces a predominantly unrecrystallized grain structure in forgings of an iron-base alloy. Billets forged this way have demonstrated improvements in yield and ultimate strengths and decreased elongation and reduction of area at break.
(See page 69)

Thin-Membrane Sensor With Biochemical Switch

A modular sensor electrochemically detects a chemical or biological agent. Possible applications include detection of bacterial toxins in food, poison gases in the air, and pesticides or other pollutants in the environment.
(See page 79)

Open-Pinned-Phase Charge-Coupled Device

These devices combine best attributes of multiphase and virtual-phase technologies. A relatively high quantum efficiency can be achieved to cover an expanded range of 1 to 11,000 Å. Other attributes include bidirectional clocking and ultralow dark-current generation.
(See page 16)

Acoustic Device Would Measure Density of Gas

A proposed sensor would measure the density of a flowing gas or mixture of gases via the amplitude of a low-frequency acoustic signal. The sensor could be configured in a variety of ways for monitoring industrial processes.
(See page 34)

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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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You can contact NASA's network of RTTCs for assistance in solving a specific technical problem or meeting your information needs. The "user friendly" RTTCs are staffed by technology transfer experts who provide computerized information retrieval from one of the world's largest banks of technical data. Data bases, ranging from NASA's own data base to Chemical Abstracts and INSPEC, are accessible through the six RTTCs located throughout the nation. The RTTCs also offer technical consultation services and/or linkage with other experts in the field. You can obtain more information about these services by calling or writing the nearest RTTC. User fees are charged for information services.

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Open-Pinned-Phase Charge-Coupled Device

Acceptable quantum efficiency can be obtained without back illumination and back-side thinning.

NASA's Jet Propulsion Laboratory, Pasadena, California

Multiphase charge-coupled devices (CCD's) have traditionally exhibited very poor sensitivity in the ultraviolet (UV), extreme ultraviolet (EUV), and soft x ray spectral regions because of the absorbing polysilicon layers associated with the technology. To bypass the problem, CCD manufacturers have been forced either to thin and back-illuminate the sensor or to deposit UV-sensitive organic phosphor coatings. Virtual-phase CCD technology, however, has resolved the frontside quantum-efficiency (QE) dilemma by leaving half of the pixel element "open," by employing a "virtual electrode" allowing photons to enter into the photosensitive bulk silicon unimpeded.

Unfortunately, unlike multiphase CCD's, virtual-phase detectors have limited usage in low-signal applications because of inadequate charge-transfer efficiency and read-out-noise impediments as well as other performance shortcomings. To circumvent these problems, a new CCD technology referred to as "open-pinned-phase" (OPP) was invented to unite the best attributes of multiphase and virtual-phase technologies. The new CCD promises to deliver high frontside sensitivity in conjunction with ultralow-signal-level performance.

In an OPP CCD (see Figure 1) as in a virtual-phase CCD, the collecting phase is directly exposed, allowing photons to enter the active regions of the semiconductor. The OPP CCD is fabricated by the same process steps as those of a three-phase CCD, except that the third level of poly is intentionally left off. In the third phase, two implants are incorporated in the open region. The first implant adds more phosphorus to the normal n channel, increasing the potential for signal charge to collect. The second implant, a concentrated but very shallow implant of boron, pins the surface potential at the Si/SiO_2 interface to the substrate potential. This pinning implant acts as a virtual gate, maintaining a fixed potential in the bulk silicon beneath the open phase. Both implants are self-aligned by poly levels one and two.

Charge transfer (see Figure 2) for the OPP CCD is accomplished as follows. In transferring charge from the open phase to phase 1, phase 1 assumes a high gate potential. Phase 2 remains at a low potential to act as a barrier to assure that no charge flows backward from the open phase to phase 1. In the next clock cycle, phases 1 and 2 are both biased high, and charge occupies both phases. Phase 1 is then set low, which in turn forces all charge into phase 2. The cycle is finished when phase 2 returns to the low state, and charge moves into the next open-phase region.

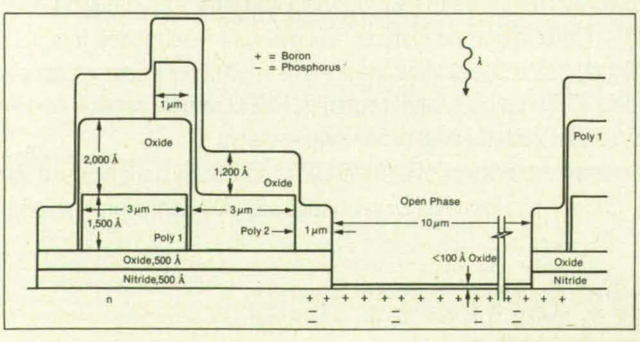
The open phase can be designed larger than the clocked phases to optimize QE performance. The QE of an OPP CCD is relatively high for wavelengths extending from 2,000 to 10,000 Å. The QE drops off rapidly for wavelengths shorter than 2,000 Å because of the absorption properties of the oxide/nitride gate layer. However, if this insulator is etched away, high QE can be achieved to cover an expanded range of 1 Å (soft x ray) to 11,000 Å (near infrared). Still higher sensitivities are possible if an antireflection coating is applied to the open phase, not possible with conventional frontside-illuminated CCD's.

Other attributes of OPP technology include bidirectional clocking (not possible with virtual-phase) and ultralow dark-current generation (for all phases are inverted during integration). Also, the OPP technology is closely related to three-phase CCD technology, which permits most multiphase CCD groups to be fabricated into OPP CCD's without significant change in their processing capabilities.

This work was done by James R. Janesick of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 124 on the TSP Request Card.*

In accordance with Public Law 96-517,

Figure 1. In this **Cross-Sectional View of an 18-μm OPP Pixel**, 12 μm are allocated for the open-phase region, and 6 μm for phases 1 and 2. The design is optimized for high QE applications working in the UV, EUV, and soft x ray regions (i.e., the gate insulator has been removed in the open region). (The vertical scale is exaggerated 10 times that of the horizontal.)



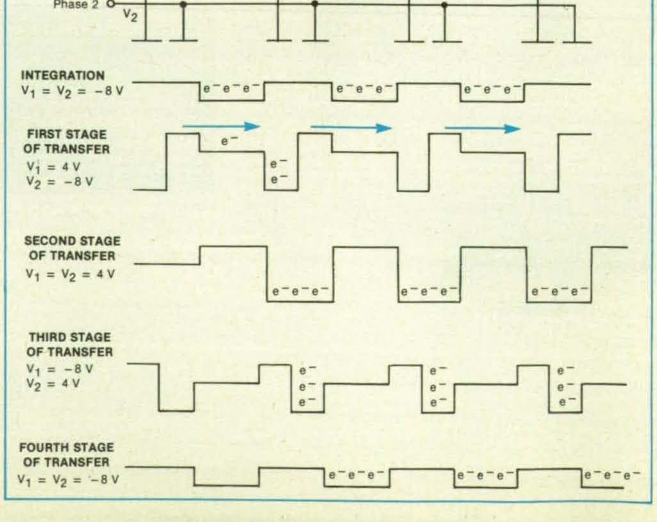


Figure 2. **Potential Diagram** shows how charge is collected within the open phase during integration and transferred during readout as different clock voltages are applied to phases 1 and 2.

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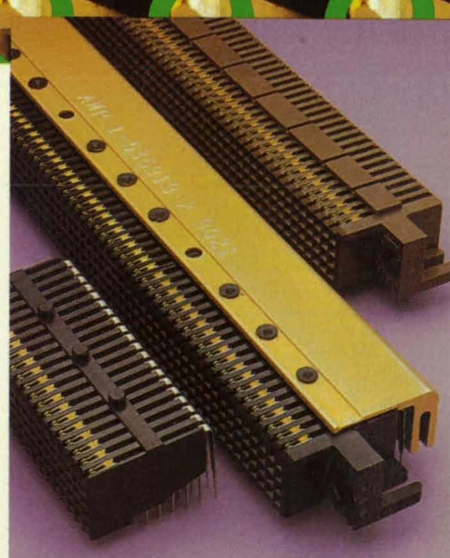

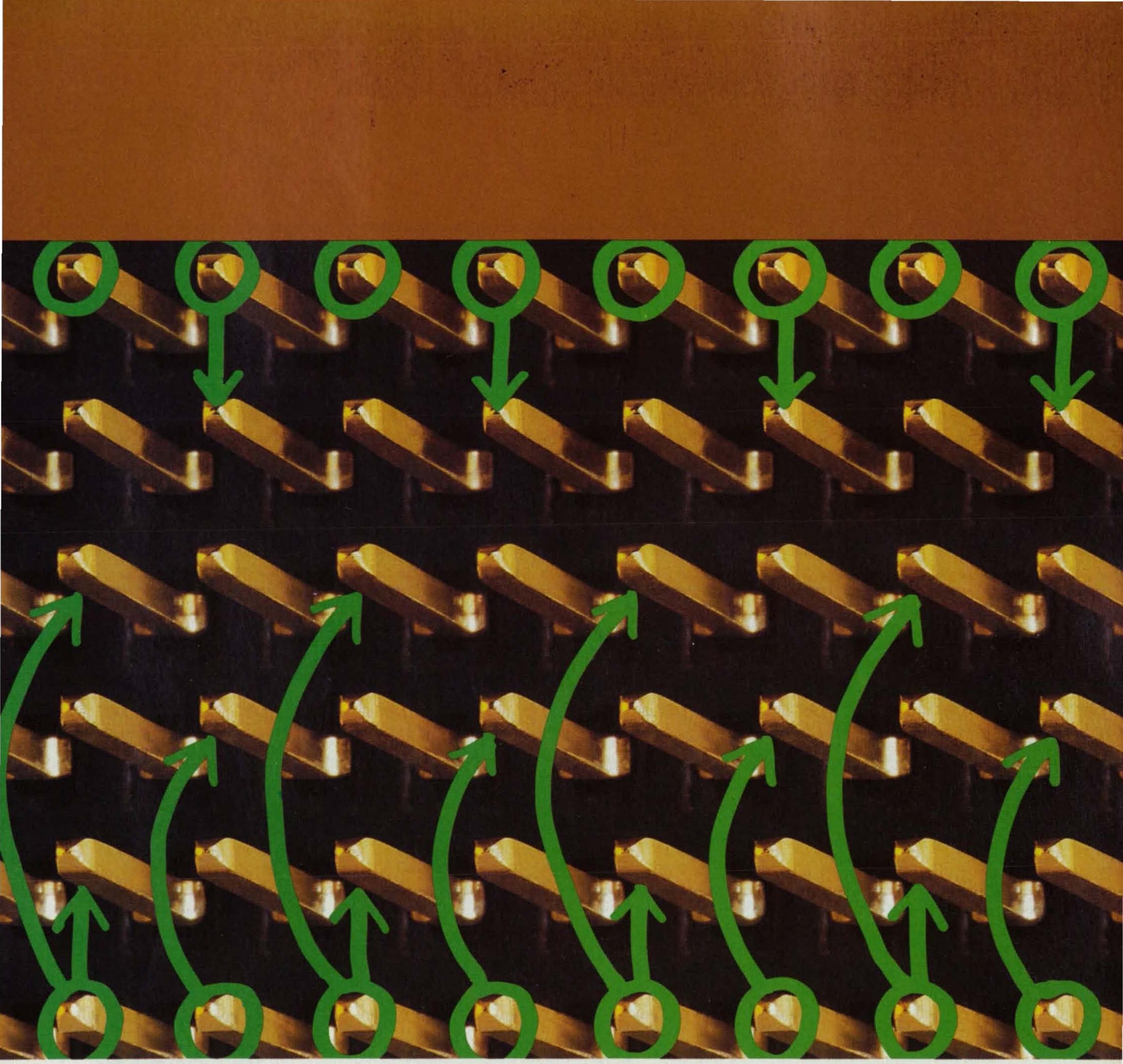

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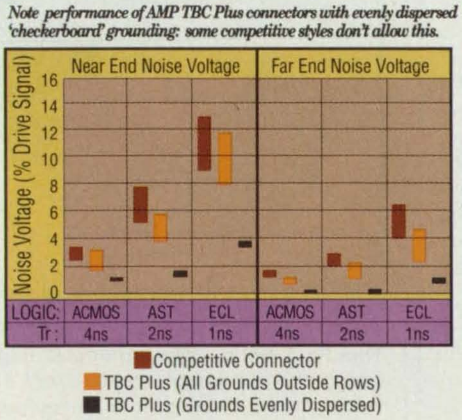

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Refer to NPO-17855, volume and number of this NASA Tech Briefs issue, and the page number.

Flexible, Thin-Film Solar-Cell Blanket

Much of the available area is used to absorb solar energy.

NASA's Jet Propulsion Laboratory, Pasadena, California

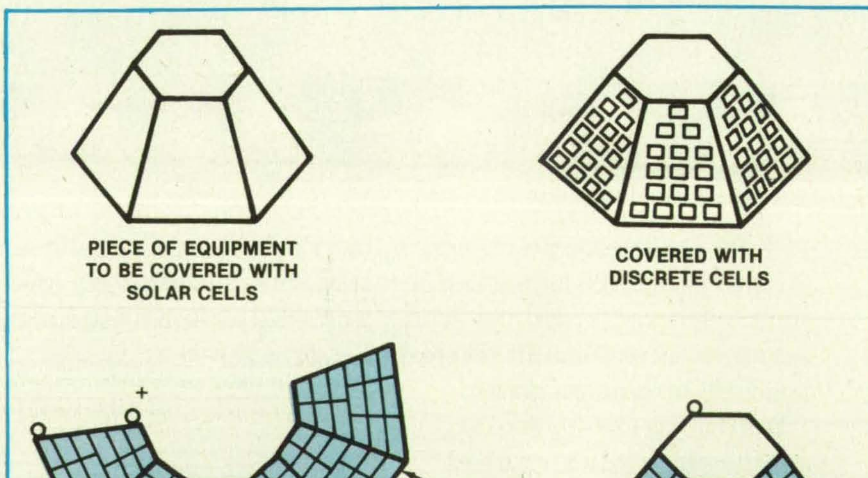
A proposed blanket of solar photovoltaic cells would be mounted on the exterior surface of the equipment it powers. It would readily conform to irregular shapes. It would not require a separate supporting structure and thus would save space. It would not be added on to the equipment but would constitute an integral part of it.

Such a blanket could be used to recharge a storage battery, for example. It would be wrapped on the outside surfaces of the battery housing and associated equipment, taking advantage of all available surface area for the generation of solar power.

The blanket would contain an array of thin-film photovoltaic cells fitted together edge to edge. Interconnection wiring would be deposited on the sheet photolithographically or by other suitable masking/fabrication methods. The complete blanket, including cells and interconnections, could, if desired, be fabricated as a rigid unit directly on, and supported by, the nonplanar surface to be covered. The cost of such a blanket might be less than that of an array of discrete solar cells. Because the space between discrete cells would be eliminated, a greater fraction of the total area would be available for the absorption of solar energy. Although thin-film cells are less efficient than discrete cells are, the use of all available surfaces and the elimination of space between cells would compensate. Only on purely rectangular surfaces might the discrete-cell-surface-utilization approach that of the irregularly shaped thin-film cell blanket.

The substrate need not be a flexible blanket. It could be jointed stiff panels shaped to suit the housing geometry: triangles, parallelepipeds, segments of circles, and the like. A thin-film photovoltaic circuit would be deposited on each panel.

This work was done by Paul M. Stella of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 62 on the TSP Request Card.*
NPO-18196



Thin-Film Solar Cells, arranged edge to edge on a flexible substrate, would be wrapped around equipment. Arrays of discrete solar cells, in contrast, must be individually mounted and interconnected, with significant space between them.

Double-Current-Confined CSP Laser

A second p/n junction increases differential quantum efficiency.

Langley Research Center, Hampton, Virginia

In spaceborne communications systems, the output emission wavelengths of lasers are chosen to be about 870 nm to avoid absorption of the emitted light by the atmosphere when communicating with ground-based terminals. Improved channeled-substrate-planar (CSP) lasers that emit at wavelengths between 860 and 880 nm have been grown by liquid-phase epitaxy (LPE). These lasers exhibit record high output powers and efficiencies, which are attained without sacrifice of desirable characteristics of the lasers.

Heretofore, in the fabrication of such a laser, a deep zinc diffusion has been performed to focus the current to the lasing area within the laser structure. This works well, but there is still some spread of the current outside the lasing area. This spread wastes some of the current, and the laser consequently operates at higher current and lower efficiency than it potentially could. Improvements could be realized if all the current could be effectively used for lasing within the laser structure.

In the fabrication of a CSP laser of the improved type, a second reverse-bias p/n junction is incorporated to reduce the required current. Such a junction permits current to flow in one direction in the laser. By incorporating two reverse-bias junctions in the CSP structure, one doubly confines the current. Thus, the structure of the improved lasers is called "double-current-confined CSP" or "DCC-CSP" (see figure).

The light generated in the active layer is absorbed in the current-blocking layer or the second reverse-bias junction, resulting in the generation of electron/hole pairs. Thus, the thickness of the layer must be larger than the minority-carrier diffusion length. If the thickness of this layer is less, minority carriers diffuse away from the blocking layer, resulting in an accumulation of majority carriers and a reduction in the barrier potential. As a result, current is permitted to flow through this layer. If the thickness of this layer is greater than the minority-carrier diffusion length, electrons and holes recombine in the layer, and the barrier to current is maintained.

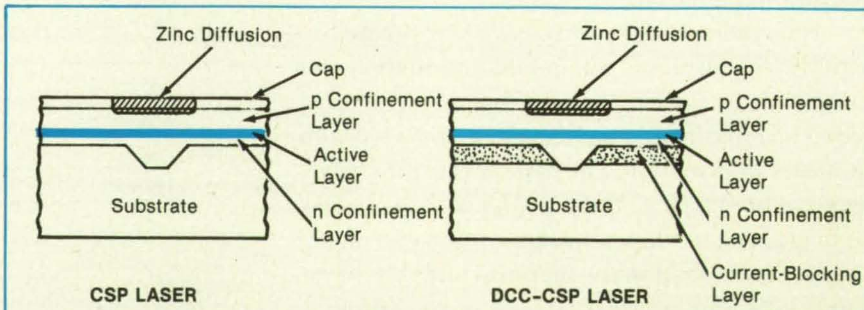
The incorporation of the second p/n junction in the laser structure requires the addition of a second growth step to the fabrication process. This growth step is best effected by metalorganic chemical vapor deposition (MOCVD). In addition, MOCVD enables growth on multiple wafers at once.

Laser devices containing DCC-CSP structures displayed a modest improvement in differential quantum efficiency over that of conventional CSP lasers, without any change in the desirable operating characteristics of the device. Operation in a single longitudinal mode was obtained at the same peak wavelength in both continuous-wave and 50-percent-duty-cycle excitations. These lasers would be used eventually as sources of light in intersatellite communications systems and, specifically, the NASA Advanced Communications Technology Satellite (ACTS) System.

This work was done by John C. Connolly of the David Sarnoff Research Center for **Langley Research Center**. *Further information may be found in NASA CR-4238 [N89-23860], "High-Power Single Spatial Mode AlGaAs Channeled-Substrate-Planar Semiconductor Diode Lasers for Spaceborne Communications."*

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 be calling (800) 336-4700.

LAR-14200



The **Blocking Layer** in the DCC-CSP laser increases efficiency over that of the CSP laser.

Simple Schlieren Light Meter

The positions of schlieren knife edges can now be adjusted objectively and accurately.

Langley Research Center, Hampton, Virginia

Schlieren optical systems are often used to observe or photograph perturbations in the refractive indices of compressible media; e.g., to make the flow of air visible in a wind tunnel. More than 20 schlieren systems dedicated to specific facilities, as well as numerous temporary systems, are in use at NASA Langley Research Center. However, since the advent of schlieren systems, the amount of cutoff of the knife edge in each system has been adjusted subjectively, and this practice has been the source of many problems.

The knife edge should be positioned at a focal point so as to obstruct half the light. Such a 50-percent cutoff makes the schlieren system equally sensitive to deflections either toward or away from the knife edge. In practice, the amount of cutoff of the knife edge has been set for the correct photographic exposure instead of for blocking half the light. Setting the knife edge objectively at the proper position will increase the repeatability of the system, independent of any bias of the operator.

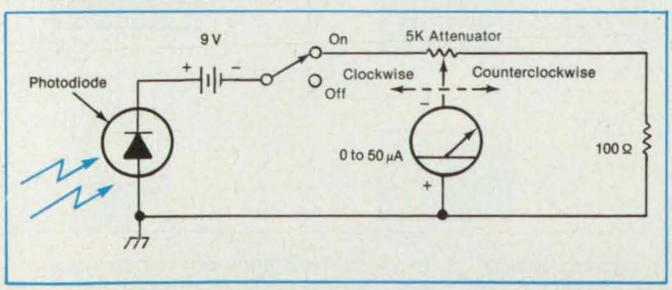
The figure is a schematic circuit diagram of a new instrument for aligning a schlieren system. A microammeter measures the current from a photodiode that is reverse-biased to produce a linear output current as a function of the intensity of light. An on/off switch is provided to disconnect the battery when the instrument is not in use. A potentiometer is connected as an attenuator to vary the sensitivity of the instrument.

In operation, the unit is turned on with the attenuator set fully counterclockwise to minimum sensitivity. The photodiode is placed in an unblocked portion of the light cone behind the position of the knife edge. The knife edge is initially adjusted to no cutoff. The attenuator is turned clockwise until the meter reads full scale, which is, in this example, 50 μA. If a full-scale reading is not possible, the peak reading is used. Next, the knife edge is advanced across the beam, increasingly cutting it off (causing the reading of the meter to decrease). When the meter reads half the full-scale or peak reading, the knife edge has reached its proper position. The photodiode should then be removed from the optical path, and the instrument turned off until it is to be used.

When the knife edge is thus properly positioned, exposure can be controlled by varying the brightness of the source of light, varying the shutter time, and/or using neutral-density filters. The exposure should not be changed by varying the cutoff of the knife edge because doing so diminishes the value of the resultant photograph in that it does not indicate deflections toward or away from the knife edge with equal sensitivity.

The use of the schlieren light meter enables the operator to check quickly the position of the knife edge between tunnel runs to ascertain whether or not the schlieren system is in alignment. A permanent measuring system can be made a part of each schlieren system. If placed in an unused area of the image plane, or in a monitoring beam from a mirror knife edge, it can provide real-time assessment of the alignment of the schlieren system.

This work was done by David B. Rhodes, John M. Franke, Stephen B. Jones, and Bradley D. Leighty of **Langley Research Center**. *No further documentation is available. LAR-14249*



This **Simple Light-Meter Circuit** is used to position the knife edge of a schlieren optical system to block exactly half the light, reducing the inaccuracies caused by the previous subjective technique for the alignment of knife edges.

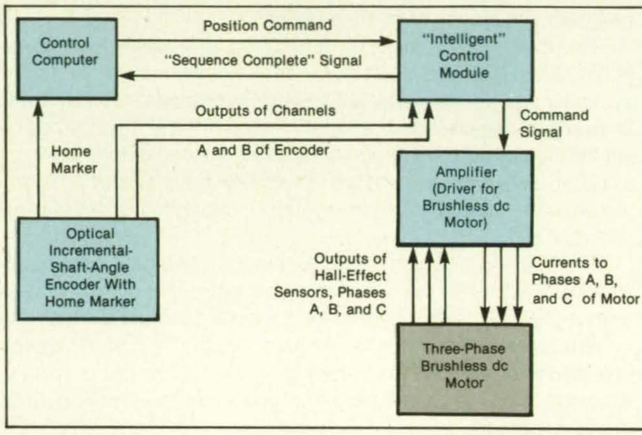
Stepping-Motion Motor-Control Subsystem for Testing Bearings

Bearings and motors can be made to undergo realistic motions for testing.

Goddard Space Flight Center, Greenbelt, Maryland

A developmental general-purpose electronic controlling and monitoring system is designed to test rotary instrumentation bearings by subjecting them to stepping motions like those in the intended applications. It can also be used to test bearing-and-motor assemblies, motors, angular-position sensors that include rotating shafts, and the like. The control subsystem can enforce a variety of low- and high-speed continuous and/or stepping motions similar to those of scanning instruments and filter wheels. The monitoring subsystem gathers data that can be used to evaluate the performance of the bearing or other article under test. The monitoring subsystem is described in more detail in the following article, "Monitoring Subsystem for Testing Bearings" (GSC-13432).

The control subsystem (see figure) includes a three-phase brushless dc motor that drives the bearing under test (other motors could be used). It also includes an optical shaft-angle encoder (to measure the angular position in limited or unlimited rotary motion) or a rotary variable-differential transformer (to measure the angular position over a limited range). Thus, it is a closed-loop angular-position-control subsystem and, as such, has the versatility to generate the required variety of stepping or continuous motions.



The **Control Subsystem** is a closed-loop angular-position-control system that can cause the motor and the bearing under test to undergo any of a variety of continuous or stepping motions.

In addition to the motor and angular-position-measuring equipment, the control system includes a computer, an "intelligent" control module, and an amplifier that energizes the coils of the brushless dc motor. Because the control module does not contain a buffer that could store a sequence of position commands, the computer is made to send position commands continuously via an RS-232-C communication line to the control module. The control module uses these commands to generate output voltages that are converted into motor currents by the amplifier. The control module uses the output from the encoder as position feedback. The control module also includes a lead-lag compensator with programmable pole, zero, and gain. Three digital Hall-effect sensors mounted on the motor provide the commutation signals for the amplifier.

This work was done by Charles E. Powers of **Goddard Space Flight Center.** *For further information, Circle 164 on the TSP Request Card.*
GSC-13418

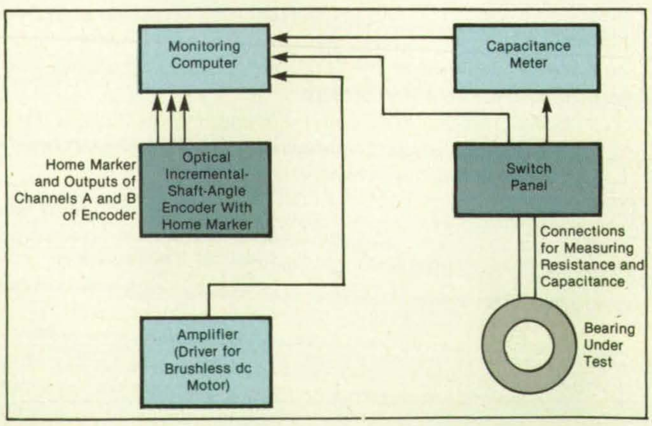
Monitoring Subsystem for Testing Bearings

The performances of bearings and motors undergoing realistic motions can be measured.

Goddard Space Flight Center, Greenbelt, Maryland

An electronic monitoring subsystem is designed to be used in conjunction with the controlling subsystem described in the preceding article, "Stepping-Motion Motor-Control Subsystem for Testing Bearings" (GSC-13418). The monitoring subsystem gathers data that can be used to evaluate the performance of a bearing motor or other rotary mechanism that is being tested by subjecting it to stepping motions like those in its intended application. The data are gathered at a rate high enough to characterize the dynamic properties of the mechanism.

The monitoring subsystem (see figure) is built around a computer with an analog-to-digital interface card. The computer executes a program that was written for instrument-control and monitoring applications. A capacitance meter is also a part of the monitoring system. During a test, the motor current, the capacitance and electrical resistance of the bearing, and the output of the shaft-angle encoder will be monitored.



The **Monitoring Subsystem** gathers data on the angular position, angular speed, capacitance, and resistance of the bearing under test.

Each of these quantities will be sampled at rate of 8 kHz during several cycles of the stepping pattern. The motor current and the angular position and velocity derived from the output of the encoder will be used to calculate bearing friction. The bearing-friction and angular-position data will be used to determine whether the bearings meet the failure criteria. The resistance and capacitance data will be used to determine whether the bearings are lubricated and, if so, possibly the thickness of the lubricating film. The data may also be subjected to other types of analysis; e.g., power spectra could be extracted.

This work was done by Charles E. Powers of **Goddard Space Flight Center**. *For further information, Circle 39 on the TSP Request Card.* GSC-13432

Books and Reports

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

Environmental Tests of Cesium Frequency Standards

Humidity affected all units, but not in the same way.

A report describes environmental tests of cesium-beam frequency standards of the United States Naval Observatory. The purpose of the tests, conducted in the Frequency Standards Laboratory of NASA's Jet Propulsion Laboratory, was to determine the effects of atmospheric temperature, relative humidity, and pressure on the frequencies.

Four standards were first stabilized for a few days in the temperature-controlled laboratory environment, then degaussed, aligned, and examined for conformance with the manufacturer's specifications. For the measurements of frequencies, the standards were placed in environmental chambers wherein each of the three environmental parameters was varied while the other two were held constant. Each combination of parameters was maintained for 1 day. The temperature range used in these tests was 17 to 33 °C, the relative-humidity range was 15 to 85 percent, and the barometric-pressure range was ±24 in. of water (±5.4 kPa). Unit 1 failed shortly after measurements were begun, and the tests were continued with units 2, 3, and 4.

