NASA Tech Briefs

Transferring Technology to American Industry and Government

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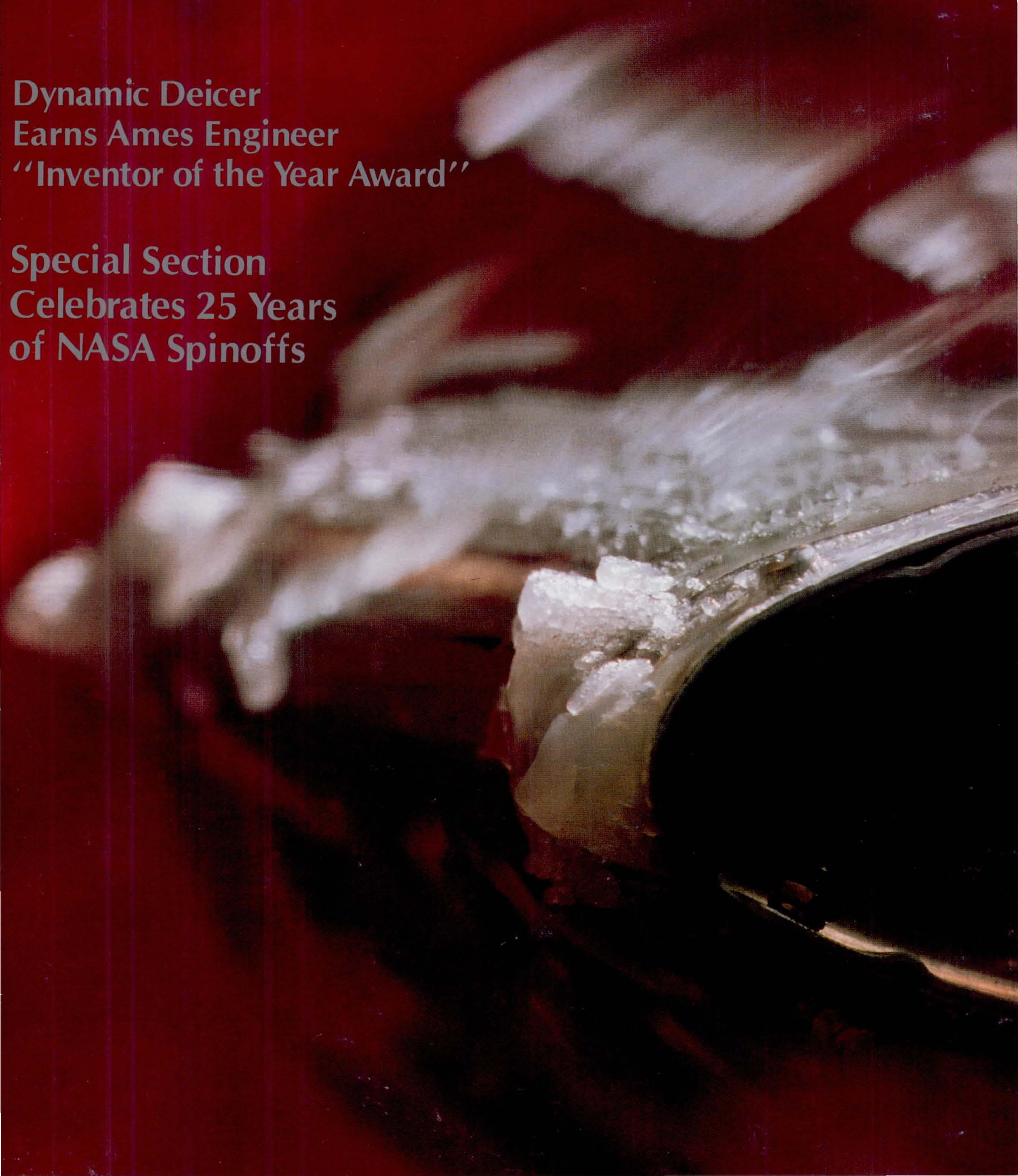
Volume 12 Number 6

Dynamic Deicer Earns Ames Engineer "Inventor of the Year Award"

Special Section Celebrates 25 Years of NASA Spinoffs

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The Constrained Curve

The Constrained Curve

The geometric path traced by a robot arm is independent of time. Now a mathematician at the General Motors Research Laboratories has devised a simple, innovative way to relate the path to time so that the machine can track the path and meet specific performance objectives without exceeding its physical operating limits.

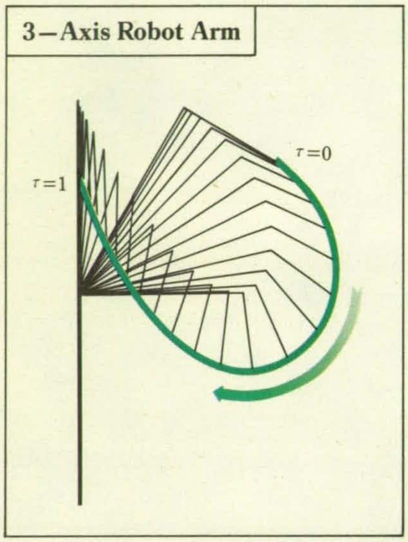
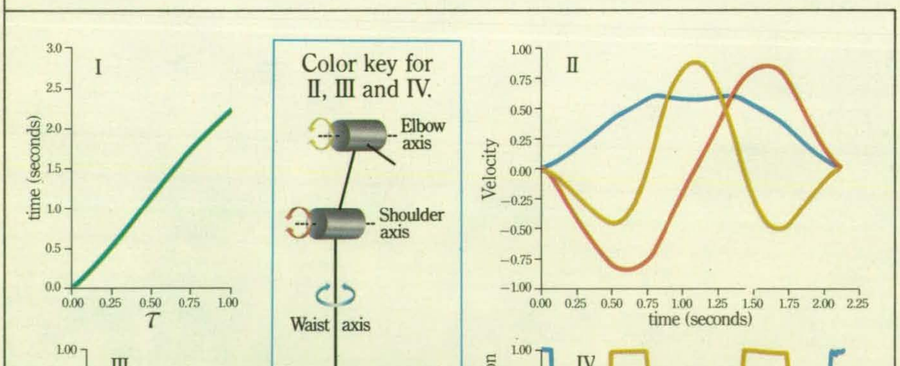


Figure 1: Schematic diagram of a 3-axis robot tracing a path in 3-space.

Figure 2: Results for Figure 1 path. I: Plot of the change of variables, $t=h(\tau)$. II, III, and IV: Normalized velocity, torque, and rate of change of acceleration for the waist, shoulder, and elbow (for any variable, a value of ±1 indicates operation at a limit).



Industrial robot arms are very good at repeating a well defined motion with a high degree of accuracy. A robot with a welding tool, a paint sprayer, or a grasping device at its tip can weld in the right spot, spray a precise pattern, or locate a part in a given place time after time.

This untiring precision makes robots valuable in a quality-oriented manufacturing process such as the assembly of an automobile. That's why General Motors has installed so many robotic manipulators in its plants, and why GM is intent on developing technology and software to use these machines to their best advantage.

When a robot is to apply sealant to a windshield opening, or move a part from one point to another, its tip is positioned at points along a fixed geometric path, always maintaining the orientation needed to perform the task.

Mathematically, tip position along the path can be described as a function of a one-dimensional position parameter τ that ranges from 0 to 1 as the path evolves from beginning to end. Actually, for a robot having three joints, Figure 1 for example, tip position is determined by a set of three functions of τ, one for each joint of the arm. Each separate joint function relates a specific angle of rotation, θ, about that joint axis to a given value of τ.

To get the robot to perform a task, however, its computer controller must associate each point on the path with some value of time—in effect telling the robot to be in position A at a certain time, position B at another time, and so on, throughout the path.

Establishing an appropriate correspondence between time and the path position parameter is an important prerequisite to actually controlling the robot to follow the path.

Dr. Samuel Marin, a mathematician at General Motors Research Laboratories, has devised an effective and efficient means of computing the required correspondence. His work addresses productivity concerns. Dr. Marin's objective is to make cycle time (the time it takes the robot to trace the path from beginning to end) as small as possible, yet to respect at all times the physical operating limits of the robot.

Dr. Marin noted that by seeking a correspondence that gives time explicitly in terms of the path position parameter, $t=h(\tau)$, the problem's character changes. It appears not so closely associated with control theory, where the problem has also been studied, but more like a problem of nonlinear optimization.

Setting $g(\tau)=h'(\tau)$, the derivative of h with respect to τ, allowed Dr. Marin to pose the minimum time problem in the following way: minimize $\int_0^1 g(\tau)\,d\tau$, subject to some constraints dictated by the physical operating limits of the robot mechanism. These limits on the robot—limits on velocity, acceleration or torque, and on rate of change of acceleration (Fig. 2)—can all be formulated as differential inequality constraints and are all expressible in terms of the unknown function $g(\tau)$, as: $g(\tau) \geq G(\tau,g,g',g'')\ \tau \in [0,1]$.

If the problem could be discretized, making it in some sense finite, it could be put on a computer and solved numerically. So Dr. Marin replaced the unknown function with a piecewise cubic approximation.

This allows the search for the unknown function to be confined to a class of functions that are completely characterized by a finite number of coefficients in a B-spline series.

He similarly discretized the constraints, replacing the infinite set of constraints with a finite dimensional subset that could be dealt with numerically.

He completed the formulation of the discrete problem by incorporating a grid-refinement strategy. Now the problem's dimension could be gradually increased to better approximate the continuous case.

What resulted was a classic nonlinear optimization problem, a finite dimensional problem in which it remained only to find the coefficients of the B-splines while satisfying the constraints.

A monotonicity property of this problem coupled with properties of the approximation method suggests that the simple technique of cyclic coordinate descent might best provide a solution.

"While not so effective in other applications, a cyclic coordinate descent-based algorithm appears to be exactly what is needed in this class of problems," notes Dr. Marin. "With modifications introduced to ensure that the iterates are strictly feasible, this method has consistently and rapidly solved the problem."

Working closely with mathematicians at Rensselaer Polytechnic Institute, Dr. Marin is confirming this method's utility. In comparisons so far with several widely used, general-purpose optimization codes, the special method consistently shows itself to be superior.

"My work in path parametrization is just part of the story here at GM," emphasizes Dr. Marin. "Many aspects of this problem's formulation are rooted in deeper concerns about how robots can be made to move faster and more accurately. These concerns originated in the work of Dr. Robert Goor, my colleague in the Mathematics Department, and have motivated several significant advances in robot control and trajectory planning.

"Until all the pieces are put together in a production system, it's difficult to gauge the full value of this work. However it will help reduce our manufacturing costs and will enhance our product quality."

General Motors

GM

MARK OF EXCELLENCE

THE MAN BEHIND THE WORK

Dr. Sam Marin is a Senior Staff Research Scientist in the Mathematics Department of the General Motors Research Laboratories. He is also the Manager of the Department's Mathematical Analysis and Computation Section.

Dr. Marin received his undergraduate degree in mathematics from St. Vincent College in Latrobe, Pennsylvania, and holds both an M.S. and a Ph. D. in that discipline from Carnegie-Mellon University. Between graduate degrees, Sam was an officer in the U.S. Navy, teaching mathematics at the Naval Nuclear Power School.

Since joining General Motors in 1978, Dr. Marin has pursued interests in numerical analysis and approximation. He has published research relating these areas to a variety of applications, including robotics, geometric curve design, and acoustics.

Sam is a member of the Society for Industrial and Applied Mathematics. He lives in Rochester Hills, Michigan, with his wife and two children.

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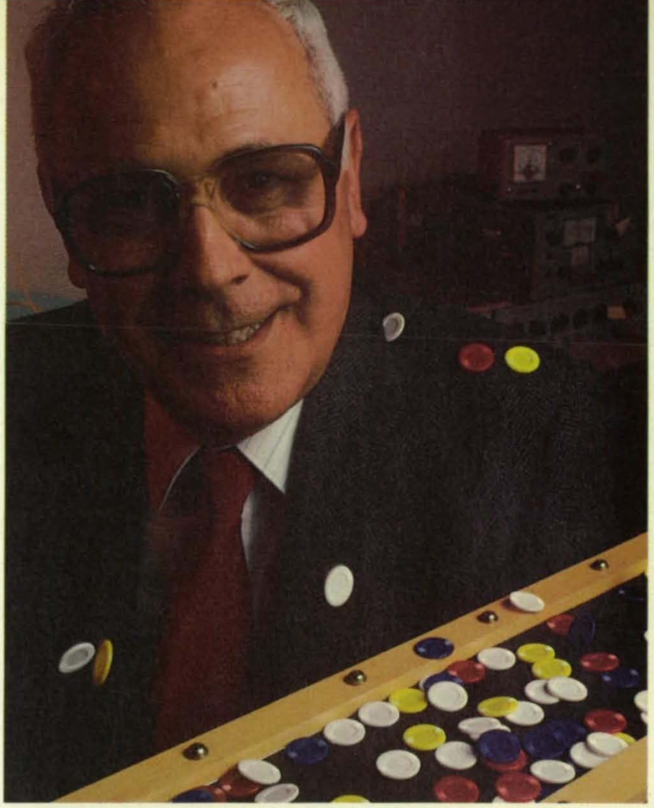
SPECIAL FEATURE

TECHNICAL SECTION



NASA Inventor of the Year Leonard Haslim pops poker chips into the air to demonstrate how his new aircraft deicer expels ice from a plane's wings. See page 34.
Photo courtesy the San Jose Business Journal.

DEPARTMENTS

On The Cover—A one-tenth inch layer of ice is blown from the surface of a wing section during icing tunnel testing of a powerful new deicer developed at NASA's Ames Research Center. Turn to page 34.
Photo courtesy Dataproducts New England, Inc. Photography by Peter Mallison.

The flame-retardant suit pictured above is just one of the many NASA spinoffs highlighted in a special section, beginning on page 16, that celebrates the 25th Anniversary of NASA's Technology Utilization Program.

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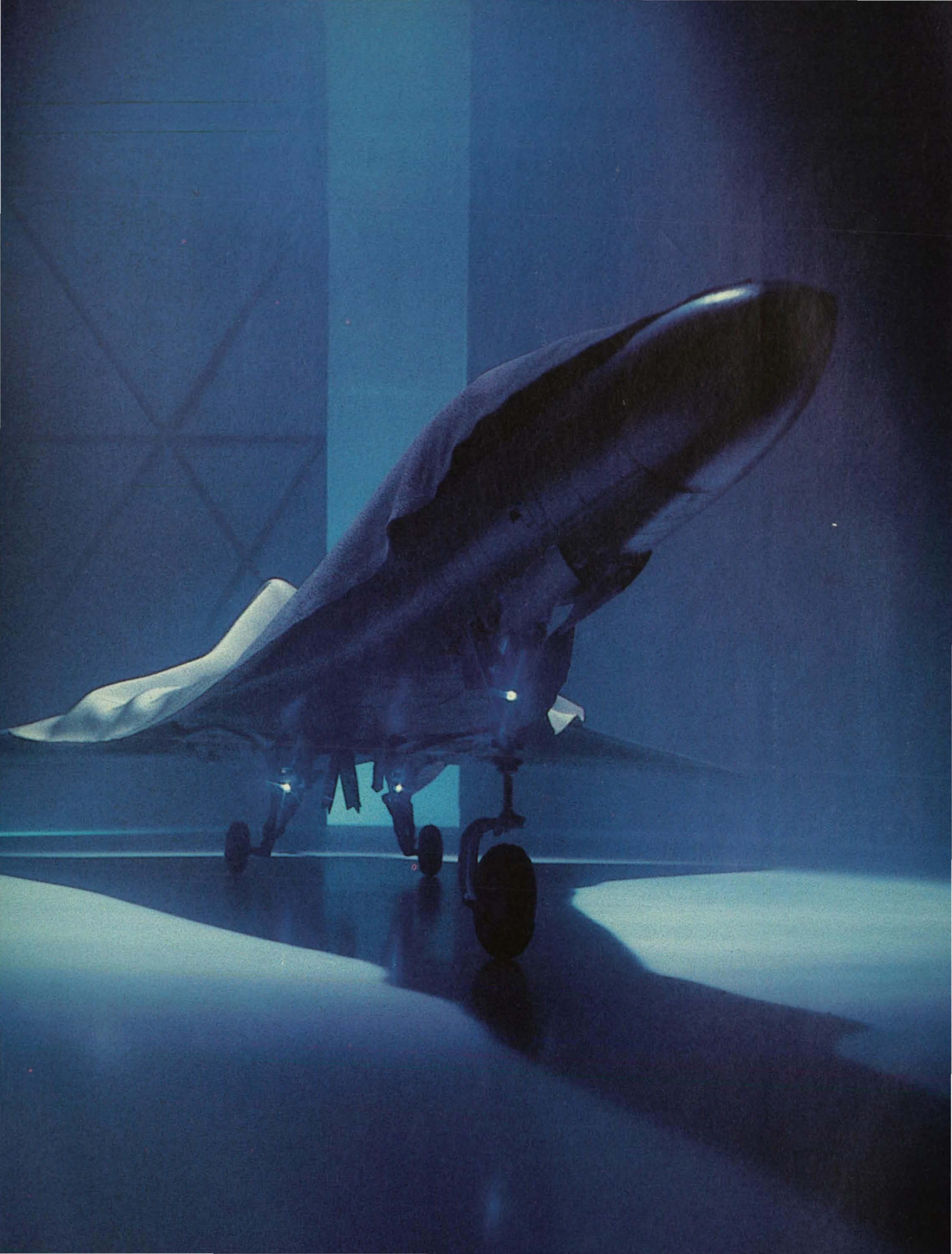

New Product Ideas

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

Dual-Cathode Electron-Beam Source

A highly-reliable electron-beam source uses two side-by-side cathodes so that if one cathode fails, the other can be turned on. The source is intended for uninterrupted service in electron microscopes, electron-beam lithography equipment, Auger instruments, and microfocused x-rays sources. (See page 37).

Video Analog Signal Divider

A video analog signal divider produces a black-and-white composite video signal based on the color ratio. The device is inexpensive, uses the signal from a standard red/green/blue camera as input, and can be used to produce quantitative thermal images on two-color phosphor coatings. (See page 44).

Diffraction-Coupled, Phase-Locked Semiconductor Laser Array

A monolithic array of AlGaAs/GaAs semiconductor injection lasers emits a far-field beam much narrower than that of a single laser of the same type. A peak output of 1.1 W was obtained under pulsed, low-duty-cycle conditions. Applications may include recording, printing, and range finding. (See page 38).

Compact Ho:YLF Laser

An improved Ho:YLF laser radiates as much as 56 mW of power at a wavelength of 2.1 mm. The new Ho:YLF laser is more compact and efficient than are older, more powerful devices of this type, thanks to the recent successes in the use of diode lasers to pump other types of solid-state lasers. (See page 66).

Continuous Production of Refractory Microballoons

A proposed continuous process for the direct production of microballoons from molten refractory materials promises to reduce the cost, improve the product uniformity in size and shape, allow for a wide selection of microballoon sizes and shapes, and eliminate costly temperature cycling. (See page 80).

Beginning in this issue, the symbol at left will appear next to technical briefs which describe inventions having potential commercial applications as new products. The process for developing a product from a NASA invention is described at the top of this page.