The barometric pressure was found to have no significant effect on the frequencies. However, the effects of temperature and humidity could be seen in measurement data plotted as frequency versus relative humidity at constant temperature and as frequency versus temperature at constant relative humidity. Unit 2 exhibited the largest changes in relative frequency (as much as 4×10^{-13} over the ranges of environmental parameters); units 3 and 4 exhibited somewhat smaller changes.

All three of the functioning standards showed marked sensitivity to humidity, but the magnitude and sign of the change in frequency vs. change in relative humidity was not the same for all standards. When the data were replotted as frequency versus absolute humidity, units 2 and 3 showed a clear trend of frequency decreasing with increasing water content, while unit 4 exhibited more-anomalous behavior, with frequency mostly decreasing with increasing water content above a temperature of 30 °C and mostly increasing with increasing water content below 30 °C.

The practical implication of the data is that, if frequency stability of 10^{-14} is to be obtained from cesium frequency standards of the type tested, not only must the temperature be controlled to a level of about ±0.1 °C, but control of humidity is essential. It appears that, at a nominal relative humidity of 35 percent, the humidity control must maintain a stability of about ±2 percent.

This work was done by Richard L. Sydnor, Thomas K. Tucker, Charles A. Greenhall, William A. Diener, and Lutfollah Maleki of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Environmental Tests of Cesium Beam Frequency Standards at the Frequency Standards Laboratory of the Jet Propulsion Laboratory," Circle 60 on the TSP Request Card.* NPO-18273

Detecting Latent Faults in Digital Flight Controls

The efficacy of statistical detection of faults is assessed.

A report discusses the theory, conduct, and results of tests that involved the deliberate injection of low-level faults into a digital flight-control system. These tests were part of a study of the effectiveness of techniques for the detection of and recovery from faults, based on the statistical assessment of inputs and outputs of parts of control systems. These statistically based fault-detection and recovery techniques are expected to offer an exceptional new capability to establish the reliabilities of critical digital electronic systems in aircraft.

Most digital flight-control systems include built-in self-testing and/or comparative monitoring of redundant outputs to detect and correct faults up to the required levels of reliability. However, a fault

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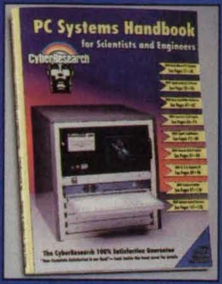

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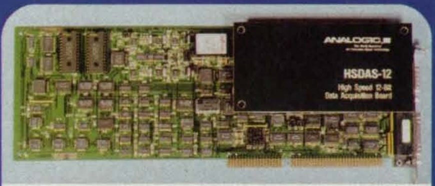

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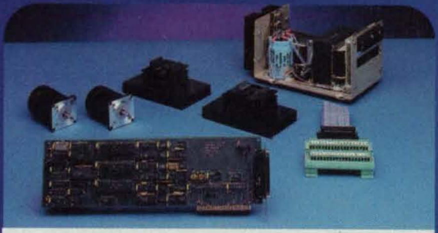
MOTION CONTROL



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may not become apparent through comparative monitoring or be recognized at the outputs of a component until the faulty component is used. Consequently, the fault could remain latent for a long time, all the while creating a probability that the system could fail in the event of an operation that depends on that component.

In the tests, a digital instrumentation system was used to inject 2,715 "stuck at" and "invert" faults at the level of pin contacts of devices of the data path and control cards of a dual/dual flight-control computer. Faults were detected by comparators located in the secondary actuator-drive electronics or by self-testing. The results of the tests are assessed statistically to ascertain the implications for the reliability at the system on the basis of a mathematical model of the statistical behavior of the system in the presence of single faults. The extension, in principle, to statistical models for multiple faults is also discussed briefly.

Most tests were done on an open-loop basis. However, the more-persistent faults were subjected to closed-loop-simulator tests to involve explicit fault-detection mechanisms. The results of the tests were found to be in reasonable accord with those of prior tests that involved different testing and tested equipment. The results of the tests were found to agree with the mathematical models of the faults in question and to indicate the value of this type of testing in practical efforts to validate the tested systems.

This work was done by John McGough of Allied/Bendix, Dennis Mulcare of Lockheed/Georgia, and William E. Larsen of the Federal Aviation Admnistration for **Ames Research Center**. *To obtain a copy of the report, "A Method of Measuring Fault Latency in a Digital Flight Control System," Circle 17 on the TSP Request Card.*
ARC-12333

Resolution of Phase Ambiguities in QPSK

Advantages and disadvantages of several techniques are described.

A report discusses several techniques for the resolution of phase ambiguities in the detection and decoding of radio signals modulated by coherent quadrature phase-shift keying (QPSK) and offset QPSK (OQPSK). There are eight such ambiguities: four associated with the phase of the carrier signal in the absence of ambiguity in the direction of rotation of the carrier phase, and another four associated with the carrier phase in the presence of the phase-rotation ambiguity.

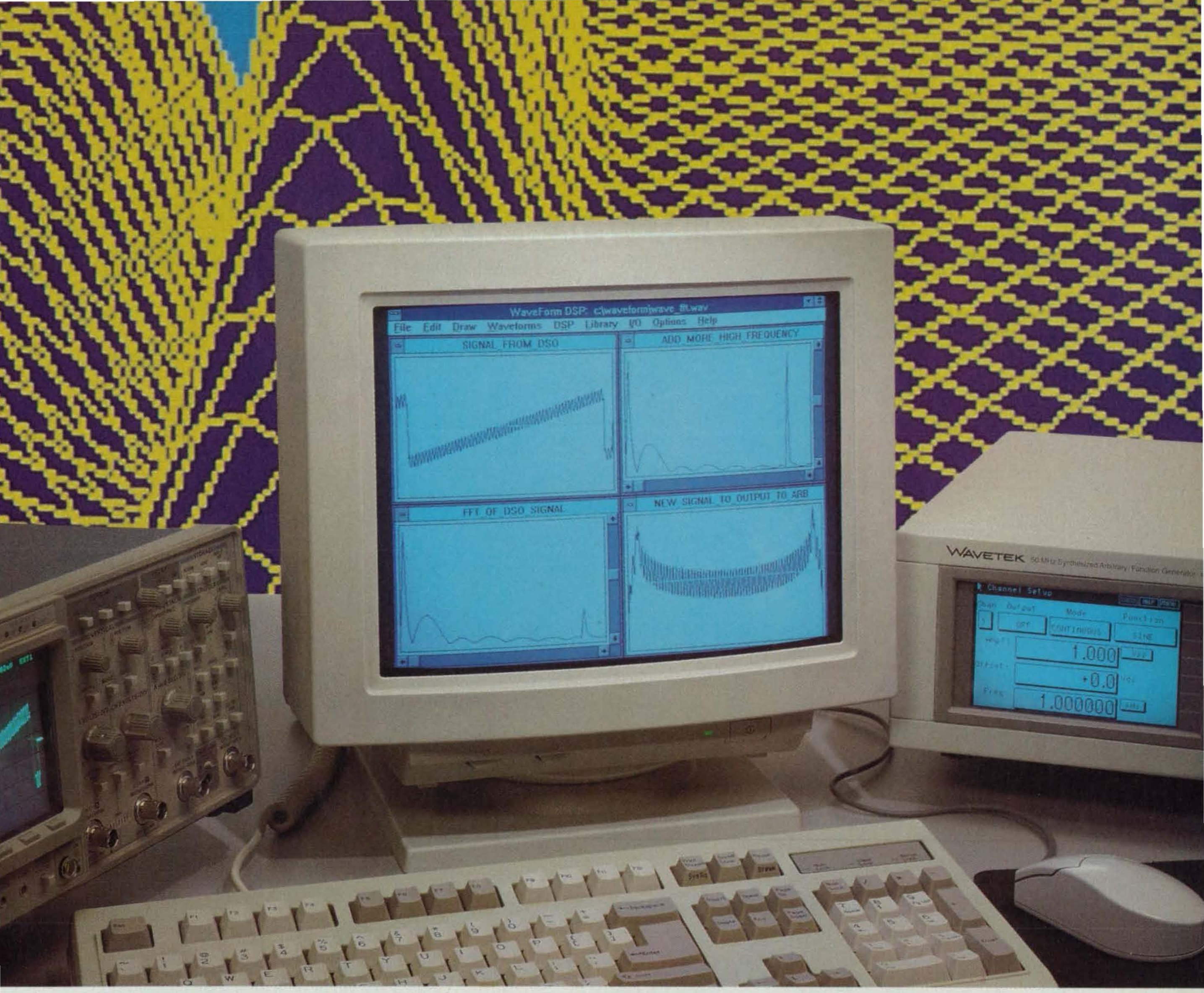
Depending on the specific QPSK or OQPSK modulation scheme and data format, the specific coding and decoding schemes and the applicable technique for the resolution of phase ambiguities can be classified as differential or nondifferential. In a differential system, the information is conveyed by changes in phase that are attributable to modulation (without having to determine the carrier phase at the receiver), whereas in a non-differential system, the information is conveyed by the actual phase relative to the carrier phase. For an uncoded system, the combination of a nondifferential decoding technique and the applicable phase-ambiguity-resolving technique can be described as a unique-word detection technique. For a coded system, the combination of a nondifferential decoding technique and the applicable phase-ambiguity-resolving technique can be regarded as a threshold decoder technique and as a unique-word detection technique.

The effects of differential and unique-word techniques on prior uncoded and coded QPSK and OQPSK modulation systems are discussed briefly. Attention is then focused on a technique developed by the author and one version of which was described in "Resolving Phase Ambiguities in OQPSK" (NPO-17853), *NASA Tech Briefs*, Vol. 15, No. 7 (1991), page 30. In this technique, a carrier-tracking loop integrated with a symbol synchronizer resolves four of the phase ambiguities, while unique-word detection by use of synchronization signals resolves the remaining four phase ambiguities. In an alternative version, a synchronizing circuit is inserted between the output of a QPSK demodulator and the input of a threshold decoder of a type that can correct a predetermined number of bit errors in a coded stream of bits. The alternative version does not require unique words or synchronization signals to resolve the phase ambiguities.

The report concludes by making the following recommendations:

1. Differential coding (without any other coding) should be used only when there is some way to prevent the "double-error" phenomenon (errors almost always occurring in pairs) that is typical of the outputs of differential decoders (in the absence of any other coding/decoding). This technique is suitable for burst-mode signals.
2. The unique-word version of the author's technique, which can utilize existing synchronization signals, is highly recommended for QPSK and OQPSK modulation systems.
3. The threshold-decoder is recommended only for a system that has to operate within a narrow frequency band.

This work was done by Tien M. Nguyen of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Techniques To Resolve Phase-Ambiguity and the Impacts of These Techniques on QPSK Modulation Systems," Circle 117 on the TSP Request Card.*
NPO-18083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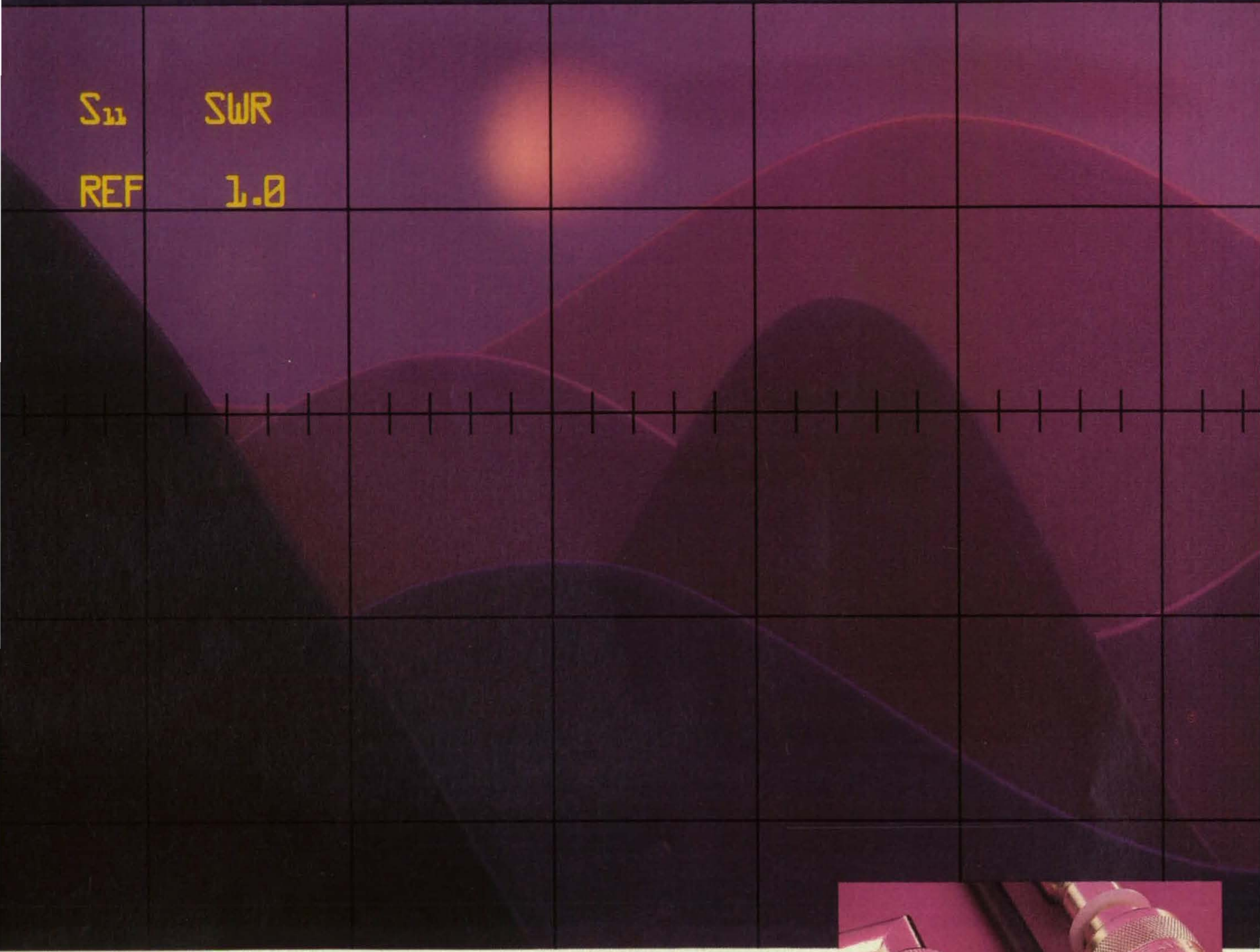

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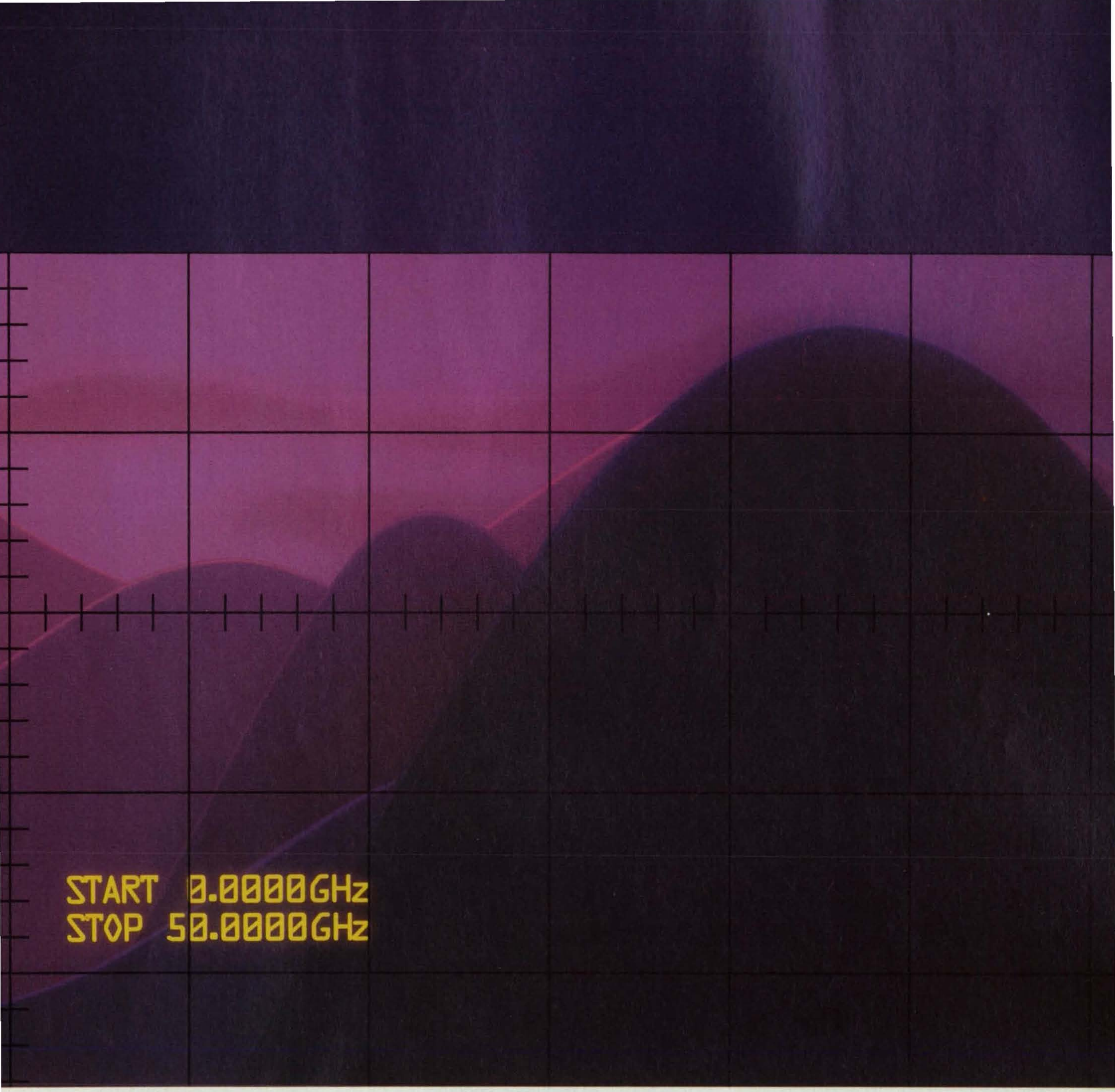

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Physical Sciences

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Noncontact Measurement of Critical Current in Superconductor

Critical current is measured indirectly via the flux-compression technique.

NASA's Jet Propulsion Laboratory, Pasadena, California

A method for determining the critical current density in a superconductive material as a function of magnetic-flux density is based on the magnetic-flux-compression technique. This method does not involve any electrical contact with the superconductor. Therefore, it does not cause the resistive heating and the consequent premature loss of superconductivity that occur in the relatively crude method of measuring current directly by attaching ordinary resistive leads to the superconductor. The present method also differs from an older noncontact magnetization method that does not always yield accurate information about the critical-current density.

The magnetic-flux-compression technique involves two steps. In the first step, one traps a magnetic field in the hole of a hollow circular cylindrical or other toroidal specimen of superconductor. This can be done, for example, by cooling the specimen below its superconducting-transition temperature while applying a magnetic field from, say, an electromagnet. When the electromagnet is turned off, the superconducted current maintains the magnetic field. In the second step, one inserts a closely fitting solid rod specimen of the superconductor (which has also been cooled to the superconducting state) in the hole. Because of the tendency of a superconductive body to conserve flux, the magnetic flux becomes compressed into the gap between the outer surface of the rod and the inner surface of the cylinder.

For the purpose of this method, an axial groove of circular cross section is made in the outer surface of the rod specimen to accommodate a dc Hall-effect probe that measures the axial magnetic-flux density near the inner surface of the cylinder (see Figure 1). This measurement is taken before the rod specimen is inserted (initial flux density, B_i) and again when the rod specimen has been inserted (final flux density, B_f). To obtain a set of data to characterize the specimens, such pairs of measurements are taken at a number of different values of B_i.

The measurements show that the compression ratio B_f/B_i varies with B_i. The measurements of B_f, B_i, the dimensions of the specimens, and other pertinent data can be analyzed by use of equations for the partial penetration of magnetic flux into the superconductor. These equations are derived from the mathematical model $J_c(B) = J_{c1}(B_{c1}/B)^n$ for $B > B_{c1}$, where B_{c1} denotes the first critical magnetic-flux density, J_{c1} denotes the critical current density at the critical magnetic-flux density, $J_c(B)$ denotes the critical current density at an axial magnetic-flux density of B, and n is a fitting parameter. By suitable manipulation of the equations and of the data, one can determine both n (Figure 2, top) and $J_c(B)$ (Figure 2, bottom).

This work was done by Ulf E. Israelsson and Donald M. Strayer of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 119 on the TSP Request Card.*

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

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Refer to NPO-18255, volume and number of this NASA Tech Briefs *issue, and the page number.*

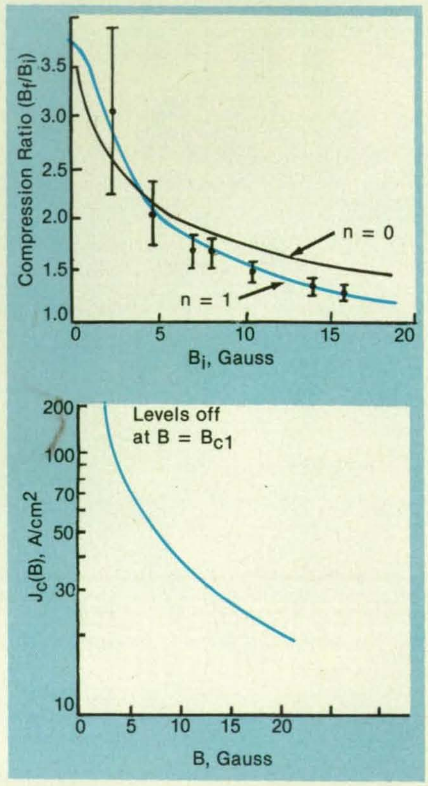

Figure 2. The **Compression Ratio** as a function of the initial magnetic field (upper plot) appears to fit the mathematical model with $n = 1$. The critical current density decreases with the magnetic field according to the model (lower plot). These data were obtained with specimens of sintered $YBa_2Cu_3O_7$, a high-temperature superconductor.

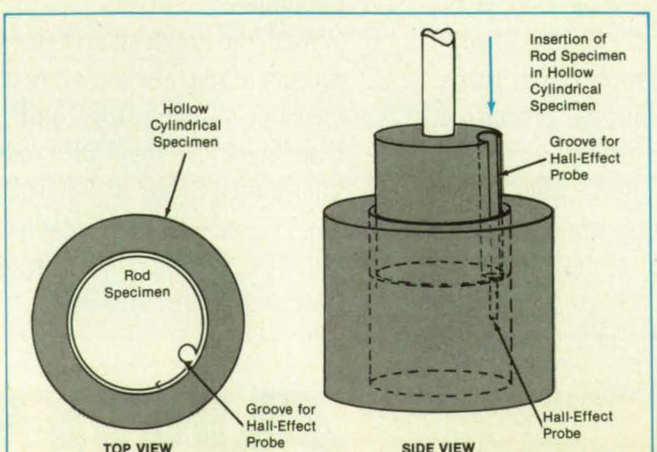

Figure 1. **Magnetic Flux is Compressed** into the gap between the superconductive hollow cylinder and the superconductive rod when the rod is inserted in the hole in the cylinder. The Hall-effect probe measures the flux density before and after compression.

Acoustic Device Would Measure Density of Gas

The amplitude of a low-frequency acoustic signal indicates density.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed acoustic sensor would measure the density of a flowing gas or mixture of gases. The sensor could be constructed in a variety of configurations for use in monitoring industrial processes.

In its basic configuration, the sensor would comprise a narrow tube closed at one end and open at the other, a sound transmitter located in the closed end, and a microphone located part of the way along the tube. The entire sensor, or at least the open end of the tube, would be placed inside the pipe or vessel that contains the gas, the density of which is to be measured (see Figure 1). The transducer would produce constant-velocity-amplitude sound waves at a frequency lower than the fundamental resonant frequency of the tube.

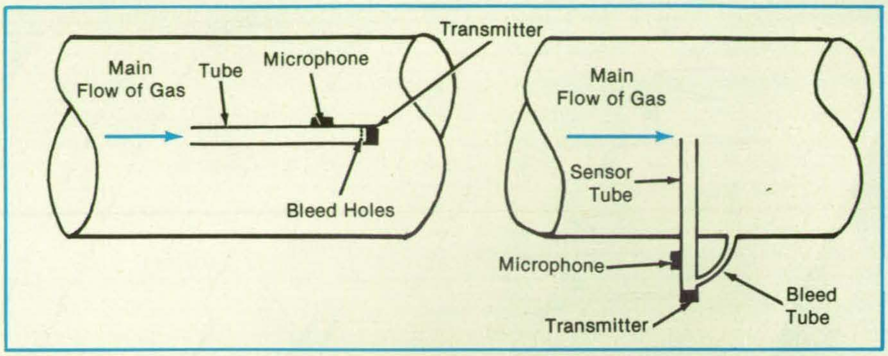

Figure 1. The **Sensor Tube** could be placed inside or partly outside the vessel containing the gas to be sampled. Many configurations other than the two shown here could be used.

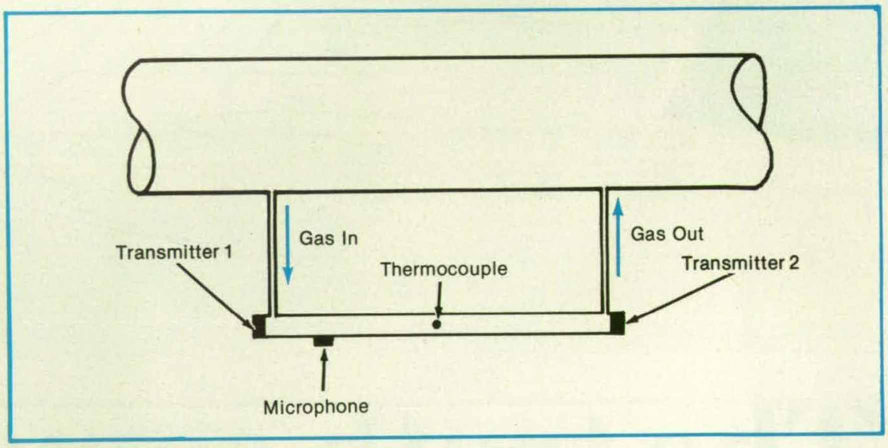

Figure 2. A **Closed-Tube Version** of the gas-density sensor would include a transmitter at each end of the tube.

The open end of the sensor tube would be located in a space large enough to make the sound-pressure amplitude at the open end of the tube be zero. That is, for the purpose of mathematical analysis of the acoustic waves in the tube, the free-space boundary condition would be satisfied. The analysis shows, among other things, that under the free-space boundary condition, and provided that the length of the tube was a small fraction of the acoustical wavelength, the density of the gas in the tube would be approximately proportional to the sound-pressure amplitude at the location of the microphone and inversely proportional to the frequency.

If necessary, the acoustic signal could be extracted from the background noise in the microphone signal by use of a narrow-band filter. Alternatively a closed-tube version of the sensor (see Figure 2) could be used where too much noise would be picked up through the open end. Where there was insufficient space to satisfy the free-space boundary condition at one end of the tube, two sound transducers would be mounted at opposite ends of the tube and driven in opposite phase. This scheme would make the sound pressures add to zero at the midpoint of the tube, thereby simulating the free-space boundary condition.

When the sensor tube was mounted partially or entirely external to the main pipe or vessel, one or more bleed holes of small cross section could be used to keep the pressure in the sensor tube the same as in the main pipe or vessel. Such an arrangement could also provide thermal isolation to protect the transducers and microphone from high process temperatures, but the measurement of density would then have to be corrected for the difference between the process and measurement temperatures.

A slight nonlinearity in the density as a function of sound-pressure amplitude could give rise to small errors (typically less than 1 percent) in the density measurements. These errors can be essentially eliminated by taking account of the dependence of the speed of sound upon temperature and accordingly adjusting the frequency of the sound so that the length of the tube remains a constant fraction of a wavelength. The required frequency, f, for a gas at absolute temperature T is given by $f = f_0(T/T_0)^{1/2}$, where f_0 and T_0 denote the frequency and absolute temperature, respectively, at which the sensor would be calibrated.

This work was done by Parthasarathy Shakkottai, Eug Y. Kwack, and Lloyd H. Back of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 4 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 14]. Refer to NPO-18155.

Measuring Thermal Diffusivity of a High-T_c Superconductor

Thermal diffusivity is deduced from propagation of an oscillatory temperature wave.