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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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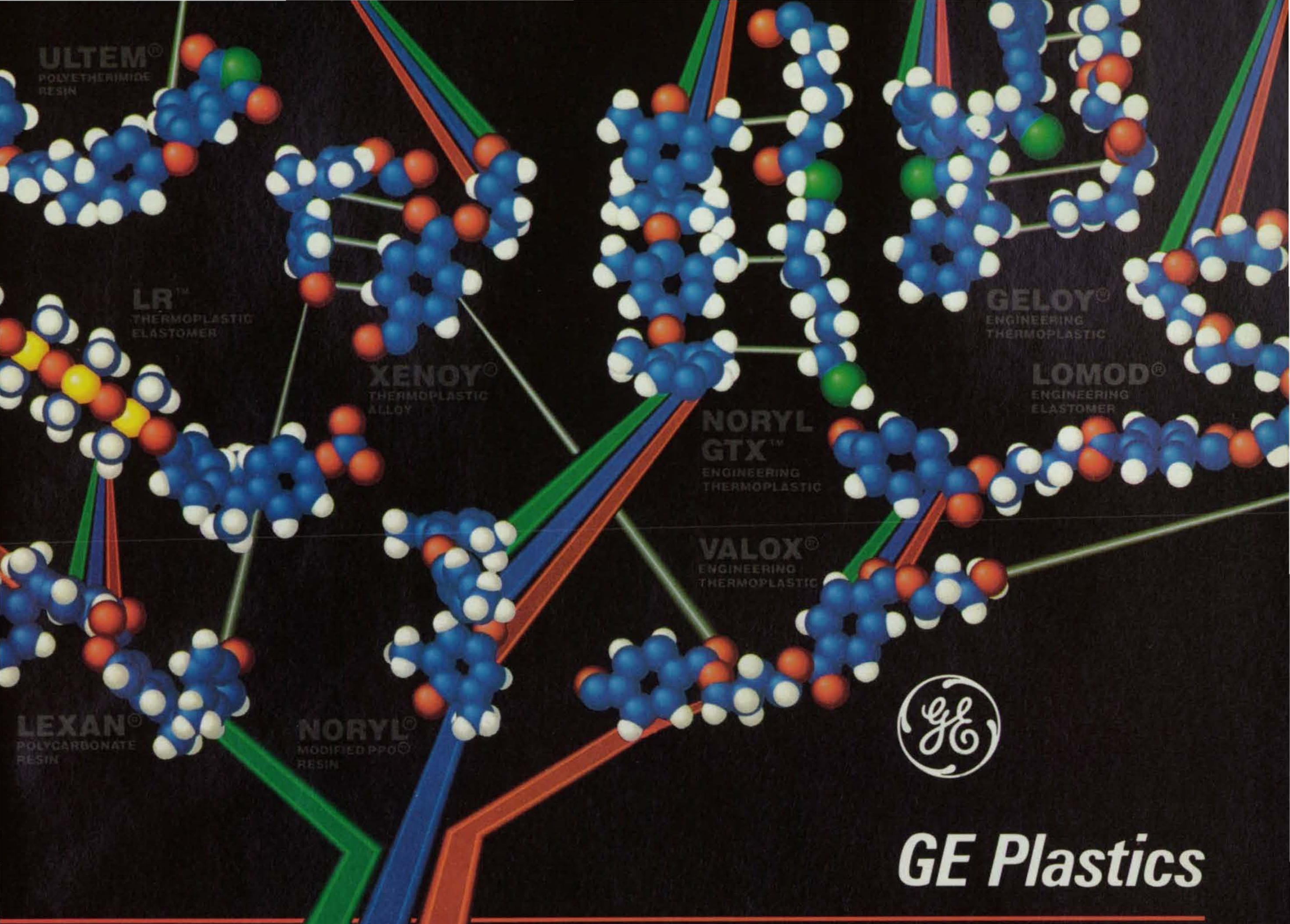

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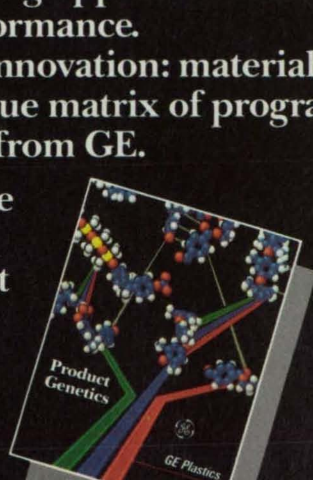

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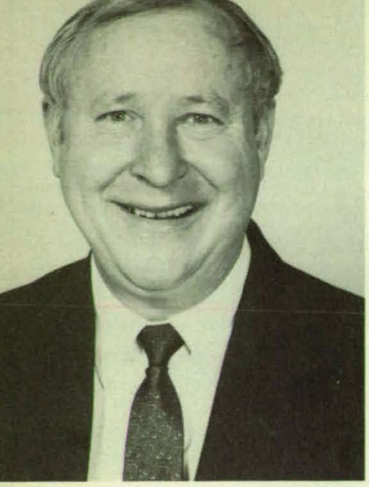

Celebrating 25 Years of NASA's Technology Utilization Program

James T. Rose
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National Aeronautics and Space Administration

By their challenging nature, NASA programs are particularly demanding of technological input. Meeting the aeronautical and space goals of the past three decades has necessitated advancements across a broad spectrum that embraces virtually every scientific and technological discipline.

This technology is simply knowledge, or "know-how," and like other forms of knowledge it is transferable; once the technology is developed, it can be reapplied to uses different—often remotely so—from the original application. Thus, the great storehouse of technology NASA has acquired constitutes a valuable national resource, a bank of knowledge available for reapplication to new products and processes of benefit to the national economy, industrial efficiency and human welfare.

By Congressional mandate, it is NASA's responsibility to promote expansion of technology transfer in the public interest. The instrument of that purpose is the Technology Utilization Program, through which NASA seeks to encourage greater use of its knowledge bank by providing a link between the technology and those who might be able to put it to advantageous use.

This year marks the 25th anniversary of the Technology Utilization Program. During the quarter century span, NASA's own efforts to reapply the technology and those of imaginative entrepreneurs have generated tens of thousands of secondary applications, or "spinoffs."

The following 16 pages describe a few of the many. It is a random sampling that illustrates the breadth and diversity of aerospace spinoff and underlines the scope of the benefits that have accrued. Some spinoffs offer only moderate increments of economic gain or lifestyle improvement. Many others, however, have economic values running to millions of dollars. Collectively, they represent a substantial return on the national investment in aerospace research in terms of contribution to the U.S. economy, job production, industrial productivity, lifestyle innovations and solutions to problems of public concern. □

Health and Medicine

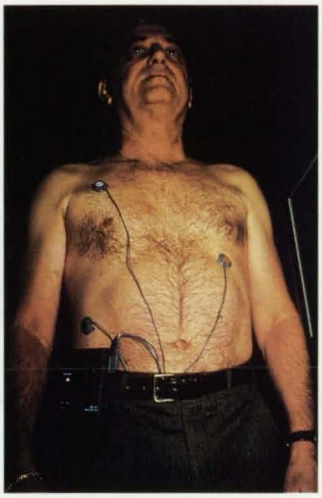
In aerospace design, every subsystem must be superefficient and ultrareliable, yet as small and light as technology permits—requirements that are shared by many types of medical devices. That's one reason why the field of health and medicine has been a particular beneficiary of aerospace spinoff.

The United States leads the world in the technology of building complete, reliable aerospace systems in incredibly tiny packages and that technology has spawned a line of life-saving medical adaptations. An outstanding example is the cooperative/development of human-implantable systems by a group of research organizations and medical equipment manufacturers who applied such space technologies as advanced long-life batteries, microminiaturized components, electronic sensors and telemetry, the wireless relay of coded signals for high-volume two-way communication between Earth and orbit. Some examples of the results:

- ▲ A rechargeable cardiac pacemaker that eliminates the recurring need for surgery to replace batteries.
- ▲ An advanced heart pacer that may be reprogrammed without surgery—via biotelemetry—as a patient's condition changes.
- ▲ A human tissue stimulator that provides relief from chronic pain by sending electrical impulses to targeted nerve centers.
- ▲ An automatic implantable "defibrillator" that senses the start of fibrillation—in which the heart loses its ability to pump blood—and corrects it by sending an electrical impulse to the heart.
- ▲ A programmable implantable system that automatically dispenses precisely-measured medication—such as insulin for diabetics—to target organs.

Described on these pages are a few of thousands of applications of aerospace technology that have provided extraordinary benefit to the field of health and medicine.▲

Wearer of a rechargeable cardiac pacemaker, the child is shown with the companion unit that sends an electrical charge to the pacer's battery without surgery.



A wearable computerized system that allows physicians to monitor ambulatory patients with coronary artery disease incorporates technology originally developed to observe the heart action of Space Shuttle astronauts. It continuously evaluates and records heart signals, alerts to danger and allows physicians to determine the efficacy of treatment.

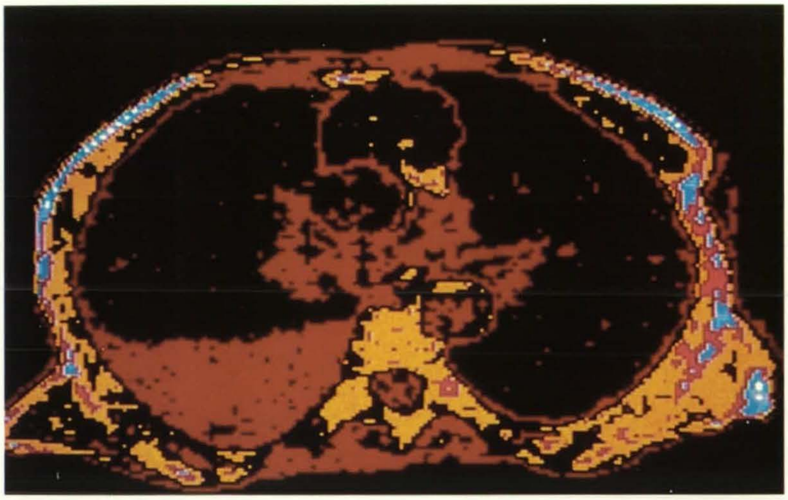
A patient (seated) is briefed on the operation of a wearable system that continuously delivers insulin—through a needle under the skin—for treatment of diabetes, a life-extending invention derived from space microminiaturization techniques.

Health and Medicine

Body imaging is the art of creating pictures of human interiors to aid physicians in diagnosis, treatment and surgery. The X-ray is a familiar example. But where the X-ray shows only bone structure, medicine now has available a broad range of body scanning equipment and techniques to penetrate bone and produce highly informative images of body tissue and organs.

Much of this technology stemmed from the space technique known as digital image processing, developed as a means of assembling a picture of a planet or moon from bits of sensor data sent to Earth in digital form by a distant spacecraft. Later advances brought ways to correct sensor errors, change picture contrast, emphasize certain features, make measurements, generally to amplify the information that can be extracted from the computerized image.

This explosively-proliferating new technology has spun off to such varied fields as defense equipment, non-destructive testing, archeology, chemistry, cartography, manufacture of printed circuitry, metallurgy, ultrasonics and seismography. Nowhere has image processing technology been more importantly or more effectively employed than in medicine, where it has enabled advancements in CAT scanning, diagnostic radiography, brain and cardiac angiography, sonar body scanning and monitoring surgery. The illustrations show a representative few of the scores of image processing spinoffs in medicine. ▲



NMR—nuclear magnetic resonance—is a promising new technique for diagnostic body scanning, but NMR imagery is complex and difficult to interpret. Space image enhancement technology offers a means of simplifying interpretation for better diagnosis. Three black and white NMR images were computer-enhanced to create this chest scan "theme map," in which each color represents a different type of tissue and a tumor mass (top center) is precisely outlined.

The medical technician is using the system pictured to get a computerized analysis of a microscope specimen that will provide far more information than visual interpretation and do it far more rapidly. This system, several related systems and the whole company that produces them are all spinoffs from NASA digital image processing technology.

Now in use in more than 20 states and a number of foreign countries, slow scan TV—a technology that originated in the U.S. space program—makes possible instant consultation between medical centers and specialists at home or in their offices. The specialist views the patient's body imagery inexpensively transmitted over a standard telephone line, allowing accelerated diagnosis that could be vitally important to an emergency patient.

For lunar exploration, astronauts needed a compact, lightweight, battery-powered long-use drill to extract core samples from beneath the lunar surface. Under NASA contract a company developed one, then used the technology to produce a line of cordless tools for consumer, industrial and medical use. That's one example of how a space requirement generates new technology for everyday products; here are a few others in the field of health and medicine:

- ▲ A contractor developed an automatic gas analyzer to monitor Apollo astronauts' respiratory gases; it is now used in hospitals for analysis of anesthetics.
- ▲ A life-search experiment on a Mars-landing spacecraft required development of miniaturized valving technology, which became the foundation of a family of civil-use fluid control devices, such as a filtering system that removes impurities from blood.
- ▲ Newborn premature babies are warmed—without noise or burn hazard—in cradles whose electricity-conducting canopies provide controlled radiant heat, an offshoot of NASA technology developed for heated cockpit canopies and astronaut helmet faceplates. ▲

The surgeon is using a self-contained instrument that needs no power source, lines or hoses, thus offers optimum freedom in the operating room. It is one of a line of cordless surgical instruments that stemmed from the developing company's work on a moon drill.

The technicians at left are preparing body fluid samples for analysis by an automatic system that detects and identifies disease-producing mechanisms in the human body. Handling as many as 240 samples at a time, it provides faster analysis—thus earlier treatment—and minimizes human error. Successful transfer of this technology, originally developed to detect bacterial contamination aboard an unmanned planetary spacecraft, resulted in formation of a new company.

A tiny mote of dust could trigger malfunction in a sensitive spacecraft system, so NASA developed contamination control technology for assembly of sensitive flight equipment in hospital-like "clean rooms." One of several offshoots of that technology base is a line of advanced, disposable, inexpensive anticontamination garments for hospitals and pharmaceutical clean rooms.

Public Safety

The field of public safety has been especially susceptible to transfer of aerospace technology: Some examples:

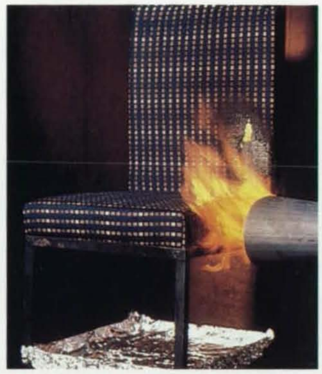
- ▲ Developed to minimize Space Shuttle fire hazard, a polyimide foam material with exceptional flame resistance is used on interior furnishings of public-use aircraft, trains and buses.
- ▲ Available to airport, municipal and industrial firefighters is a "bayonet-type" spray nozzle, developed for Shuttle landing emergencies, that can be thrust through the skin of a transportation vehicle or certain building materials to deliver extinguishants to the interior.
- ▲ A NASA-developed device for detection of invisible flames in liquid hydrogen propellant tanks has become a commercial product for use in hydrogen generating plants and pipelines.
- ▲ The sophisticated smoke/fire detecton system used in the Skylab manned spacecraft provided the technology for a home use detection/warning device.
- ▲ A special type of electronic circuitry developed for space telemetry provided technology for a supersensitive industrial gas leak detector; the same technology was later applied to a post-fire arson detection device and a visual alert system for the hearing impaired.
- ▲ An underwater device that signals the location of a downed

Ocean-landed Apollo astronauts waited for helicopter pickup in inflatable rafts specially stabilized to prevent overturn by the helicopter's downwash. The NASA-patented water ballast stabilization system was employed in a widely used commercial raft that does not capsize in heavy seas.

The workmen are cutting grooves in a highway surface to improve wet weather tracton. Developed by NASA to curb skids of landing aircraft, the grooving technique has been applied to hundreds of airport runways worldwide and to many highways in North America, Europe and Asia.

A thin, lightweight, flexible fire-resistant fabric developed for Apollo astronauts' space suits found application in a fire-entry suit for fire-fighters and industrial workers exposed to high heat, steam or hot liquids.

airliner's flight recorder borrowed technology from a NASA/Navy-developed sonar search/locator system. ▲



The first two photos above show a conventionally covered chair after 30 and 90 seconds exposure to high temperature. The latter two photos show the effect of the same exposure on a chair covered by a fabric containing fireblocking fibers of a formula originally developed for astronaut flight suits. As is evident, the fibers curb flame spread, hence offer increased safety in a wide range of civil applications from airline seat cushions to auto racing driving suits to foundry workers protective apparel.

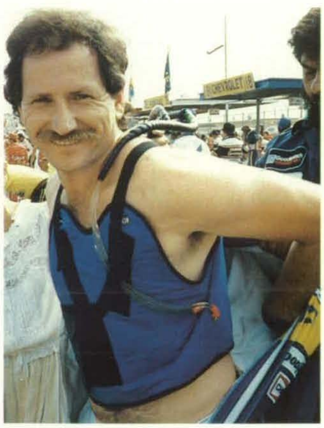
These firefighters are wearing a breathing apparatus for protection against smoke inhalation, the result of a multiorganizational development project that adapted aerospace materials and technology to a national need for lighter, less bulky firefighting equipment.

NASA design technology for "hard shell" pressure suits—intended to protect future lunar colonists against micrometeorites—was incorporated in this advanced deepwater diving system, which has fluidic joints to permit 75 percent normal human mobility.

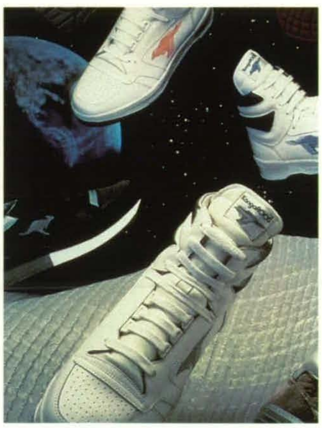
At left is one of several products that spun off from NASA research in x-ray telescope instrumentation, an x-ray inspection system for examining luggage at airports and other security areas; it produces high quality images at extremely low radiation dosages.

Consumer/Home/Recreation

Echo 1, NASA's first experiment in satellite communications, was a 10-story-size balloon used as a giant reflector for "bouncing" radio signals from one point on Earth to another. For its skin, NASA needed a material that was exceptionally thin and light yet highly reflective. A NASA contractor came up with a metal-coated plastic film so fine that the balloon's skin was half the thickness of the cellophane on a cigarette package. That development triggered the growth of a whole new industry making metallized products with extraordinary heat reflection or heat retention characteristics. The technology transfer process went through a second circuit when NASA found that metallized materials were ideal for protection of spacecraft crews and components from solar radiation and extensive space use, plus additional R&D, spawned another round of spinoffs. The list of applications for consumer/home/recreational use alone is uncommonly broad—stadium blankets, tents, suntanning pads, wall coverings, drapery liners, window shades, bedwarmers, windbreakers, candy wrappings, food packaging, to mention only a few among scores—and there are many additional applications in other fields. ▲



Auto racing champion Dale Earnhardt displays a "cool vest," part of a personal cooling system many drivers use to combat cockpit temperatures that often get above 130 degrees Fahrenheit. The cool suit, which includes a helmet liner, is a derivative of space suit technology.



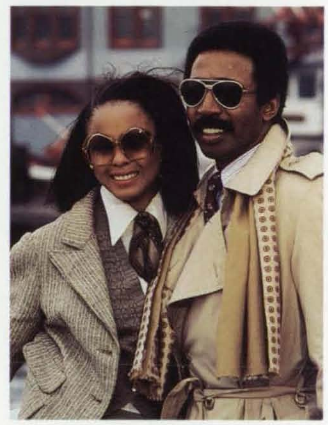
For moonwalking safety and comfort, astronauts' lunar boots featured a three-dimensional "spacer" material for cushioning and ventilation. That material, in modified form, has turned up in a popular line of athletic shoes designed for improved shock absorption and reduced foot fatigue.

A highly reflective insulating material developed to protect spacecraft and crews from intense solar radiation became an energy-saving window insulator. A thin metallized film bonded to windows of homes, schools, office buildings and other facilities, it reflects the Sun's heat and glare outward, cutting down on energy costs for cooling.

A computerized beauty makeover system incorporates NASA image analysis technology originally developed to construct and analyze pictures of distant planets. Directed by a makeup expert, the system analyzes the client's skin color, considers thousands of makeup color combinations and offers a selection of "new looks."

This ice show troupe is performing on an "instant rink" built atop a theater stage in *one* day by means of a spinoff portable icemaking system. The key is an innovative flexible tube circulation system for the refrigerated coolant, an adaptation of a solar collector heat distribution network developed under NASA sponsorship.

Winner of the 1987 America's Cup, the racing yacht *Stars and Stripes* got an assist from NASA-developed "riblets," tiny grooves in the yacht's hull that contributed to increased boat speed. The world's largest jetliner producer is now planning to incorporate riblets in its transports to reduce air drag and improve fuel efficiency.



To protect plastic surfaces of aerospace equipment from harsh environments, NASA developed an abrasion-resistant coating that found commercial application in a popular line of sunglasses. The NASA technology was combined with the company's own research to produce a long-wearing lens with scratch resistance better than glass.

Spinoffs in

Environment and Resources Management

Several aerospace technologies have found spinoff utility in environmental and resources management applications. NASA-pioneered satellite survey of Earth resources, provided a technology base for commercial remote sensing networks. Space image processing is being used in geology, archeology and pipeline monitoring. And many types of aerospace instruments and materials are being employed in such areas as air quality monitoring and noise abatement. ▲

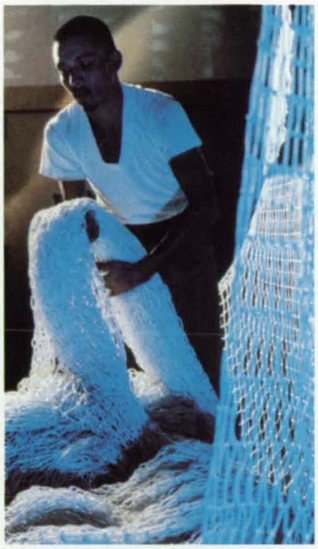
NASA's need to protect ground and flight equipment from corrosion — in particular coastal area erosion induced by salt spray — led to development of many types of coatings that have spun off to commercial use. In the photo, a bridge maintenance inspector is checking a girder covered by an inorganic coating — produced under NASA license — with superior corrosion resistance. The Statue of Liberty wears a NASA-developed interior coating and a variety of other coatings are protecting office buildings, tank farms, ships, oil rigs and other structures.

For future space colonists and long-duration space flights, NASA has extensively explored the use of aquatic plants — which absorb impurities from sewage — as a means of treating and recycling wastewater. This research has found broad civil application; dozens of small towns are using water hyacinths as their primary wastewater treatment system and one major city uses them in a secondary treatment technique. In the photo, a hyacinth aquaculture filtration tank in San Diego, California.

In Washington, D.C., a crew is installing a sewer monitor that tracks wastewater processing, warns of potential overload and reports how the system is functioning generally. In use in hundreds of cities, it employs multiple aerospace technologies, in particular sensors, microcomputers and redundant subsystems.

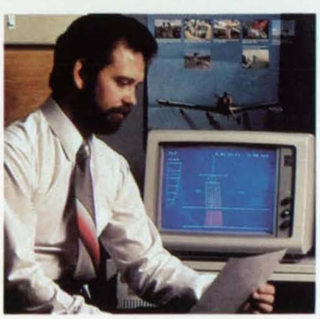
Food and Agriculture

A microwave system dries agricultural crops with less chance of quality loss and a lower energy requirement than hot-air blowers; it is a spinoff from space-simulating vacuum chamber technology. For increased hog production, some farmers are using a robotic sow—an artificial nursing machine for piglets—whose key element is a miniature heat pump developed for satellites. These are examples of many widely varied aerospace spinoffs in food and agriculture; a few more are illustrated.▲



Not your ordinary fishing net is the one pictured; it is a spinoff seine that sinks faster and arrives at its fishing depth quicker than conventional nets, thus traps extra tons of fish that would otherwise dart away. The key is a superstrong twine and a twisting process first used in a safety net for personnel working on the Space Shuttle.

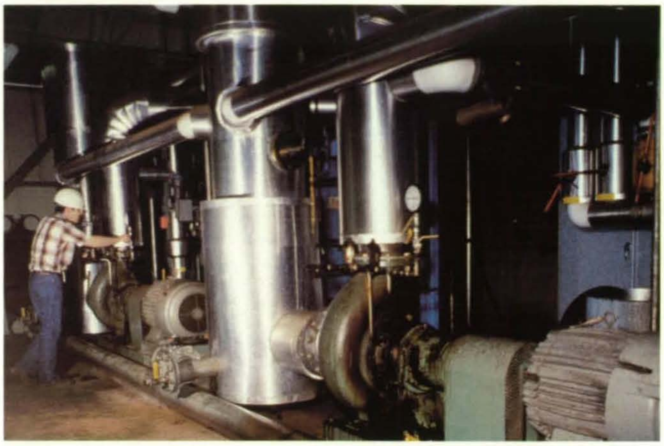
More than a decade of research by NASA and the Department of Agriculture brought a solution to a major crop dusting problem: wasteful and environmentally unacceptable drift of chemicals beyond target areas. The answer: a complex computer program that considers all variables and provides information on how to adjust spray height, nozzle position or other factors to get the desired coverage with minimal drift.



This irrigation system rotates around a center pivot, watering multi-acre areas in a single revolution. Each three-ton wheeled "tower" has its own electric motor; power is transmitted to the wheels by individual gear boxes that incorporate NASA technology to protect them from wear and heat stress.

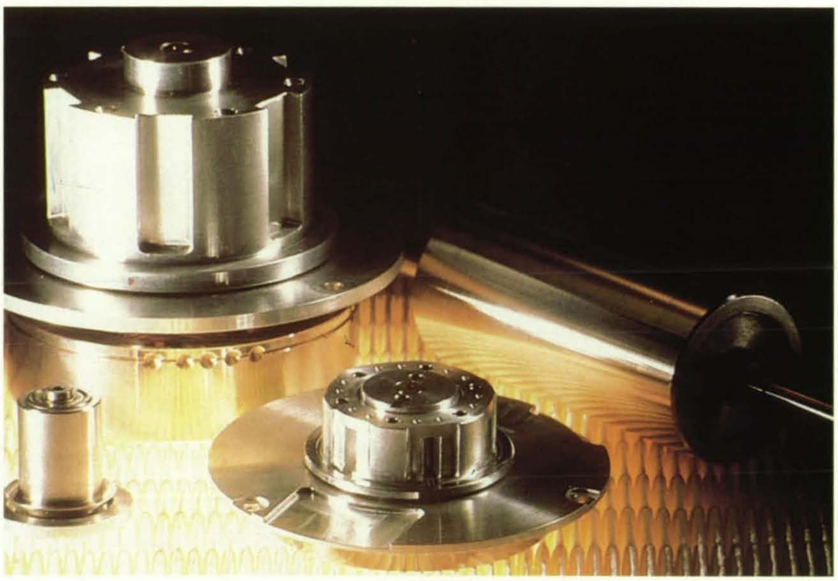
Manufacturing Technology and Industrial Productivity

Among examples of aerospace technology being put to productive use in industrial facilities are an air flotation system that allows heavy loads to "float" over the plant on air bearings, an adaptation of the method used by NASA to move multi-ton launch vehicle segments; use of the material in Space Shuttle thermal tiles as an insulator for the heating chambers of a high temperature laboratory system; and a NASA-developed system that facilitates robotic welding by employing closed-circuit TV to guide an arc welding torch without human intervention. Some other examples are pictured. ▲



To increase the thrust of liquid fuel rockets, NASA developed an "inducer" to boost the flow rate of rocket fuel pumps. A pump manufacturer used the NASA technology to increase the speed of special purpose pumps such as the one shown, which is used to recirculate wood molasses.

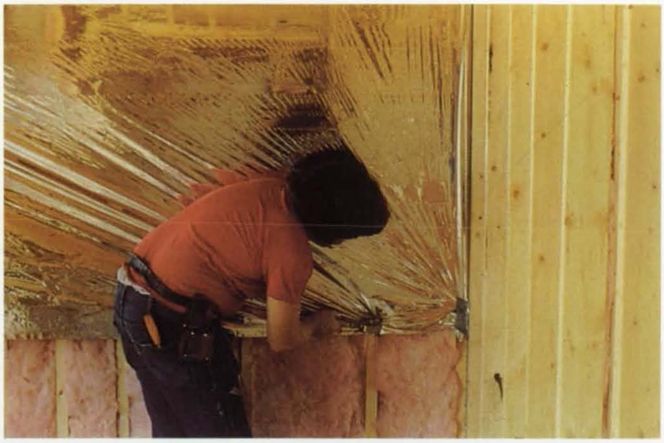
Pictured above is a batch of microspheres, plastic beads so tiny that a vial as long as an index finger can hold 15 million of them. Perfectly spherical because they were grown in gravity-free space, they serve an important need among industrial laboratories and manufacturing facilities as reference standards for calibrating instruments with extreme accuracy.



In the photo are a variety of ferrofluid bearings. Ferrofluids are liquids provided with magnetic properties. They had their origin in the space program when scientists experimented with drawing weightless fuel into a rocket engine by magnetizing it. NASA licensed the technology to a company formed specifically to commercialize it. Ferrofluids offer unique advantages in manufacture of electronic products, industrial processes, medical equipment, visual displays, automated machine tools and a wide range of other applications.

Energy

Space-pioneered solar energy technology has found wide usage in Earth heating, cooling and electricity-generating applications. Among other spinoff technologies are heat pipes used to cool spacecraft electronics and a variety of techniques originally designed to minimize energy use in aircraft and spacecraft, now serving the same purpose in Earth applications. Among unusual spinoffs are the employment of space telemetry in an automatic oil well production reporting system, and the use of space-developed power amplifiers to reduce TV stations' transmission costs. ▲



The aluminized "heat shield" being applied holds out or keeps in heat, cold air and water vapors. Once used as a radiant heat barrier in Apollo and other spacecraft, the heat shield insulation is the key element of a sophisticated energy conservation technique for homes and office buildings that offers dramatic energy savings and is finding rapidly increasing acceptance in the U.S.

Within the upright supports of the Alaska pipeline are some 76,000 heat pumps, compact, no-moving-parts devices that, in space use, alternately heat or cool spacecraft components subjected to varying temperatures. In Alaska, the permafrost soil alternately freezes and thaws. That could weaken the pipeline's support structure—except for the heat pipes; they keep the ground near the pipeline permanently frozen, protecting against pipeline ruptures that could cause economic loss or environmental disaster.

To conserve energy in aerospace systems, NASA developed a controller for electric motors that senses a motor's load and feeds it only the minimum voltage it needs to do its job—hence sharply cuts power wastage. Installed in manufacturing facilities—such as the home products conveyor line pictured—it can save big companies millions a year in power costs.

Construction

Fabric structures and flat conductor cable for building electrification are examples of extraordinary spinoff benefit to the field of construction, but there are many others that offer important gains in economy, safety and construction simplification. A random selection:

▲ NASA's long experience in fracture toughness testing for aerospace hardware contributed to safety-enhancing test procedures and requirements for all U.S. federal-aid highway bridges.

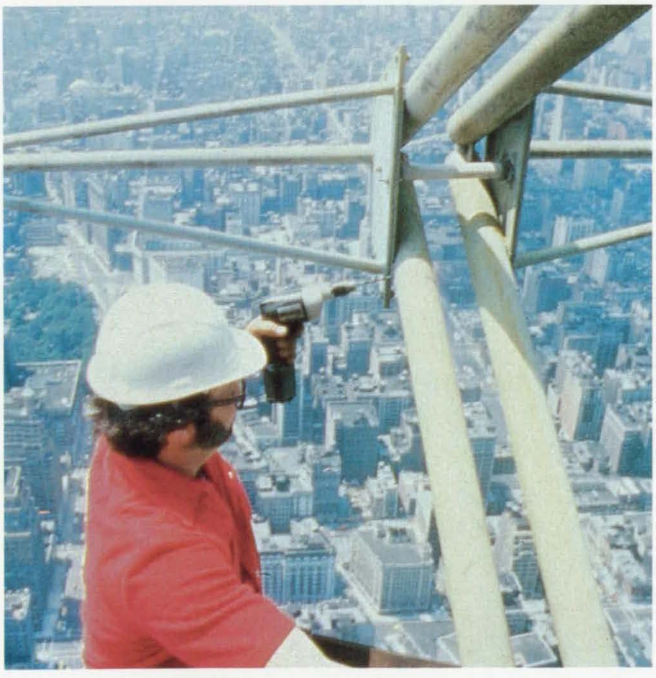
▲ An aluminum color finish that improves the weather resistance and attractiveness of commercial buildings is based in part on an anodizing process developed to produce a hard protective finish for spacecraft exterior surfaces.

▲ Developed for measurement of bolt stress in wind tunnels, a NASA bolt monitor provides extremely precise information on bolt tensioning in construction jobs and reduces chance of serious accidents caused by overtightened or undertightened bolts. ▲

In the 1960s, two contractors teamed to produce a special fabric for space suits that was thin, light, flexible, yet durable and noncombustible. The material provided the basis for later development of heavier, construction-use fabrics with similarly advantageous properties. The first adaptation was Michigan's Silverdome (left). Their relatively low cost has inspired widespread acceptance of fabric-roofed structures in shopping malls, stadiums, field houses, schools, theaters, exhibit halls and industrial facilities. American companies are also taking the technology abroad; in the upper photo is the Haj Terminal at King Abdulaziz International Airport in Saudi Arabia.

Use of flat conductor cable (FCC)—rather than round cable—to reduce the size and weight of aircraft and spacecraft systems sounds like a simple switch but it took years of research. NASA subsequently applied that know-how in a multiyear, multi-organizational effort to adapt the technology to design of electrification systems for commercial buildings and obtain approval from fire protection and insurance authorities. Offering speedy installation, reduced cost of rewiring and simplified building construction, use of FCC has expanded rapidly since the first commercial installation in 1979. Above left, an undercarpet installation. With wiring out of sight and no vertical wiring enclosures needed, interior designers have new latitude in planning attractive "open landscape" office layouts such as that in top center.

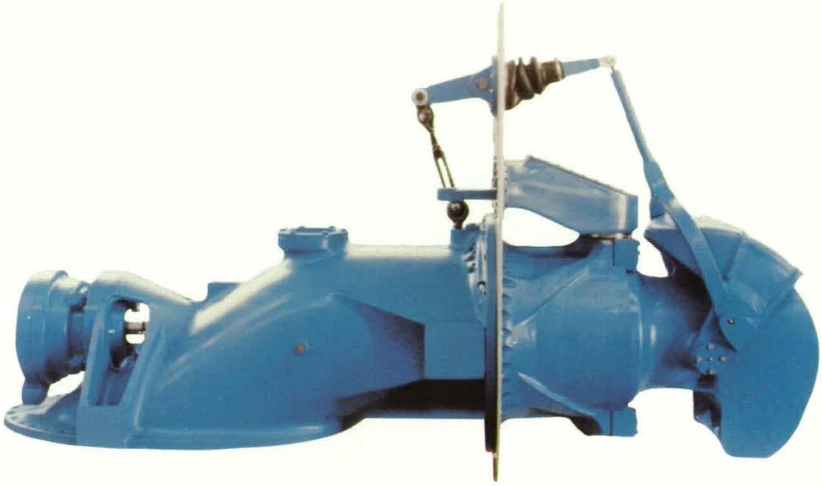
Strong winds can cause a lot of problems for buildings, particularly tall buildings, so architects are increasingly employing "wind engineering," a relatively new discipline that involves testing models of new buildings in wind tunnels. In the photo, a leading wind engineer is setting up a test in a university wind tunnel; his special technique incorporates NASA predictive technology for comparing simulated with actual wind flows at levels below 2,000 feet.

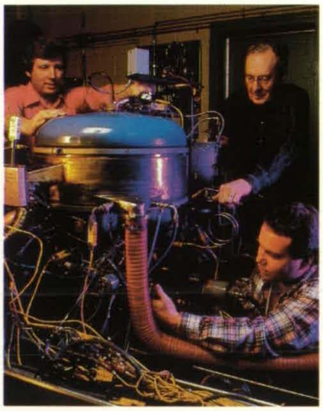


A line of cordless tools and instruments based on technology developed for a lunar subsurface drill includes self-contained construction tools for use where a power source is not readily available.

Transportation

Many of the aerodynamic, propulsion and other advances that have made American-built airliners the most widely operated in the world originated in NASA aeronautical research. NASA also applies aviation-acquired propulsion expertise to automotive research. And many other aerospace technologies have found adaptation, via the spinoff route, in surface transportation applications.▲





The mighty turbopumps of the Saturn V moonbooster fed fuel to the launch vehicle's engines at the rate of 200,000 gallons a minute. The turbopumps (above) later found commercial utility as primary propulsion systems in a type of high speed crewboat and supply vessel (left) for the offshore oil industry.

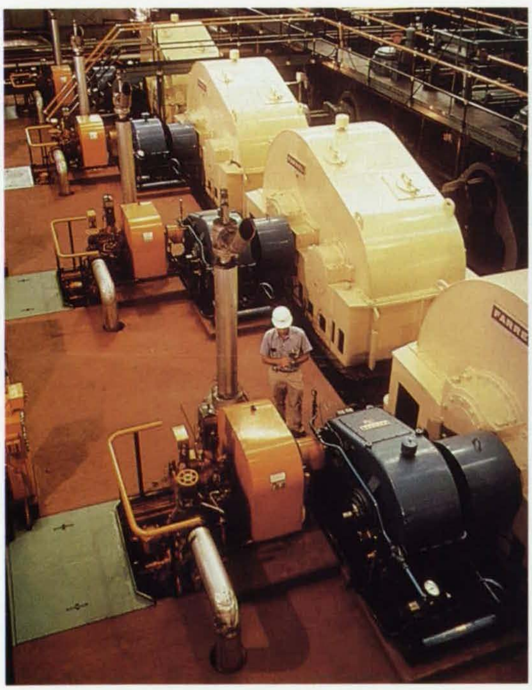
In cooperation with truckers, engine manufacturers, and other government agencies, NASA is developing—for cars, buses and trucks—an advanced Stirling external combustion engine that offers dramatically lower fuel consumption and environmental gains in reduced noise and exhaust emissions.

The Space Shuttle's sophisticated, computerized propellant management system, especially designed to monitor the flow of supercold cryogenics, provided the technology for a system that measures precisely the cryogenics loaded and offloaded by liquefied natural gas tankers like the one pictured.

Structural Analysis

For years, aerospace engineers have employed a design technique in which they create mathematical models of an airplane or space vehicle and "fly" it by means of computer simulation; that enables them to study the behavior of a number of different designs before settling on a final configuration. For this technique, NASA developed the NASTRAN program—NASA Structural Analysis—which takes an electronic look at a computerized design and predicts how the structure will perform under service use conditions. Quick and inexpensive, it minimizes trial and error in the design process, this has become one of the most widely employed spinoffs, used to analyze autos, trucks, railroad cars, ships, nuclear reactors, steam turbines, bridges, rollercoasters, office buildings and hundreds of other structures.▲

A decade ago the U.S. auto industry began designing cars with help from the NASA-developed NASTRAN program. Today the NASTRAN program is incorporated in the computer design processes of sevaral major auto companies.