Goddard Space Flight Center, Greenbelt, Maryland

A technique for measuring the thermal diffusivity of a superconductor of high critical temperature (high T_c) is based on Angstrom's temperature-wave method. In Angstrom's method, the thermal diffusivity of a material is deduced from measure-

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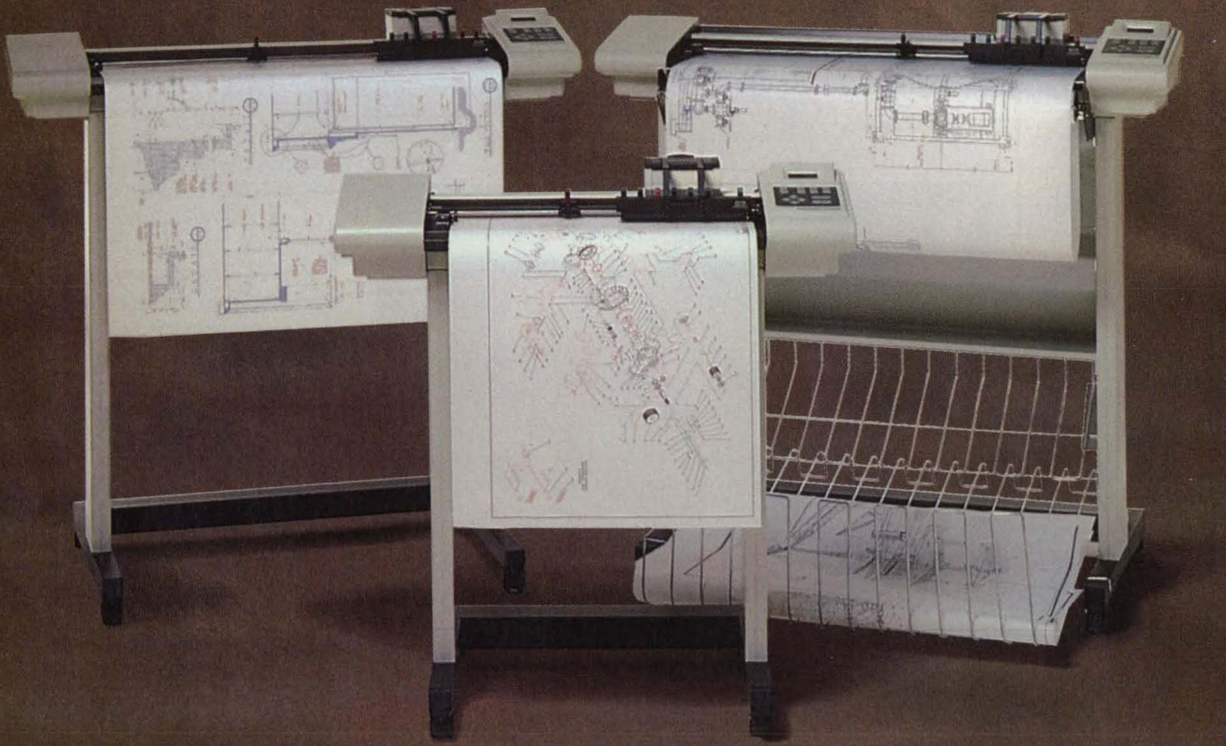

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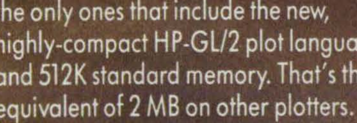

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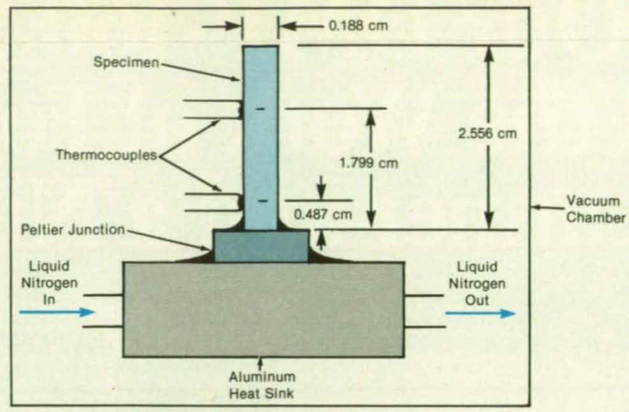
ments of the propagation of a temperature wave along a rod specimen of the material. The temperature wave could be a steady-state oscillation or a transient; in this case, a steady-state sinusoidal oscillation is chosen.

The specimen is mounted on a Peltier junction, which, in turn, is mounted on an aluminum heat sink (see figure). Two thermocouples are attached to the specimen. Liquid nitrogen flowing through the aluminum block cools the block, junction, and specimen to a specified steady initial temperature. The entire assembly is partially thermally insulated from the environment by mounting it in a vacuum: this enables measurements at initial temperatures from 150 to 300 K. Future mounting in a cryostat will enable measurements at initial temperatures from 10 to 300 K.

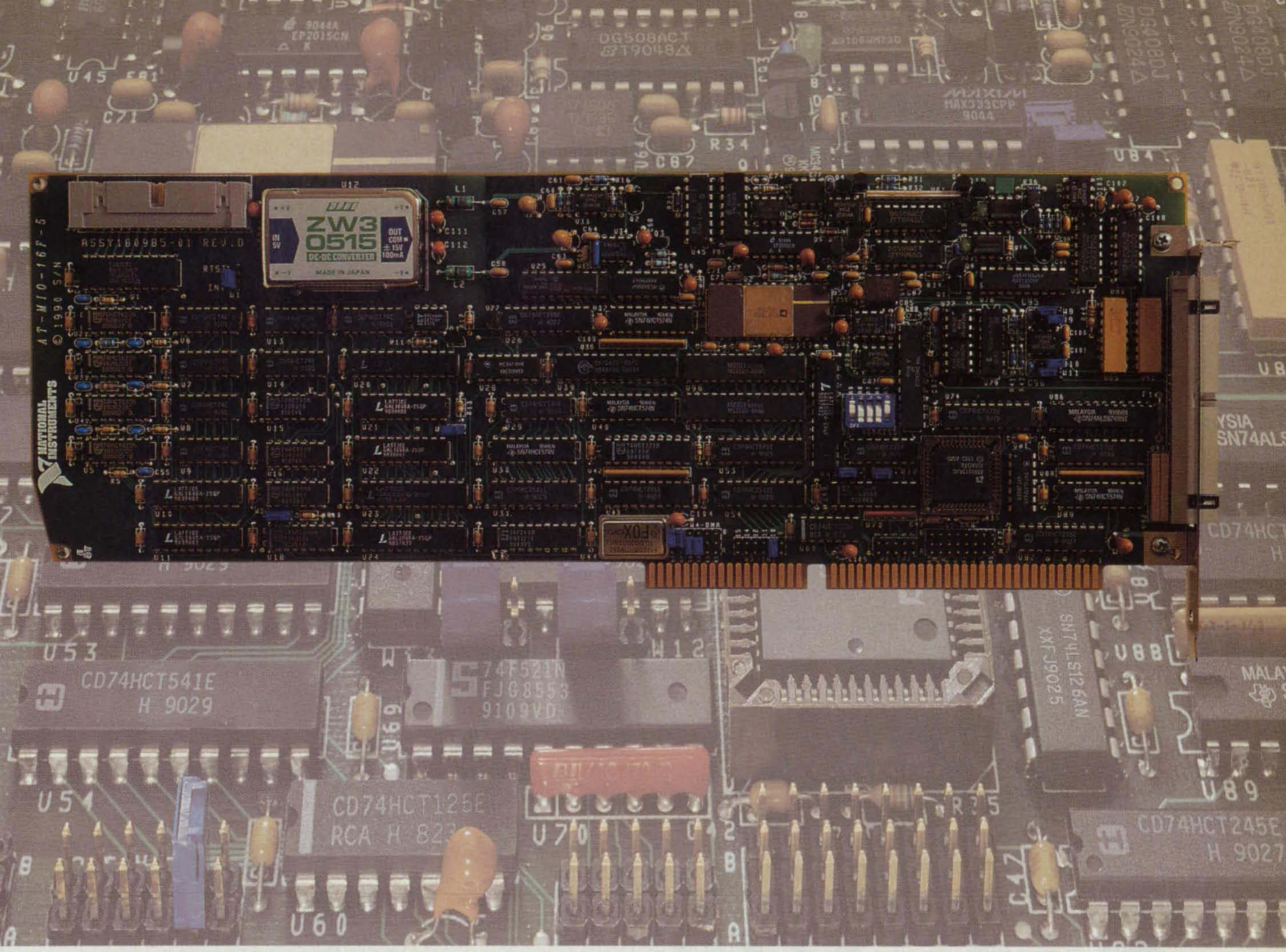


The **Peltier Junction Generates Temperature Oscillations**, which propagate with attenuation up the specimen. The thermal diffusivity of the specimen is calculated from the distance between thermocouples and the amplitudes and phases of the oscillatory components of the thermocouple readings.

The sinusoidal temperature wave is introduced into the specimen at its lower end by exciting the Peltier junction with a sinusoidal voltage. The frequency of oscillation is typically chosen to be some value between 0.01 and 0.05 Hz. The voltage across each thermocouple is sampled once per second, yielding between 20 and 100 measurements per cycle at each thermocouple location. These samples are processed to obtain the amplitudes and phases of the temperature oscillations at each thermocouple. The thermal diffusivity can then be calculated as a function of the ratio between the amplitudes, the difference between the phases, and the distance between the thermocouples. This oscillatory-temperature-wave technique offers several advantages:

- It eliminates most of the lateral thermal losses and thermal interfaces typical of other longitudinal-heat-flow methods. This feature is necessary to obtain accurate results from specimens of low thermal conductivity.
- It is more suitable for use on brittle materials because no pressure is applied to the specimens. In contrast, other longitudinal-heat-flow methods require the application of pressures, which tend to fracture the specimens.
- The use of an oscillatory temperature wave is made possible by the Peltier junction, which can both heat and cool the specimen. This, in turn, means that there is no net heating of the specimen during a measurement at a specified initial steady temperature. In contrast, other longitudinal-heat-flow methods rely on resistive or other "one-way" heating, causing the position-averaged temperature of the specimen to increase in time and thereby degrading the accuracy of the results.

This work was done by Charles E. Powers, Gloria Oh, and Henning Leidecker of **Goddard Space Flight Center**. *For further information, Circle 155 on the TSP Request Card.*
GSC-13392



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AT-MIO-16L-9 AT-MIO-16L-25	AT	16 SE 8 DI	100,000	12	±10, ±5, 0 to 10	1, 10, 100, 500	2	12	8	3	✓ ✓	✓ ✓	✓ ✓	✓ ✓		✓ ✓
Lab-PC	XT	8 SE	62,500	12	±5, 0 to 10	1, 2, 5, 10, 20, 50, 100	2	12	24	3	✓	✓	✓	✓		✓
PC-LPM-16	XT	16 SE	50,000	12	±5, 0 to 10 ±2.5, 0 to 5	1	–	–	16†	3	✓	✓	✓			
AT-DIO-32F PC-DIO-96 PC-DIO-24	AT XT XT	– – –	– – –	– – –	– – –	– – –	– – –	– – –	32 96 24	– – –	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓			✓ ✓
PC-TIO-10	XT	–	–	–	–	–	–	–	16	10	✓	✓	✓			

* SE – Single-Ended, DI – Differential, SS – Simultaneous Sampling

† 8 Channels In, 8 Channels Out

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Gel-Filled Holders for Ultrasonic Transducers

A transducer is cast in place at the desired angle and position on an object or patient.

Langley Research Center, Hampton, Virginia

A need exists in medicine and industry for the ability to use ultrasound to look into materials at known fixed angles to the surfaces while maintaining good acoustical contact and low attenuation. In medical applications, current equipment for doing this includes motor-driven or phased-array sector scanners and various types of fixed-head probes. For industrial use there are variations of the above, with the addition of poly(methyl methacrylate) angle blocks, and squirter systems. In both realms, water baths are used extensively. None of these devices is well suited for use on an ambulatory patient or on a large, irregular, object.

In a new technique, an ultrasonic transducer is embedded in a rubbery, castable, low-loss gel to enable the transducer to "look" into the surface of a test object or human body at any desired angle (see figure). The gel is composed of a solution of water and ethylene glycol in a collagen matrix. The water, which can be as much as 80 percent of the mixture, is an excellent conductor of ultrasound. The ethylene glycol serves to reduce the rate of evaporation, thereby extending the usable lifespan. The collagen enables the gel to hold its shape.

The gel can be made up quickly and inexpensively. Because it is quite fluid when fresh, it can be catalyzed and poured into a mold easily. Once the material has been catalyzed with formaldehyde, it sets up into a solid within a few minutes. The resulting material is not mechanically tough, but it tolerates high temperatures and does not dry. Its acoustic impedance is close to that of water or human tissue.

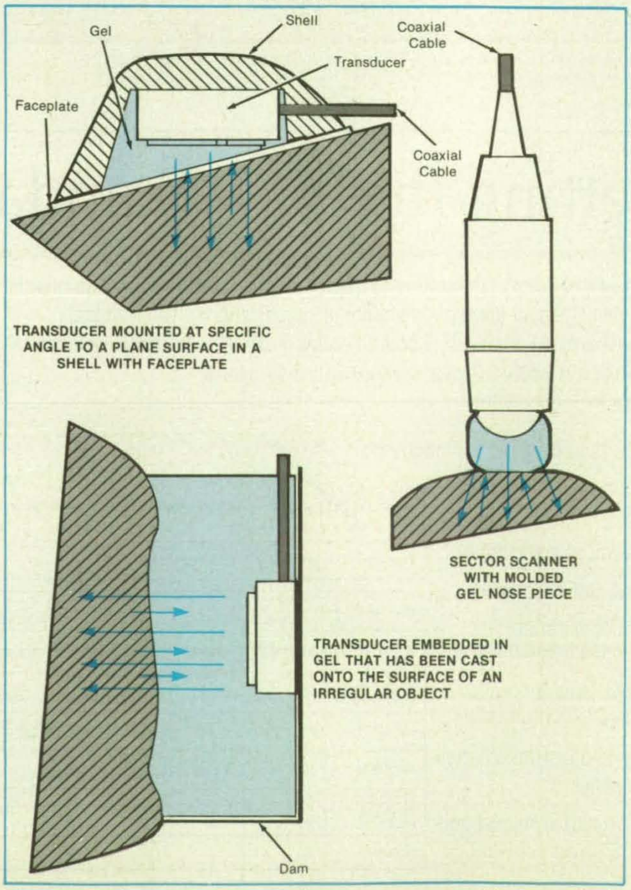
If a reusable assembly is required, a transducer can be secured at the desired angle to the back wall of an enclosure, which can then be filled with the gel. Because of the nondrying characteristic of the material, sealing is not critical. The face of the transducer housing can be fitted with a thin plastic skin to provide resistance to abrasion if a large number of uses is contemplated. For the short term, or to provide better coupling, the skin can be eliminated.

To achieve the best possible coupling, or in the case of an irregular surface, the gel can be cast right onto the surface. The enclosure would then take the form of a dam, to be filled from the back. This arrangement would simply be peeled off the surface and off the transducer and discarded after use. Because the material is somewhat flexible, it is possible to vary the angle of the transducer slightly.

The technique described here can provide the total contact of a water bath but can be used on bodies or objects that are too large for water baths, even if they are moving. The technique can provide the look angles of a poly(methyl methacrylate) angle block with the potential of reduced acoustic impedance and refraction. It can be custom-tailored to the task at hand, and the gel is sufficiently inexpensive so that it can be discarded upon completion. It is easy to couple ultrasound in and out of the gel, minimizing the losses and artifacts of other types of standoffs employed in ultrasonic testing.

This work was done by John A. Companion of Planning Research Corp. for **Langley Research Center**. *For further information, Circle 19 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 14]. Refer to LAR-14027.



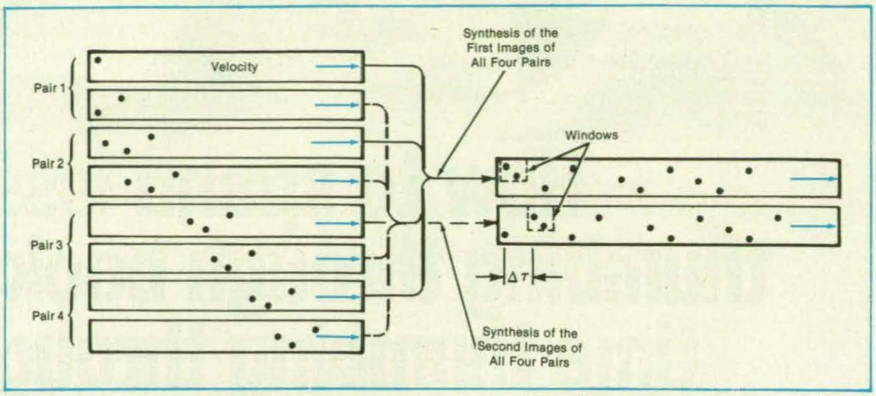
The **Nondrying, Low-Loss Gel** serves as a versatile transmission medium for an ultrasonic transducer.

Digital Correlation in Laser-Speckle Velocimetry

A periodic recording helps to eliminate spurious results.

Marshall Space Flight Center, Alabama

An improved digital-correlation process extracts the velocity field of a two-dimensional flow from laser-speckle images of seed particles distributed sparsely in the flow. Some prior methods of laser-speckle velocimetry have involved various combinations of optical and electronic techniques, have tended to be slow, and have required considerable intervention by analysts. A more recent method that led to the present improved method involved the semiautomated digital correlation, on a desktop computer, of speckle images recorded at equal intervals of time. This predecessor method was relatively fast because, unlike methods that included optical techniques, it did not require mechanical scanning of images. The new method, which involves the digital correlation of images recorded at unequal intervals, can be completely automated and, therefore, has the potential to be the fastest yet.



Laser-Speckle Images of seed particles are recorded in pairs, with an equal interval within each pair and unequal intervals between successive pairs. A synthesis of the first images of all the pairs is then correlated with a synthesis of the second images to obtain the velocity field.

Digital correlation is a method for the recognition of patterns, in which a small portion of a first image is located and identified in a small portion (called the "window") of a second image, which could be distorted and displaced with respect to the first image. In this case, the images are the laser-speckle patterns taken at two slightly different times, and the second pattern is slightly distorted and translated with respect to the first one because of the flow. The resemblance between the second and first images is measured via a coefficient of correlation:

$$\rho(m,n) = \frac{\Sigma_x\Sigma_y[f(x,y) - \langle f\rangle][w(x-m,y-n) - \langle w\rangle]}{\{\Sigma_x\Sigma_y[f(x,y) - \langle f\rangle]^2\,\Sigma_x\Sigma_y[w(x-m,y-n)\langle w\rangle]^2\}^{1/2}}$$

where $\rho(m,n)$ is the coefficient of correlation for a window centered at coordinates m,n in the second image, $f(x,y)$ is the intensity of the second image at point x,y within the window, $w(x-m, y-n)$ = the intensity of the first image at the corresponding point, $\langle f\rangle$ is the average intensity of the window portion of the second image, and $\langle w\rangle$ is the average intensity of the corresponding part of the first image. The position m,n for which $\rho(m,n)$ is a maximum is the position at which the second image is considered to match the first image best.

In the basic approach to velocimetry via digital correlation, systematic matches of intensity samples are extracted from a sequence of digitized speckle patterns recorded at different times. Displacements between matched patterns are then divided by the increments of time between exposures to obtain a velocity field.

When the speckle images are recorded at equal intervals of time, periodicity and sparseness in the spatial patterns can give rise to false correlation peaks. To suppress the tendency toward false correlations, images can be enriched and partly randomized. The images are still recorded in pairs with the interval between the first and second images in each pair equal to the interval between the first and second images in every other pair. However, the pairs are recorded at unequal intervals (see figure). An enriched, randomized first image is synthesized by adding together the intensity patterns of the first images of all the pairs. An enriched, randomized second image is synthesized similarly from the second images of all the pairs (see figure). Then the correlation is performed between the synthetic first and second images to obtain a velocity field more nearly free of errors.

This work was done by John A. Gilbert of the University of Alabama in Huntsville and Donald R. Mathys of Marquette University for **Marshall Space Flight Center**. *For further information, Circle 114 on the TSP Request Card.*
MFS-26122

Joule-Thomson Cooler Produces Nearly Constant Temperature

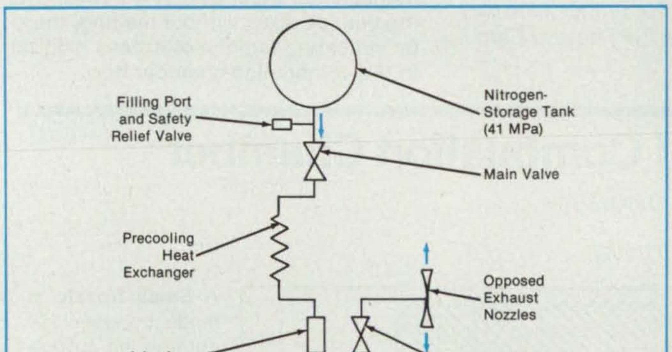
Variations in atmospheric pressure have little effect on temperature.

NASA's Jet Propulsion Laboratory, Pasadena, California

An improved Joule-Thomson cooler maintains a nearly constant temperature in its cold head, despite variations in atmospheric pressure. Coolers of this type could provide the stable low temperatures required for the operation of such devices as tunable diode lasers in laboratory and balloon-borne instruments that detect contaminants in the atmosphere.

The cooler (see figure) is of the "blowdown" type, in which the nitrogen working fluid is supplied as gas pressurized in a tank at ambient temperature. When the main valve is opened, gas at high pressure flows from the tank and is precooled by the ambient atmosphere via an external heat exchanger. The gas then passes through an adsorber, which removes impurities, before entering the cryostat. In the cryostat, the gas is cooled further in a counterflow recuperative heat exchanger before expanding through the Joule–Thomson valve, which is essentially an orifice. The isenthalpic expansion in the Joule-Thomson valve causes a decrease in temperature and partial liquefaction of the nitrogen. The liquid nitrogen is vaporized by the combined heat load from the laser or other devices to be cooled and from parasitic heat leaks.

The cold vapor returns through the recuperative heat exchanger and is exhausted to the atmosphere. The temperature of the liquid produced by the Joule-Thomson valve is the saturation temperature that corresponds to the exhaust pressure. To prevent fluctuations in atmospheric pressure from affecting the exhaust pressure and, thereby, the temperature of the liquid, the exhaust is passed through an absolute-pressure relief valve.



The **Absolute-Pressure Relief Valve** helps to stabilize the temperature of the cold head despite variations in atmospheric pressure. The feedback-controlled electrical heater provides additional stabilization. The demand-flow Joule-Thomson valve requires less nitrogen than does a fixed-orifice Joule-Thomson valve that provides the same amount of cooling.

Like many other blowdown Joule-Thomson coolers used in scientific, military, and industrial applications, this one includes a thermostatically self-regulating demand-flow mechanism that automatically throttles the Joule-Thomson orifice from its wide-open, high-flow-rate position during initial cooldown to a low-flow-rate position during steady operation. The demand-flow configuration reduces the consumption of gas by 65 percent below that of a fixed-orifice Joule-Thomson valve.

Low power (0 to 500 mW) is supplied to an electrical heater on the cold head in response to feedback from a temperature sensor on the cold head. This feature provides further stabilization and fine adjustment of the temperature. In conventional Joule-Thomson systems, temperatures in steady operation may fluctuate 1 to 2 K, with periodic fluctuations of about 5 K. In this system, temperature drift rates of less than 0.1 mK per minute have been measured.

This work was done by Steven Bard, Jiunn-Jeng Wu, and Curtis A. Trimble of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 112 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 14]. Refer to NPO-18184.

Rhenium-Foil Witness Cylinders

A simple device indicates an excess of oxidizer in combustion-chamber flow.

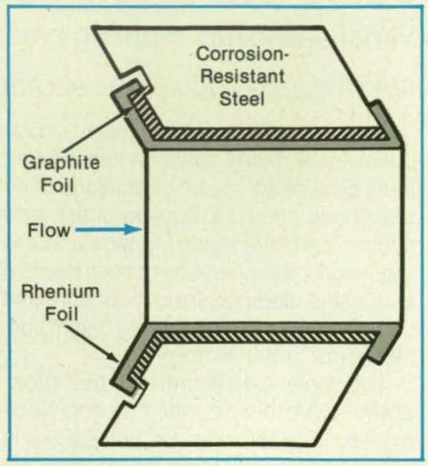
NASA's Jet Propulsion Laboratory, Pasadena, California

Cylinders of rhenium foil have been used to obtain qualitative indications of locations and amounts of excess oxidizer gas in the oxidizer-and-fuel mixture flowing from a bipropellant injector into the combustion chamber of a rocket engine. It is necessary to obtain these indications in design tests because excess oxidizer can damage the wall of the chamber. Rhenium witness foils might also be useful in detecting excess oxygen or other oxidizers at temperatures between 2,000 and 3,600 °F (about 1,100 and 2,000 °C) in the burner cores of advanced gas-turbine engines.

The rhenium foil, 0.003 in. (0.08 mm) thick, is mounted on a corrosion-resistant steel holder, insulated from the holder by a layer of graphite foil 0.015 in. (0.38 mm) thick (see figure). The inner surface of the rhenium cylinder thus formed serves as a temporary replacement and witness cylinder for that portion of the wall of the combustion chamber in which damage by oxidation was observed previously.

Rhenium oxidizes easily at the combustion temperature but melts at the much higher temperature of 5,700 °F (about 3,100 °C). The amount of rhenium lost is therefore roughly proportional to the amount of oxidizer at the wall of the combustion chamber. A fresh rhenium witness cylinder is installed to evaluate the effect of each change in design upon oxidation of the wall.

This work was done by B. L. Knight of Aerojet TechSystems for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 103 on the TSP Request Card. NPO-18224*



A Cylindrical Portion of the Wall of the combustion chamber is replaced with rhenium foil mounted on a holder. The rhenium oxidizes without melting, thereby indicating regions of excess oxidizer in the combustion-chamber flow.

Orifices for Fuel-Film Cooling of Combustion Chamber

Injected fuel cools the wall and neutralizes excess oxidizer.

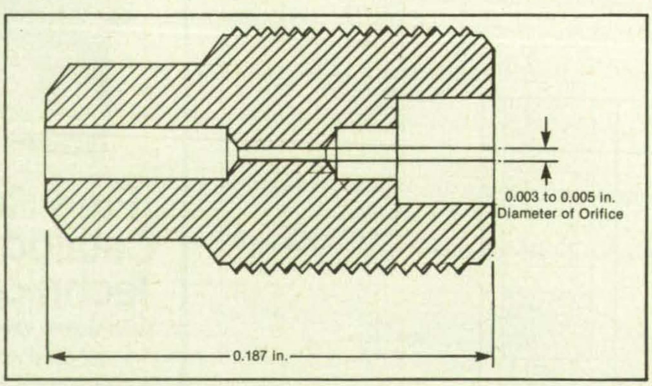
NASA's Jet Propulsion Laboratory, Pasadena, California

A boundary-layer film of fuel flows along the wall of the combustion chamber mentioned in the preceding article, "Rhenium-Foil Witness Cylinders" (NPO-18224), cooling the wall and neutralizing the excess of oxidizer in the vicinity of the wall. This boundary-layer cooling flow enters the chamber through 16 small, replaceable nozzles placed around the periphery of the fuel-and-oxidizer injector.

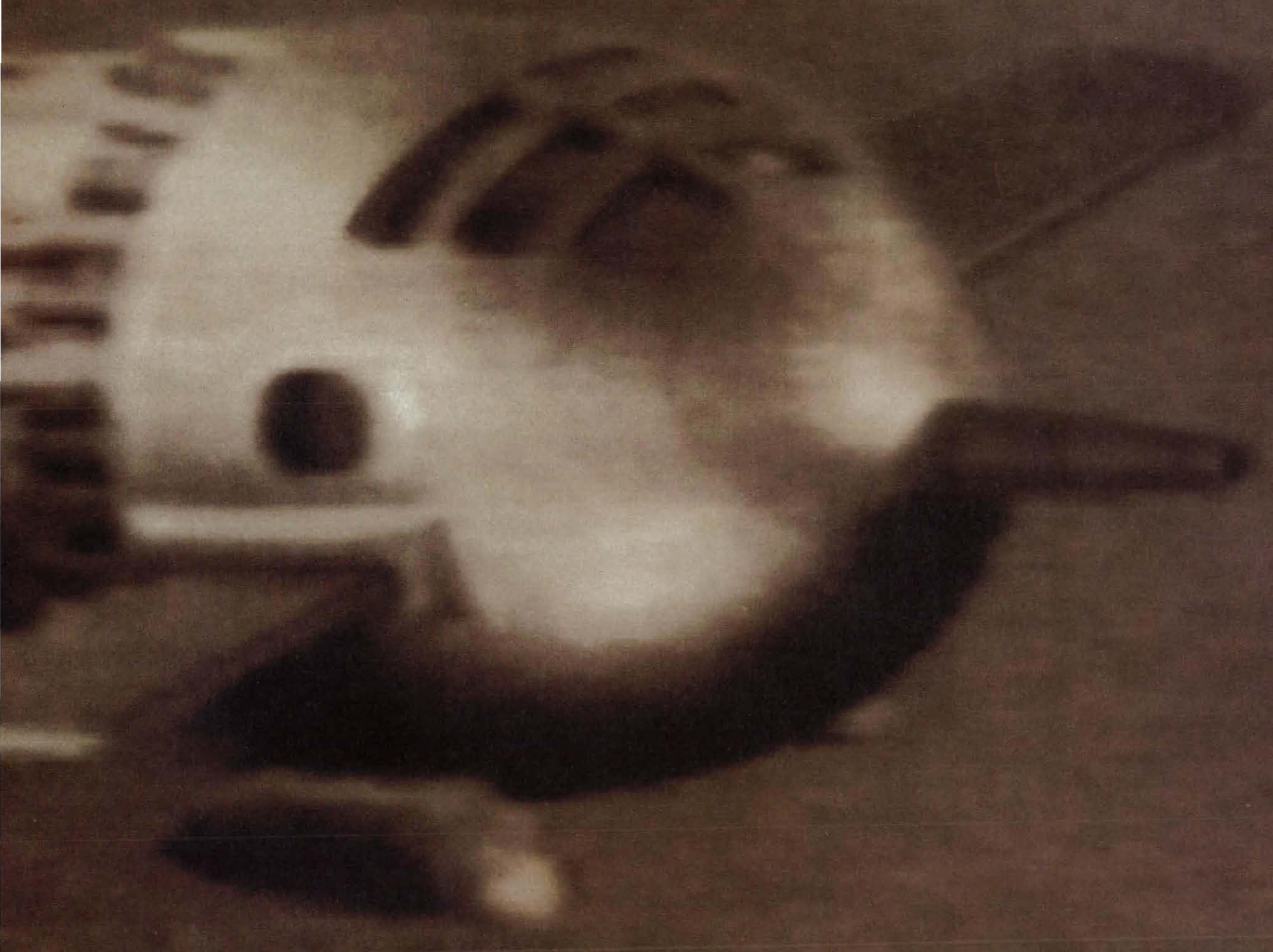
The boundary-layer cooling flow of fuel at each of the 16 locations can be adjusted, independently of the main injected flow of fuel and oxidizer, by selection of a nozzle that passes a larger or smaller flow. A larger flow at a given location would be selected, for example, if a rhenium-foil hot-fire test like the one described in the preceding article indicated an excess of oxidizer at that location.