A machinery manufacturer used the NASTRAN program to design these steam turbines. A predictive tool, NASTRAN analyzed the dynamic behavior of turbine components, allowing substantial savings in development costs.

A major shipbuilder used the NASTRAN program in designing the U.S. Navy's *Kidd Class* destroyers, one of which is pictured, and the *CG-47 Class* of guided missile cruisers.

In the photo, a mammoth valve for a nuclear power plant is undergoing shock and vibration testing on a "shake table." In designing a line of valve products, the manufacturer uses the NASTRAN program to identify high stress areas and to establish design adequacy under the most severe conditions the valve might encounter in service use, including earthquakes.

Spinoffs in

Computer Programs

NASA and other government agencies develop many types of computer programs that frequently can be adapted—with little or no modification—to secondary uses, often remote from their original purpose. In the interest of national productivity, NASA's Computer Software Management and Information Center (COSMIC) offers adaptable programs to industry at a fraction of their originial cost. Since a customer gets a return many times the investment, COSMIC's service has become one of the broadest areas of spinoff applications. COSMIC offers some 1,400 programs and their potential secondary uses would fill a catalog; the illustrations show a few of the many examples.▲

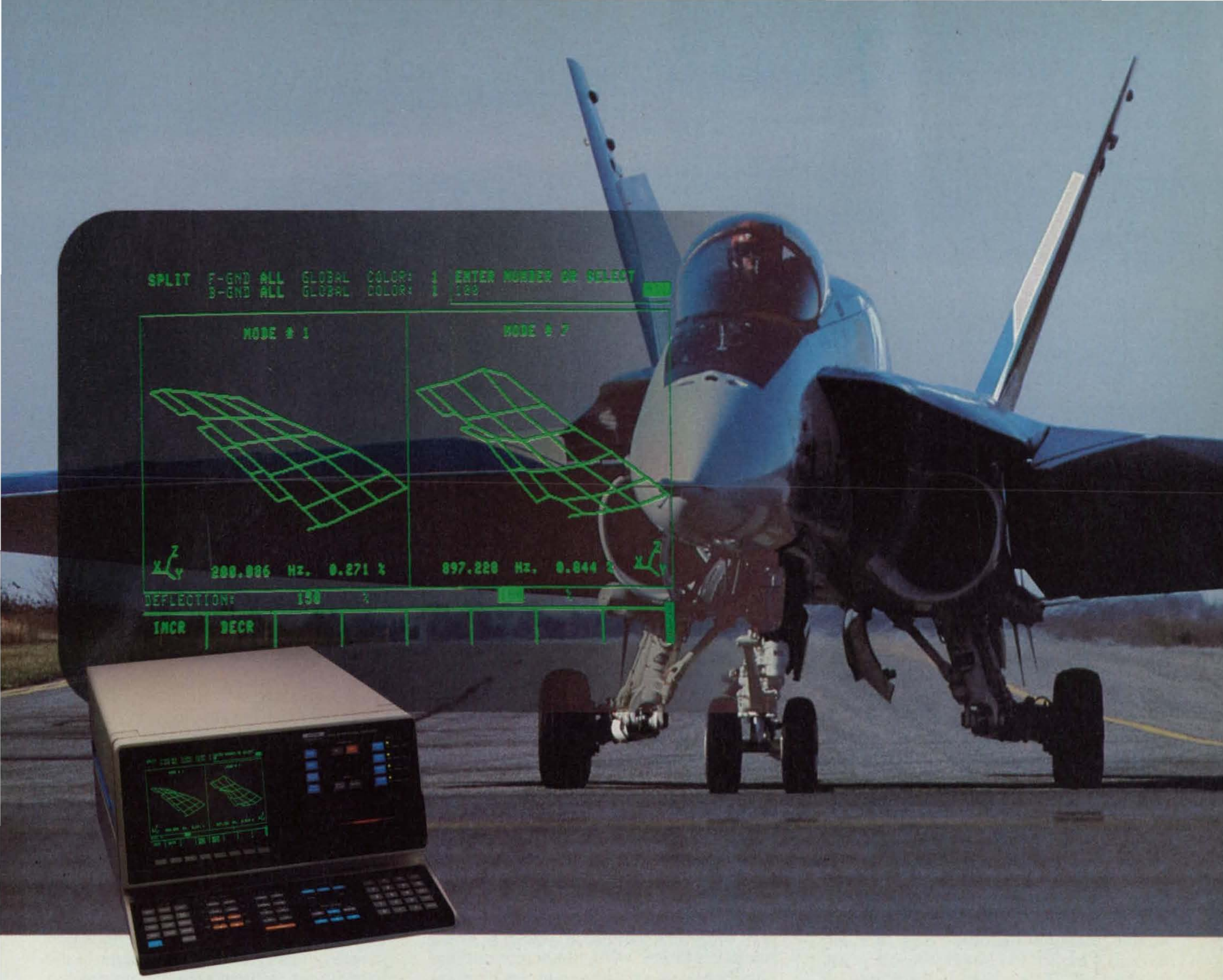
A COSMIC software package helps an insurance company catch data processing errors before they affect the company's customer service or its profitability.

A COSMIC-supplied computer program is used in an offshore oil industry project aimed at developing a capability for predicting the best pile driving technique for each new offshore platform.

How various chemical structures will hold up when used in plastic products—like the containers shown—is analyzed by COSMIC software supplied to a manufacturer of chemical compounds for plastics.

Two COSMIC computer programs that predict noise levels of machinery were employed in a noise analysis performed for a tobacco company that sought to reduce noise so its employees would not have to wear ear protection devices.

A waterfowl preservation society uses NASA-developed software to interpret satellite data on the continually changing conditions of waterfowl habitats.



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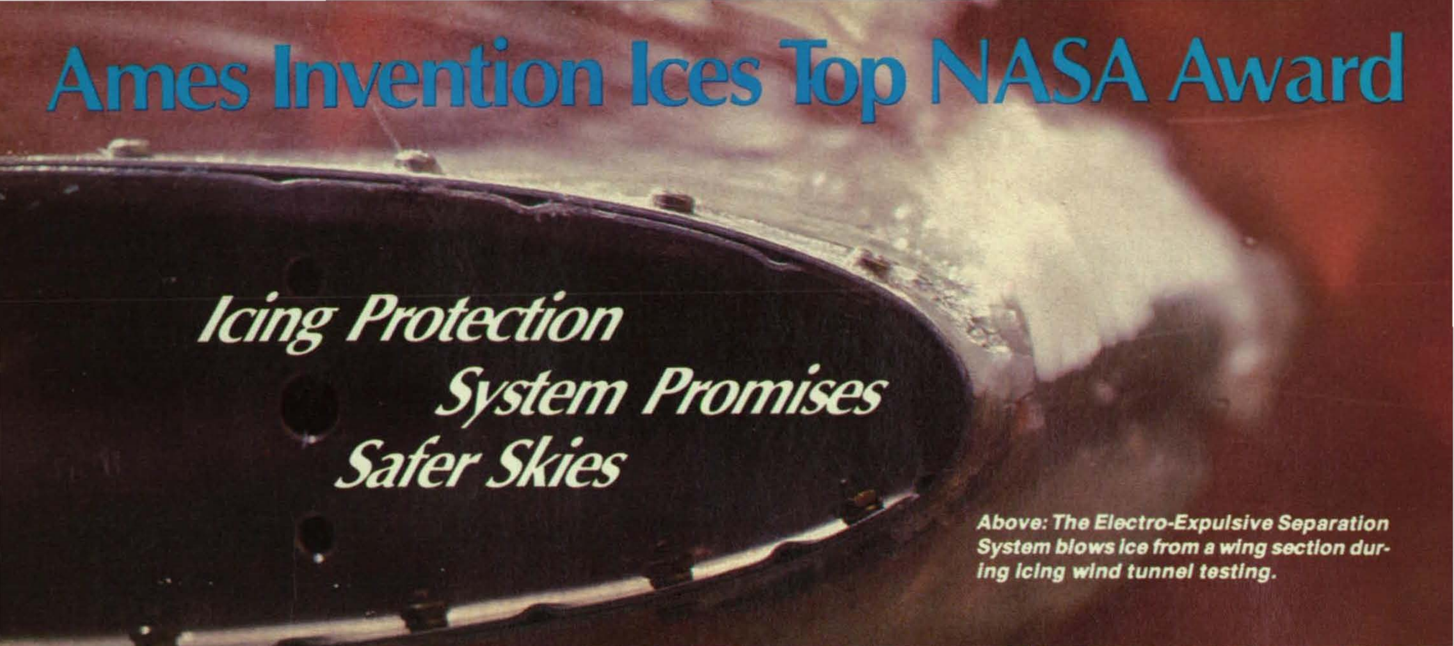
Icing Protection System Promises Safer Skies



Above: The Electro-Expulsive Separation System blows ice from a wing section during icing wind tunnel testing.

Photo courtesy Dataproducts New England, Inc. Photography by Peter Mallison.

A dynamic new invention promising to improve aircraft safety, speed industrial processes, and aid ailing hearts has earned engineer Leonard A. Haslim NASA's 1988 Inventor of the Year Award. Haslim's patented invention, the "Electro-Expulsive Separation System," has generated strong interest from the commercial airline industry and the military because of its immediate potential as an aircraft deicing system. The device uses pulses of electricity to pulverize ice accumulations, which unchecked can degrade aeroperformance and cause engine failure.

Although numerous methods already exist to combat airframe icing, most have serious drawbacks, according to Richard Adams, National Resource Specialist on Aircraft Icing for the Federal Aviation Administration. "Thermal deicers that heat ice are widely used but they consume a lot of power and present the problem of melted ice refreezing on other parts of the aircraft," he said. "Pneumatic boots are another option, but they're slow to inflate and deflate and require up to a half inch of ice before they start working."

Haslim's innovation uses a thousandth of the power and one-tenth the weight of existing systems, can remove ice of thicknesses from mere frost to a one inch glaze in less than a millisecond, and is easily retrofitted to most aircraft. It consists of an elastomeric boot embedded with flexible conducting ribbons. A large direct current released from a power supply flows through opposite sides of the conductors and creates an electromagnetic field that forces the adjacent conductors violently apart, causing the boot surface to jump and repel the ice. Slits in the deicer boot allow the conductors to flex during current flow.

The amount of force generated to expel the ice is a function of the size and spacing of the conductors, according to Mr. Haslim, Program Manager for the Advanced Plans and Programs Office at NASA's Ames Research Center. With ribbon conductors one inch wide and one-tenth millimeters apart, each pulse of 1,000 amperes will produce a force equal to 2,240 pounds per lineal foot. "That's like using a sledgehammer to pound ice off the airframe," said Haslim, "but without the resultant physical deformation."

The idea for the expulsion system emerged from experiments Haslim performed in the mid-1970's in which he accelerated protons using a high voltage and strong current. "It dawned on me that I could store a great deal of current in a capacitor and cause it to pulse at very high rates," the 59-year-old inventor said. "By combining this concept with the principle of electrical repulsion, I realized I could create a powerful device that would expel ice without using a lot of current."

The Ames inventor developed a desktop model in 1982, enlisting Robert Lee, a retired electronics engineer, to design the power supply. Mr. Lee was later designated co-inventor. "At first, Lee was convinced the system wouldn't work," said Haslim. "But then he turned it on and shot his tester to the ceiling. That changed his mind."

Haslim persuaded the BF Goodrich Company to fund and develop a prototype of the deicer boot, which recently completed flight testing on a Twin Otter at NASA's Lewis Research Center. "The test results were impressive," said Nathan Pisarki, Project Engineer for BF Goodrich. "The boot removed ice three-eighths of an inch thick at airspeeds up to 120 knots."

The deicing system will next be tested on the engine inlet of an F/A-18 fighter attack

(continued on page 69)

The Problem Solver

Leonard Haslim's career as an inventor began with a challenge from a college professor. "I was taking an undergraduate engineering design course at San Diego State (University) taught by an instructor who was very glib and sure of his ideas," recalled the soft-spoken engineer. "One day he was going on and on about how the chopstick was an example of a design that had withstood the test of time and couldn't possibly be improved upon. Well, I've always resented being told something can't be done, so I stood up in the middle of class and told him I could improve apon the design. He then bet me I couldn't come up with a design by the next week's class."

Haslim returned the following week carrying a bowl of wonton soup and a pair of custom-designed chopsticks. "I went to the front of the class and began eating the wontons with my chopsticks. When only soup was left, I took out two straws and inserted them lengthwise through each of the chopsticks, which I had hollowed out with a drill. I then proceeded to drink the soup through the chopsticks. It was the first time I'd ever seen that instructor speechless."

Haslim's next invention should have made him famous, but fate would have it otherwise. While working as a gas station attendant in 1945, Haslim devised a ladder-like device for gas pump handles that would allow attendants to go wash a window while filling a gas tank. "I outfitted the station's pumps and soon other stations were having

(continued on page 69)

Leonard Haslim shows off the Inventor of the Year Award he won for his Electro-Expulsive Separation System.

Synchronous Photodiode-Signal Sampler

Synchronous switching provides background subtraction.

NASA's Jet Propulsion Laboratory, Pasadena, California

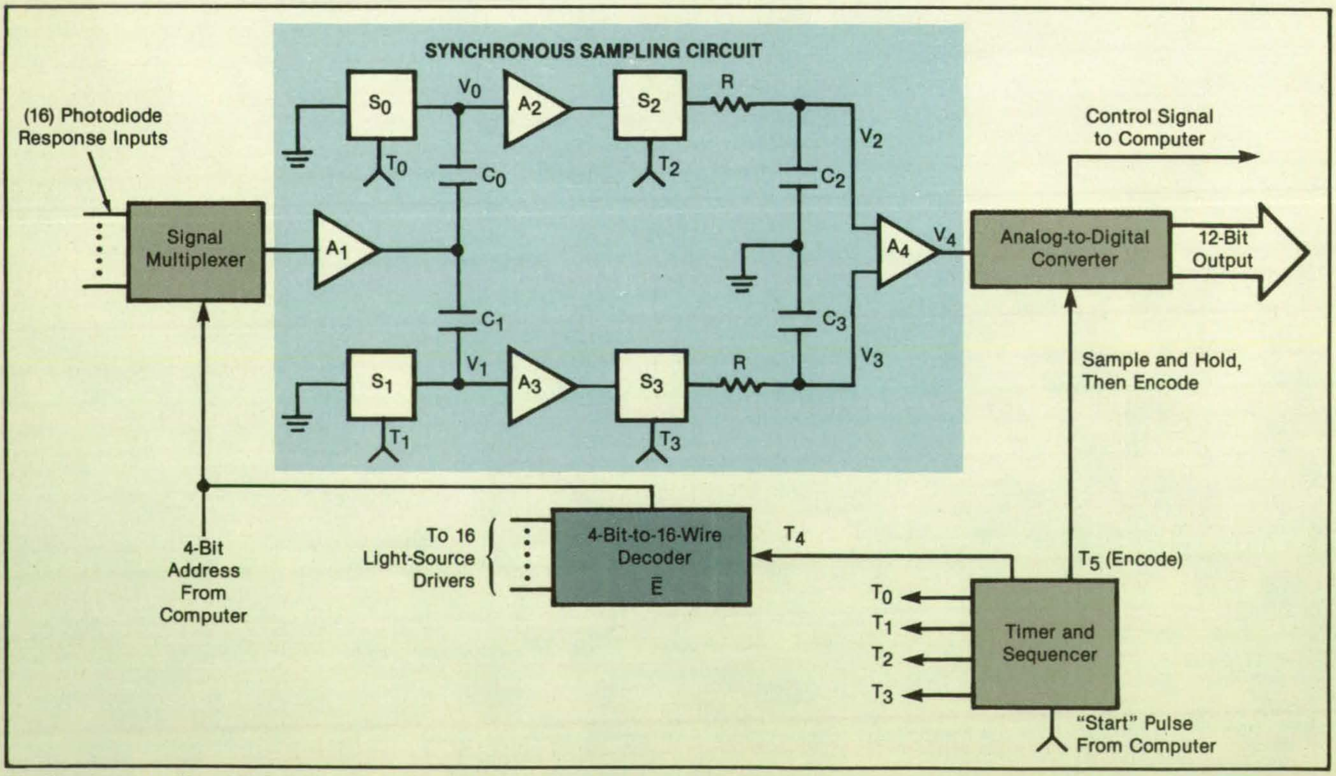
A synchronous sampling circuit increases the signal-to-noise ratio of measurements of a chopped signal of known phase and frequency in the presence of low-frequency or dc background noise. The circuit (see figure) has been used with a linear array of photoelectric sensors for locating the edge of a metal plate. In this application, a multiplexing circuit cycles through 16 light-emitting-diode/photodiode pairs, under computer control. The sampling circuit is synchronized with the multiplexer, so that the edge detector makes one background-subtracted signal measurement per emitter/detector pair in turn. (Of course, the synchronous sampling circuit could also be used for repeated measurements of one signal.)

The chopped signal from each light-emitting diode, which is switched on and off by waveform T_4, is detected by the corresponding photodiode. Amplifier A_1 feeds this chopped signal to coupling capacitors C_0 and C_1, which remove the dc and low-frequency signals generated by ambient light. During the portion of the cycle when the light-emitting diode is off, switches S_0 and S_1 are closed, thereby grounding the inputs of amplifiers A_2 and A_3 and preventing signal transmission. S_0 is opened just before the light-emitting diode comes on, and S_2 is opened shortly thereafter, so that the amplified photodiode response is passed to the integrating circuit of R and C_2.

When the light-emitting diode is turned off, S_0 is again closed to ground the input of A_2, while S_2 is opened to allow signal transmission to A_3. Shortly after this, S_3 is closed to pass the photodiode output to the integrator formed by R and C_3. Integrator voltage V_2 thus includes the background plus light-emitting-diode signal components, while integrator voltage V_3 includes the background component only.

V_2 and V_3 are fed to differential amplifier A_4, which subtracts one from the other. Therefore V_4, the output of A_4, is proportional to the signal voltage from the light-emitting diode. An analog-to-digital converter reads this signal voltage once during each cycle, after V_2 and V_3 have been acquired.

In addition to suppressing the re-



The **Synchronous Signal Detector** is controlled by timing signals T_0 through T_3. The light-emitting diodes producing the signals to be measured are controlled by timing signal T_4. In the application shown, a 4-bit address supplied by a computer determines which one of 16 light-source/photodiode-detector pairs is to be used at any given moment.

sponse to steady and slowly-fluctuating ambient light, this synchronous sampling circuit removes background noise outside the frequency pass band determined by the sampling pulse width. This feature is particularly desirable when it is necessary to detect the signal in the presence of such interference as fluorescent lamps or flashing light from a nearby welding arc.

This work was done by Howard K. Primus of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 8 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-16698, volume and number of this NASA Tech Briefs *and the page number.*

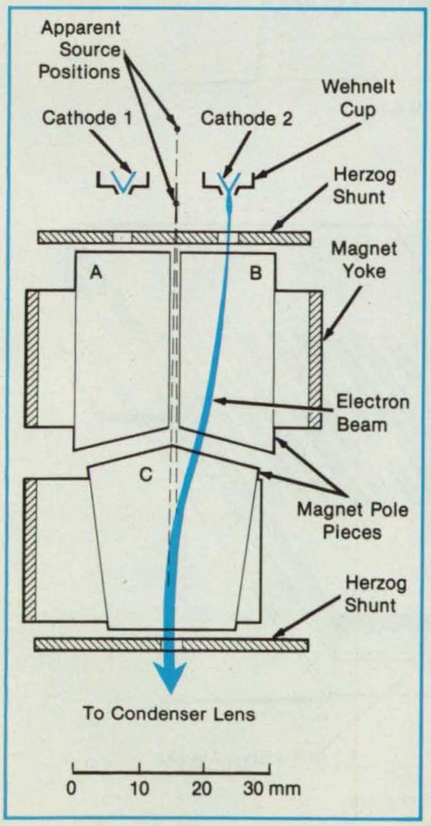
Dual-Cathode Electron-Beam Source

The beam from either cathode is electromagnetically aligned with an exit port.

NASA's Jet Propulsion Laboratory, Pasadena, California

An electron-beam source contains two cathodes for reliability. If one cathode fails, the other can be turned on. The source is intended for applications where uninterrupted service is needed; for example, in scanning electron microscopes, transmission electron microscopes, electron-beam lithography equipment, Auger instruments, and microfocused x-ray sources.

The designers of the electron-beam source considered the use of a shuttle or carousel that would move a replacement cathode into position on the electron-beam axis. However, they rejected the scheme because it would be heavy, expensive, and possibly unreliable. Instead, they chose to



An **Electron Beam From Either of Two Cathodes** is deflected by magnetic and electric fields to a central axis. Mechanical alignment of the beam is easy because the cathode axes, the anode apertures, and the electron trajectories are coplanar.

use two fixed cathodes side by side and to deflect the beam from either to a common electron-optical axis. Three electromagnets with electrically-isolated pole pieces deflect the beams.

The cathodes are located 8 mm on either side of the electron-optical axis (see figure). Their tips are 5 mm from the top of the magnet assembly, which is the anode. To use the electron beam from cathode 2, for example, magnets B and C are turned on with opposite polarities, and the currents in the magnet coil windings are adjusted until the beam follows a sigmoid path that brings it into coincidence with the axis.

The radius of curvature of the trajectory is 107.75 mm, and each deflection angle is 15.19°. The magnetic field needed to deflect the electrons, which have −15 keV energy, is small — only 3.8×10^{-3} T. The magnet yokes can therefore be made thin and light.

The beam position is coarsely adjusted by rotating and translating the cathode assembly. A sliding seal between the movable assembly and the housing preserves the vacuum in the electon-beam chamber.

Herzog shunts and gaps at the entrance and exit of each magnet control the boundaries of the magnetic fields. The controlled boundaries ensure that the beam trajectory is symmetrical about its inflection point. Once the mechanical coarse adjustment has been done, the symmetry eliminates gross errors in the beam position at the exit of the assembly that might result from small changes in the cathode voltage.

Usually, the magnetic fields alone are not enough to bring the beam into exact coincidence with the optical axis, and electrical potentials of up to ±150 V are therefore applied to the electrically insulated pole pieces of the electromagnets to deflect the electrons to precise coincidence with the optical axis. The magnetic and electrostatic deflections are in mutually perpendicular directions, and both are perpendicular to the electron beam. The use of both magnetic and electric fields in the same region yields a highly compact unit.

If cathode 2 should fail, power can be applied to cathode 1 to continue the supply of electrons. The coarse adjustment for cathode 2 has already put cathode 1 in nearly the proper position; it is necessary only to perform the fine adjustment with the magnetic and electric fields.

This work was done by James G. Bradley and Joseph M. Conley of Caltech and David B. Wittry of the University of Southern California for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 32 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 14]. Refer to NPO-16878.

Diffraction-Coupled, Phase-Locked Semiconductor Laser Array

A stable, narrow far field is produced.

NASA's Jet Propulsion Laboratory, Pasadena, California

A monolithic array of AlGaAs/GaAs semiconductor injection lasers emits a far-field beam much narrower than that of a single laser of the same type. Such as array would be useful where relatively high power and a stable radiation pattern are required. Applications may include recording, printing, and range finding.

The lasers are fabricated together on one substrate but are isolated from each other along the middle portions of their waveguide lengths (see Figure 1). They interact with each other only by diffraction in the end portions near the laser mirrors: Light in any one of the waveguide sections is reflected back and forth in that section, but part of the light is also reflected and diffracted into the other waveguide sections. This diffraction coupling is sufficient to produce phase locking. Phase locking is evident not only by the narrowing of the output beam but also by the fact that the coupled lasers produce identical spectra.

The shape of the radiation field far from the array is determined by the phase of each individual laser field and of the field coupled to each laser from its neighbors. When all of the lasers operate at the same phase, the resulting far-field pattern has a single sharp lobe (see Figure 2). Multiple sharp lobes and broadening of the beam occur when one or more of the lasers differ in phase from the others. In either case, the radiation pattern changes little as the output power is increased.

Because of nonuniformities introduced by the fabrication process, the output beam is wider than it would be if all lasers were identical and operating in a single mode. Electrical current is fed to all lasers in parallel, but not all lasers operate at the

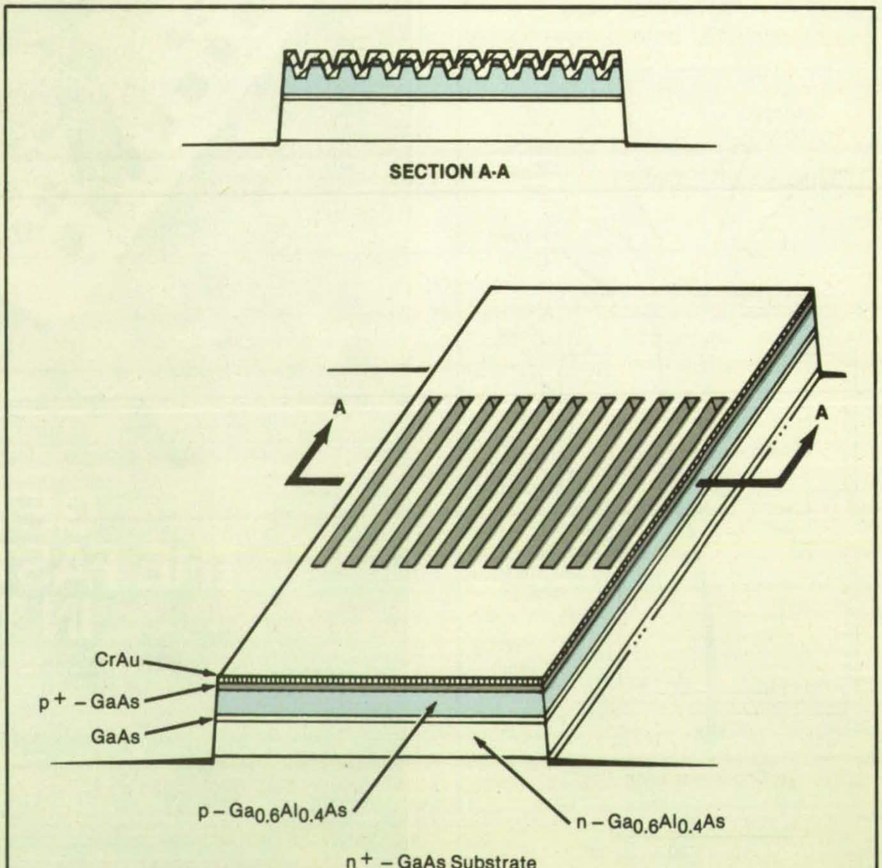


Figure 1. An **Array of Lasers** is fabricated on a single chip. The individual laser waveguides are isolated from each other except in the end portions, where diffraction coupling takes place.

same level above the threshold current. Array threshold currents are as low as 250 mA, with a typical value of 400 mA. This corresponds to threshold current densities between 1 and 1.5 kA/cm^2.

The differential quantum efficiency of the array is 40 percent. The light output varies linearly with current above the threshold current. A peak output of 1.1 W was obtained under pulsed, low-duty-cycle conditions.

This work was done by Joseph Katz, Amnon Yariv, and Shlomo Margalit of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 137 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 the California Institute of Technology. Inquiries concerning licenses for its commercial development should be addressed to

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Refer to NPO-16198, volume and number of this NASA Tech Briefs *issue, and the page number.*

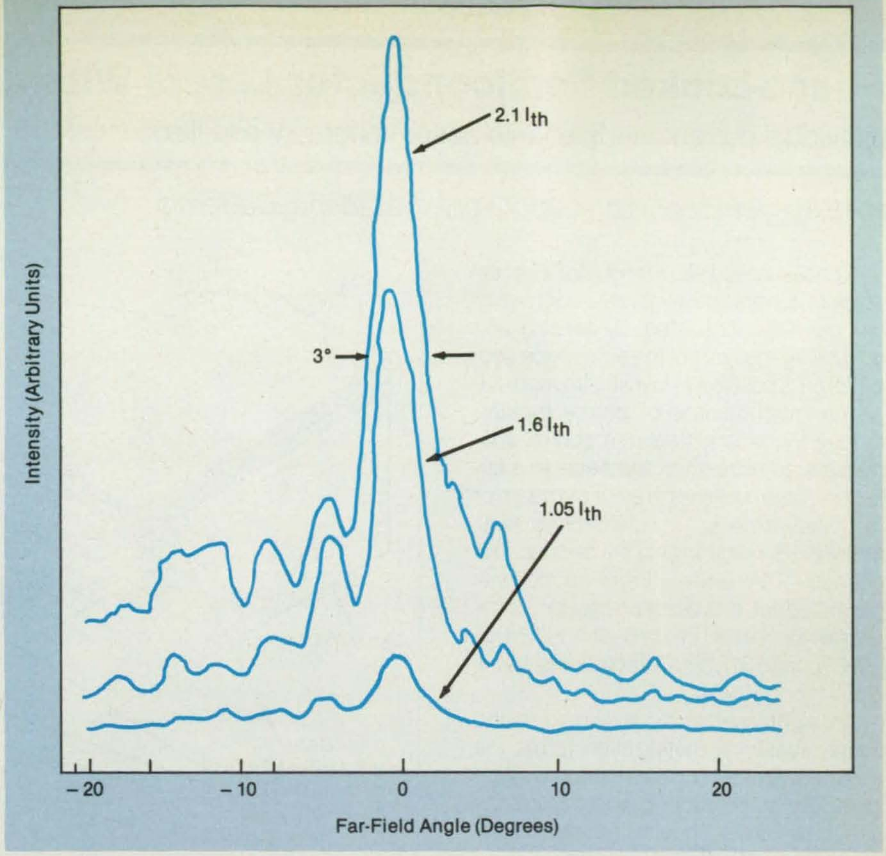


Figure 2. The **Radiation Pattern** far from the laser array has a single, sharp central lobe when all the lasers operate in phase with each other. The shape of the lobe does not vary appreciably with the array current. (The array current is indicated here in units of I_{th}, the threshold array current.)

Phase-Locked Semiconductor Lasers With Separate Contacts

Individual current feeds enable better uniformity and flexible control.

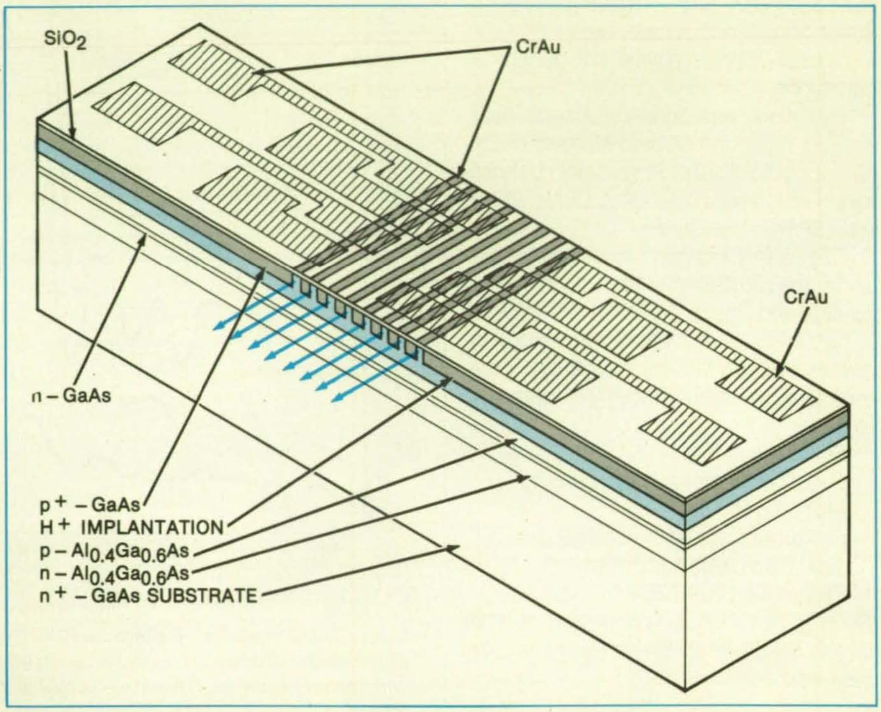
NASA's Jet Propulsion Laboratory, Pasadena, California

A phase-locked semiconductor laser array with a separate contact to each laser has been demonstrated. By feeding and controlling the current to each device separately, it is possible to investigate more fully the mechanisms of phase locking among the lasers. Separate control enables the adjustment of the near- and far-field radiation patterns to steer the beam or to compensate for nonuniformities (e.g., threshold current) among the devices. The concept of separate current control was described for a two-laser array in "Semiconductor Laser Phased Array" (NPO-15963), page 317, *NASA Tech Briefs*, Vol. 8, No. 3 (Spring 1984).

An eight-laser array is shown in the figure. Two-level metalization forms the separate contact for each stripe-contact laser. The stripe width is about 5 μm; the center-to-center spacing between adjacent layers is 9 μm.

Fabrication begins with the liquid-phase epitaxial growth of the n^+-GaAs substrate. The subsequent layers are then grown in the ascending order shown in the figure. A layer of CrAu contact stripes is then deposited. The spaces between the stripes are formed by proton bombardment or chemical etching. Next, a layer of SiO_2 is evaporated on, and contact holes are etched through it. The second layer of CrAu is then applied, and the contact pattern is defined by etching.

The typical threshold current of an individual laser is 50 mA. When only one laser in the array is operating, the far-field beam width is about 8°. With four lasers operating, the beam width is reduced to about 2°. The extent of controllability was demonstrated in an experiment in which adjacent lasers were made to operate at a phase difference of π rad, resulting in a far field with two main lobes 7° apart.



Separate Contacts for the lasers in the array enable the control of the output radiation pattern and the compensation of manufacturing nonuniformities among the lasers.

This work was done by Joseph Katz, Amnon Yariv, and Shlomo Margalit of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 153 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 the California Institute of Technology. Inquiries concerning licenses for its commercial development should be addressed to

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Refer to NPO-16254, volume and number of this NASA Tech Briefs *issue, and the page number.*

Matching Network for Microwave Preamplifier

Stable operation and broadband, optimum noise performance are achieved.

NASA's Jet Propulsion Laboratory, Pasadena, California

A 2,385-MHz amplifier stage has a gain of 16.5 dB and a noise figure of 16.5 dB. The amplifier is designed by a new method of matching the input impedance for an optimum noise figure and stability. The amplifier output is more nearly constant over a wider frequency range than that of prior, more complicated circuits.

The main task in the design is to minimize the portion of the output thermal noise that arises in the signal-source impedance. This is done by deliberately mismatching the input network in such a way as to minimize the transfer of noise power at the input and output ports.

The mismatch diminishes the gain and may cause instability. To compromise between the gain and the noise figure, constant-noise and constant-gain circles for the circuit are plotted on a Smith chart, and the source impedance that satisfies the noise and gain requirements is picked.

Practical results show that a single-line input-matching network is the best type for achieving an optimum noise figure and unconditional stability. This type of network features a low ratio of reactance to resistance (Q), with consequent broadband operation and relative insensitivity of tuning. In the prototype of the 2,385-MHz amplifier stage, the input-matching network is a suspended-ribbon transmission line extending from the input port and is easily tuned in a few minutes by welding gold-ribbon extensions in place until the optimum match is achieved.

It was found experimentally and analytically that the amplifier stage can be stabilized unconditionally by placing a 10-Ω re-

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DEC

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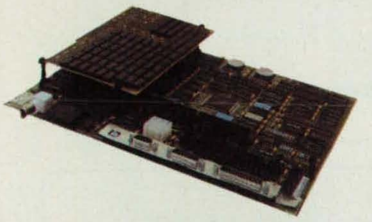

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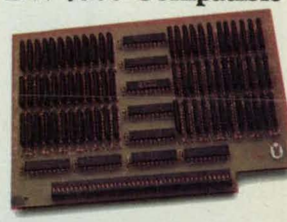

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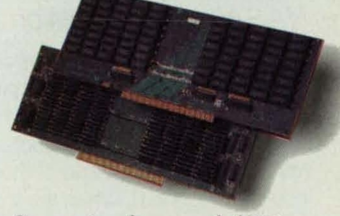

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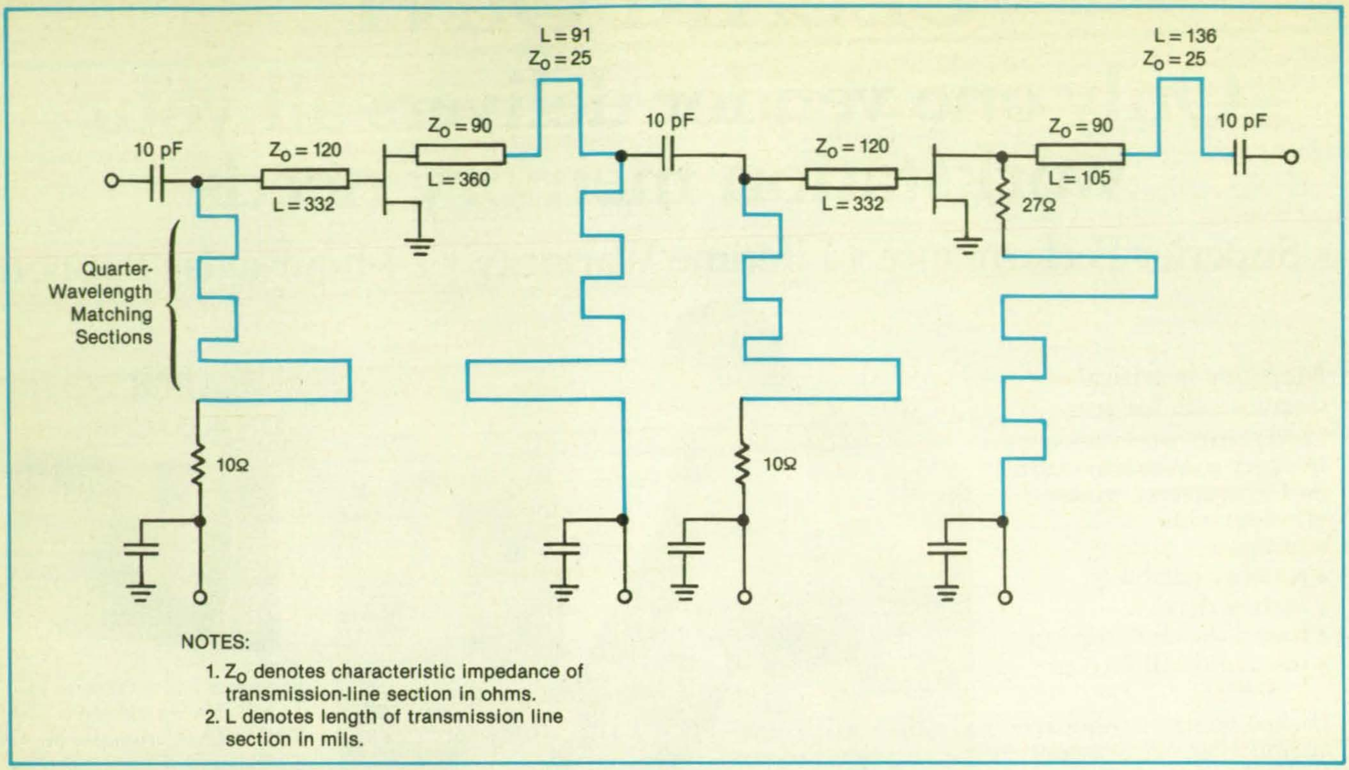


A **Two-Stage Microwave Amplifier** is designed according to input-matching principles that assure low noise, stability, and operation over a wide frequency range.

sistor at the input and either an isolator at the input or else a 27-Ω shunt resistor at the output. In a two-stage version (see figure) comprising stages designed according to these principles, unconditional stability is achieved by placing a shunt resistor at the output of the second stage and an isolator at the input of the first stage. The two-stage amplifier has a gain of 29 dB and a noise figure of 0.95 dB.