Each nozzle (see figure) is a small setscrew. An orifice that has a diameter between 0.003 and 0.005 in. (0.08 and 0.13 mm) is laser-machined into the setscrew. A small cylindrical screen filter in a cavity upstream of the orifice prevents clogging of the orifice. To distribute the cooling flow more evenly around the circumference of the chamber, the jet of cooling fuel from each such nozzle is aimed at an angled splash plate in the resonator cavity of the chamber to convert the jet to a fine, atomized spray.

This work was done by B. L. Knight of Aerojet TechSystems for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 105 on the TSP Request Card. NPO-18225*



A **Small Nozzle** is made by laser-machining an orifice along the axis of a setscrew. A similar nozzle with a larger or smaller orifice is selected to increase or decrease the flow, respectively.



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Materials

Hardware, Techniques, and Processes

Determining the Degree of Graphitization in Carbon Composites

An effective solubility parameter is inferred from an infrared reflectance spectrum.

NASA's Jet Propulsion Laboratory, Pasadena, California

A method for determining the degree of graphitization of a carbon/carbon composite material combines an infrared spectral experimental technique with a thermodynamical theoretical model of solubility. By interrupting the manufacturing process at almost any time and applying the method, one can judge the quality of the composite and monitor the chemical transformations that take place during the process.

A carbon/carbon composite material is made by pyrolyzing a starting composite of carbon fibers in an organic (often, epoxy or aerosol) matrix. The fibers are relatively pure carbon; they have both a high strength-to-weight ratio and a high solubility parameter that can approach those of diamond. These parameters are related in that the solubility parameter of a material is the square root of its cohesive-energy density. If the initially different solubility parameters, δ, of two materials in contact (in this case, the fibers at $\delta \approx 179$ cal$^{1/2}$ cm$^{-3/2}$ and the matrix at $\delta = 9$ to 20 cal$^{1/2}$ cm$^{-3/2}$) become sufficiently close, the materials can mix and then possibly react chemically to form a new material (in this case, a graphitic material that does not have the strength-to-weight ratio of diamond).

During pyrolysis, the fibers remain in an almost-pure-carbon state, while the matrix material loses H_2O, CO_2, and other byproducts, becoming more like pure carbon. The solubility parameter of the matrix therefore increases toward that of pure carbon (see Figure 1), raising the possibility of mixing and chemical reaction between the fibers and matrix. Accordingly, it becomes important to infer the solubility parameters of the composite to assess the chemical composition of its constituents and the relationship between these compositions and the final strength-to-weight ratio of the composite.

In the new method, specimens of the various materials of interest are subjected to infrared reflection spectroscopy (see Figure 2) at wavelengths in the vicinity of 3.3 μm — the characteristic absorption band of carbon/hydrogen bonds. One obtains a reference spectrum from a specimen of cured but unpyrolyzed matrix material and a spectrum from a specimen of the carbonized composite at any desired intermediate stage or after completion of the pyrolysis. Inasmuch as the matrix loses hydrogen during the pyrolysis, one can infer the degree of chemical conversion by comparison of the carbon/hydrogen-bond absorptions computed from the infrared spectra, the processed specimen, and the specimen of unpyrolyzed matrix material. From the infrared absorptions and volume fractions of the constituents, one can infer the solubility parameters of the constituents.

One can also compute an effective solubility parameter for the composite considered as an unitary material. This parameter has significance for subsequent fabrication steps that involve chemical treatments; e.g., coating or joining with adhesives. For example, in a demonstration of the new method, the solubility parameter of a carbon/carbon composite was estimated at 106.8 cal$^{1/2}$ cm$^{-3/2}$, which is the solubility parameter of copper. Copper was deposited on the composite and found to adhere very well.

This work was done by Daniel D. Lawson and Paul M. McElroy of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 82 on the TSP Request Card.*
NPO-18073

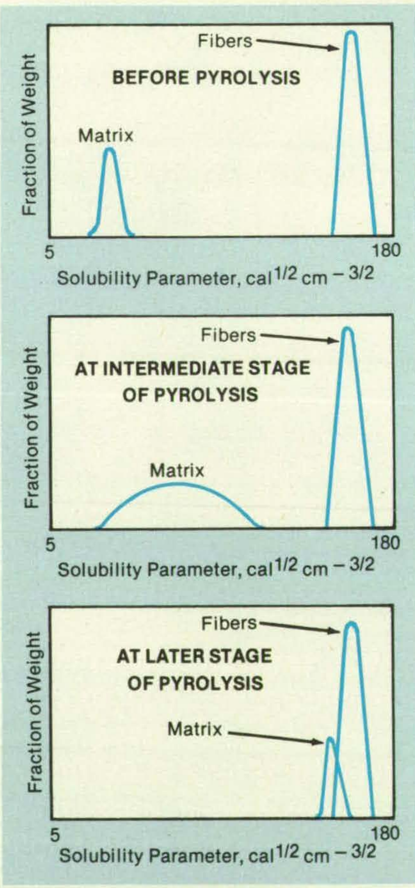


Figure 1. The **Solubility-Parameter Spectra** of the organic matrix and carbon fibers in a composite of the two move toward each other as the composite is pyrolyzed.

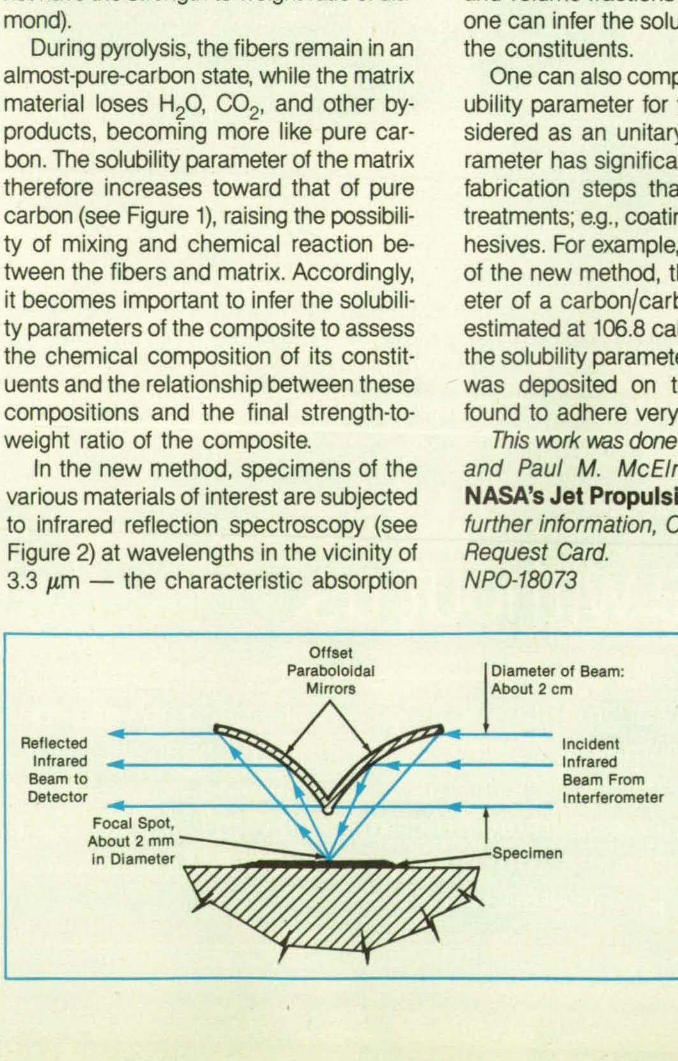


Figure 2. **Infrared Reflection Spectroscopy** is used to measure the absorption of specimens at wavelengths around 3.3 µm. From the spectra of reference and pyrolyzed specimens, one can infer the solubility parameters of the pyrolyzed specimens.

Ceramic-Fibrous-Insulation Thermal-Protection System

Graded fibrous composite forms with the underlying ceramic insulation.

Ames Research Center, Moffett Field, California

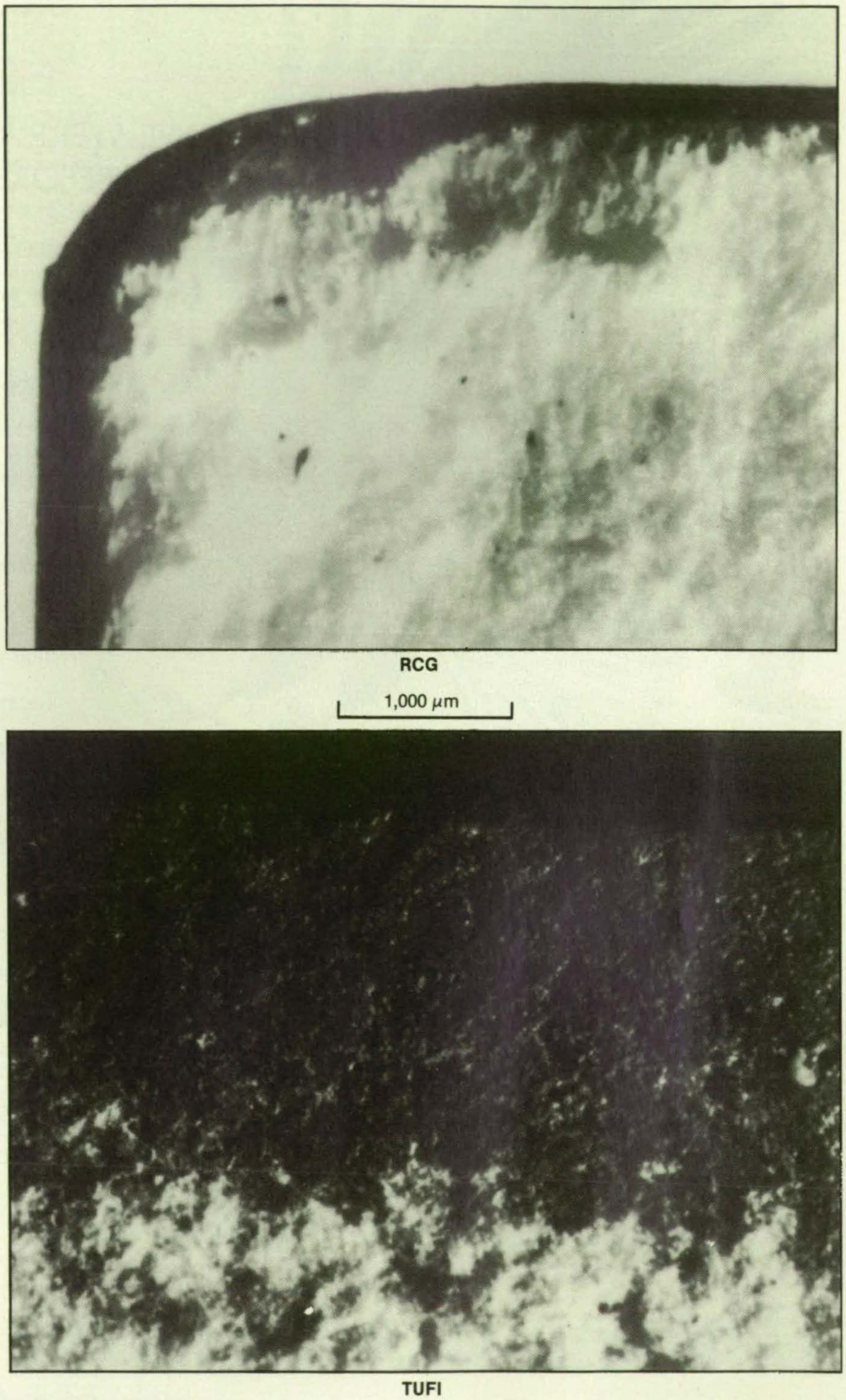
A new composite thermal-protection system has been developed in which a glass-ceramic was impregnated into the surface of a fibrous insulation. The system called TUFI for toughened unipiece fibrous insulation was developed as a replacement for the currently used tiles with a reaction-cured-glass (RCG) coating. The impregnation of the glass-ceramic results in a thermal protection system with insulating properties comparable to the existing system but with 20 to 100 times more resistance to impact.

The formulation and the application process for TUFI differ from those for RCG. The main ingredients of RCG include silica and boron oxide powders (which form a borosilicate glass) and silicon tetraboride powder (which gives the requisite emittance). These ingredients are mixed in an ethanol carrier to make a slurry, which is sprayed on a tile, dried, then sintered to form a hard, protective surface layer.

TUFI is also made in part from silica and boron oxide powders and silicon tetraboride in an ethanol slurry. An additional emittance agent — molybdenum disilicide — is included because it is more stable during sintering. The powders are ground more finely than in RCG so that they penetrate the porous tile more deeply. The TUFI slurry is applied in approximately twice the quantity of RCG in three spraying applications to aid penetration.

The many large pores in TUFI inhibit the propagation of cracks from impact sites, thereby increasing toughness. The pores also readily absorb waterproofing materials. TUFI is not simply a surface layer: it is a graded composite fiber-reinforced surface/subsurface layer that blends smoothly with the porous ceramic substrate. Whereas a sharp interface lies between RCG and its substrate, TUFI has a diffuse interface, changing gradually in color from black at the surface to white in the interior (see figure).

In impact tests, the RCG coating cracked in a star pattern at impact energies as small as 0.005 joule. In contrast, in impacts of as much as 0.5 joule on TUFI, damage was limited to the impact sites only. (The precise point at which impact failure occurs in TUFI is difficult to define because of its graded composite nature.)



The **Graded Interface of the Surface Layer** with the porous ceramic substrate in TUFI contrasts with the sharp interface of RCG. The TUFI layer is considerably thicker than the RCG layer (about 0.25 cm vs. about 0.03 mm).

This work was done by Daniel Leiser, Rex Churchward, Victor Katvala, and David Stewart of **Ames Research Center**, *and Aliza Balter of Eloret Institute. For further information, Circle 69 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 14]. Refer to ARC-11888.

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Physical Sciences

Eleven-Species Thermochemical Model of Air

The SPECIES program computes thermodynamic and transport properties and equilibrium constants.

The accurate numerical prediction of a high-temperature, chemically reacting flow field requires a knowledge of the physical properties and reaction kinetics for the species involved in the reacting gas mixture. Assuming an 11-species mathematical model of air at temperatures below 30,000 K, SPECIES (Computer Codes for the Evaluation of Thermodynamic Properties, Transport Properties, and Equilibrium Constants of an 11-Species Air Model) computes values for the thermodynamic and transport properties of the species, diffusion coefficients, and collision cross sections for any combination of the 11 species, and rates for the 20 chemical reactions that normally occur among the species.

The species represented in the model are diatomic nitrogen, diatomic oxygen, atomic nitrogen, atomic oxygen, nitric oxide, ionized nitric oxide, the free electron, ionized atomic nitrogen, ionized atomic oxygen, ionized diatomic nitrogen, and ionized diatomic oxygen. Sixteen subroutines compute the following properties for (1) a single species, interaction pair, or reaction, and (2) an array of all species, pairs, or reactions: specific heat and static enthalpy of the species, viscosity of the species, frozen thermal conductivity of the species, diffusion coefficient, collision cross section (OMEGA 1,1), collision cross section (OMEGA 2,2), ratio between collision cross sections, and equilibrium constant.

The program uses least-squares polynomial curve fits of the most accurate data believed available to provide the requested values more quickly than is possible with table-lookup methods. The subroutines that compute transport coefficients and collision cross sections include additional code to correct for any electron pressure when working with ionic species.

SPECIES was developed in 1990 on a SUN 3/280 computer running the SunOS 3.5 operating system. It is written in standard FORTRAN 77 for use on any computing machine and requires roughly 92 KB of memory.

SUN and SunOS are registered trademarks of Sun Microsystems, Inc.

This program was written by Richard A. Thompson of **Langley Research Center** *and Kam-Pui Lee and Roop N. Gupta of Scientific Research and Technology. For further information, Circle 150 on the TSP Request Card.* *LAR-14447*

Analyzing Satellite Images of the Ocean

A user-interactive program analyzes archival image data for oceanographic research.

PC-SEAPAK is a user-interactive software package specifically developed for the analysis of data from satellites in oceanographic research. The program is used to process and interpret data obtained from the Nimbus-7/Coastal Zone Color Scanner (CZCS) and the NOAA Advanced Very High Resolution Radiometer (AVHRR). More specifically, PC-SEAPAK is a microcomputer-based image-analysis program that provides the user with a flexible, user-friendly, standardized interface and facilitates relatively low-cost analysis of oceanographic data.

The CZCS scanning radiometer aboard the Nimbus-7 satellite was designed to measure the concentration of photosynthetic pigments and degradation products thereof in the ocean. AVHRR data from the NOAA 6, 7, 9, and 11 satellites are used to compute sea-surface temperatures. The CZCS operated from November 1978 to June 1986. CZCS data may be obtained free of charge from the CZCS archive at NASA/Goddard Space Flight Center. AVHRR data may be purchased through the NOAA Environmental Satellite Data Information Service.

PC-SEAPAK is a collection of over 100 independent programs organized into categories, which include CZCS level-2 analyses, statistical analyses, extraction of data, remapping to standard projections, manipulation of graphics, manipulation of image-board memory, and general utilities. Most programs provide for interaction with the user through menu and command modes and by the use of a mouse. Most programs also provide for the generation of ASCII files for further analysis in spreadsheets, graphics software packages, and the like.

Although PC-SEAPAK was developed on a COMPAQ Deskpro 386/20 computer, it can be run on almost any 386-compatible computer with an AT bus, EGA controller, Intel 80387 coprocessor, and MS-DOS 3.3 or higher. Other requirements include a Matrox MVP-AT image board with appropriate monitor and cables, a Microsoft mouse (serial version), 2-MB random-access memory, and 100-MB hard-disk memory space. Nine-track tape, 8-mm tape, and optical disks are supported and recommended for ingestion of data and backup recording of data. Users who have the commercial software package HALO88 (or a subsequent version) from Media Cybernetics can optionally choose to annotate images.

PC-SEAPAK has been under development since 1988 and is a derivative of VAX-SEAPAK, which has been under development since 1981. Version 3.0 was released in the summer of 1990, and only executable code is distributed. Distribution of PC-SEAPAK is handled through the Computer Software Management and Information Center at the University of Georgia. It is available only as a set of 29 1.2-MB 5.25-in. (13.3-cm) diskettes in IBM PC DOS format. PC-SEAPAK is a copyrighted product with all copyright vested in the National Aeronautics and

Space Administration. Phar Lap's DOS-Extender run-time version is integrated into nine of the programs. These programs are duplicated only at GSFC under license from Phar Lap. Version 4.0 will be released in the Fall of 1991.

This software package was developed by Charles R. McClain of **Goddard Space Flight Center**. *For further information, Circle 68 on the TSP Request Card.*
GSC-13320

Mechanics

Vortex-Blob Simulation of Two-Dimensional Flows

Two programs compute flows about bodies of arbitrary shape.

A software package includes two programs: KPD12 and KPD12P. Both programs use the vortex-blob method to simulate flow around solid bodies. KPD12 treats an unbounded domain, while KPD12P treats a domain that has periodicity in one direction. The main advantage of the vortex-blob method is the ability to handle situations involving arbitrary shapes, including multiple bodies. The user supplies only points on the solid boundaries; there is no grid.

The KPD12 program has worked successfully on bluff bodies, stalled wings, and multiple-element airfoils. The KPD12P program has been used successfully on high-solidity separated cascades and on cases of rotating stall in cascades of thin airfoils. However, the programs do not capture such subtle viscous effects as incipient separation and friction drag.

The KPD12 and the KPD12P programs apply the vortex-blob method to time-dependent, high-Reynolds-number flows around solid bodies. Both programs solve the two-dimensional incompressible Navier–Stokes equations, neglecting the viscous effects away from the walls. By creating new vortexes along the wall at every time step, they treat the no-penetration and no-slip boundary conditions while using an influence matrix. The code automatically controls the number of vortexes. Furthermore, the code includes the option of treating the boundary layers by simple integral methods to determine the separation points. The output of KPD12 includes forces, moments, and pressure distributions on the bodies. The output of KPD12P also includes the turning angle and loss of total pressure.

The source code is in Cray FORTRAN and contains a few calls to Cray vector functions, which are vectorized with the Cray compiler. However, substitutes for these vector functions are provided. The code is set up to plot the bodies, positions of the vortexes, and streamlines by use of the DISSPLA graphics software. The software requires a mainframe computer with at least 589K of memory available running under COS 1.16.

This program was written by Philippe Spalart of **Ames Research Center**. *For further information, Circle 12 on the TSP Request Card.*
ARC-12810

Computer Program for Variable-Conductance Heat Pipes

VCHPDA solves nonlinear equations to compute transient and steady-state performance.

The VCHPDA computer program was developed in response to the need for accurate and efficient prediction of the performance of variable-conductance heat pipes used in the thermal-control systems of spacecraft. The features that make these heat pipes ideal for applications on spacecraft also make them attractive for nonaerospace uses. The need to understand these devices better arose when four thermal anomalies that occurred on the Communications Technology Satellite were attributed to transient failures in the variable-conductance-heat-pipe system. As a result of investigations into these anomalies, VCHPDA was written to provide accurate mathematical models of the transient as well as the steady-state performance of variable-conductance heat pipes over a wide range of operating conditions.

VCHPDA applies to variable-conductance heat pipes with either cold, wicked or hot, nonwicked gas reservoirs and uses the ideal-gas law and the "flat-front" (negligible vapor diffusion) gas theory. Given the distribution of temperature along the wall of a variable-conductance heat pipe, VCHPDA calculates the length of the gas-blocked region and the temperature of the vapor in the active portion of the heat pipe by solving a set of nonlinear equations for the conservation of energy and mass.

VCHPDA is a collection of subroutines that must be used in conjunction with the lumped-parameter thermal-analyzer program SINDA. The original version, developed in 1980, was written in FORTRAN IV and implemented on a CDC 6000-series computer. The latest version, developed in 1985, is written in FORTRAN 77 and implemented on both an APOLLO computer under AEGIS and a VAX computer under VMS.

This program was written by D. Antoniuk of TRW, Inc., for **Lewis Research Center**. *For further information, Circle 15 on the TSP Request Card.* *LEW-14933*

Computing Large-Angle Transients in Structures

The LATDYN software is applicable to a variety of jointed and unjointed structural configurations.

LATDYN is a computer code for calculating the large-angle transient dynamics of flexible articulating structures and mechanisms that include joints about which members rotate through large angles. LATDYN extends and brings together some of the aspects of finite-element analysis of structures, the dynamics of multiple bodies, and the analysis of control systems — three disciplines that, historically, have been separate. It combines significant portions of their distinct capabilities into one analysis software tool.

The finite-element formulation for flexible bodies in LATDYN extends the conventional finite-element formulation by use of a convected coordinate system to construct the equations of motion. The formulation in LATDYN allows for large displacements and rotations of finite elements subject to the restriction that strains and deformations within each element are small. Also, the finite-element approach implemented in LATDYN provides a convergent path for verifying solutions simply by increasing the density of the computational mesh.

For rigid bodies and joints, LATDYN borrows extensively from methodology used in computing the dynamics of multiple bodies, wherein rigid bodies may be defined and connected together through joints (hinges, ball joints, universal joints, sliders, and the like). Joints can be represented in mathematical models either by constraints or by adding joint degrees of freedom.

To eliminate errors brought about by the separation of the analyses of controls and of structures, LATDYN provides symbolic capabilities for mathematical modeling of control systems integrally with the analysis of dynamics of structures. Its command language contains syntactical structures that perform symbolic operations that are also connected directly with the finite-element model of a structure, bypassing the modal approximation. Thus, when the dynamical equations that represent the model of the structure are integrated, the equations that represent the control system are integrated along with them as part of a coupled system. This procedure also has the side benefit of enabling a dramatic simplification of the user interface for the mathematical modeling of control systems.

The LATDYN software consists of three FORTRAN computer programs: the LATDYN program, the Preprocessor, and the Postprocessor. The Preprocessor translates the user's commands into a form that can be used while the LATDYN program provides the computational core. The Postprocessor enables the user to plot and interactively manage a data base of results of LATDYN analyses of transients. It also includes special facilities for mathematical modeling of control systems and for programming those changes in the model that take place during an analysis sequence.

The documentation of the LATDYN software includes a demonstration problem manual for the evaluation and verification of results and a postprocessor guide. Because the program should be viewed as a byproduct of research on the development of technology, the scope of LATDYN is limited. It does not have a wide library of finite elements, and three-dimensional graphics are not available. Nevertheless, it does have a measure of "user friendliness."

The LATDYN program was developed during an interval of several years and was implemented on a CDC NOS/VE and Convex Unix computer. It is written in FORTRAN 77 and has a virtual-memory requirement of 1.46 MB. The program was validated on a DEC MICROVAX computer operating under VMS 5.2.

This program was written by Jerrold M. Housner and Maria V. Mitchum of **Langley Research Center**, *A. Louis Abrahamson, Che-Wei Chang, Michael G. Powell, and Shih-Chin Wu of COMTEK, and Brandford D. Bingel and Paula M. Theophilos of Computer Sciences Corp. For further information, Circle 34 on the TSP Request Card. LAR-14382*

Plotting Program for Aerodynamical Computations

Output data from a panel-method program can be plotted in a variety of formats.

Researchers who construct mathematical models to solve problems in aerodynamics must be able to generate report-quality graphics to present their results effectively. PMAPP, the Panel Method Aerodynamic Plotting Program, has been written by Sterling Software for scientists at NASA's Ames Research Center to plot the results of aerodynamical analyses (flow data) from PMARC (ARC-12642), a program for the computation of three-dimensional flow by a low-order panel method. PMAPP is an interactive, color-capable graphics program designed to work with a variety of computer terminals and printers.

The program accepts unformatted PMARC plot-data files as input. These files store a variety of data, including data on wire-frame geometrical models, data on the geometries of wakes, aerodynamic parameters defined on the model geometry, and data on off-body velocity scans and streamlines. PMAPP could be used to plot data from other programs, provided that the files that contain those data are defined according to the PMARC conventions.

PMAPP reads the three-dimensional data from the files and produces plots in several formats. Plotting options include plots of three-dimensional geometry with off-body streamlines, off-body velocity scan contours, off-body velocity scan vectors optionally superimposed, and data curves superimposed over two-dimensional sections of the model geometry. A postprocessor is supplied to remove hidden lines from the three-dimensional-appearing plots.

The program includes the Ames Standard Plot (ASP) graphics library to convert the data to be plotted into device-independent plot (DiP) files. A set of file-conversion programs supplied with PMAPP enables plotting on a large selection of equipment including Versatec printers, PostScript printers, QMS and ATI laser printers, Tektronix terminals, and any terminal or computer able to emulate a Tektronix 40xx terminal.

PMAPP is written in FORTRAN77. It was developed on a DEC MicroVAX computer with the VMS 4.6 operating system and is designed to run on any VAX or MicroVAX computer with the VMS operating system. PMAPP requires the TCS (Tektronix Control Sequence) library, available through Tektronix, to display data on terminal screens and to create geometrical plots with hidden lines removed.

This program was written by L. J. Wigren and P. K. Lovely of Sterling Software for **Ames Research Center**. *For further information, Circle 138 on the TSP Request Card.*
ARC-12751

Program Solves Euler Equations of Supersonic Flow

EMTAC features an efficient space-marching solution technique.