This work was done by Jack D. Sifri of Hughes Aircraft Co. for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 77 on the TSP Request Card. NPO-16851*

Searching Circuit for a Servoloop

The feedback error voltage is forced into the range of stability.

NASA's Jet Propulsion Laboratory, Pasadena, California

A searching circuit restores stability in a servofeedback control loop that slips into an unstable voltage range in which it cannot lock. The circuit is connected in series with the error-voltage line of the feedback loop (see Figure 1). When the loop is operating normally in the stable region, the searching circuit does not disturb its operation, and the error-voltage output of the loop filter is the control voltage. However, when the servo unlocks and the error-voltage output of the loop filter wanders into an unstable range, the searching circuit forces the control voltage to sweep through the stable region repeatedly until lock is recovered.

The searching circuit (see Figure 2) consists of two halves that are identical except that the polarities of some parts in each half are the opposites of those of the corresponding parts in the other half. If the searching circuit is in the idle state, then $V_1 = -V_L$ and $V_3 = +V_L$. If the input voltage V_e varies but remains within the stable region, $-V_L \leqslant V_e \leqslant +V_L$, then the searching circuit remains in the idle state, without pulling V_o up or down from V_e.

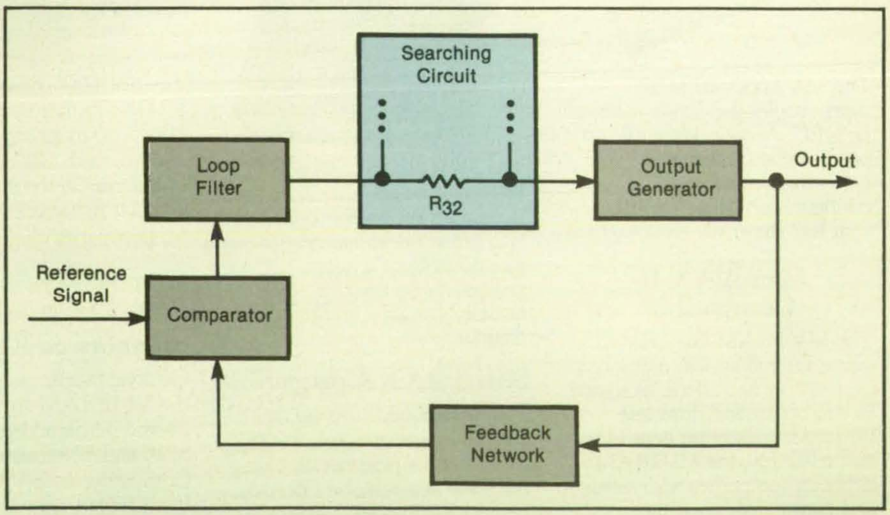


Figure 1. As **Part of the Feedback Loop**, the searching circuit plays no role during normal operation, other than to insert a nominal series resistance. When the loop wanders from the stable operating region, the searching circuit sweeps the control voltage through the stable region repeatedly until stable operation (lock) is regained.

Suppose that output voltage V_o falls below limiting voltage $-V_L$. Then the output V_{o1} of U_1 goes toward positive saturation and drives V_2 and V_{o2} positive with a time constant $T_1 = R_2 C_2$. As V_{o2} rises, D_5 begins to conduct and causes V_o to follow V_{o2} upward in search of the lockup voltage.

If the servoloop (which has a time con-

stant $T_L < T_1$) comes close to lockup during the search, then it causes V_o to rise faster than does V_{o2}, and D_5 turns off. Shortly thereafter, V_o becomes more positive than V_1, causing the output of U_1 to ramp negative. This causes V_2 and V_{o2} to go negative with a time constant $T_2 = (R_2 \| R_1) C_2$. Meanwhile, the charge on C_1 holds V_1 more negative than V_o to keep U_1 in negative saturation. Eventually, V_{o2} reaches negative saturation and holds V_1 at $-V_L$ to return the circuit to the idle condition.

If the servoloop does not lock up during the search, then V_{o2} continues pulling up V_1 until D_4 goes into Zener breakdown at a V_1 slightly less than $+V_L$. When V_o rises above this value, the input polarity of U_1 reverses and V_{o1} goes negative, causing V_2 and V_{o2} to return toward the idle state with time constant T_2. If $V_o < -V_L$ when the circuit reaches the idle state, the circuit begins a new search cycle.

The circuit behaves similarly, but with opposite polarity, when V_o exceeds $+V_L$. In that case, U_1 and U_2 remain idle, and U_3 and U_4 are activated to sweep V_o downward from $+V_L$ toward $-V_L$.

This work was done by E. H. Sigman of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 89 on the TSP Request Card. NPO-17003*

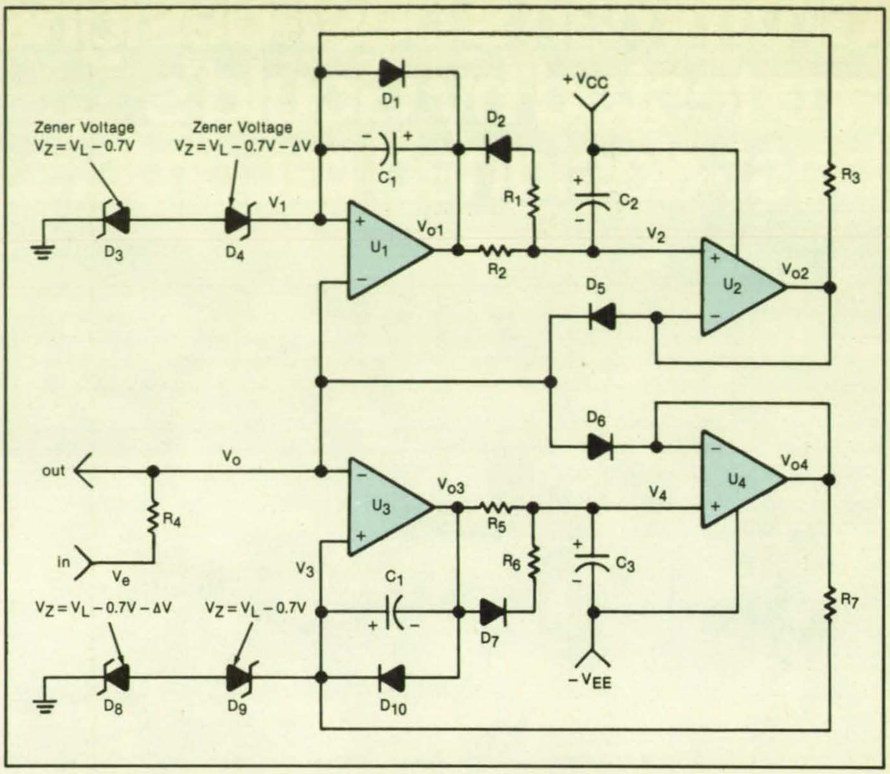


Figure 2. The **Searching Circuit** contains sawtooth-waveform generators that become activated when V_o rises above $+V_L$ or falls below $-V_L$. The waveform time constants are determined by resistors R_3, R_2, and R_1 and capacitors C_1 and C_2.

Video Analog Signal Divider

This inexpensive device also produces thermal images in conjunction with standard color camera systems.

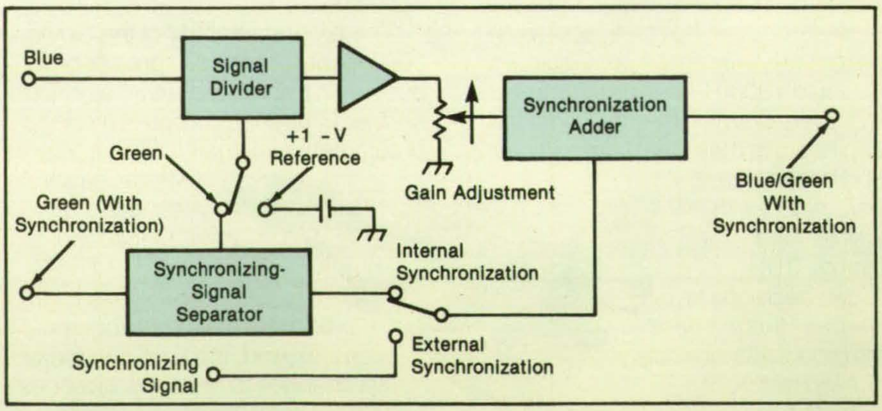
Langley Research Center, Hampton, Virginia

A system known as a video analog signal divider produces a video image based on the color ratio, as distinguished from the usual object brightness or color-component brightness that the typical video signal represents. This device is particularly useful in thermal mapping because the color distribution of certain phosphors is independently a function of temperature. Analog video circuitry is used to provide an inexpensive real-time image-processing technique.

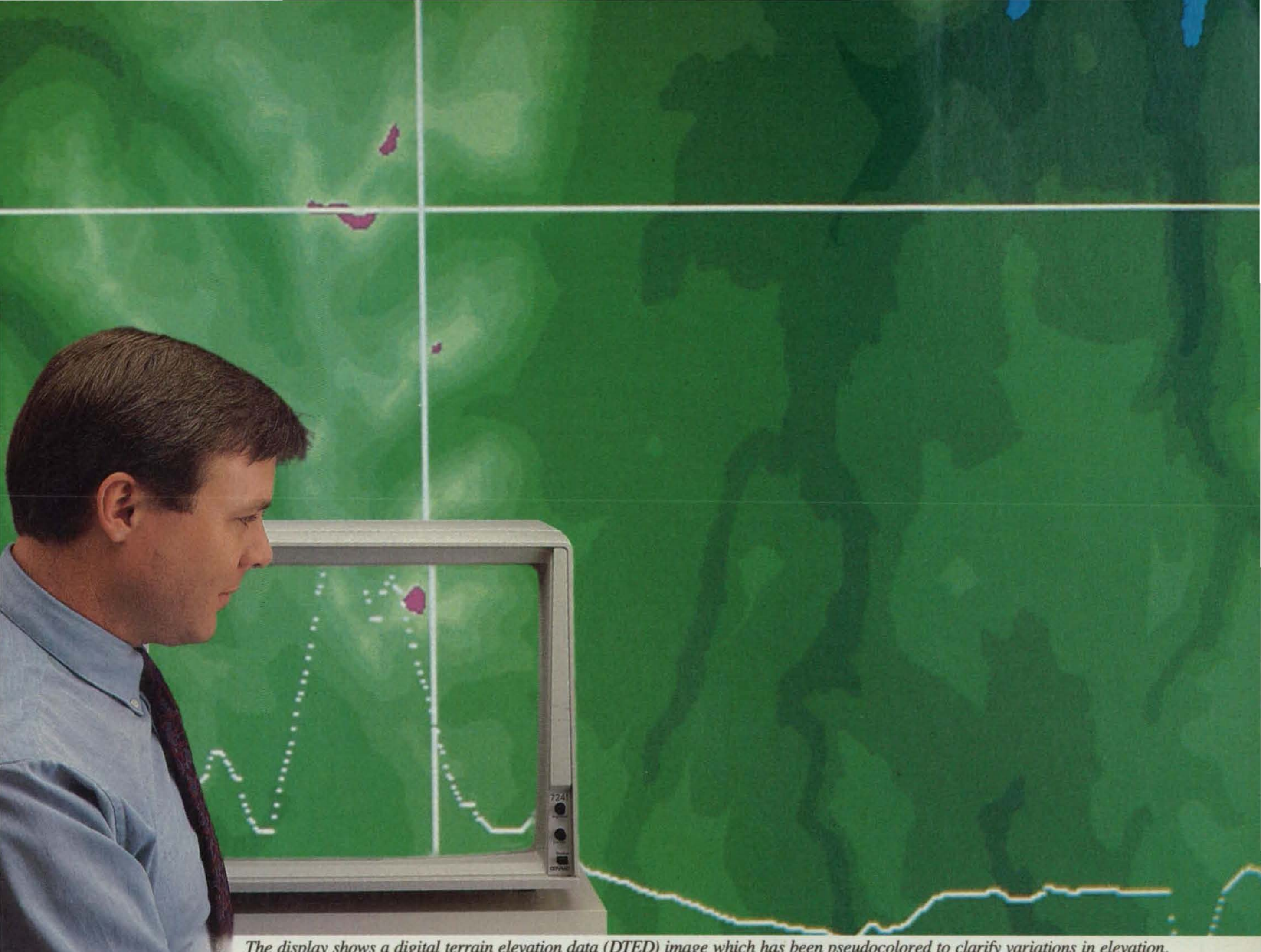
The video analog signal divider works with a standard three-tube color camera with red/green/blue output. Because the synchronization signal in a standard camera system can be either separate or combined with the green signal, the circuit includes a toggle switch to accommodate these two alternatives. The configuration shown in the figure, with its blue and green inputs, represents an application for thermal imaging in which a blue/green thermographic phosphor is used. A toggle switch to a 1-volt divisor and an external gain adjustment are included in the circuit for calibration purposes. The heart of the signal divider is an integrated circuit functioning as a wideband linear divider with a signal bandwidth of 60 MHz.

This work was done by Gregory M. Buck of **Langley Research Center**. *No further documentation is available.*

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-13740.



The **Video Analog Signal Divider** produces a black-and-white composite video signal based on the color ratio. The device is inexpensive, uses the signal from a standard red/green/blue camera as input, and can be used to produce quantitative thermal images of two-color phosphor coatings.



The display shows a digital terrain elevation data (DTED) image which has been pseudocolored to clarify variations in elevation.

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.

Time-Zone-Pattern Satellite Broadcasting Antenna

Phase and amplitude constraints are applied at overlapping feeds to minimize power losses.

Direct-broadcast satellite antenna designs that provide contoured beams to match the four time zones in the 48 contiguous states and spot beams for Alaska, Hawaii, and Puerto Rico are presented in a 29-page report. The antennas would be used on two separate satellites transmitting at about 12.5 GHz, one located at 101° W. longitude, covering Puerto Rico and the Eastern and Central time zones, the other at 157° W., covering the Mountain and Pacific time zones, Alaska, and Hawaii.

The report includes descriptions of the procedures used to arrive at the optimized designs. The arrangements, amplitudes, and phases of the antenna feeds are presented in tables. Gain contours are shown graphically. Additional tables of performance data are given for cities in the service area of the Eastern satellite.

The contoured beams are produced by a planar array of feeds radiating toward an off-axis parabolic reflector. The beam pattern for each time zone is optimized by selecting the position, phase, and amplitude of each of the feeds radiating the signal for that time zone.

Most of the feeds serve only one of the two time-zone beams, but the feeds along the boundary between the beams serve both beams. To minimize the power losses at the boundaries between adjacent beams, the amplitudes of all the shared feeds within each beam are made equal, and the phase of each shared feed is constrained to be the same in both beams it serves. In the designs presented, there are four such constrained feeds in the Eastern/Central beam and five in the Mountain/Pacific beam. The total numbers of feeds used in the Eastern, Central, Mountain, and Pacific beams are 17, 16, 19, and 14, respectively.

The constrained design results in an average power loss of about 0.5 dB in the isolation network required to drive the shared feeds with the separate signals for the two beams. In contrast, the isolation methods used in previous designs incurred losses of about 3 dB. These losses result in similar signal-strength reductions along the boundary between the two time zones on the ground.

This work was done by Victor Galindo, Yahya Rahmat-Samii, and William A. Imbriale of Caltech for **NASA's Jet Propulsion Laboratory** *and Herb Cohen and Ronald R. Cagnon of TRW, Inc. To obtain a copy of the report, "Constrained Overlapping Feed Arrays for Contiguous Contour Beam Reflector Antennas," Circle 59 on the TSP Request Card.*
NPO-16522

Tests of Amorphous-Silicon Photovoltaic Modules

Progress in identification of strengths and weaknesses of amorphous-silicon technology is detailed.

A report describes recent achievements in testing the reliability of solar-power modules made of amorphous-silicon photovoltaic cells. The paper is based on an investigation of modules made by U.S. manufacturers. Modules were subjected to field tests, to accelerated-aging tests in the laboratory, and to a standard sequence of qualification tests developed for modules of crystalline-silicon cells.

For the laboratory tests, a large-area pulsed solar simulator was modified by the addition of filters to provide an internationally-recognized standard illuminating intensity and spectrum. The combination of the modified simulator with generic amorphous-silicon reference cells yields measurements repeatable within 1 percent, without detailed characterization of the spectral responses of the amorphous-silicon cells and modules under test.

In general, the modules performed well in the sequence of qualification tests — about as well as crystalline-silicon modules did at a similar early stage of development. Some large modules with 3-mm-thick covers of annealed glass were not as resistant to hail as the qualification test requires. However, modules made with structurally-supported and partially-tempered glass covers proved to meet the requirements.

Most modules exhibited minor deficiencies in endurance with respect to temperature and humidity. Types of degradation included softening and warping of plastic parts, delamination, and loss of power due to increases in series resistance. In hot-spot tests, amorphous-silicon modules behaved much like crystalline-silicon modules and, in some cases, were more tolerant of hotspots.

The field tests showed that certain failure mechanisms are particularly important. These include effects induced by light, corrosion of connections between cells, electrochemical corrosion between cells and module frames, electrical breakdown between cell strings and frames, and thermal diffusion of dopants and other materials into and among the thin-film layers of the cells.

This work was done by Ronald G. Ross, Jr., of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Recent Achievements in Module Reliability Research: Testing of Amorphous Silicon Modules," Circle 7 on the TSP Request Card.*
NPO-17303

Corrosion in Amorphous-Silicon Solar Cells and Modules

Moisture severely affects amorphous-silicon units, but encapsulation helps.

A paper reports on corrosion in amorphous-silicon solar cells and modules. The paper, based on field and laboratory tests, discusses the causes of the corrosion, ways of mitigating the effects, and consequences for modules already in the field.

In general, modules exposed to a natural outdoor environment corroded more than modules exposed to uniform temperatures and humidities in the laboratory. The outdoor environment is apparently more severe, involving direct contact with water in the form of dew, rain, and snow. Moreover, natural cycles of temperature and humidity induce damaging stresses in cells and modules. To make matters worse, the concentration of moisture in a module tends to increase during long exposures outdoors because modules tend to retain sorbed moisture.

Laboratory tests at 85 °C and 85 and 100 percent relative humidity showed that encapsulation of a cell retards the gross loss of metalization in the active region of the cell. However, when the metal is resistant to corrosion, the encapsulation does not seem to retard the increase in the sheet resistivity of a cell.

The paper suggests the sealing of the edges as a way of reducing the entry of moisture. Cell-free perimeters or sacrificial electrodes are suggested to mitigate the effects of sorbed moisture. The development of a truly watertight module may prove to be more cost-effective than attempting to mitigate the effects of moisture.

This work was done by Gordon R. Mon, Liang-Chi Wen, and Ronald G. Ross, Jr., of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the paper, "Corrosion of Amorphous Silicon Cells and Modules," Circle 33 on the TSP Request Card.* *NPO-17302*

Preventing Arc Welding From Damaging Electronics

Appropriate shielding, grounding, and cable routing protect delicate parts.

Lewis Research Center, Cleveland, Ohio

A shielding technique has been developed to protect sensitive electronic equipment from damage due to electromagnetic disturbances produced by arc welding. Certain applications may require the welding of tubing or other structural components in the presence of electronic equipment that cannot be removed without considerable difficulty and cost. For example, because of new developments in the Centaur hydrazine-propellant-feed system, an all-welded tubing system is now utilized. However, it is necessary to repair or replace portions of this system after avionics are installed. The removal or disconnection of the avionics prior to welding results in a break of inspection requiring reverification after the weld. It was necessary to develop a technique for welding with the avionics in place, without the risk of damage or the necessity for reverification, to avoid delays in launching.

The basic piece of equipment used to weld the tubing is an orbital arc welder. This unit radiates electromagnetic interference (EMI) in excess of MIL-STD 461A. Work was initiated to measure the welder EMI, then to develop shielding methods to enable the welder to operate in compliance with MIL-STD 461A.

Many shielding, grounding, and cable-routing schemes were tested to arrive at a configuration that was repeatable and verifiable. This investigation established an acceptable alternative in those instances in which the electronic equipment cannot be removed prior to arc welding. Guidelines were also established for open, unshielded welds. This procedure may be applicable to robotics or computer-aided manufacturing.

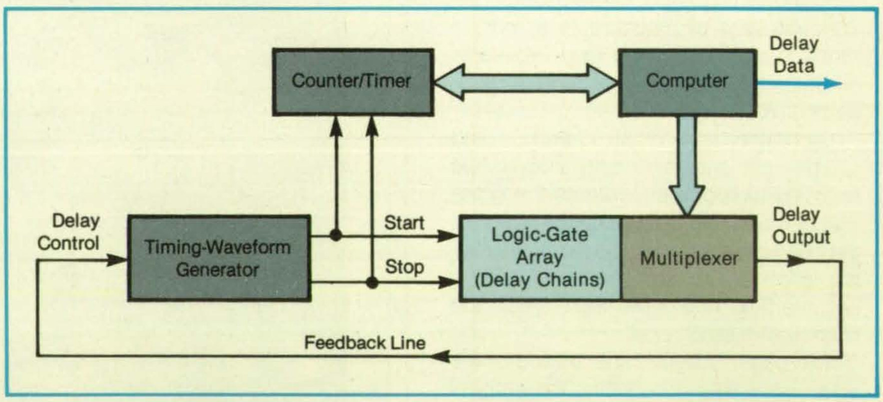
This work was done by Noel Sargent of **Lewis Research Center** *and D. Mareen of General Dynamics Corp. No further documentation is available.*
LEW-14480

System Measures Logic-Gate Delays

Many gates on a chip are tested automatically.

NASA's Jet Propulsion Laboratory, Pasadena, California

An automatic testing system measures the signal-propagation delays of an experimental integrated-circuit array of logic gates. The system (see figure) includes a controlling computer, a counter/timer, and a feedback-controlled timing-waveform generator. In addition, a multiplexer is included on the integrated-circuit chip with the logic-gate array to be tested. The delays measured by the system serve as valuable data for the design of fast logic and memory chips.



The **Timing System** includes a timing sampler fabricated as part of the integrated circuit to be tested. The timing-waveform generator puts out "start" and "stop" pulses, the interval between which is adjusted until it equals the signal-propagation delay to be measured. The counter/timer then measures the interval.

The integrated circuit is described more fully in the following article. The logic-gate array includes 128 delay chains. Eight of the chains are metal traces. Each of the other 120 chains consists of a series of 40 identical inverters. The inverter chains differ from each other in transistor geometries and inverter loadings. The delays of the metal traces are taken to be the minimum parasitic delays; these must be subtracted from the overall measured chain delays to obtain the portions due to the inverter gates alone.

The input ends of all the delay chains are connected to a common input "start" line. The output end of each chain is connected to one of the two inputs of a bistable circuit called a "C-element". The other input of each C-element is connected to a common input "stop" line. The timing-waveform generator feeds "start" pulses to the "start" line and "stop" pulses to the "stop" line.

The output signal for the C-element depends on which signal arrives first, the "start" pulse propagated through the delay chain or the "stop" pulse coming directly from the timing-waveform generator. If the delayed "start" signal arrives first, then the overall measured chain delay is less than the interval between the "start" and "stop" pulses; if the "stop" signal arrives first, then the measured delay is more than the "start"/"stop" interval.

The computer controls the multiplexer, which selects the chain to be tested by connecting its C-element output terminal to the feedback line. As the chain is tested, the C-element output signal is fed back to the timing-waveform generator as a control signal to increase or decrease the interval if the delay is longer or shorter, respectively. The feedback cycle is repeated until the interval reaches the actual delay and begins to dither about that value.

The computer then commands the counter/timer to measure the interval. The counter/timer operates with pseudorandom time-base modulation and averaging to obtain a resolution of 0.1 ns over 10^5 measurement cycles. From these measurements the computer calculates the average delay of a single gate in each chain as the overall chain delay minus the parasitic delay, divided by the number of gates (40) in the chain.

This work was done by Brent R. Blaes of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 151 on the TSP Request Card.*

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

Edward Ansell,
Director of Patents and Licensing
Mail Stop 301-6
California Institute of Technology
1207 East California Boulevard
Pasadena, CA 91125

Refer to NPO-16646, volume and number of this NASA Tech Briefs *issue, and the page number.*

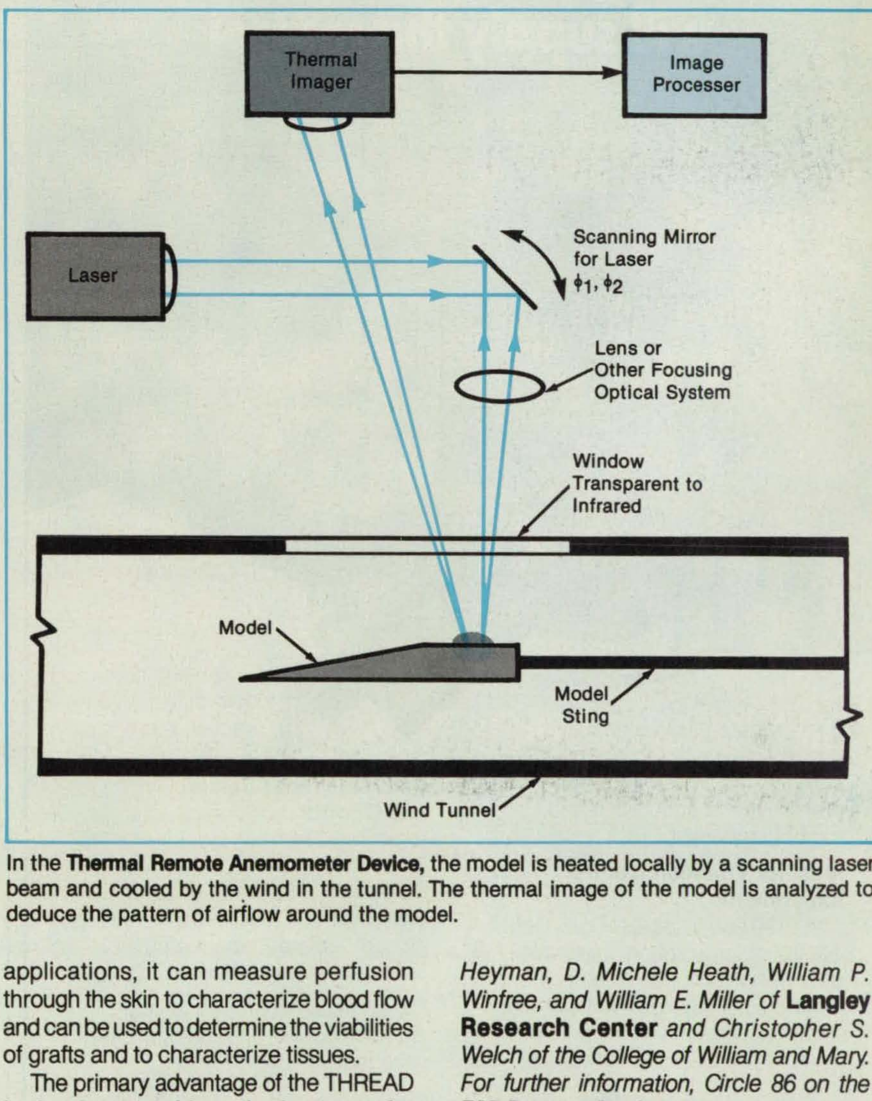
Thermal Remote Anemometer Device

A focused laser and a thermal imager are combined for remote temperature measurement.

Langley Research Center, Hampton, Virginia

The Thermal Remote Anemometer Device (THREAD) was developed for remote, noncontacting, passive measurement of the thermal properties of a sample. (It is passive from the point of view of the sample, in that the sample does not have to provide its own thermal surface radiation to be measured.) The primary use of the THREAD is for the characterization of gas flow over models in wind tunnels. Other applications include measurements for materials characterization.

The components of the THREAD are shown in the figure. The thermal energy input is derived from the laser operated in a pulse mode. The laser beam propagates to the laser scanner, which can scan the beam in two orthogonal angles, ϕ_1 and ϕ_2. The beam is focused to the surface of the sample in the wind tunnel by the lens or other focusing optical system through the infrared-transparent window. The beam impinges on the model, mounted on the wind-tunnel model sting. The thermal energy imparted by the laser beam to the model surface is reradiated to the thermal imager and analyzed by the image processor.



In the **Thermal Remote Anemometer Device,** the model is heated locally by a scanning laser beam and cooled by the wind in the tunnel. The thermal image of the model is analyzed to deduce the pattern of airflow around the model.

The infrared imager measures the radiation from the model surface as a function of time over the entire model. Prior to heating, the background thermal patterns can be examined. Later, the background thermal pattern is deconvolved from the pattern of the heat injected by the laser. After heating, the energy (heat) loss to the surrounding medium can be determined, thus characterizing the nature of the gas flow over the model. This rate increases as gas flow increases and becomes very small if the model is placed in a vacuum. This rate can be determined at various sites on the model to portray the gas flow during the test as an image over the model.

For materials applications, the system can be used for the evaluation of thin films and the determination of thermal diffusivity and adhesive-layer contact. For medical applications, it can measure perfusion through the skin to characterize blood flow and can be used to determine the viabilities of grafts and to characterize tissues.

The primary advantage of the THREAD is that it can achieve the heat-transfer measurements remotely and without contact. The model does not have to be altered with holes, wires, and tubes. The system is fast and can be multiplexed with several sources to increase the speed of data acquisition.

This work was done by Joseph S. Heyman, D. Michele Heath, William P. Winfree, and William E. Miller of **Langley Research Center** *and Christopher S. Welch of the College of William and Mary. For further information, Circle 86 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 14]. Refer to LAR-13508.

Designing Estimator/Predictor Digital Phase-Locked Loops

Signal delays in the equipment are compensated automatically.

NASA's Jet Propulsion Laboratory, Pasadena, California

A new approach to the design of a digital phase-locked loop (DPLL) incorporates concepts from estimation theory and involves the decomposition of the closed-loop transfer function into an estimator and a predictor. The estimator provides recursive estimates of the phase, frequency, and higher order derivatives of phase with respect to time, while the predictor compensates for the delay, called "transport lag," caused by the PLL equipment and by the DPLL computations. The previous approach to design was based on the trial-and-error placement of open-loop poles and zeros under the guidance of experience with similar designs, and did not account for the transport lag. The new approach, using techniques from suboptimal and optimal estimation theory, provides a systematic design procedure.

The basic purpose of a DPLL is to generate a signal, with phase $\bar{\theta}(z)$, that approximates the phase $\theta(z)$ of a received signal. If there were no transport lag, then from the perspective of linear estimation theory, this problem would have a straightforward solution. First, a linear state model for $\theta(z)$ and a corresponding measurement model would be defined. Next, statistical models for state (or process) noise and measurement noise would be developed. Finally, some type of optimal estimator (for example, a recursive least-squares estimator) would be selected.

In the new design procedure, the effect of the transport lag is compensated by a predictor that extrapolates the state estimate by an appropriate time interval. Using the z-transform representation, the closed-loop DPLL transfer function has the form:

$$H(z) = D(z)C(z)z^{-N}$$

where $H(z)$ is the closed-loop DPLL transfer function, $D(z)$ is the predictor transfer function, $C(z)$ is the estimator transfer function, and N is the DPLL transport lag in units of the loop update interval, T.

The figure illustrates the conceptual development of a DPLL that functions as described by the equation. In the third conceptual stage, the estimator/predictor/delay combination is replaced by actual components: a numerically controlled oscillator (NCO) of transfer function $Q(z)$, and a digital filter of transfer function $S(z)$ that satisfies

$$S(z) = [D(z)C(z)/Q(z)]z^{-N}$$

The fourth conceptual stage shown in the figure is based on considerations of practical equipment. Phase-detection functions and the physical execution of the functions of the NCO are performed by custom circuitry, while the summing junction, $S(z)$, and the software functions of the NCO are excuted in a computer. Both the "hardware NCO" and the "software NCO" have identical mathematical representations, as the latter simulates the operation of the former.

The previous design procedure and the new concepts are melded into a new five-step design procedure that resembles the old procedure in parts. The first step is to select a model for the received phase process. This model can include the process dynamics and statistics on process noises and measurements noise.

The second step is to develop the mathematical model of the equipment; that is, of the NCO, transport lag, and phase detector. The transport lag can be incorporated

Klinger positioning systems can travel far, travel fast, and still enjoy a long, stable life.

Suppose you need to measure signals across the surface of a dish antenna? You'll need a system that can move quickly over great distances and make hundreds of stops and starts.

A screw-driven system would require an extremely long precision screw with many threads which is difficult and very expensive to manufacture. The performance of the system would degrade in time due to screw wear and tear caused by the friction induced heating during high speed operation.

KLINGER'S RACK AND PINION SYSTEMS REDUCE WEAR AND TEAR.

The GV88 system is a long travel system which eliminates these problems by utilizing a rack and pinion drive design. It enables the system to travel far and fast, with incredible precision, without wear and tear.

The carriage rides on hardened rails that are ground absolutely straight and smooth. The rack is cut directly into the cross-shaped rail. This eliminates the need to mount a separate rack, and ensures the parallelism between the rack and the ground guide rails, and reduces backlash in the system. A set of preloaded ball bearings, housed within the carriage assembly, completely eliminates play.

The result is accuracy of 50 microns/meter and repeatability of better than 10 microns.

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Our modular carriage design is available in extended lengths to accommodate cantilevered loads. When the center of gravity of the applied load hangs over the rail, the extended carriage allows stress to be removed from the bearings and improves the trajectory quality of the system.

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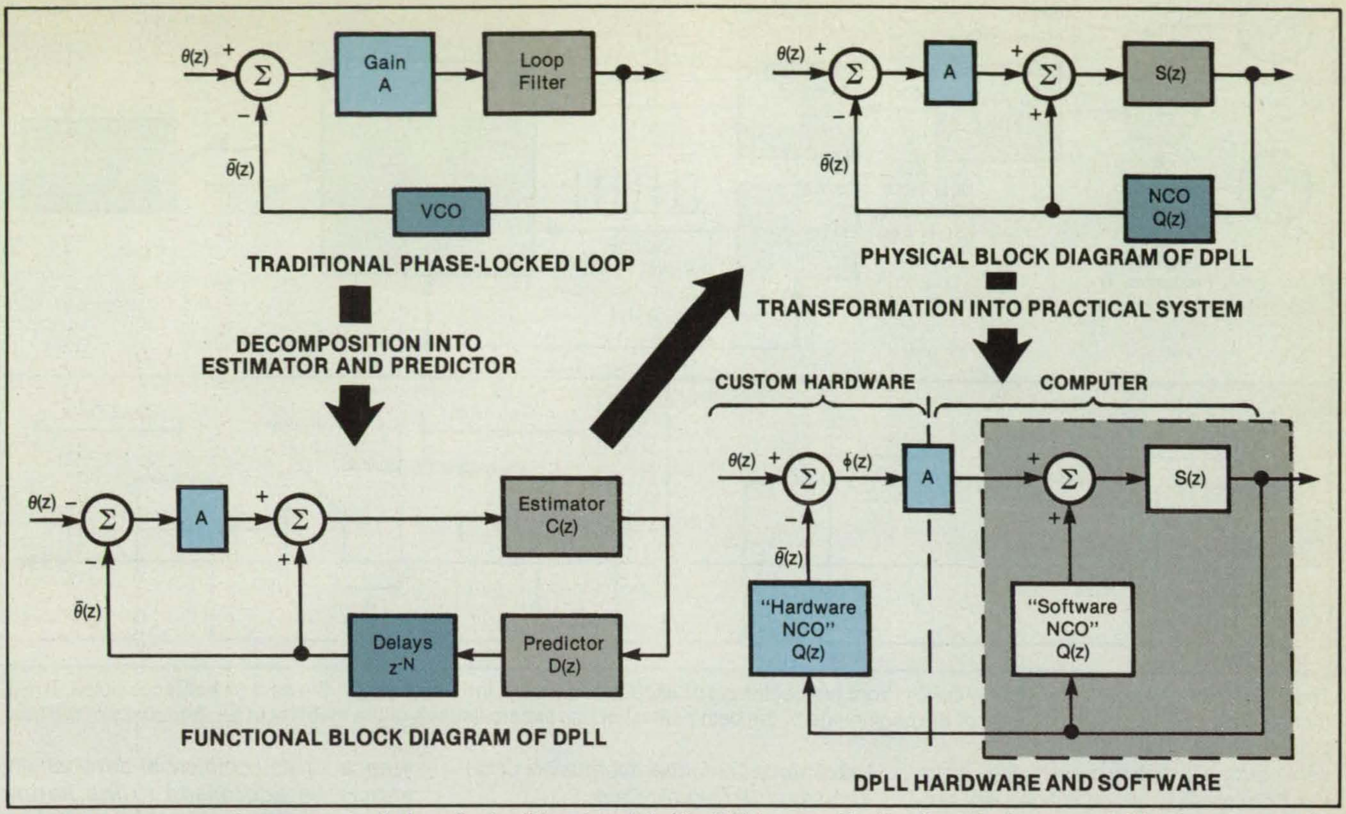


The **DPLL Structure** evolves conceptually from the traditional model of the PLL to a practical hardware/software model that incorporates the estimator and predictor functions.

as part of $Q(z)$.

The third step is the selection of an estimator, based on the model of the received phase and on the covariance matrices of the process and measurement noises. Possible realizations of the estimator include some variations of Kalman filters or other least-squares estimators.

The fourth step is the determination of a predictor to compensate for the transport lag. The last step is to assure that the loop is stable.