The analysis of supersonic flow over a three-dimensional surface, such as that of a jet fighter or the Space Shuttle, is efficiently mathematically modeled by space-marching techniques. The EMTAC (Euler Marching Technique For Accurate Computation) computer program employs an Euler marching algorithm for computing supersonic flows. This algorithm enables accurate nonlinear analysis of the nonlinear dynamics of supersonic flow over a wide range of supersonic mach numbers and angles of attack. The EMTAC program is based on the exact equations of the dynamics of an inviscid gas and is valid for computations of flows at low and high supersonic mach numbers that exhibit strong shocks and rotational effects.

SIMP (Supersonic Implicit Marching Program For Nonlinear Full Potential Analysis, LAR-13413) is a program capable of handling subsonic pockets near the canopy, the junction between the wing and body, the leading edge of the wing, and the tip of the wing at low supersonic mach numbers. However, because of assumptions of isentropy, SIMP is unable to handle strongly shocked flows with rotational and vortex effects. The EMTAC and SIMP programs have been extensively validated against each other in the range of mach numbers at which the assumptions of isentropy are valid.

The EMTAC program features an efficient space-marching technique based on Euler equations of unsteady flow. Finite-volume implementations of total-variation-diminishing discretizations that have high accuracies (up to third order) are used to make the technique more accurate and reliable than are other Euler space-marching and time-marching techniques that are based on central-difference approximations. EMTAC incorporates a planar Gauss–Seidel relaxation method that reduces to a simple marching technique in supersonic parts of the flow field. In subsonic parts, both forward and backward Gauss–Seidel sweeps are used. The EMTAC program can also be easily used for inviscid three-dimensional flows that are fully subsonic or transonic (subsonic with supersonic pockets).

EMTAC is written in FORTRAN V and is intended for use on supercomputers that have the ability to utilize UPDATE directives. After the UPDATE directives are used to change parameters and boundary conditions, the program can be used on a smaller computer such as a VAX. A sample UPDATE file and modified source code are included as examples on the distribution tape. The modified source code was created by using the UPDATE directives on a CYBER 960 computer running NOS and has been successfully implemented on a MicroVAX 3600 computer under the VMS operating system. EMTAC was developed in 1987.

VAX, MicroVAX, and VMS are trademarks of Digital Equipment Corp. CYBER 960 and NOS are trademarks of Control Data Corp.

This program was written by Kuo-Yen Szema, Sukumar Chakravarthy, and Vijaya Shankar of Rockwell International Corp. for **Langley Research Center**. *For further information, Circle 35 on the TSP Request Card.*
LAR-14228

LOP — Long-Term Orbit Predictor

This program computes long trajectories of spacecraft around planets.

The Long-Term Orbit Predictor (LOP) trajectory-propagation computer program is a useful tool in analysis of the lifetime of an orbiting spacecraft. LOP is suitable for studying planetary-orbit missions with reconnaissance (flyby) and exploratory (mapping) trajectories. LOP includes sample data for a study of the drift cycle of a geosynchronous station, a strategy for radar mapping of Venus, a frozen orbit about Mars, and an orbit characterized by a repeating ground trace.

LOP is based on the use of the variation-of-parameters method in the formulation of the equations of motion. Terms that involve the mean anomaly are removed from numerical integrations so that large step sizes, on the order of days, are possible. Consequently, LOP can be executed much faster than can such programs based on Cowell's method as the companion program ASAP (the Artificial Satellite Analysis Program, NPO-17522, also available through COSMIC). LOP incorporates a force model with a gravity field of up to 21 by 21, lunisolar perturbation, drag, and solar-radiation pressure.

The input includes classical orbital elements (either mean or oscillating), orbital elements of the Sun relative to the planet, reference time and dates, drag coefficients, gravitational constants, radius of the planet, and rate of rotation of the planet. The printed output contains the classical elements for each time step or event step, and such additional orbital data as true anomaly, eccentric anomaly, latitude, longitude, periapsis altitude, and the rate of change per day of certain elements. In addition, selected items of output are written to a plot file for postprocessing by the user.

LOP is written in FORTRAN 77 (requiring the Lahey F77 V2.0 compiler and Microsoft Linker V3.3X) for batch execution on an IBM PC-series computer operating under a version of DOS and requires a minimum central random-access memory of 256 KB. The LOP software package includes examples that use LOTUS 1-2-3 for graphical displays, but any graphics software package should be able to handle the ASCII plot file. The LOP program was written in 1986 and last updated in 1989.

This program was written by Johnny H. Kwok of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 65 on the TSP Request Card.*
NPO-17052

Mathematics and Information Sciences

Automatic Generation of Countdown-Simulating Software

The ANPS program generates simulation programs from the user's specifications.

The development of some of the large simulation projects of the space program — like the project that involves the simulation of the countdown sequence prior to the lift-off of a spacecraft — requires the support of automated software and techniques. The number of preconditions that must be met for a successful spacecraft launch and the complexity of interrelationships among these preconditions account for the difficulty of creating an accurate mathematical model of the countdown sequence. Researchers have developed the ANPS computer program for the NASA Marshall Space Flight Center to assist programmers who are attempting to model the prelaunch countdown sequence. ANPS is designed to write simulation programs for problems concerning the prelaunch activities of space vehicles and the operation of ground support equipment and has potential for use in developing network-reliability models for systems and subsystems of equipment.

Incorporating the elements of automatic programming as its foundation, ANPS aids the user in defining the problem and then automatically writes the appropriate simulation program in GPSS/PC code. The interactive user-dialogue interface of this program creates an internal problem-specification file from the user's responses. This file includes the time line for the countdown sequence, the attributes of the individual activities that are part of a launch, and the relationships of dependency among the activities. The automatic simulation-code generator of the program receives the file as input and selects appropriate macroinstructions from a library of software modules to generate the simulation code in the target language GPSS/PC. The user can recall the problem-specification file for modification to effect any desired changes in the source code.

ANPS was developed in 1988 for use on IBM-PC or compatible computers. The program requires at least 640 KB memory and one 360-KB disk drive, PC DOS Version 2.0 or above, and GPSS/PC System Version 2.0 from Minuteman Software. The program is written in Turbo Prolog Version 2.0.

GPSS/PC is a trademark of Minuteman Software. Turbo Prolog is a trademark of Borland International. IBM-PC and PS DOS are registered trademarks of International Business Machines Corporation.

This program was written by Bernard J. Schroer, Shou X. Zhang, and Fan T. Tseng of **Marshall Space Flight Center**. *For further information, Circle 85 on the TSP Request Card.*
MFS-26091

Menu-Driven Solver of Linear-Programming Problems

This program assists the inexperienced user in formulating linear-programming problems.

Linear programming is a widely used engineering and management tool. Scheduling, allocating resources, and planning production are all well-known applications of linear programs (LP's). Because most linear-programming problems are too large to be solved by hand, over the decades many computer codes have been developed to solve such problems.

The A Linear Program Solver (ALPS) computer program is a full-featured LP analysis program. ALPS can solve plain linear-programming problems as well as more-complicated mixed-integer and pure-integer programs. ALPS also contains an efficient technique for the solution of purely binary linear-programming problems.

One of the many weaknesses of computer programs for the solution of linear-programming problems ("LP solvers," for short) is the lack of interaction with the user. ALPS is a menu-driven program, with no special commands or keywords to learn. In addition, ALPS contains a full-screen editor to enter and maintain the LP formulation. ALPS provides for portability, in that formulations can be written to and read from plain ASCII files. For users less experienced in LP formulation, ALPS contains a problem "parser," which checks formulations for errors. ALPS creates fully formatted, readable reports that can be sent to a printer or output file.

ALPS is written entirely in IBM's APL2/PC software, Version 1.01. The program exists in two forms. The APL2 workspace program, which contains all the ALPS code, can be run on any APL2/PC system (AT or 386). This configuration, on a 32-bit system, can take advantage of all extended memory. The user can also examine and modify the ALPS code. Alternately, the APL2 workspace program has been "packed" to be run on any DOS system (without APL2) as a stand-alone "EXE" file, but has limited memory capacity on a 640K system. A numeric coprocessor (80×87) is optional but recommended. The packed program contains licensed material that is the property of IBM (copyright 1988, all rights reserved).

This program was written by L. A. Viterna of **Lewis Research Center** *and D. Ferencz of Case Western Reserve University. For further information, Circle 5 on the TSP Request Card.*
LEW-14978

Software for Generating Graphs and Charts

Plots and pie charts can be generated quickly.

The Common Graphics Library (CGL) computer program is designed to enable users to generate graphs and charts of quality sufficient for publication or optical projection. CGL quickly and easily generates linear, logarithmic, bar, pie, and composite charts. Features of linear charts include automatic scaling, increasing or decreasing numerical axes, and character axes. Features of pie charts include segment labels, exploded segments, and chart keys. One of the general features is horizontal or vertical orientation of figures.

The CGL program has two user-interface levels. The Langley Easy (LEZ) routines provide a simple way to generate complete charts of quality sufficient for use in reports. Special knowledge of CGL or of DI-3000 graphics software library supplied by the user is not required. The second user interface enables the user to manipulate components of charts and design specific charts for unique or unusual purposes.

CGL version 2.1 was written in 1988 in ANSI FORTRAN 77 and requires the commercial graphics software package DI-3000 (Precision Visuals) as the underlying graphics package. CGL is therefore machine-independent within the support range of the DI-3000 software.

This program was written by Dana P. Hammond, Alicia S. Hofler, David L. Miner, and Pauline M. Theophilos of Computer Sciences Corp. and Nancy L. Taylor of **Langley Research Center**. *For further information, Circle 110 on the TSP Request Card.*
LAR-14505

Fault-Tree Compiler Program

This program facilitates the description of a fault tree and speeds analysis.

FTC, the Fault-Tree Compiler program, is a reliability-analysis software tool used to calculate the probability of the top event of a fault tree. Five different types of gates are allowed in the fault tree: AND, OR, EXCLUSIVE OR, INVERT, and M OF N. The high-level input language of FTC is easy to understand and use. In addition, the program supports a hierarchical fault-tree-definition feature that simplifies the process of description of the tree and reduces execution time.

A rigorous error bound is derived for the solution technique. This bound enables the program to supply an answer with a precision (within the limits of double-precision floating-point arithmetic) of a number of digits specified by the user. The program also facilitates sensitivity analysis with respect to any specified parameter of the fault tree, such as a rate of failure of a component or the probability of a specific event, by enabling the user to vary one rate of failure or the probability of failure over a range of values and plot the results.

The solution technique is implemented in FORTRAN, and the user interface is in Pascal. The program is written to run on a DEC VAX computer operating under the VMS operating system and uses 143K of memory. FTC was developed in 1989.

DEC, VAX, and VMS are trademarks of Digital Equipment Corp.

This program was written by Ricky W. Butler of **Langley Research Center** *and Anna L. Martensen of PRC Kentron, Inc. For further information, Circle 31 on the TSP Request Card.*
LAR-14586

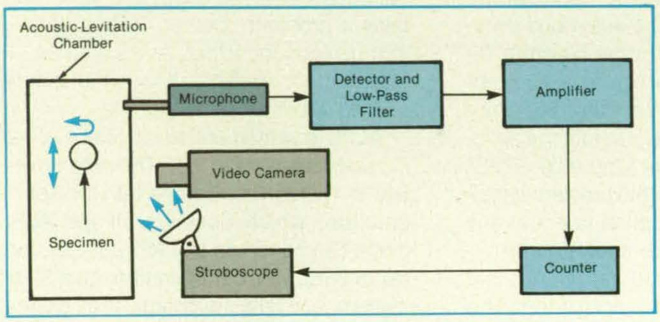
Acoustic Measurement of Periodic Motion of Levitated Object

The levitating acoustic signal is modulated by object motion of lower frequency.

NASA's Jet Propulsion Laboratory, Pasadena, California

Some internal vibrations, oscillations in position, and rotations of an acoustically levitated object can be measured by use of a microphone that is already installed in a typical levitation chamber for tuning the chamber to resonance and monitoring its operation. The motions in question are usually characterized by frequencies less than that of the levitating acoustic carrier signal. These motions affect the acoustic field in such a way as to cause amplitude modulation of the carrier signal in the output of the microphone. The amplitude modulation can be detected and analyzed spectrally to determine the amplitudes and frequencies of the motions.

The figure illustrates an experiment that was performed to verify this measurement concept. A specimen was levitated in a 20-kHz sound field and made to undergo a stable vertical vibration. The output of the microphone was filtered and amplified, and the peaks of the amplified signal were counted to determine the frequency of the modulation. A stroboscope aimed at the specimen and synchronized with the counting pulses was used to verify that the counter was reading the frequency of vibration.



Some Translational and Rotational Oscillations of the specimen were detected via amplitude modulation of the levitating signal. That the oscillations of the specimen were synchronous with the modulation was verified stroboscopically.

This work was done by John L. Watkins and Martin B. Barmatz of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 130 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 14]. Refer to NPO-18191.

Rapidly Deployable Enclosure

Balloons expand to surround and seal off equipment.

Marshall Space Flight Center, Alabama

A lightweight temporary enclosure protects equipment from immersion in seawater or contact with harmful atmospheres or other corrosive media. The enclosure can be fully deployed within a few seconds.

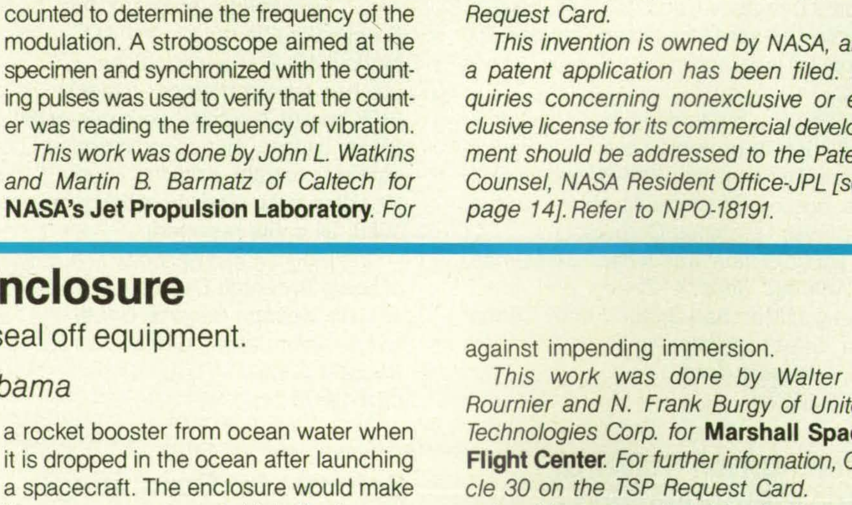
The undeployed enclosure consists of a folded balloon on the circumference of a circular housing (see figure). At the moment of deployment, a chemically inert gas (helium in the original application) is forced into the balloon. As the balloon expands, it forces open magnetic or clamping seals on the doors of the housing and bursts outward to surround the equipment. Expansion takes about 1 s.

When expansion is complete, a motor retracts a pull cord that encircles the open end of the balloon. This action cinches a closure flap shut and draws the cinched flap through a "bear-trap" clamp. The clamp, which has a stiff spring, snaps shut after a preset length of flap enters it, thereby forming a water- and gas-tight seal. The entire deployment process takes only 4 s.

The enclosure was conceived to shield a rocket booster from ocean water when it is dropped in the ocean after launching a spacecraft. The enclosure would make it unnecessary to refurbish the booster after recovering it from the ocean. The shape of the housing balloon could, presumably, be adapted to suit terrestrial equipment that must be shielded quickly against impending immersion.

This work was done by Walter L. Rournier and N. Frank Burgy of United Technologies Corp. for **Marshall Space Flight Center**. *For further information, Circle 30 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 14]. Refer to MFS-28512.



The **Housing of the Undeployed Enclosure** encircles the equipment to be enclosed. The deployed enclosure surrounds the equipment and seals it from the environment.

Two-Dimensional Vernier Scale

Simple manipulation of a pair of overlays gives accurate readings of coordinates in two dimensions.

Lyndon B. Johnson Space Center, Houston, Texas

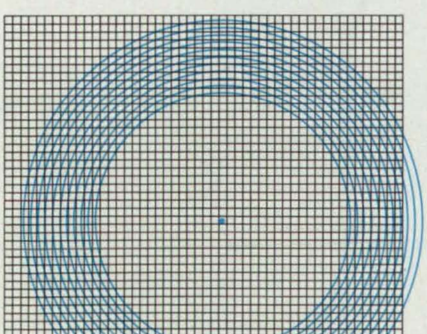
A modified vernier scale gives accurate two-dimensional coordinates from maps, drawings, or cathode-ray-tube displays. Like the linear vernier caliper familiar to machinists and mechanical engineers, the scale enables the user to interpolate between the finest divisions of a regularly spaced rule simply by observing which mark on an auxiliary vernier rule aligns with a mark on the primary rule.

The tool consists of two transparent overlays: a fixed one containing a cartesian grid and a movable one containing concentric circles (see figure). The space between the circles is nine-tenths that between the lines of the grid (the same as on the auxiliary rule on the conventional one-dimensional vernier caliper).

The user places the center of the circles on the point, the coordinates of which are to be measured. The user observes the *x* and *y* values of the grid lines nearest the point and interpolates to additional significant figures by noting the *x* and *y* values of the grid lines with which the circles coincide. The measurements are done easily and quickly.

The movable overlay can contain a second cartesian grid instead of circles and can be used in the same way — by noting the coincidences of lines on the fixed and movable overlay. However, the movable grid would have to be kept in strict orthogonal alignment with the fixed grid. This requirement does not apply to the circular grid; the accuracy of its measurement is unaffected by rotation.

The method can be adapted to noncartesian grids — for example, a slanted grid that is a linear transformation of a cartesian grid. The circles on the movable overlay would be calculated as for the cartesian grid, then modified according to the same linear transformation. In this case, interpolation would be done by noting the coincidences of ellipses with lines. In this case, the ellipses would have to be maintained in angular alignment with the fixed grid.



The **Movable Circular Overlay Rests** on a fixed rectangular-grid overlay. The pitch of the circles is nine-tenths that of the grid and, for greatest accuracy, the radii of the circles are large compared with the pitch of the grid.

This work was done by Richard D. Juday of **Johnson Space Center**. *For further information, Circle 55 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, Johnson Space Center [see page 14]. Refer to MSC-21700.

Ribbon Cable Strap Partly Free of Backlash

A connection across a limited-rotation joint operates at cryogenic temperatures.

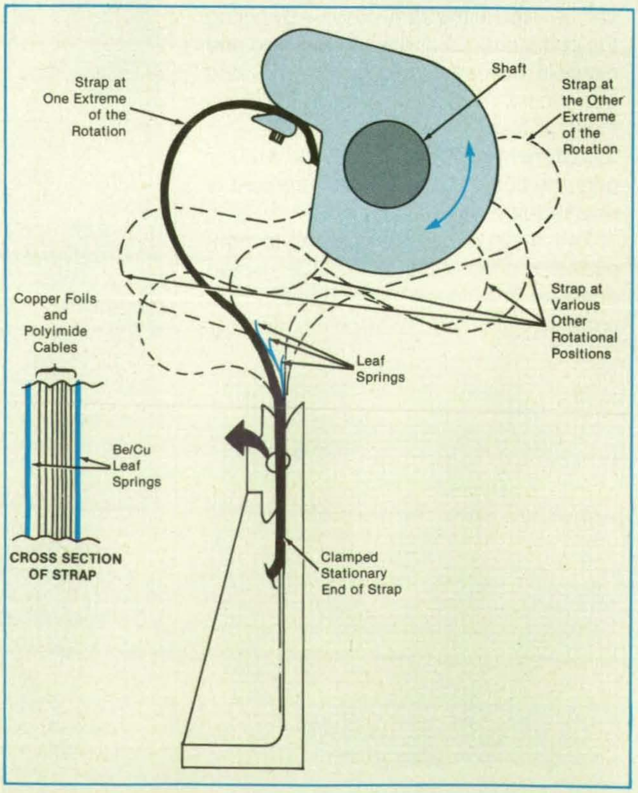
Goddard Space Flight Center, Greenbelt, Maryland

A flexible ribbon cable strap carries heat and electrical signals across a rotational shaft without creating backlash torques at both extremes of rotation through a limited angular range. The strap keeps its flexibility and nonbacklash properties at cryogenic temperatures. It thus can be used to connect delicate equipment, such as movable infrared sensors, that require precise positioning.

The strap consists of layers of 30 gold-plated copper foils and 3 polyimide ribbon cables. At its stationary end, the strap is sandwiched between beryllium/copper leaf springs (see figure). At one extreme of the rotary motion, the strap is curved like a question mark. At the other extreme of the rotary motion (217° from the first extreme), the strap forms a reverse question mark. Both extreme positions are stable in that the strap produces zero torque there. The leaf springs act in concert with an offset of the stationary end of the strap from centerline of the shaft to eliminate undesirable snapping of the strap as the shaft rotates from one extreme position to the other.

A strap of this type can readily be adapted to a greater or lesser angular travel by changing its length and offset and the bias of the ribbon cables.

This work was done by Rodger Farley and Armando Morell of **Goddard Space Flight Center**. *For further information, Circle 49 on the TSP Request Card. GSC-13371*



The **Ribbon Strap** is designed to exert no backlash torque at two extreme positions of limited rotation at the temperature of liquid helium. The copper foils provide ample cross section for the transfer of heat. The leaf springs stop the strap from snapping as it passes from one extreme position to the other.

Lubricant for Use in Liquid Oxygen

An inexpensive grease extends the lives of bearings in a turbopump.

Marshall Space Flight Center, Alabama

An inexpensive grease, Braycote 640 AC-MS (or equivalent), increases the operating lifetimes of ball bearings in a liquid-oxygen turbopump. In a demonstration, the grease was used in 57-mm bearings. After operation from 27,000 to 31,500 rpm for 25,700 s, the balls showed no signs of wear and had lost a negligible amount of weight. In contrast, under the same operating conditions, balls lubricated by fluoroethylpolypropylene solid lubricant coating on glass-filled polytetrafluoroethylene separators showed obvious surface distress after only 1,440 s and had lost 270 mg of material (see figure).

The fluoroethylpropylene coating process cost about $150 per bearing cage (1990 prices). Implantation of ions in balls and raceways runs $10,000 per bearing and yields only limited improvement in life expectancy. The new grease costs less than 50 cents per bearing (1990 prices).

The fluoroethylpropylene coating on a cage provides only a small reservoir of lubricant. When it is consumed, the balls scrub the separator, exposing the fiberglass reinforcement in it. The balls then wear faster.

The improved grease can be stored and supplied very efficiently. The addition of a coat of the grease only 3 to 4 mils (0.08 to 0.10 mm) thick to the surfaces of the separator pockets is sufficient. In the cryogenic liquid, the grease film freezes. However, during operation, the balls are warm and melt the grease upon contact so that an ultrathin film of the grease comes to adhere to each ball. The ball carries the film to the raceway, where it lubricates the contact surface.

This work was done by Robert F. Beatty and Scott E. McVey of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information, Circle 28 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 14]. Refer to MFS-29760.

Decreased Wear is evident in bearing balls lubricated by a grease compatible with liquid oxygen. Balls lubricated by fluoroethylpropylene showed pronounced wear after only 24 min.

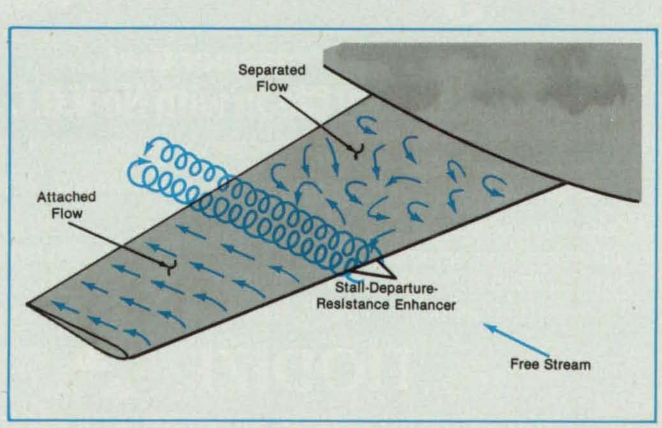
Stall-Departure-Resistance Enhancer

A device enhances spin resistance and increases lift at poststall angles of attack.

Langley Research Center, Hampton, Virginia

The stall-departure-resistance enhancer is a device that improves the stall departure resistance of aircraft operating at or near the stall angle of attack of a wing. The device induces vortical flow over the upper surface of the wing. Vortex generators of various configurations have been used to delay or control the separation of flows on wings. Previous devices typically consisted of small wedges on and perpendicular to the upper surfaces of wings.

The stall-departure-resistance enhancer, as specified in a new design developed at NASA Langley Research Center, is placed at the leading edge of a wing to create vortexes over the upper surface of the wing at near-stall conditions. The wedge delays stall by preventing the wing lift from suddenly decreasing after the angle of attack of the wing increases beyond what would otherwise be the stall angle. The vortical flow produced by the wedge adds energy to the boundary layer by mixing some of



The **Stall-Departure-Resistance Enhancer** imposes a lesser drag penalty than do nortex generators of older types. It increases lift by as much as 30 percent at angles of attack that would otherwise be in the poststall region.

the high-energy fluid from the external flow into the low-energy shear layer near the upper surface of the wing and acts as an aerodynamic fence that prevents separated flow from spreading to the outboard portion of the wing (see figure). Thus, the flow about the outboard portion of the wing remains attached at higher angles of attack, and the stall departure resistance of the airplane is increased.

The device is a flat plate wedge with a 60° sweep angle and is attached so that it protrudes from the leading edge of the wing. The tip is a sharp point, and the edges are made thin and sharp to induce good vortical flow. When the device is mounted on a wing, the centerline of the device should be aligned with the freestream direction. A test conducted at the NASA Langley 12-ft (3.7-m) Low-Speed Wind Tunnel showed the device to work very well on a wing with a leading-edge-sweep angle of 26°. Flow-visualization techniques showed that it produced vortexes that kept the flow organized at higher angles of attack.

An improved design includes a hinged attachment so that the device is aligned with the freestream at low angles of attack. As the stall angle of attack is approached, the device encounters a limiter, which sets the device at an angle of attack to induce vortical flow. The advantage of this type of device is that the hinged action tends to minimize the cruise- or climb-performance penalties.

Obvious applications include those intended to increase safety for a broad range of aircraft, including trainers, fighters, general-aviation aircraft, and commercial transport aircraft. The device may also have nonaerospace applications where flow stall is a problem under certain conditions, such as in the control of separation in flow diffusers. There may also be other applications in fluid machinery and fluid flow.

This work was done by Holly M. Ross of Lockheed Engineering and Sciences Co. and Joseph L. Johnson, Jr., Long P. Yip, and H. Paul Stough III of **Langley Research Center**. *For further information, Circle 145 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 14]. Refer to LAR-14221.

Gauge Measures Large Spherical Bearing Surfaces

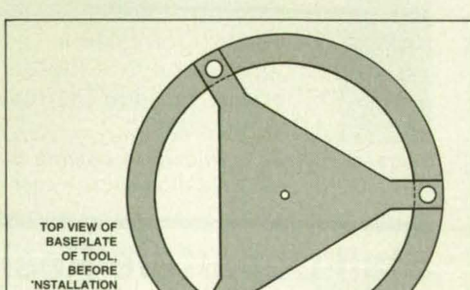
Radii can be determined without time-consuming electronic inspections.

John F. Kennedy Space Center, Florida

A simple mechanical tool provides data on the radii of large exterior spherical bearing surfaces. The tool can be used onsite, so that it is unnecessary to ship bearings to a laboratory for examination by computerized test equipment.

The tool is, in essence, a four-point measuring device (in principle, four points determine a sphere). The tool consists of a depth gauge on a platform supported by three precise tooling balls. These balls are placed in contact with the nominally spherical bearing surface to be measured, the depth gauge is moved inward until it makes contact with the bearing surface, and the reading of the depth gauge is recorded. If necessary, this procedure can be repeated, obtaining depth-gauge readings at several positions to obtain indications of deviations from sphericity and/or from regularity. Point-to-point variations manifest themselves directly as variations in the depth-gauge surface readings, and the spherical radius at each point can be calculated from the reading. The tool is calibrated before its first use by using it on a reference bearing traceable to the National Institute of Standards and Technology.

This work was done by George L. Davis of Lockheed Space Operations Co. for **Kennedy Space Center**. *For further information, Circle 76 on the TSP Request Card.* KSC-11485



The **Radius of the Spherical Portion** of the surface can be computed from the reading of the depth gauge. The measuring tool is calibrated by applying it to a reference spherical surface of the known radius.

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.

Rotordynamic Behavior of Sawtooth-Pattern Damping Seals

Hole-pattern damping seals are probably better.

A report describes a comparative experimental and theoretical study of the rotordynamics of several different annular liquid pump seals. A seal of this type resembles a journal bearing except that it has a larger radial gap, along which the lubricating fluid is pumped, usually with enough axial pressure drop to make the flow in the gap turbulent. In addition, a damping seal exhibits significant direct stiffness (in effect, radial centering stiffness).

The performance of an annular liquid pump seal is usually characterized in terms of the rotordynamic coefficients of a linearized small-lateral-displacement mathematical model. In addition to the direct stiffness, these coefficients include the direct damping and cross-coupling stiffness and damping, which expresses the coupling between a motion in one direction perpendicular to the axis of the shaft and the reaction force that such a motion produces in the other direction perpendicular to the axis. Performance is also characterized with respect to the volume rate of flow (leakage) of fluid along the seal.

A damping seal is an annular liquid pump seal in which the inner surface of the stator (which is the outer member) is roughened to reduce the asymptotic circumferential velocities of fluid in the gap. This, in turn, is intended to reduce the cross-coupling stiffness and the destabilizing force that it causes, thereby increasing the rotordynamic stability. In a previous study directed toward increasing rotordynamic stability, promising theoretical and experimental results were obtained by pockmarking the inner surface of the stator with many small round holes (shallow pits, not drilled through). This study introduces damping seals of a new type in which the inner surfaces of the stators have sawtooth-cross-section axial grooves interrupted at regular axial intervals by circumferential dams. The teeth of the sawtooth patterns are directed against the rotations in an attempt to reduce further the asymptotic circumferential velocities of the fluids.

Eleven different sawtooth-pattern seals were tested in pumped $CBrF_3$ (a fire-extinguisher fluid) at various speeds of rotation and pressure drops in an apparatus instrumented with gauges and probes to measure the dynamic response. For comparison, similar tests were performed on a smooth-surface annular seal and an optimized round-hole-pattern damping seal. The seals were also studied by use of a previously developed turbulent-flow theoretical model that includes the simplifying assumption of directional homogeneity of surface roughness; the author notes that, strictly speaking, this assumption does not apply to the sawtooth seals.

The damping in the sawtooth seals was found to be less than that of the hole-pattern seal but more than that of the smooth seal. The stiffnesses of the sawtooth seals were found to be comparable to that of the hole-pattern seal. Both the sawtooth and the hole-pattern seals leaked less than the smooth seal did. The sawtooth seal that exhibited maximum damping leaked more than the hole-pattern seal did. The theoretically predicted rotordynamic coefficients of the sawtooth seals did not agree well with the measured coefficients.

This work was done by Steven A. Nolan of Texas A&M University for **Marshall Space Flight Center**. *To obtain a copy of the report, "An Experimental and Theoretical Comparison of Rotordynamic Coefficients for Sawtooth-Pattern Damper Seals," Circle 101 on the TSP Request Card.* *MFS-27242*

Bifurcations in Unsteady Flows

Implications for testing are discussed.

A report discusses the various types of bifurcations that can occur between steady and unsteady aerodynamic flows. It provides examples to illustrate the ways in which bifurcations influence the results of experiments. It recommends that experimenters take bifurcation phenomena into account in the interpretation of measurements.

The bifurcations discussed are mostly those that occur in flows under steady boundary conditions. Such bifurcations include transitions from steady-state, single-valued to steady-state, multiple-valued; to unsteady periodic; to unsteady quasi-periodic; or to chaotic flow. As an example of the first-mentioned type, the coefficient of lift (C_L) of an airfoil might branch from a single value to either of two values at an angle of attack (α) greater than a critical angle. At a bifurcation, the Frechet derivative ($dC_L/d\alpha$ in the example) ceases to exist. The effects of bifurcations on tests that involve unsteady aerodynamics are reviewed by means of examples of both forced and free oscillatory motions. The main observations can be summarized as follows:

The motion of a body can be critical when passing through a bifurcation. The existence of a subcritical bifurcation or a fold can lead to the measurement of a spurious damping if a hysteresis loop is ignored. Motion combined with bifurcation can cause major changes in the characteristics of the aerodynamics, such as those that occur in dynamic stall. Moreover, bifurcations can lead to changes in the characteristics of the motion itself. For example periodic shedding of vortexes from an elastically mounted circular cylinder in crossflow can cause the cylinder to undergo a chaotic motion.

These observations lead to the following recommendations concerning the consideration of bifurcation phenomena in experiments involving unsteady aerodynamics: (1) There should be a complete base of testing under static boundary conditions that encompasses all possibilities for the presence of hysteresis. (2) Tests should be conducted in each domain or type of aerodynamics under consideration and across all bifurcation points. (3) The analysis of data must allow for the presence of bifurcations to ensure the proper interpretation of results.

This work was done by Gary T. Chapman and Murray Tobak of **Ames Research Center**. *Further information may be found in NASA TM-100083 [N88-22014], "Bifurcations in Unsteady Aerodynamics — Implications for Testing."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. *ARC-12232*

More About Nonobstructive Particle Damping

The concept and its implementation are described in more detail.

A report presents additional information about the engineering concept described in "Nonobstructive Damping for Parts Vibrating in Flows," *NASA Tech Briefs*, Vol. 14, No. 1 (January, 1990), page 61. According to this concept, the vibrations of a structure are damped by powders, balls, or other particles packed and sealed into holes in the structure. The concept is called "nonobstructive particle damping" (NOPD) because it was originally intended as a means to damp vibrations in a vane immersed in a flow of cryogenic liquid without obstructing the flow.

The report implies that NOPD is applicable not only to vanes immersed in flows but also to other vibrating structures. Furthermore, damping fillings could include not only powders and balls but also slurries or even liquids. According to the generalized version of the NOPD concept presented in the report, the damping holes and fillings are placed in the main load path of a structure, where they help to dissipate vibrations by friction, exchange of momentum, and flexure.

The dimensions and location of the holes and the amount and type of filling are chosen according to parametric and tradeoff design studies. The vibrations of a structure are analyzed initially by finite-element computations, which provide information on frequencies, damping ratios, and the locations of greatest displacement of the various modes of vibration. The results of these computations are correlated with those of experiments as part of a process of optimization. The damping cavities and fillings are designed and placed according to the locations of maximum displacement and the dominant energy-dissipation mechanisms in the mode(s) to be damped.

It is also necessary to analyze stresses and strains in the structure to determine whether any given damping cavity concentrates stresses sufficiently to jeopardize the structure. In a good NOPD design, the overall beneficial effect of the reduction in vibration should be at least sufficient to offset the overall detrimental effect of the concentration of stress.

Provided that the damping fillings are welded or otherwise appropriately sealed in the cavities, the NOPD treatment should last much longer than do more conventional treatments that involve viscoelastic materials, which disintegrate gradually by outgassing and embrittlement. Because the mass of the damping filling is usually less than the mass of the structural material removed to make the damping holes, the NOPD treatment offers the additional advantage of a slight decrease in the weight of the structure. Another advantage of NOPD is that it is largely independent of temperature, pressure, centrifugal force, or other environmental parameters. Yet another advantage is that once the NOPD design has been determined, it is relatively easy to implement because the damping holes can be drilled routinely during fabrication.

This work was done by Hagop V. Panossian of Rockwell International Corp. for **Marshall Space Flight Center**. *To obtain a copy of the report, "Non-Obstructive Particle Damping," Circle 44 on the TSP Request Card.*

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457(f)], to Rockwell International Corp. Inquires concerning licenses for its commercial development should be addressed to

Harry B. Field (Patent Counsel)
Rockwell International Corp.
6633 Canoga Avenue
Canoga Park, CA 91304

Refer to MFS-29752, volume and number of this NASA Tech Briefs *issue, and the page number.*

Finding the Laminar-to-Turbulent Transition

Four methods — including direct visualization — are reviewed.

A technical memorandum evaluates four techniques for determining the location at which laminar flow about an airfoil changes to turbulent flow. The four techniques were studied in flight experiments on an F-14 variable-sweep-wing aircraft.

One of the techniques involves measurements by hot-film anemometer sensors. Because changes in the boundary-layer flow change the cooling effect of the flow on the heated active elements of the sensors, the outputs of the anemometers provide indications of the flow conditions.

Another technique involves measurements by boundary-layer rakes, each an array of pressure probes. The pressures at the probes are sampled electronically in sequence to obtain a map of pressure (and velocity) over the airfoil.

In the third technique, measurements are taken by pitot tubes arrayed on the airfoil, flush with its surface. The pressures sensed by the pitot tubes are also sampled in sequence electronically.

In the fourth technique, the test airfoil surface is coated with pressure-sensitive liquid crystals, to make the pressure pattern of the flow visible. The liquid crystals change color at the boundary-layer transition. The airfoil is photographed in flight from a chasing airplane.

In the F-14 experiment, measurements by the hot-film anemometers proved to give the most accurate indication of the laminar-to-turbulent transition. The anemometer data, obtained at 10 percent chord increments, were found to be accurate within ± 2.5 percent. The sensors would have to be more closely spaced, however, to define the entire transition region.

The measurements taken by the boundary-layer rakes were found to be good secondary indications of the location of the transition. The data from the boundary-layer rakes agreed within ± 5 percent with those from hot-film anemometers. Boundary-layer rakes have an added advantage: they also provide data on parameters related to skin friction.

The measurements taken by the surface pitot tubes did not consistently indicate the location of the transition. Often, the data indicated two such locations. The first location generally agreed with that indicated by the hot-film-anemometer data at lower altitudes, while the second location agreed with that indicated by the hot-film-anemometer data at higher altitudes.

The liquid-crystal coat was found to be useful for the visualization of the flow: it gives a global picture of the location of the transition, unlike the other techniques, which are limited to sampling at discrete points on the transition. Only a camera is needed for documentation. One of the minor disadvantages of the liquid-crystal technique is that dust and insects tend to adhere to the coat, producing localized turbulence. Another disadvantage is that unevenness in the thickness of the coat causes changes in color, interfering with the interpretation of the color pattern.

This work was done by Bianca T. Anderson, Robert R. Meyer, Jr., and Harry R. Chiles of **Ames Research Center**. *Further information may be found in NASA TM-100444 [N88-30093], "Techniques Used in the F-14 Variable-Sweep Transition Flight Experiment."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703)487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. *ARC-12390*

An Implementation of the Solution-Adaptive-Grid Method

The formulation of the method and instructions for use of a computer code are presented.

A NASA technical memorandum discusses the solution-adaptive-grid method and the Self Adaptive Grid Evolution (SAGE) computer code, which implements the method. This particular adaptive-grid method, described in more detail in a previous issue of *NASA Tech Briefs*, provides for redistribution of points in grids used to compute flows — especially supersonic and hypersonic flows that contain shocks, and other strong gradient regions, discontinuities, and shear layers. It is necessary to redistribute the grid points because frequently the initial choice of a computational grid does not capture the flow structures well enough to yield an accurate solution. The redistribution of points (the adaptation of the grid) is performed on the basis of the flow solution obtained on the initial grid, then the flow is recomputed on the adapted grid.

The document is divided into three parts. The first part presents a formulation of the method for a two-dimensional flow. The adaptation concept is based in part on a version of the variational principle of mechanics. The adaptation procedure is analogous to applying, at each grid point, tension and torsion spring forces proportional to the local flow gradient computed on the initial grid, then finding the equilibrium configuration into which the spring forces distort the grid. The tension springs redistribute greater numbers of grid points into regions of strong flow gradients; the torsion springs relate information between adjacent lines in such a way as to keep the lines as nearly smooth and the grid as nearly orthogonal as possible.

The adaptation of a two-dimensional grid is performed as a sequence of two one-dimensional adaptations — marching along the first coordinate while adapting the second coordinate, then marching along the second coordinate while adapting the first coordinate. It is important to point out that the result of this adaptation is not unique; nor is it an exact solution to the variational problem because it depends on which coordinate is adapted first and on the directions of marching along both coordinates. However, the nonuniqueness of the adapted grid is acceptable because it reduces errors in the flow computed on the grid.

The second part of the report presents instructions for the use of the SAGE computer code. This part does not require detailed knowledge of the mathematical concepts explained in the first part and can be read as an independent document. It includes a detailed description of the input control parameters (including the user's specification of the sequence of coordinates and directions of marching), descriptions of computing routines, nomenclature, and other information needed to run the code. Stated briefly, the code reads three input data files: one that contains the coordinates of the initial grid, another that contains the flow-field variables computed on the initial grid, and a third that contains the input-control parameters. The code then adapts the grid to the flow field according to the principles described in the first part of the report.

The third part of the report contains several examples to familiarize the user with the adaptive-grid process. Each example includes plots of the initial grid and flow-field contours, the control parameters used in the adaptation, the adapted grid, and a discussion of the choice of the control parameters. The examples are supersonic flow in an inlet, hypersonic flow about a blunt body, impingement of a shock on a blunt body, hypersonic flow in an inlet, and flow in an axisymmetric plume.

This work was done by Carol B. Davies and Ethiraj Venkatapathy of **Ames Research Center**. *Further information may be found in NASA TM-102198 [N90-12211], "A Simplified Self-Adaptive Grid Method, SAGE."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. ARC-12736

Machinery

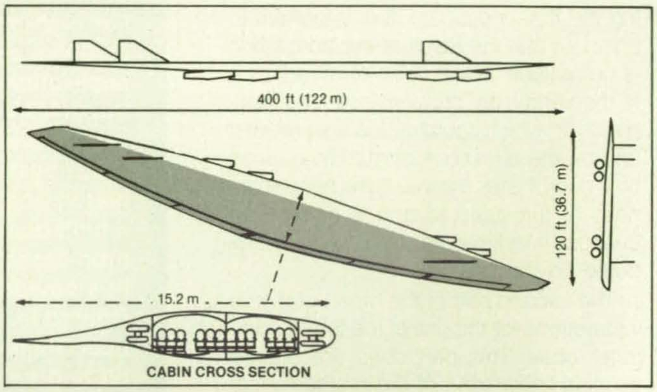
Hardware, Techniques, and Processes

Oblique-Flying-Wing Supersonic Transport Airplane

A previously abandoned design concept is reintroduced.

Ames Research Center, Moffett Field, California

An oblique-flying-wing supersonic airplane for the transport of passengers and cargo has been proposed as a possible alternative to the B747B (or equivalent). The oblique-flying-wing concept was first proposed in 1957 by Dr. R. T. Jones but was abandoned because of then-insoluble problems of stability and control. Since that time, the technology of artificial stabilization has advanced sufficiently to warrant reintroduction of the concept.



The **Oblique Flying Wing** would transport passengers and cargo as fast as twice the speed of sound at the same cost as current subsonic transports. It could fly at the same holding speeds as those of present supersonic transports but require only half the takeoff distance.

In the baseline configuration (see figure), the airplane would accommodate 462 passengers and 16 cabin crewmembers. The interior would resemble that of a widebody aircraft, with an average aisle height of 1.91 m. Windows would be installed in the leading edge, and emergency exits would be located in the leading- and trailing-edge sides of the passenger cabin. The cockpit would be located at left end of the cabin for a pilot and a copilot. The pilot would have good visibility during approach and climb.

The wing would have an elliptic planform with a nearly elliptic spanwise thickness-to-chord distribution, resulting in minimum wave drag for a given volume. The wing would be curved upward slightly to obtain an elliptic spanwise lift distribution. The wing can be swept from 35° at takeoff to 72° in cruise to achieve the maximum lift-to-drag ratio for any speed from mach 0.2 to mach 2.0. To achieve the required lift with minimal drag and a nearly level cabin floor, during cruise, the center of gravity would be shifted to the required position by a fuel trim system. The airplane would have a conventional monocoque and honeycomb structure incorporating the aluminum alloy RR.58-AU2GN (or equivalent) developed for the Concorde. By limiting the speed to mach 2, one would reduce the equilibrium skin temperature from 130°C to 100°C, thereby increasing the life of the airframe over that of the Concorde.

To increase yaw control in case of the failure of one engine and to minimize the wave drag and wing stress, the engines would be podded in four nacelles. The nacelles could be pivoted over a 35° range and would be distributed optimally along the span. In view of the limitations of the artificial-stability-and-control system, the nacelles would have to be placed as far forward as possible. Four 250-kN engines of conventional design would be used. The undercarriage would include six legs with four tires each.

The maximum takeoff weight would be 20 percent less than that of the B747. The aircraft would operate from conventional runways within the FAR 36 stage 3 noise requirements. The oblique-flying wing can also operate overland at the boomless supersonic cruise mach number of 1.2. Stability and control around the roll and pitch axes would be provided by a 10-percent-multisegmented tailing-edge flap. Segmenting the trailing-edge flap would increase the reliability of the system and enable the control of roll. Such a flap system could help to smooth out any gusts and allow the use of a more-cambered wing and a higher design lift. The artificial-stability-and-control system for this flap would include a standard proportional/integral/derivative controller that would relate the angle of pitch and its first and second derivatives with respect to time to an optimum flap deflection.

This work was done by Alexander J. M. Van der Velden of Stanford University for **Ames Research Center**. *Further information may be found in NASA CR-177529 [N89-25233], "The Conceptual Design of a Mach 2 Oblique Flying Wing Supersonic Transport."*

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

ARC-12525

Two-Axis Track Rollers

A compact, lightweight design would reduce side friction.

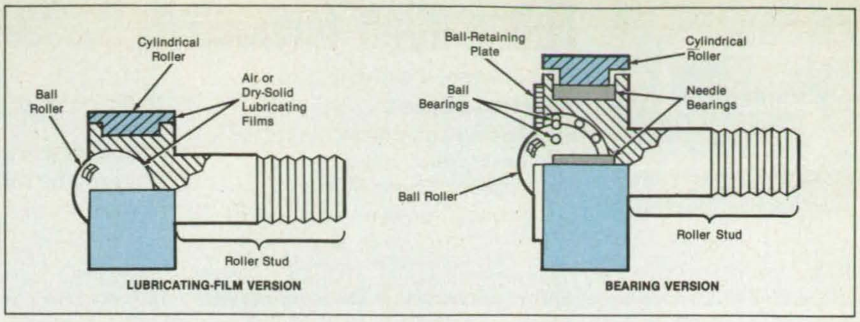
Marshall Space Flight Center, Alabama

A set of proposed two-axis track rollers would enable a sliding door to follow a curved track in both directions without binding. The rollers are intended for use on sliding hatch covers on the proposed Space Station *Freedom* and would probably also be useful on Earth to ensure ease and reliability of motion in sliding doors, windows, covers, and partitions.

The basic problem is to design a lightweight, compact roller that can follow a track similar to that on a sliding garage door, without binding. In the formulation of this design, any device used to reduce the side friction that causes binding must not, itself, cause binding. In the intended Space-Station application, the design of the rollers would also affect the design of a switching mechanism that would control the paths of the rollers along the track. Two previous solutions were tried and rejected:

1. A combination of three rollers mounted on a pivoting track: Two of the rollers would follow the track while the third, placed between the other two, would keep the other two from binding on the inside of the web of the track; the whole assembly would pivot to accommodate the curves in the track. This mechanism would be bulky and heavy and would necessitate both a track that is larger and a switching mechanism that is more complicated than are those envisioned for the initial application.
2. An assembly including a cam follower with a ball transfer attached to its end: This design required a track of excessive depth.

The proposed two-axis track roller evolved from the second of the rejected designs. It would be essentially a roller of the cam-follower type, with a large ball embedded in its end to minimize side friction on the roller. In the version illustrated on the left side of the figure, the roller would incorporate an air or a dry-solid lubricating film. The version illustrated on the right side of the figure would incorporate needle and roller bearings. An alternative version might incorporate some combination of film lubricant(s), needle bearings, and/or roller bearings. The choice of combination is not critical, though a dry-film design would tend to be the most compact and lightweight. A suitable dry lubricant might be Karon (or equivalent), which is being considered for use in outer space.



The **Two-Axis Track Roller** would be a combination of a cylindrical cam-follower-type roller and a large ball end roller.

This work was done by John M. Melinick and Kenneth O. Juebschman of Boeing Aerospace & Electronics for **Marshall Space Flight Center**. *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 14]. Refer to MFS-28470.

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.

Lifting Loads With Two Helicopters

Force-balance equations serve as a basis for coordination in flight.

A report discusses the theoretical equilibrium characteristics of a dual-helicopter lifting system. Such systems have been employed in both the military and civilian sectors to deliver weapons, vehicles, and construction materials. However, dual-helicopter lifts have not been optimized with respect to consumption of fuel by the helicopters, stability, maneuverability, and other critical operating characteristics. The analysis presented in the report provides the mathematical basis for the selection of lifting configurations and flight parameters.

In the system under study, the cargo is suspended by two cables, one attached to each end of a spreader bar. Each end of the spreader bar is suspended by a tether cable from one of the helicopters. The analysis is based on the application of the force-balance equations to the centers of gravity of the load and helicopters and to the endpoints of the spreader bar.

The analysis is simplified. It does not consider the degrees of freedom of the attitudes of the load and helicopters but, rather, assumes that these attitudes are stable. The analysis also assumes that the aerodynamic forces on these bodies are independently calculable as functions of the trajectory of the system or that they can be measured in flight. These simplifications make it possible to solve the force-balance equations in closed form, with the equilibrium aerodynamic forces appearing parametrically.

The results of the analysis are given for the angles of orientation of the components; for the internal forces of the system; and for the required helicopter thrusts (for identical or nonidentical helicopters) under any static or accelerating but otherwise equilibrium flight condition, any orientation of the system relative to the direction of flight, and any distribution of the load between the two helicopters. Optimum tether angles that minimize the sum of the required thrust magnitudes are also determined. These results can be applied to coordinate the system in flight.

A given system can have many equilibrium orientations, with three angles that can be selected by the pilot or autopilot: (1) the formation angle (the heading of the spreader bar relative to the ground-track direction), (2) the tilt of the spreader bar relative to the apparent gravitation of the suspended load (including the aerodynamic forces), and (3) the tilt of one of the tethers relative to the spreader bar. The analysis shows that the required thrusts vary strongly with the tether angle but are nearly invariant with respect to the other angles. Consequently, the tether angle can be selected to minimize the sum of the required thrusts. This choice not only maximizes the margin of safety of available thrust but also minimizes the rate of consumption of fuel in the case of identical helicopters.

The tilt of the spreader bar controls the distribution of the load to the two helicopters. The analysis shows that, in general, the tilt can be selected for any distribution for which all cables remain under tension and for which both helicopters have margins of safety of thrust. The load can always be distributed in such a way that the thrusts required of the helicopters are proportional to their maximum available thrusts.

The formation angle can be set at a fixed value as in conventional formation flying. However, with automatic flight control, it may be possible to vary the formation angle during flight.

This work was done by L. S. Cicolani and G. Kanning of **Ames Research Center**. *Further information may be found in NASA TP-2615 [N88-19407], "General Equilibrium Characteristics of a Dual-Lift Helicopter 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.
ARC-11812

Fabrication Technology

Tomographic Measurement of Laser-Bored Holes

A nondestructive technique detects internal variations in arrays of small holes.

Marshall Space Flight Center, Alabama

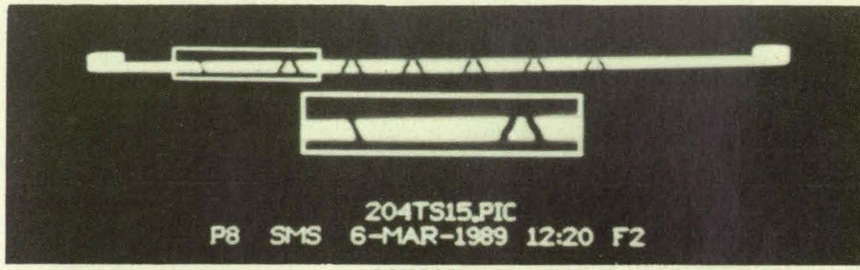
An inspection method checks laser-bored holes for accuracy. The method combines computed tomography and digital laminography.

The usual methods of inspecting narrow holes are not suitable for those made by laser. For example, the insertion of a wire gauge into a hole yields only crude information on the direction and size; it cannot detect the internal changes that occur with laser boring. Moreover, the insertion of wires is time consuming and subject to error from subjective biases and variations in the inspector's touch and feel.

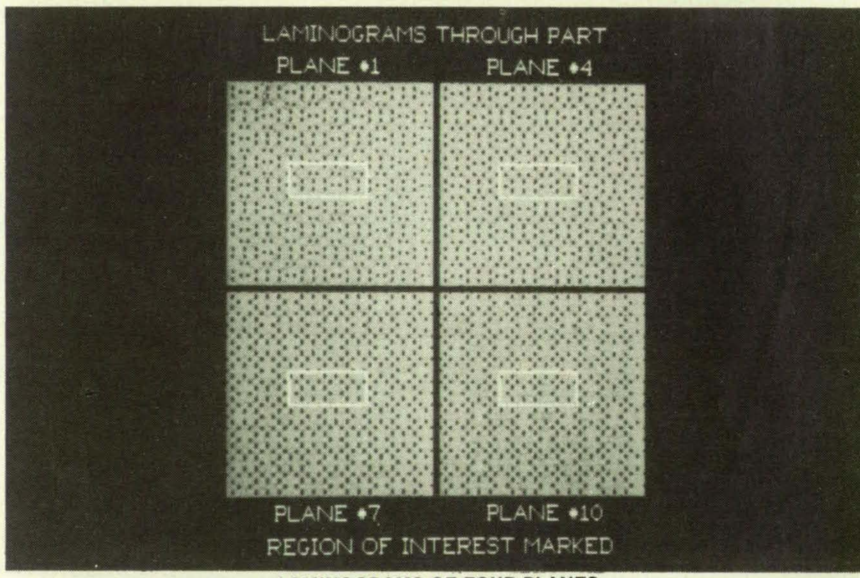
In the new method, a plate containing an array of laser-bored holes is scanned by a high-resolution x-ray system that generates both tomographic views and digital laminograms (see figure). The tomographic views are transverse cross sections that show the axial geometries of the holes. The laminograms are longitudinal cross sections that show the radial geometries of the holes. Both types of views are made at many parallel planes within the plate. The system also prints out tables of measured and standard deviation of diameter at all planes for each hole.

This work was done by James D. Willenberg, Jack Roy, and Lyle B. Spiegel of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information, Circle 153 on the TSP Request Card.*

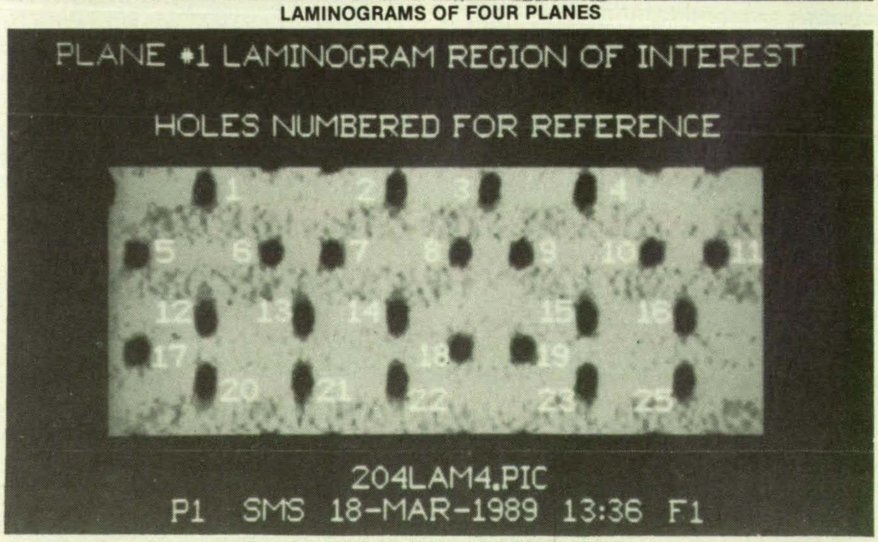
Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 14]. Refer to MFS-29770.



TOMOGRAM



LAMINOGRAMS OF FOUR PLANES



MAGNIFIED VIEW OF REGION OF INTEREST IN LAMINOGRAM OF PLANE 1

Internal Nonuniformity is clear in a computed tomographic axial view of laser-bored holes (top). Variations of shape and dimensions among holes appear in laminograms (center), especially in the closeup of a region of interest. The holes in these pictures are nominally about 0.025 in. (0.64 mm) in diameter.

Improved Warm-Working Process for an Iron-Base Alloy

Forgings are stronger than are those produced by the prior warm-working process.

Marshall Space Flight Center, Alabama

A warm-working process produces a predominantly unrecrystallized grain structure in forgings of the iron-base alloy A286 (PWA 1052 composition). As a result, the yield strength and ultimate strength are increased, and the elongation and reduction of area at break are decreased. The improved process can be used on forgings up to 10 in. (25 cm) thick and weighing up to 900 lb (408 kg). This process is a refined version of the previous warm-working process (see figure), which could handle only plates no thicker than 0.5 in. (about 1.3 cm).

Unusual features of the improved process include the following:

- The inclusion of a recrystallization cycle before the final warm-working operations;
- Warm working in steps when necessary, with progressively cooler reheating;
- Limiting the maximum forging rate; and
- The definition of a properly processed microstructure.

These features help to ensure that the predominantly unrecrystallized structure is formed. Such a structure is necessary to obtain strength significantly greater than that of conventionally processed material. These features of the improved process also help to maintain the structure by inhibiting development of dynamic recrystallization, which would reduce tensile strength.

In a representative procedure, a starting billet 12.5 in. (32 cm) in diameter and 18 in. (46 cm) tall is first thermally recrystallized at 1,900 °F (1,038 °C), then cooled to below 1,000 °F (538 °C). The billet is then heated to 1,600 °F (871 °C), followed by a 40-percent upset cool to below 1,200 °F (648 °C). Then the billet is heated to 1,500 °F (816 °C) and forged, followed by a 30-percent upset water quench. Forging is done at an average rate no greater than 2 in./s (5 cm/s).

	TEMPERATURES (°F) FOR STAGES OF THREE PROCESSES		
	Conventional Process	Prior Warm-Working Process (U.S. Patent 3,708,353)	Improved Warm-Working Process
Final Deformation Cycles	1,800 to 2,000	1,550 to 1,800	1,500 to 1,700
Solution Heat Treatment	1,750 to 1,800	—	—
Stabilization Heat Treatment	—	1,400 to 1,500	—
Precipitation Heat Treatment	1,325	1,300	1,200 to 1,300

The **Improved Warm-Working Process** involves, among other things, slightly lower temperatures.

Test specimens from billets forged in this way and in the conventional way had the following properties:

- 0.2-percent-yield strength: 144 to 156 kpsi (993 to 1,076 MPa) versus 100 kpsi (689 MPa) for the conventionally processed specimen.
- Ultimate strength: 172 to 183 kpsi (1,186 to 1,261 MPa) versus 160 kpsi (1,103 MPa) for the conventionally processed specimen.
- Elongation at break: 11 to 13 percent versus 22 percent for the conventionally processed specimen.
- Reduction in area at break: 20 to 25 percent versus 40 percent for the conventionally processed specimen.

This work was done by Fred P. Cone, Brendan J. Cryns, John A. Miller, and Robert Zanoni of United Technologies Corp. for **Marshall Space Flight Center**. *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 14]. Refer to MFS-28503.

High-Pressure Lead-Through Joint

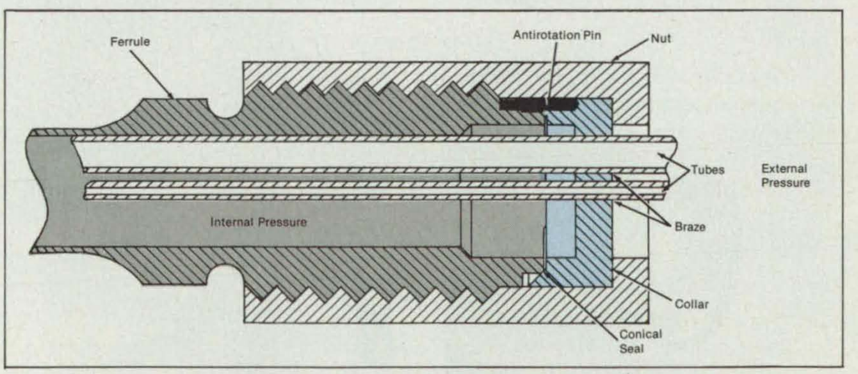
A simple joint forms a tight seal without washers or O-rings.

Marshall Space Flight Center, Alabama

An improved ferrule-type joint carries multiple tubes for probes and wires into a pressure vessel. The joint can readily be installed and removed without damage to the tubes. It forms a virtually leakproof seal and can withstand extreme operating environments.

A typical conventional ferrule-type lead-through joint includes a washerlike blob of sealing material that has to be compressed by applying a high torque to a nut. The sealing material must be carefully selected to suit the operating conditions. In another type of conventional lead-through joint, tubes must be brazed in place for assembly (and unbrazed in place for disassembly), and the brazing heat can damage surrounding materials.

The improved ferrule-type joint includes a ferrule on which a nut holds a collar that contains the tubes (see figure). The tubes are inserted into predrilled holes in the collar and brazed to it before assembly. The brazing is done before assembling the joint because the brazing heat could damage the ferrule and possibly other components of the joint.



The **High-Pressure Joint** consists of four parts: ferrule, collar, antirotation pin, and nut. The collar is easily removed and replaced. Tubes are brazed to the collar before the joint is assembled on the pressure vessel.

The probes and wires (if any) are threaded through the tubes. The collar is inserted in the ferrule along with a pin that fits in axial slots in the collar and ferrule to prevent the collar from rotating in the ferrule and thereby twisting the tubes. The nut is then tightened over the collar, forcing the internally chamfered edge of the collar axially against the ferrule end to form a conical seal.

When the pressure in the vessel is greater than the pressure outside, the pressure assists the seal by adding to the axial force of the ferrule against the collar. Consequently, a low tightening torque on the nut is adequate. However, even when the pressure inside is greater than the external pressure, less torque is needed than in a conventional seal because there is no need to compress a blob of sealing material.

The collar and tubes can be removed simply by unscrewing the nut. If it is necessary to separate the brazed tubes from the collar, heat can be applied to it after it has been removed from the ferrule so that the ferrule and other components of the joint do not have to be exposed to heat.

This work was done by Patrick B. Melton of United Technologies Corp. for **Marshall Space Flight Center**. *For further information, Circle 10 on the TSP Request Card. MFS-28404*

Platable Filler and Sealant

An easy-to-use material resists heat and chemicals.

Marshall Space Flight Center, Alabama

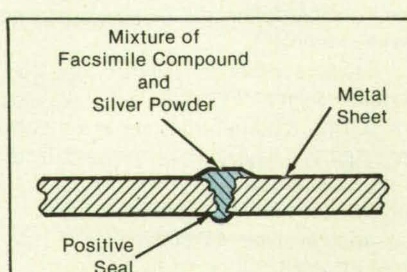
A mixture of a commercial molding ("facsimile") compound and silver powder is used in the repair of small holes in metal. The facsimile compound is used to fill the holes. The silver powder makes the filling electrically conductive, so that the repair can be electroplated to make a smooth, continuous surface.

The mixture is first applied to the hole and smoothed over. The silver additive slows the curing process somewhat; the facsimile compound normally cures in 6 to 8 minutes, but the additive prolongs the cure to 30 to 45 minutes. Nickel, copper, or other metal can be electrodeposited on the cured material.

The compound does not deteriorate in high plating-bath temperatures, unlike wax and other fillers. It provides a surface to which plated metals can readily adhere. Moreover, if plating is not completely successful and the plated layer must be removed, the compound is not adversely affected by stripping solutions.

This work was done by Todd R. Heerman and Jerome G. Volkenant of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information, Circle 133 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 14]. Refer to MFS-29735.



A **Mixture of Facsimile Compound and Silver** powder forms a positive seal in a small hole in a metal sheet. The filled hole can be plated over by standard electrodeposition.

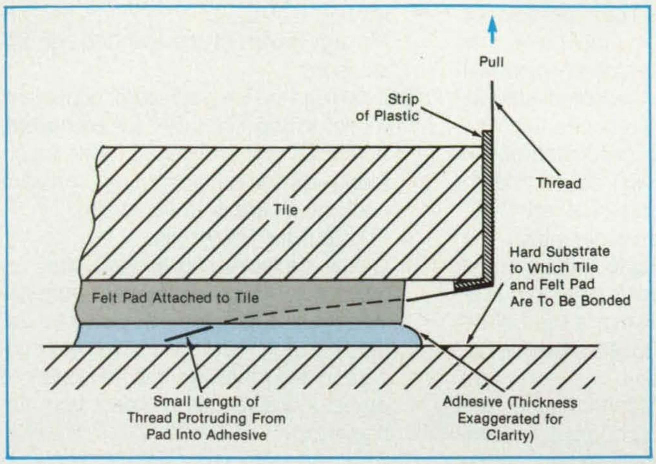
Thread-Pull Test of Curing Adhesive

The force required to withdraw a thread indicates the degree of cure.

Lyndon B. Johnson Space Center, Houston, Texas

A test indicates whether an adhesive layer has attained the proper degree of cure. In the test, one measures the force required to withdraw a thread embedded in the adhesive. The test can be used, for example, where a soft, penetrable material like felt is bonded to a similar material or to a hard substrate like aluminum or ceramic.

In one version of the test, a Nomex (or equivalent) polyamide thread, 0.006 in. (0.15 mm) in diameter, is inserted through a felt pad attached to a ceramic tile that is to be bonded to a hard substrate by use of room-temperature-vulcanizing silicone rubber. The thread is drawn through the pad with a needle so that it protrudes from the pad at approximately the center of the area to be bonded, where curing is likely to be slowest.



Hardness (and Degree of Cure) of an adhesive layer is measured by pulling a previously inserted thread out of the layer. The strength of the bond is measured directly on the assembly rather than on samples, which can be misleading.

After the required curing time, the thread is pulled out of the assembly. (A thin, removable strip of plastic could be used to protect the side of the assembly from the pulled thread.) The force required to remove the thread has been found to be approximately proportional to the hardness of the adhesive layer and thus indicates the extent of the cure.

Any thread material suitable to a particular application can be used, but a force-vs.-hardness calibration curve must first be established for the particular combination of thread and adhesive. Several threads can be inserted at different positions in the assembly, then removed individually to trace the progress of the cure. Because the withdrawal of a thread leaves only a small void, the test should have little, if any, adverse effect on the strength of the bond.

This work was done by James A. Johnson of Rockwell International Corp. for **Johnson Space Center**. *For further information, Circle 106 on the TSP Request Card.* *MSC-21782*

Simulating Welding-Robot Trajectories for Previewing

Simulation time and errors are reduced.

Marshall Space Flight Center, Alabama

A new method has been devised for generating those welding-tool paths that are parts of the off-line-programmed test trajectories of a computer-controlled welding robot. The method reduces the time necessary to set up a simulation of the welding process and eliminates some errors by reducing the amount of repetition. Throughout the process of generating the trajectory of the welding tool, the method provides visual feedback similar to that of the graphical simulation that is used in the off-line-programming process after the development of a model.

The method is applicable to the Unigraphics (or equivalent) computer-aided-design software and relies, in part, on the availability of a MicroVAX (or equivalent) computer. The new method is best understood in the context of the old method, which is summarized as follows:

1. Transfer the three-dimensional computer-aided-design model to the Unigraphics (or equivalent) computer-aided-design software, and add "go to" points. File the model.
2. Make a sketch of the tool and "go to" locations.
3. Download the Unigraphics (or equivalent) model to the MicroVAX (or equivalent) computer, and use PLACE (or an equivalent) off-line-programming software package to create a vector file.
4. Print out the vector file.
5. Create the tool-verification-trajectory file by manually entering the data from the vector file. (There are nine sets of numbers for each vector.) If a typing error occurs midway through, it is necessary to go back and reenter the data from the beginning.

The new method consists of the following steps:

1. Transfer the three three-dimensional computer-aided-design model to the Unigraphics (or equivalent) software.
2. Create the tool "go to" points by use of the Unigraphics (or equivalent) manufacturing software module. The operator sees both a three-dimensional computer-aided-design model of a tool and a three-dimensional torch moving along the tool path. The operator can accept or reject and redefine each "go to" point as it is created. The resulting file, which contains the "go to" points, is downloaded to the MicroVAX (or equivalent) computer.
3. Execution of the program "CLART2PAR" (or equivalent) automatically converts the "go to" file to the trajectory file used to verify the programming of the robotic welding tool. This program takes 5 to 15 seconds to run.

This work was done by Maureen L. Levitt and Karen E. Sliwinski of Rockwell International Corp. for **Marshall Space Flight Center**. *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 14]. Refer to MFS-29747.

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.

Gas Contamination in Plasma-Arc-Welded Aluminum

Contaminated welds can easily be identified visually.

A document describes an experimental investigation on the visible and tactile effects of gaseous contaminants in variable-polarity plasma arc (VPPA) welding of 2219 T-87 aluminum alloy. There are many possible sources of contamination in VPPA welding, including contaminated gas bottles, leaks in gas plumbing, inadequate flow of the shielding gas, condensed moisture in the gas tubes or the body of the torch, and excessive contaminants on the workpiece. It is particularly important to avoid such contamination in VPPA welding for several reasons:

- The large area of contact between the gas and the workpiece favors the absorption of impurities in the weld pool.
- The small weld pool that is characteristic of VPPA welding can easily become supersaturated with such impurity gases as hydrogen, which cause porosity when the pool solidifies.
- Gases active on the surface of the weld pool can alter flow patterns, causing undercutting and other defects.
- The high speed of VPPA welding allows little time for absorbed impurities to effervesce from the weld pool.

In the investigation, contaminant gases (nitrogen, methane, oxygen, and hydrogen) were introduced in the argon arc and in the helium shield gas in various controlled concentrations. The report presents the results of the experiments in the form of photographs of the fronts, backs, polished cross sections, and etched cross sections of welds made with various contaminants at various concentrations. It provides a detailed discussion of the conditions under which the welds were made.

The document also verbally describes the appearances of welds to guide the welder in identifying the presence and type of contamination. It suggests that the welder look for the following:

- A smooth, almost-ripple-free keyhole pass. The cover pass should show even less rippling. Increased rippling on the front surface is one of the first indications of all impurities except oxygen.
- Fine, regularly spaced ridges on the back side of the weld. When the finger is run along the back side, the welder should feel the ridges, but no sharp crests. Oxygen can be detected readily by feeling a significantly rougher back side.
- The ridges on the back side should be perpendicular to the direction of the weld. Slanting of these ridges is an indication of undercutting.
- A dull, matte appearance on the front side.
- At most, only slight granular extrusions on the edges of the weld bead and none on the bead. Noticeable granular extrusions on the bead and moderate extrusions on the edges indicate contamination by methane.

This work was done by John C. McClure, Martin R. Torres, Alan C. Gurevitch, and Robert A. Newman of the University of Texas at El Paso for **Marshall Space Flight Center**. *To obtain a copy of the report, "The Effect of Impurity Gases on Plasma Arc Welded 2219 Aluminum," Circle 47 on the TSP Request Card.*
MFS-27233

Moving and Working on Space Structures

A clawlike device would attach boots to rails.

A memorandum presents, in sketches and brief text, a concept for a boot-toe clip that would help an astronaut move about outside on structures being built at the Space Station. The clip would also help the astronaut maintain a stable position at the worksite. The concept may be adaptable to underwater work on such structures as offshore oil rigs.

According to the concept, clawlike extensions on the toe of a boot would grasp a rail. The wearer would move along the rail by sliding the clip. Changing from one rail to another, the wearer would eventually arrive at the worksite. (The rails would actually be part of the Space Station structure.) The clip would be able to grasp rails that are either vertical or horizontal with respect to the wearer.

A portable rail would also be available. The portable rail would have grappling devices at both ends so that it could bridge between fixed handrails, truss struts, sockets, and other members. With it, an astronaut could use the boot clip to move to worksites outside the Space Station truss structure and on the exterior of Space Station modules.

This work was done by Pat B. McLaughlan of **Johnson Space Center**. *To obtain a copy of the report, "Astronaut Boot Toe Translation and Restraint Device," Circle 38 on the TSP Request Card.*
MSC-21556

VOUS Software Facilitates Development of Other Software

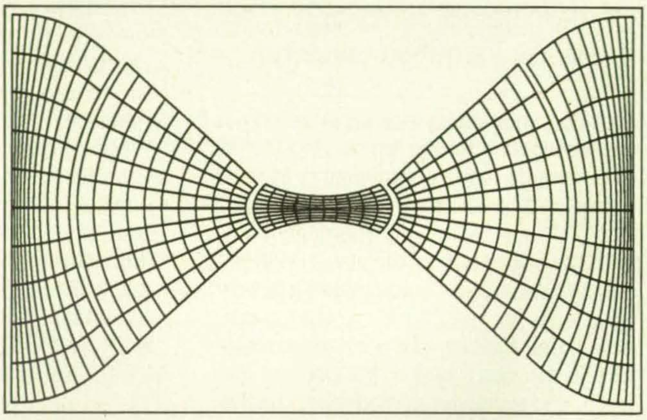
Graphical functions and editing of programs and other texts are included.

Ames Research Center, Moffett Field, California

The Visual Object Oriented Unification System (VOUS) computer program provides a facility for the development of other, high-level software. VOUS does not replace, but rather extends, preexisting software tools for the development of other software. It provides a comprehensive, graphical, interactive medium for all phases in the development of a computer code from the early exploration of concepts, through the detailed coding-and-error-checking process, to the final reporting of the finished code and compilation of the instruction manual for its use. As such, VOUS simplifies and partly automates the programmer's task, even at what heretofore has been the pencil-and-paper stage of theoretical analysis and preliminary design with its pseudo code fragments and/or flow charts.

The current version of VOUS is the early product of a continuing effort to unify and integrate the various functions provided by such software tools as text editors, graphics editors, text formatters, hypertext (in which textual information can be linked to external references and sources), and structured-decomposition tools. VOUS uses a very general data structure that can manifest itself in a variety of visual forms while enabling the user to create and manipulate easily such abstract objects as large, general-purpose, hierarchically structured programs, data structures, and documents.

From the user's point of view, VOUS functions as a "what-you-see-is-what-you-get" (WYSIWYG) text editor. The user can augment text with pictures, icons, buttons, and structured graphical objects. The text and graphics can be decomposed into logical pages with icons or buttons linking them together. A document can be constructed either in a linear sequence or in a structured top-down hierarchical fashion, depending on its complexity and nature. VOUS can also be used to design templates that can be used in the manner of HyperCard (a type of hypertext) documents to organize information. The unique feature of VOUS is its ability to support objects of various types within a single document.



This **Nonrectangular Multiple Grid** was created by VOUS. Such grids are particularly useful for the computation of flows in domains of arbitrary shape.

The fundamental paradigm of VOUS is the traversal of a directed graph, the nodes of which represent data objects or operators. Just as a compiler employs a back end that operates on an abstract syntax tree that represents a program, VOUS enables the construction and execution (i.e., traversal) of a directed graph of polymorphic data nodes, the meaning of which graphs can be defined by the user. Such a visual representation can be very useful in the following applications:

- A general data-flow programming "language" in which a variety of existing software tools can be ordered and connected together graphically. This can provide a procedural specification for combining many large programs together and passing information back and forth between them.
- A graphical UNIX "make" facility in which files are represented by icon nodes and dependencies are formed by linking icons with arcs. Inner nodes can represent "actions" that are invoked to transform dependent files into target files.
- An n-dimensional "spread sheet" on which polymorphic data cells are formed out of recursive lists rather than only simple arrays. The lists can also represent n-dimensional arrays, the elements of which can, in turn, be other lists or arrays.
- Software systems based on the hypertext and HyperCard systems, where textual information can be linked to external references and sources.
- Higher-level shell programming.
- Creation of complicated data structures and data sets for existing programs; e.g., composing hierarchical, composite grid structures for use in computational fluid dynamics (see figure).
- Outline editors for writing books or other large publications.
- Structured painting and drawing programs.

This work was done by Joseph Oliger, Ramini Pichumani, and Dulce Ponceleon of Stanford University for **Ames Research Center**. *For further information, Circle 9 on the TSP Request Card.*
ARC-12571

Computer Aids Delineation of Boundaries in Farmlands

Computer-aided delineation is about six times as fast as manual delineation is.

Ames Research Center, Moffett Field, California

The computer-aided stratification (CAS) procedure is a developmental procedure of image-processing computer equipment and programs that partly automates the delineation of boundaries between areas. These areas, also called "primary sampling units," are images of primarily agricultural lands composed by melding digital Landsat Thematic Mapper data and

Digital Line Graph data from the United States Geological Survey. As used here, "stratification" denotes the division of land areas into land-cover or land-use groups (called "strata") on the basis of interpretation of the Thematic Mapper imagery. Each primary sampling unit is a group of 6 to 10 smaller areas, called "ultimate sampling units." Primary sampling units are typically bounded by such relatively permanent features as roads and rivers. The CAS output data are used as inputs for subsequent sampling procedures from which statistics on the uses of agricultural lands are developed.

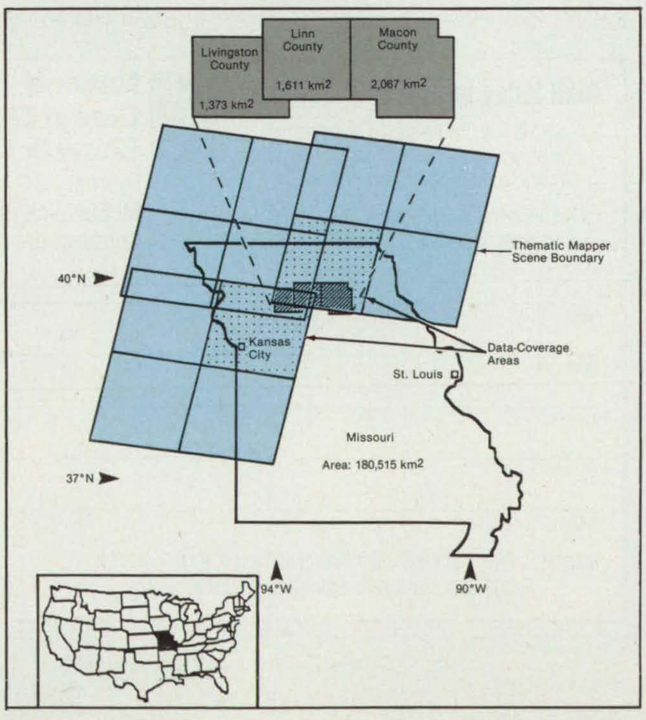
The digital Thematic Mapper data on the land area of interest are displayed on a display monitor of 512×512 picture elements of a graphics workstation with an 8-bit intensity in each of the primary colors — red, green, and blue. The range of brightness in each primary color can be adjusted to enhance the subimages of selected land-use features. Next, the Digital Line Graph data are overlaid on the Thematic Mapper imagery for use as references in delineation. By selecting applicable CAS programs, the Digital Line Graph data are edited for display to show such requested features as transportation routes or bodies of water. The CAS software provides precise registration of the Thematic Mapper imagery and Digital Line Graph data by use of tie points and least-squares transformations.

The operator delineates the primary sampling units by using a keyboard and a multibutton cursor on a digitizing tablet. The operator types in an identifying number for the primary sampling unit and stratum in question and delineates the area of interest by using the cursor to enclose it in a polygon. As the polygon is closed, the CAS software automatically annotates it and computes its area. A set of subcommands in one of the CAS programs enables the operator to identify overlaps and gaps between polygons and to correct these deficiencies or otherwise modify the polygons. The polygonal boundaries and associated data on the primary sampling units are written into a polygon file for subsequent processing.

The CAS-assisted procedure was tested by applying it to a three-county area in Missouri (see figure). For comparison, a manual digitization-and-delineation procedure was applied to the same area. The CAS system was found to speed the delineation process by a factor of about 6. Because the boundaries of the primary sampling units can be edited easily on the basis of changes in the land-use pattern, the larger area frames that contain the primary sampling units can be updated more frequently. It was also found that the precision of surveys could be enhanced by using CAS because the simultaneous display of the Thematic Mapper and Digital Line Graph data may increase the probability that an operator will assign a primary sampling unit to the correct stratum.

This work was done by R. Slye of **Ames Research Center**, *T. Cheng and M. Ma of TGS Technology, Inc., and G. Angelici of Sterling Federal Systems. Further information may be found in NASA TM-102243 [N90-16313], "Computer-Aided Boundary Delineation of Agricultural Lands."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
ARC-12805



Three Counties in Missouri for which three partially overlapping Thematic Mapper scenes and 7.5'-quadrangle Digital Line Graph (U.S. Geological Survey) data were available were divided into primary sampling units by (1) the CAS (computer-aided stratification) procedure and (2) a manual digitizing-and delineating procedure. The time required for one operator to complete the task for Macon county was 15 days (manual) vs. only 2.5 days (CAS).

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.

Evaluation of Threshold Functions for Searches Among Data

A quantitative measure of the information content of such a function is presented.

A paper presents an information-theoretical analysis of the problem of building a system of inferences from a large collection of data (data base). More specifically, the problem is to design searches of the data base for informative conjunctive production rules. The results of this analysis may eventually lead to the design of more-economical and more-effective electronic neural networks that can draw inferences from data bases.

The concept of the linear threshold function with binary (0,1) weights is introduced as the paradigm of a search rule. A Boolean function of this kind implements the logical function that means "X of these N inputs are ON," also called an "(X of N) rule." Two examples include a (1 of N) rule, which is an OR function, and an (N of N) rule, which is an AND function. These rules and functions are compatible with the way people reason in searching among data. In terms of the amount of memory necessary to describe a basic logical unit, an (X of N) rule lies between the general linear threshold function on the one hand and the logical AND and OR functions on the other hand.

In this analysis, the J measure is used as a quantitative indication of the information provided by a linear threshold function with binary weights. The J measure was used originally to quantify the expected change in information provided by a production rule and in that context also serves as a measure of how well such a rule predicts the outputs from the given inputs.

There are efficient algorithms for searching through a data base for informative conjunctive production rules. The difficulty with this approach arises in a data base with noisy input values (or where the unmodeled domain information is effectively noise), because in such a case, the use of AND and OR rules requires an exponentially large number of units to describe explicitly the possible representations of a single input with the added noise. The number of units is exponential in the expected number of inputs changed by noise.

In contrast, a single (X of N) rule captures the concept of a prototype. A prototype together with a Hamming distance defines a class of inputs centered about the prototype. The (X of N) rule defines a prototype with Hamming distance $N-X$. Prototypes are important units of knowledge for several reasons. One is that they are effective in communicating knowledge with humans. Systems that can be understood at the lowest level by humans allow for justification of results and for possibly better training procedures. A second advantage is the stability of prototype rules with respect to noisy data. The third advantage is that input sample points provide useful starting points for efficient searches for prototype rules with a high J measure.

The paper proposes three ways to conduct an efficient search for the most informative rules (the ones that have the highest J measures). The first is based on a process of specialization in which rules of higher order are extensions of rules of lower order. The second is based on a process of generalization in which rules of lower order are developed from prototypes defined by input samples. The third involves a recursive procedure in which the set of training attributes is added as a set of derived attributes to a number of the most informative rules.

This work was done by Rodney M. Goodman, John W. Miller, and Padhraic J. Smyth of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "The Information Provided by a Linear Threshold Function With Binary Weights," Circle 40 on the TSP Request Card.*
NPO-18113

Supercomputers of the Future

Key technologies will demand speeds and memory capacities that are astounding but nonetheless possible.

A report evaluates the supercomputer needs of five key disciplines: turbulence physics, aerodynamics, aerothermodynamics, chemistry, and mathematical modeling of human vision. The report predicts that these fields will require computer speed greater than 10^{18} floating-point operations per second (FLOP's) and memory capacity greater than 10^{15} words. By way of comparison, today's most advanced computers offer speeds of about 10^{9} FLOP's. Despite the disparity, the report predicts that new parallel computer architectures and new structured numerical methods will make the necessary speed and capacity available in the foreseeable future.

Simulations of turbulent flows at modest Reynolds numbers about simple geometries will be used routinely to study the basic physics of turbulence and to test theories of turbulence. The direct simulation of turbulent flow over a complete aircraft at realistic Reynolds numbers will remain out of reach for years. However, large-eddy simulation, in which only large-scale motions are computed and small-scale motions are approximated by simplified mathematical models, will soon be practical for designers.

Computational aerodynamics is advancing rapidly in both research and design. Reasonably complete three-dimensional mathematical models have already been produced. In the future, combined models of aerodynamics, propulsion, structures, and controls will predict integrated aircraft performance.

Computational aerothermodynamics involves equations of motion in which the kinetic energy of the vehicle is high enough to cause dissociation, ionization, and electronic excitation of the impinging air or other gas. Such equations are extremely complicated. For example, on the best of today's computers, about 400 h will be needed to calculate the flow around an aeroassisted orbital-transfer vehicle. For the foreseeable future, it will be necessary to rely on empirical models to account for chemical reactions and collision dynamics.

Computational chemistry on supercomputers has already made contributions. For example, it is used to predict radiative intensity factors, high-temperature transport properties, and rate constants of reactions in flow fields of aerospace vehicles. Within the next decade, computational chemistry will help develop improved catalysts, fuels, and materials.

The mathematical modeling of human vision promises practical returns of extraordinary value: it could help give robots sight, cure eye diseases, and design displays that optimally exploit the properties of vision. Computational science is being applied to the mathematical modeling of biological visual systems at the cell level and to the development of algorithms to solve specific vision problems. One major challenge is the complete simulation of the primary visual cortex. Another is the development of a synthetic computer vision system for the autonomous guidance of a rotorcraft in low-level flight; this problem is well beyond the capacity of available computers but within the realm of possibility.

This work was done by Victor L. Peterson, John Kim, Terry L. Holst, George S. Deiwert, David M. Cooper, Andrew B. Watson, and F. Ron Bailey of **Ames Research Center**. *To obtain a copy of the report, "Supercomputer Requirements for Selected Disciplines Important to Aerospace," Circle 42 on the TSP Request Card.*
ARC-12416

Assessment of Accuracies of Remote-Sensing Maps

Classifications of clusters of picture elements are subjected to statistical tests.

A report describes a study of the accuracies of the classifications of picture elements in a map derived by digital processing of Landsat-multispectral-scanner imagery of the coastal plain of the Arctic National Wildlife Refuge. A classification of the type in question is one in which each picture element is assigned, according to its spectral characteristics, to a class, called a "stratum" in statistical parlance, that represents one of several (in this case, twelve) predetermined categories of vegetation or land cover.

The accuracies of portions of the map are analyzed with the help of a statistical sampling procedure called "stratified plurality sampling," in which all the picture elements in a given cluster are classified in the stratum to which a plurality of them belong. The strata thus derived then provide the statistical population from which stratified samples are taken and compared with field surveys to determine the accuracies of the classifications. The motivation for this procedure is that picture elements in classes that occur infrequently are more likely to be sampled in their plurality classes than they would be in ordinary stratified-cluster sampling, wherein the strata are usually selected by visual inspection of imagery or of maps (called "base maps") made previously by means independent of the Landsat imagery.

The results of the statistical analysis are tabulated as percentages of correct classifications overall as well as per category of land cover, with associated confidence intervals. The authors conclude that although the percentages correct were disappointingly low for most categories, the study was useful in highlighting sources of errors in classification and in demonstrating the inadequacies of stratified plurality sampling. Spectral confusion among categories, spatially complicated mixtures of land covers of different categories, incomplete descriptions of the categories, and changes in land cover between the time of the classification and the time of this study are found to be sources of errors in the classification. Especially in areas like the Arctic coastal plain, which contains spatially complicated mixtures, the fixed size and shape of the picture elements in the Landsat format and the binary choice of "correct" or "incorrect" for each picture element are sources of much of the error. The appropriate definition of a category is relative to the scale at which it makes sense, and this scale may not coincide with the scale of a picture element. The dependence of the definition of a category on scale causes such errors of classification as inclusions and confusions among picture elements, and can be analyzed correctly only by use of classification schemes more sophisticated than are those that operate on one picture element at a time. The adequacy of the stratified-plurality-sampling scheme used was found to be limited by the insufficient numbers of samples, caused by the insufficiency of resources available for field surveys.

This work was done by Don H. Card of **Ames Research Center** *and Laurence L. Strong of TGS Technology. Further information may be found in NASA TM-101042 [N89-17339], "Accuracy Assessment, Using Stratified Plurality Sampling, of Portions of a Landsat Classification of the Arctic National Wildlife Refuge Coastal Plain."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
ARC-12371

Thin-Membrane Sensor With Biochemical Switch

The sensor could be used as an alarm for chemical or biological materials.

Marshall Space Flight Center, Alabama

A modular sensor electrochemically detects a chemical or biological agent, indicating the presence of the agent via a gate-membrane-crossing ion current triggered by the chemical reaction between the agent and a recognition protein conjugated to a channel blocker. This sensor could be used in such laboratory, industrial, or field applications as the detection of bacterial toxins in food, military chemical agents in the air, and pesticides or other contaminants in the environment. It could also be used in biological screening for hepatitis, acquired immune-deficiency syndrome, and the like.

The sensor (see figure) includes (a) a bioresponse-simulator module on which the recognition material is mounted and (b) a transducer module on which a gated membrane is affixed to a conductive measuring surface. A self-contained source of dc voltage and an output terminal connected to an alarm circuit are connected to the transducer, and a poised polarizing electrode makes contact with the bioresponse simulator.

The bioresponse simulator module consists of a hydrophilic film-forming layer containing, in a buffer solution of generally neutral pH, the recognition biomolecule for the analyte of interest. Typical examples of the recognition biomolecule might include such a protein as an immunoglobulin-type antibody or albumin, to which a hapten, a segment of nucleic acid, or another protein segment might be attached, depending on the analyte to be detected.

The recognition biomolecule is conjugated to a channel-blocker substance, which prevents the permeation of ions through the gate membrane. Channel-blocker materials include guanidinium compounds (e.g., tetrodotoxin, saxitoxin, and neurotoxic organic derivatives such as tetramethylguanidine), divalent cations (e.g., Ca^{+2}, Sr^{+2}, Ba^{+2}, and Cd^{+2}), and polyvalent cations (such as La^{+3}, Eu^{+3}, Dy^{+3}, and Gd^{+3}. Polyvalent cations, particularly the lanthanides, are the preferred cations because of their substantially greater affinities as channel blockers; effective blockage is achieved at concentrations of the order of one-thousandth those of the divalent cations. Conjugation of lanthanide ions to the protein moiety occurs via coordination bonding and may be performed in aqueous buffer solutions or while the cation is bound to ion channels in the gate membrane; in the latter case, the channels remain blocked. The reaction between the channel blocker (conjugated to the recognition protein) and the analyte of interest at the ion-channel site in the gate membrane results in the removal of the blocker from the ion channel and the consequent onset of ion current.

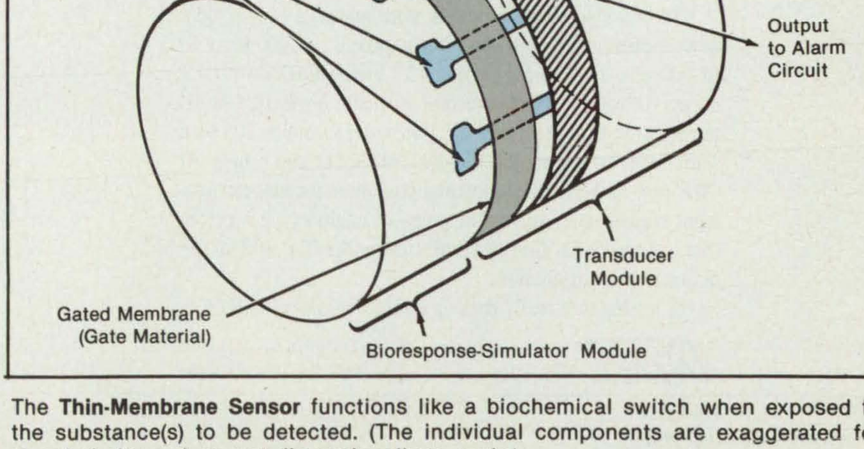
Ion channels conductive to monovalent cations serve as the gate material in the gate membrane. Examples include physiological sodium channel proteins, acetylcholine receptor protein, and such channel-forming antibiotics as the gramicidins; the gramicidins are preferred because of their high conductance, stability, ease of handling, high loading capacity, and availability. Physiological membranes containing ion channels can be used directly. Alternatively, ion channels can be inserted from solution phase into artificial membranes previously prepared by conventional Langmuir–Blodgett techniques.

The gate membrane consists of a hydrophobic material that is essentially impermeable to ions, particularly monovalent cations. Gate membranes can be prepared from phospholipids or from such polymerizable unsaturated organic compounds as diacetylenic derivatives of fatty acids.

In the poised state, the recognition material is bound to the gate material in the membrane in such a way as to block permeation of the membrane by ions. When the sensor is exposed to a chemical or biological agent of interest, this agent reacts with the recognition material, pulling it away from the gate material. This, in turn, enables an ion current to flow across the membrane. The resulting surge of current is sensed at a measuring-electrode surface in the transducer, triggering an alarm.

This work was done by George D. Case of Resource Technologies Group, Inc., and Jennings F. Worley of West Virginia University for **Marshall Space Flight Center**. *For further information, Circle 1 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 14]. Refer to MFS-26121.



The **Thin-Membrane Sensor** functions like a biochemical switch when exposed to the substance(s) to be detected. (The individual components are exaggerated for visual clarity and are not dimensionally to scale.)

Tissue-Simulating Gel for Medical Research

The nonhardening, translucent gel more nearly simulates soft human or animal tissue.

Langley Research Center, Hampton, Virginia

A unique gel combines a number of properties important for use in the simulation of soft human or animal tissue in medical research. Because of its thermal stability, the gel should be especially useful for the investigation of hyperthermia as a treatment for cancer.

A number of formulas exist for producing tissue-simulating gels. Many of these are based on agars, simple hydrated collagen gels, or polyacrylimides. Hydrated gels dry out, some gels melt at the high temperatures experienced in hyperthermia experiments, some become hosts to micro-organisms, and some are simply too expensive or difficult to make. The new formulation overcomes most of these deficiencies.

The new gel differs in that it includes a substantial percentage of ethylene glycol in the solution. The first step in preparing the material is to dissolve sodium or potassium chloride in distilled water to attain the desired dielectric constant. A 300-bloom gelatin is then stirred into the solution in the proportions of 10 g per 100 mL of the final quantity. The resulting slurry is set aside at room temperature for several hours, with occasional stirring.

The mixture is then heated slowly to 140 to 150 °F (60 to 66 °C) with constant stirring. It is kept in this state until all of the gelatin is dissolved. The ethylene glycol is then added and stirred to form the final solution. It is then removed from the heat and deaerated. The mixture can be stored at this time.

The mixture solidifies, but can be remelted when needed. When a tissue phantom is required, the material is melted and catalyzed. Formaldehyde is added in the ratio of 10 mL per 100 mL of solution. The solution must be mixed thoroughly and poured into the mold quickly. The working life is less than 10 minutes. After cross-linking has taken place, the gel will no longer melt and can be removed from the mold.

The gel can be modified to be softer or harder by altering the proportions of the ingredients. Fillers can be added to change the electrical, mechanical, heat-conducting, or sound-conducting/scattering properties. In this manner, different types of tissues can be simulated. The gel does not support the growth of micro-organisms, and it neither hardens nor dries. A polyurethane skin can be sprayed on the gel to provide resistance to abrasion if desired.

The gel can be molded to any desired shape and has sufficient mechanical strength to maintain that shape without a supporting shell. In the absence of a shell, the ultrasonic transmissive characteristics are only those of the gel itself, thus simplifying the analysis of experimental results. The gel is rubbery, so that hypodermic needles or catheters can be inserted as into flesh. Substances can be injected as into real tissue. In addition, because the gel is reasonably transparent, it is possible to inspect the interior visually.

This work was done by John A. Companion of Planning Research Corp. for **Langley Research Center**. *For further information, Circle 16 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 14]. Refer to LAR-14036

Subject Index of all 1991 Briefs

The following pages contain a cross-referenced index of all technical briefs published in *NASA Tech Briefs* during 1991 (Volume 15). You can receive copies of these briefs and their accompanying Technical Support Packages (TSPs) by contacting NASA's Center for AeroSpace Information (see page 14).

Circle Reader Action No. 531

1991 Annual Subject Index

1991 Annual Subject Index

1991 Annual Subject Index

1991 Annual Subject Index

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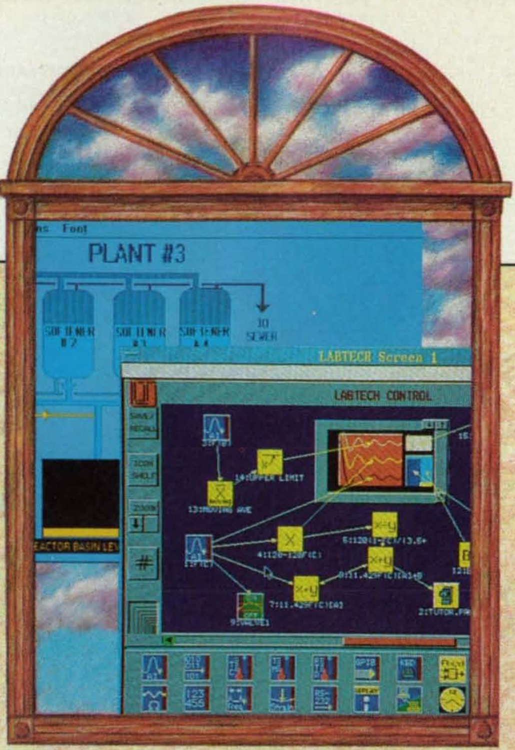

PLANT #3
LABTECH Screen 1
LABTECH CONTROL

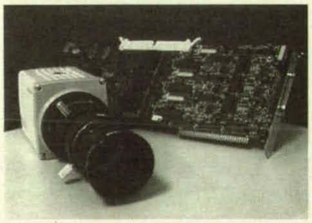
1991 Annual Subject Index

1991 Annual Subject Index

New on the Market

Dolch Computer Systems, Milpitas, CA, has announced the industry's first implementation of **full-motion video on a TFT color flat-panel display**, enabling multimedia computing on any of Dolch's PAC 386® and PAC 486® portable platforms. Video input can be from any NTSC-, PAL-, or SECAM-compatible analog source. Presented within the Multimedia Extensions of Microsoft Windows™, the image can be scaled and positioned at will, and shown with any number of freeze-frame video windows.
Circle Reader Action Number 774.

HyComp 400, a high-temperature **epoxy resin** developed by Dexter Composites Inc., Cleveland, OH, has a glass transition temperature of 256° C and retains 70 percent of its room temperature properties at 232° C. Processing ease, resistance to hot/wet conditions, and relatively low viscosity make it suitable for industrial and aerospace applications in primary and secondary composite structures.
Circle Reader Action Number 798.



An innovative **image acquisition system** developed by i Sight Inc., Orangeburg, NY, achieves a wider dynamic range than existing electronic imaging technology. By emulating the biological processing performed by the human eye and brain, the system enables conventional electronic cameras to capture high-contrast scenes without compromising image quality, resolution, or signal-to-noise ratio. This technique, called Adaptive Sensitivity™, expands the camera's dynamic range to about 100 dB or 100,000:1.
Circle Reader Action Number 776.

FLIR Systems, Portland, OR, has introduced the IQ 325 **thermal imager** for detecting, measuring, analyzing, processing, and displaying infrared radiation. It provides the industry's highest-resolution, thermal real-time image, according to the manufacturer, for use in process control, preventative maintenance, microelectronics, and R&D. The system's hard disk drive permits storage, retrieval, and analysis of more than 500 images.
Circle Reader Action Number 800.

The FAX VOdem™ from Yamaha Systems Technology Div., San Jose, CA, provides **multimedia capabilities on a single chip**, enabling the transmission of graphics, data, and voice messages over a single line. Caller identification is also available. The chip uses 0.8 micron technology and Sigma-delta modulation techniques. A CMOS device, it requires only 300 milliwatts in active mode from a 5v power supply.
Circle Reader Action Number 788.

The 900 series of **machine vision systems** from Acumen Inc., Corvallis, OR, can determine the position, orientation, and scale of arbitrary gray-scale image patterns. Fully configured, they can perform gray-scale normalized correlation at a throughput rate of 3.4 billion operations per second. The systems provide sub-pixel accuracy for solving problems in alignment, inspection, measurement, optical character recognition and verification, robot guidance, and color image acquisition.
Circle Reader Action Number 784.

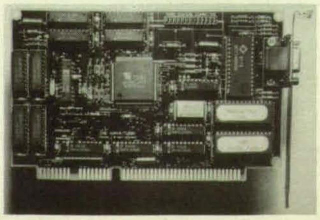
An advance in **diamond film production** has been announced by Applied Science and Technology Inc., Woburn, MA. The invention, called the Large-Area Diamond System (LADS), is the first plasma source to grow eight-inch-diameter films with 25 percent uniformity and coat complex shapes. Powered by a 5000-watt microwave generator, with the plasma torch operating in a resistively-heated furnace, LADS achieves high temperature stability to yield films with low stress.
Circle Reader Action Number 780.

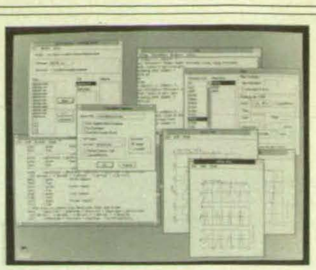
John Fluke Mfg. Co., Everett, WA, has introduced Philips PM 9372 TeleGnostics **software**, which enables troubleshooting and repair of complex electronic equipment using digital storage oscilloscopes (DSOs) supported by telephone lines. The package provides a phone link between a remote DSO and a PC located at a central service center. Diagnosticians at the center can monitor and analyze captured waveforms and relay instructions to the on-site technicians.
Circle Reader Action Number 794.

Land Infrared, Bristol, PA, has introduced a line of **infrared linescan systems** for temperature measurement from 300° to 1200° C. The Landscan linescanners provide accurate, noncontact temperature measurement across an object's entire surface. Software features include acquisition of up to 1000 temperature samples per scan at 25 scans per second and real-time image transfer and display as a 16-color thermal map.
Circle Reader Action Number 786.

Philips Semiconductors, Slatersville, RI, has created the industry's first monolithic, fully-protected **MOSFET**. Called TOPFET® (Temperature and Overload Protected Field Effect Transistor), it provides temperature and short circuit protection using N-channel enhancement-mode DMOS technology. TOPFET offers temperature protection for T_j above 150° C, rugged overvoltage clamping for inductive load repetitive switching, and input ESD protection. Characteristics include immunity to high dv/dt and a low operating input current.
Circle Reader Action Number 778.

The industry's fastest 16-bit, 1 MB **VGA adapter card** is available from Bell Computer Systems, Van Nuys, CA. The new 32,000 Freedom Hi-Color tested at 10,150 characters per millisecond on Landmark 2.0. The ISA-bus-compatible card delivers 32,000 colors at 640 x 480 and 800 x 600 resolutions, and 256 colors at 1024 x 768 resolution.
Circle Reader Action Number 796.

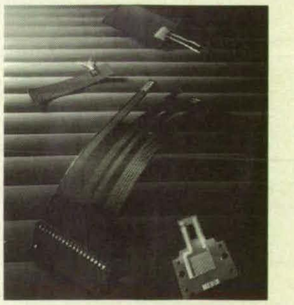




ACSL/Windows, the first **Windows-based, nonlinear simulation environment** for the PC, has been announced by Mitchell & Gauthier Associates Inc., Concord, MA. Employing a menu-driven point-and-click format, the program allows users to produce simulation models with no size limits. Models developed on a PC can be moved to any other platform and vice versa.
Circle Reader Action Number 790.

NEEL Electronics Inc., Laguna Niguel, CA, has announced the DSA100, a single-board, multiple-channel **digital synthesizer and analog analyzer**. Two independently-programmable synthesizers provide flexibility in waveform generation and can be phase-locked, while the analog analyzer enables wide-frequency analyses in frequency domain. Both heterodyne and homodyne analyses are possible for frequencies up to 100 kHz.
Circle Reader Action Number 782.

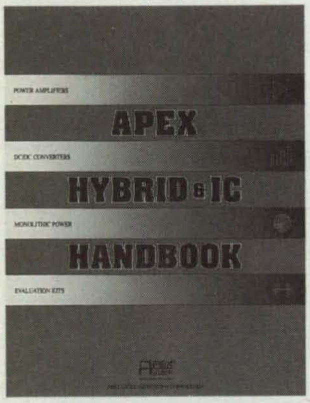
A line of flexible **temperature sensors** that conform to curved, cylindrical, and conical surfaces has been introduced by Elmwood Sensors Inc., Pawtucket, RI. Their ability to sense the temperature of an entire surface area and their thin, lightweight construction ensure fast, reliable response to surface temperature changes, according to the manufacturer. Applications include motor protection, air and liquid level sensing, laboratory instruments, and laminating equipment .
Circle Reader Action Number 772.



A new **CAD/CAM system** from TekSoft Inc., Phoenix, AZ, runs the entire CNC manufacturing process from a PC. Drafting, design, prototyping, and tool path generation programs can be created for mill, lathe, punch, laser, plasma, and wire EDM machines. Users also can work on part geometries imported from other systems through IGES, DXF, or VDA translaters.
Circle Reader Action Number 792.

New Literature

The new product handbook from Apex Microtechnology Corp., Tucson, AZ, spotlights the company's power and high-voltage operational **amplifiers**. This 264-page guide features the new DB2800 series of DC/DC converters and the PA41, the first 350 v monolithic op amp. Also included are application notes discussing MOSFETs, wideband, low-distortion techniques, and DC/DC converter performance enhancements.
Circle Reader Action Number 710.

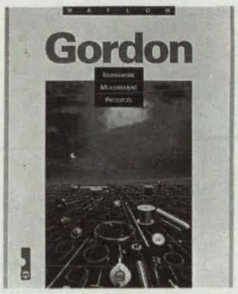


Bearings and Gears 1991, a comprehensive report covering the development, analysis, and manufacture of **materials for bearings, gears, and other machine elements,** is offered by ASM International, Materials Park, OH. Derived from international databases and 800 corporate case studies, the report details the design, fabrication, and selection of materials, lubricants, and components for mechanical systems in commercial and industrial applications. Materials covered include steels, ferrous and nonferrous metals and alloys, intermetallics, engineered plastics, polymers, and composites.
Circle Reader Action Number 706.

Premium cutting, grinding, mounting, and polishing supplies for **materials preparation** are described in a full-color catalog from Excel Technologies Inc., Enfield, CT. The 24-page brochure is also available on 3 ½" or 5 ¼" disk.
Circle Reader Action Number 704.

How to Select Pressure Transducers, a 16-page handbook from Trans Metrics Inc., Solon, OH, covers pressure ranges, accuracy, output signals, circuitry, electrical connections, transducer interchangeability, and application environments. It provides a worksheet to aid engineers in transducer specification.
Circle Reader Action Number 712.

A 24-page catalog describes two-wire and four-wire **temperature transmitters** from S-Products Inc., Fairfield, CT. The full-color publication features an ultraminiature two-wire RTD transmitter that provides ±0.5 percent accuracy, as well as two-wire fully-isolated head-mount transmitters, fully-linearized head-mount thermocouple transmitters, and scaleable four-wire rail- or wall-mount transmitters.
Circle Reader Action Number 708.



Watlow Gordon, St. Louis, MO, has released a 365-page catalog of **temperature measurement** products including several hundred styles of sensors, controls, wire, and accessories. New products include three types of infrared sensors and a noise-suppressed interconnect cable. The publication also features a 65-page technical guide addressing thermocouple practice, troubleshooting, calibration techniques, and standards.
Circle Reader Action Number 702.

An eight-page brochure from the Fidelis Group's Cyborg Div., Newton, MA, describes its line of modular **data acquisition and signal conditioning platforms**. The systems are supported by LabSoft I and II Programmer's Toolkit and Discovery DAS menu-driven software.
Circle Reader Action Number 714.

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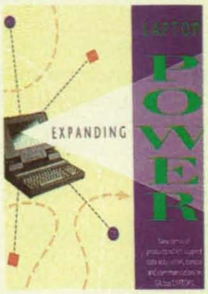

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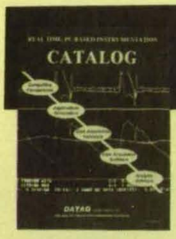

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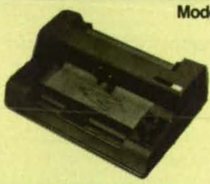

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Subject Index

Truly: Spinoffs Will Spur Economy

(continued from page 11)

Mars has been quiescent for millions of years. There is every possibility that as we explore its deep canyons, climb its towering mountains, and traverse its plains, we will make an exponential leap in understanding the origin and evolution of the solar system, of our planet, and perhaps even life itself.

To achieve these goals, NASA has embarked on a new cycle of technology development. We are, or will be, working in such areas as artificial intelligence, virtual reality, advanced robotics, artificial self-sustaining ecological systems, telepresence and teleoperation, process automation, new materials, highly advanced computers, and hypersonic flight.

Last year, Dr. Allan Bromley (presidential science advisor and Technology 2000 keynote speaker) said the real importance of a conference and exposition such as this is to allow people to see for themselves and to ask questions. That leads to insights, which, in turn, lead to creative ideas.

You hold the potential to convert these ideas into reality. American industry must take the lead in capturing the immense opportunities resident in our space program. ❑

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Mission Accomplished

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.

Image processing software developed for the space shuttle offers a host of terrestrial uses.

Photo courtesy of Electronic Imagery Inc.

Like travelers who return home to find their best photos marred by overexposure, shuttle crews analyzing films of their missions have often wished for a chance to reshoot pictures captured with the craft's electronic camera system. New image processing software from Electronic Imagery, Delray Beach, FL, provides that opportunity by allowing mission photos to be viewed while in orbit. The software produces high-resolution images that can be enhanced and downlinked to ground-based scientists, who can relay evaluations and recommendations in near-real-time.

A grant from NASA's Small Business Innovation Research (SBIR) program, along with input from researchers at the Johnson Space Center, helped Electronic Imagery develop ImageScale PLUS. "NASA chose our package for its openness and flexibility," said Cindy Seiffert, the company's president.

ImageScale PLUS flew on Discovery in September 1991, becoming the first image processing software used aboard a shuttle. "The software enabled the astronauts to correct problems in their photographic techniques before it was too late," said Doug Holland, an engineer with the NASA electronic still camera project. According to Holland, every shuttle crew on the current flight manifest has requested the software be on board. It will help document crew activity, satellite deployment, troubleshooting, and microscopic biological experiments.

ImageScale PLUS allows the user to display the high-resolution images on a small monitor—a necessity in the shuttle's confined quarters—and then, employing a variable-size crop-box, to select a portion for closer examination. As the user telescopes in on an image's details, the program provides with each successive subsampling the maximum resolution possible with the monitor.

In addition to generating photographs of Earth from space, useful in assessing natural disasters and other phenomena, the software is being applied in agriculture, atmospheric science, petroleum core sampling, neurology, particle analysis, and textile design. Features important in the processing of satellite images, such as lossless compression, are likewise critical in fields such as radiology and ophthalmology.

"The software is designed to be the engine behind any application employing digital images," said Jean Molnar, Electronic Imagery's director of communications. The laptop-compatible package can process digital data from CCD cameras, live video, scanners, microscopes, and ultrasound or MRI devices. The images can be any size or pixel depth, at resolutions up to 4096 x 4096. A user-friendly interface allows even novices to successfully process images, while more experienced users can implement macros or create custom menus. Other features include a full complement of drawing and text utilities, histogram sliding and stretching, full-color transformations, and unique zoom and pan capabilities.

As ImageScale PLUS accompanies shuttle crews on upcoming flights, company researchers will continue to enhance the software's capabilities for both space and Earth applications. Plans include porting to UNIX and Windows and further development of compression techniques. ❑

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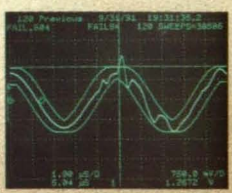

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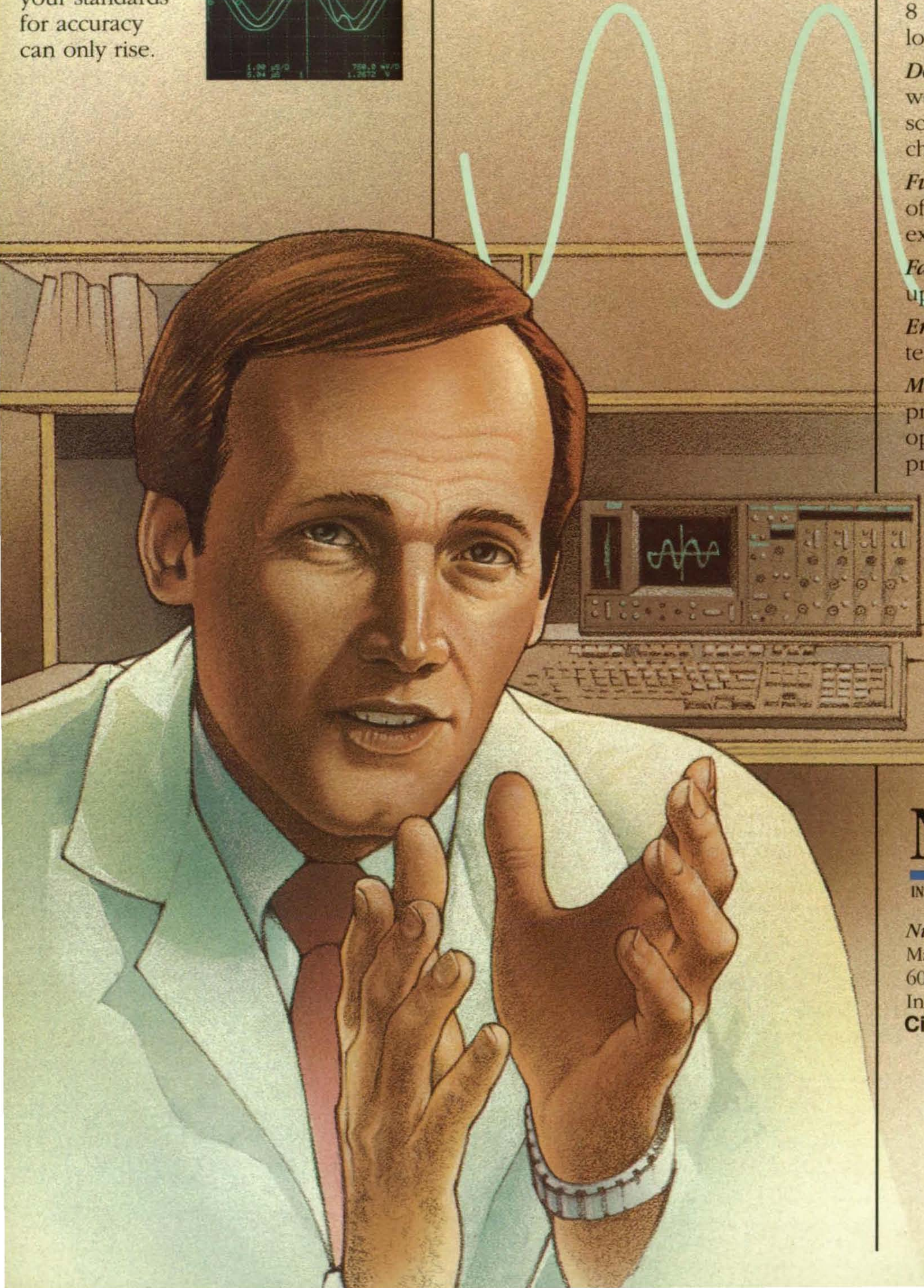

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