This work was done by J. I. Statman and W. J. Hurd of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 126 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-17196.

Interval Counter Measures Stability of Frequency

Propagation of errors and effects of dead time are suppressed.

NASA's Jet Propulsion Laboratory, Pasadena, California

A system that includes a precise timing-pulse generator with an interval counter and a suitably programmed computer determines the relative stability or instability of frequency of two signals that differ in frequency by about 1 Hz. The system was designed for use in a frequency-standards laboratory.

The two signals to be compared are mixed to produce a beat note. The sinusoidal beat note is passed through a zero-crossing detector, which produces a square wave or other pulse train at the beat frequency of about 1 Hz. The instability of frequency of the two signals is expressed in terms of the fractional deviation in frequency, which can be determined by measuring the times of the zero upcrossings of the beat pulses.

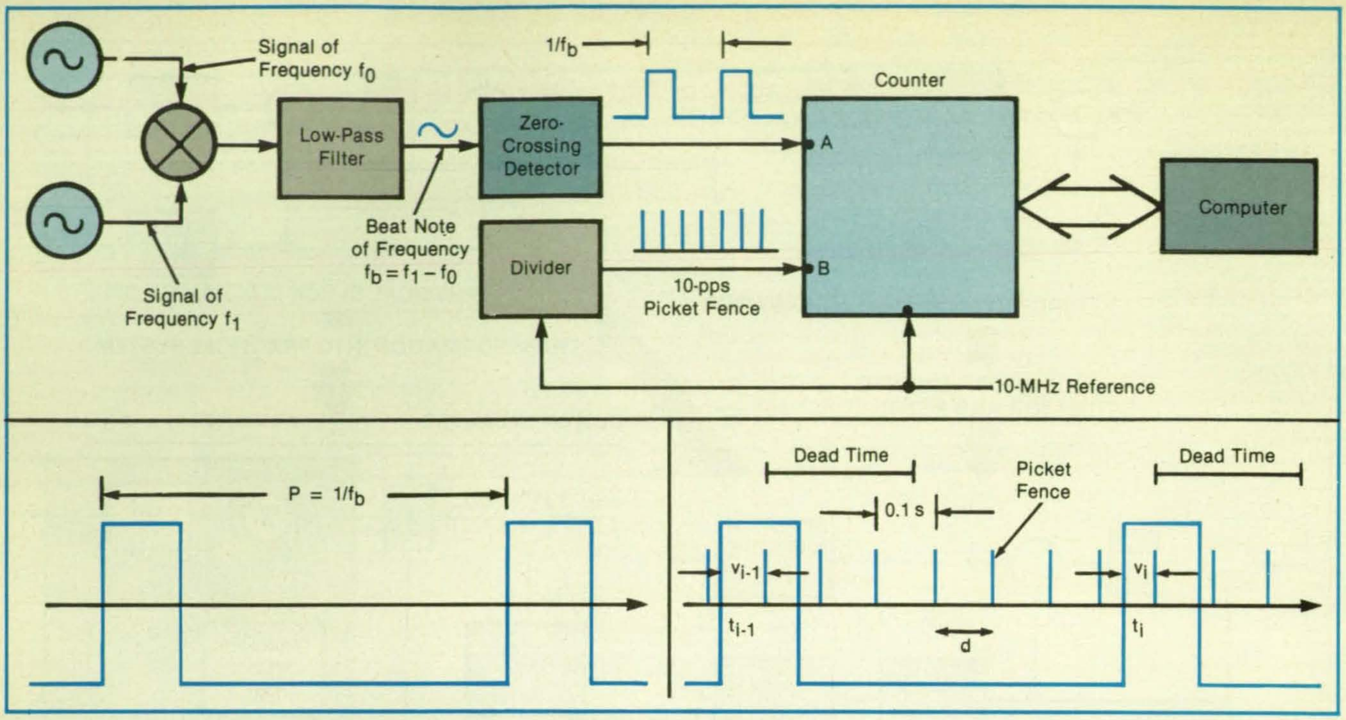
The particular combination of equipment (see figure) and algorithm measures the times of the zero upcrossings (with respect to a starting time) and not merely the lengths of the intervals between successive upcrossings; thus, it prevents the propagation of errors. The combination also overcomes the effect of the dead time of the interval counter, which would otherwise cause the counter to ignore alternate cycles.

The counter measures intervals to within 1 ns. The frequency reference for the counter is provided by a precise 10-MHz signal. The reference frequency is also divided to produce a "picket-fence" signal of sharp pulses every 0.1 s. The beat pulses are fed to the A input of the interval counter to start the count. The picket-fence pulses are fed to the B input to stop the count. Thus, the counter measures the interval v_i from each upcrossing at time t_i to the next picket-fence pulse, and the dead time ends well before the next anticipated upcrossing.

Each t_i differs from each $-v_i$ by an unknown integral multiple of the 0.1-s picket-fence period. The algorithm that resolves the ambiguity and determines the beat-note periods $P_i = t_i - t_{i-1}$ is based on the following assumptions:

- The first period P_1 differs from a nominal initially measured value P by less than 0.05 s, and each subsequent period P_i differs from the previous period P_{i-1} by less than 0.05 s. This guarantees the unique resolution of the 0.1-s ambiguities.
- Every P_i exceeds the sum of 0.1 s plus the dead time of the counter. This guarantees that no upcrossing is missed.

Because the t_i increase quickly and contain important information in their least-significant digits, they are awkward to compute, store, and use. Consequently, the algorithm computes the time residues $x_i = t_i - t_o - iP$. The algorithm incorporates



The **Interval Counter** measures the interval v_i from the beginning of each beat pulse to the beginning of the next picket-fence pulse. These measurements establish the times t_i of the beginnings of the beat pulses for use in calculations of the stability of the frequency of the beat pulses.

some error handling to prevent one bad input from spoiling all the subsequent outputs.

This work was done by C. A. Greenhall of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 41 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-17325.

Consistent Data Distribution Over Optical Links

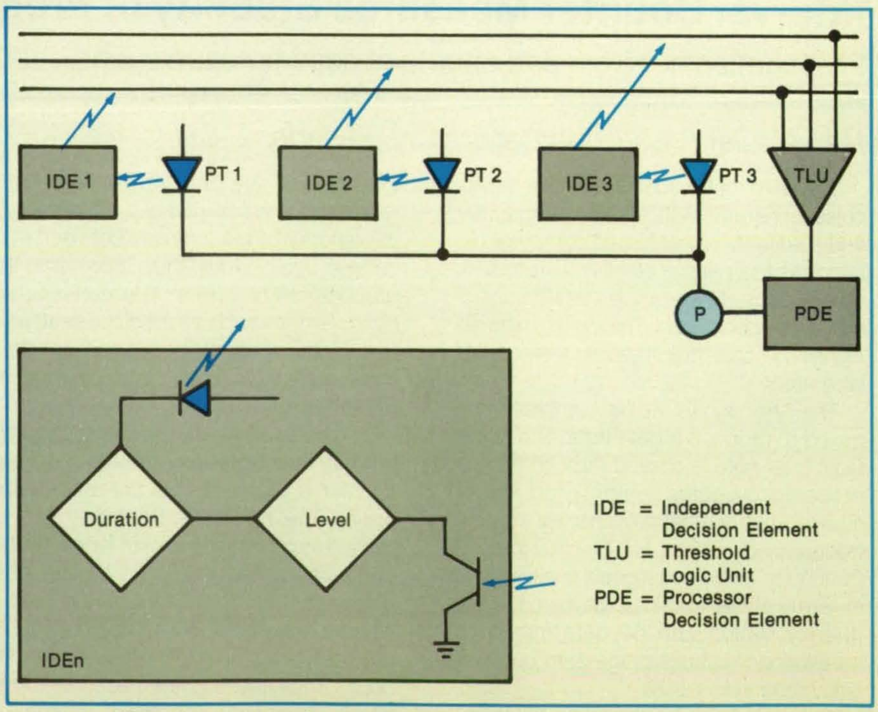
Fiber optics combined with IDE's provide consistent data communication between fault-tolerant computers.

Langley Research Center, Hampton, Virginia

A data-transmission-checking system has been designed to provide consistent and reliable data communications for fault-tolerant and highly reliable computers. The primary disadvantage of previous methods or algorithms that achieve consistency of data lies in the reliance on other processing sites for retransmission of the data. The new technique performs a variant of an algorithm for fault-tolerant computers and uses fiber optics and independent decision elements (IDE's) to require fewer processors and fewer transmissions of messages.

The function of an IDE in a system (see figure) is to transmit an independently derived copy of a message over an optical bus. Another special component, the threshold logic unit (TLU), is used to vote the message while it is still in its optical form. All the components shown belong to one processor.

First, processor P sends a message, in the form of a stream of bits, to its three transmitters, PT1, PT2, and PT3. The stream is received simultaneously by the three IDE's. Each IDE decides whether



The **Optical Data Bus** provides for a level of redundancy limited only by the number of wavelengths that the bus can accommodate.

and when the PT changes state (i.e., goes from logic 0 to logic 1, or vice versa). This decision is based on both the level and the duration of the signal. For example, a signal may cross the threshold from the 0 state to qualify as a 1 but not be held long enough to guarantee consistent recognition by all elements.

The three IDE's are isolated from each other and from the processor to obtain three independent interpretations of the output of the processor. After interpretation, the IDE's transmit the data over the optical bus to which they are attached. Each IDE associated with a P uses the same wavelength. Each IDE is attached to a different optical bus. Other computers attached to this bus use different wavelengths.

The data are received by a TLU. Its input levels can be weighted, and its output cannot fire unless the sum of the three weighted inputs exceeds a predetermined threshold. Proper setting of the TLU enables it to vote on the optical stream of bits. The stream of bits is then interpreted by the decision element, PDE, of the processor. Finally, the message is received and used by the processor.

The interactive consistency provided by this system guarantees that all participating processors receive the same message from any single source. It is a guarantee of uniform distribution of data but not of the correctness of those data. This system enables fault-tolerant computers operating at different levels of redundancy to communicate with each other over a triply redundant bus. The level of redundancy is limited only by the maximum number of wavelengths that can be active on the bus. For example, if 10 optical wavelengths can be multiplexed on a single fiber-optic cable, then a quad (4), a triplex (3), a dual (2), and a simplex (1) computer can all communicate with each other over the bus.

This work was done by Daniel L. Palumbo of **Langley Research Center**. *No further documentation is available.*
LAR-13672

Synchronous Boxcar Averager

A periodic disturbance is rejected.

Marshall Space Flight Center, Alabama

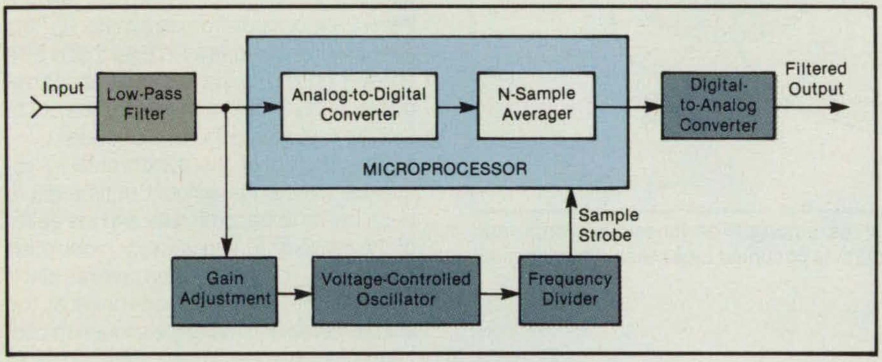


Figure 1. The **Digital Filter** is synchronized with the fundamental component of the periodic fluctuation in the input signal.

A digital electronic filtering system produces a series of moving-average samples of a fluctuating signal in a manner that results in the removal of an undesired periodic signal component of known frequency. The filter was designed to pass the steady or slowly varying components of fluctuating pressure, flow, pump speed, and pump torque in a slurry-pumping system. The filter concept could be useful for monitoring or control in a variety of applications including machinery, power supplies, and scientific instrumentation.

The filtering system (see Figure 1) is a synchronized boxcar averager — essentially a moving-average sampler that is synchronized with the source of the periodic disturbance. During one input-signal disturbance cycle of duration T, the system takes N samples of the input signal at equal intervals of T/N (shown in Figure 2 for $N = 4$). At each sampling time, the system generates the average of the latest N samples. The sequence of average values is fed to a digital-to-analog converter, which produces a smoothly-varying output signal. Because the average of a periodic fluctuation is zero during one period, the output signal represents the slowly-varying, nonperiodic component of the input signal.

To assure the removal of the periodic fluctuation, the system must satisfy the Nyquist sampling criterion; consequently, N must be at least twice the order of the highest harmonic in the fluctuation. The settling or response time of the system is T: Thus, the fluctuation is not removed until the first N samples have been taken; and if the nonperiodic component of the input suddenly

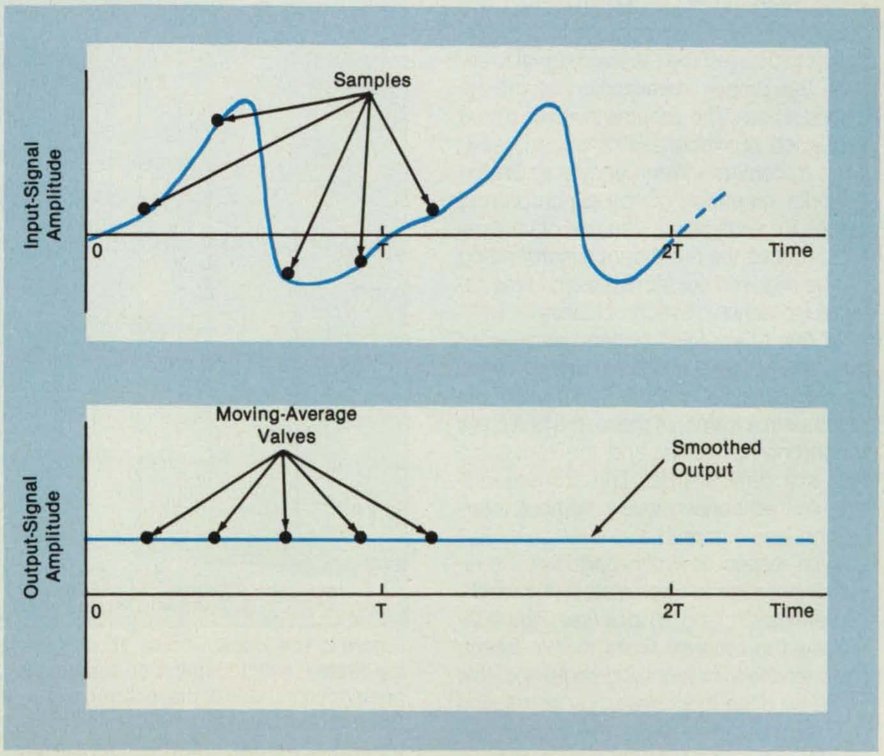


Figure 2. The **Input Signal Is Sampled** at a harmonic (in this case, the fourth harmonic) of the fundamental fluctuation frequency. The output signal contains only the slowly varying component of the input.

changes from one steady value to the other, the output values respond by progressing smoothly from the first steady value to the second steady value during a sequence of N samples.

This work was done by Thomas W. Rogers of United Technologies for **Marshall Space Flight Center**. *For further information, Circle 40 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-28223.

Synchronization Scheme for PPM Communication

Synchronization is achieved even under difficult, low-signal conditions.

NASA's Jet Propulsion Laboratory, Pasadena, California

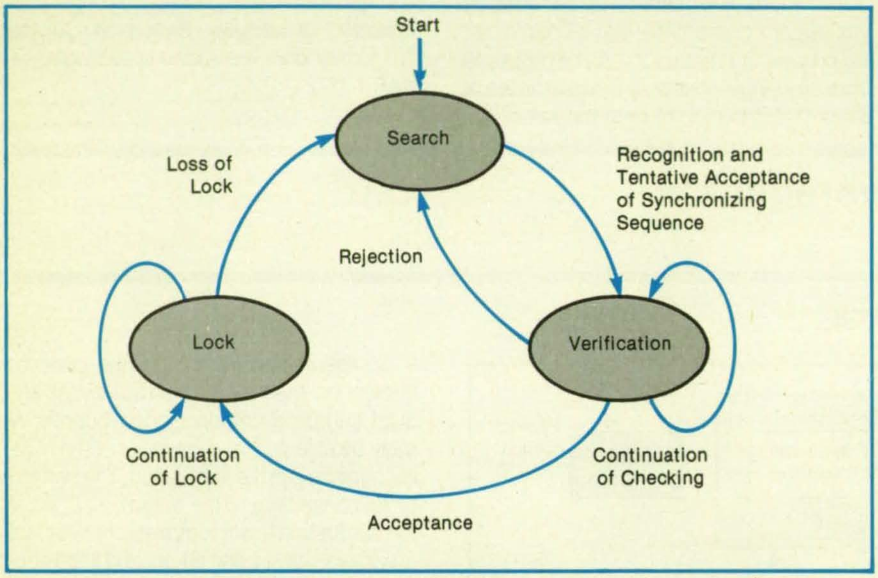


Figure 1. **Three Time Scales** show the relationships among PPM timeslots, words, and frames. In each PPM word, only one of the timeslots is occupied by a pulse. The occupied timeslot determines the value of the word.

A synchronization scheme for pulse-position modulation (PPM) matches the pulse, word, and frame timeslots of the receiver to those of the received signal to ensure the proper identification of the received pulses. The scheme involves a brief sequence of synchronizing pulses within each transmitted frame and relies on the periodic repetition of the synchronizing pulses for verification. The use of verification reduces the number of synchronizing pulses required but increases the time required to achieve synchronization.

In this M-ary PPM system, each word contains M basic timeslots, one of which contains a pulse. N words are transmitted together in a frame; of these, the first L are synchronizing words, and the remaining N-L are data words. The frames are transmitted consecutively, without interruption (see Figure 1).

With respect to synchronization, the receiver operates in three states: (1) search, (2) verification, and (3) lock (see Figure 2). Initially, the receiver waits in the search state for the synchronizing sequence: this could be done most simply by correlating the timeslot data with the known sequence. Once it has found such a correlation, the receiver enters the verification state, in which it looks for repetitions of the sequence after the passage of multiples of the known frame length.

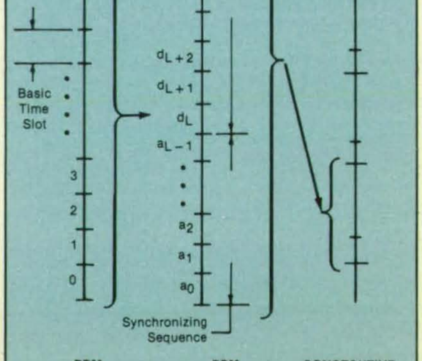


Figure 2. The **Receiver Has Three Operating States**, which depend on the past and present conditions of the received signal. In the search state, it attempts to find the synchronizing pulses. In the verification state, it has tentatively identified the synchronizing sequence. In the lock state, it has accepted the tentative synchronization.

If the receiver recognizes the synchronizing sequence A_{th} times in succession (where A_{th}, the rejection threshold, is an integer that is chosen on the basis of performance requirements), then the tentative synchronization is accepted and the receiver goes into the lock state. Thereafter, the receiver continues to check for synchronization by looking for the synchronization sequence at the beginning of each frame. If the sequence is not observed during R_{th} successive frames (where R_{th}, the rejection threshold, is an integer that is also chosen on the basis of performance requirements), then the receiver goes out of lock and returns to the search state.

The choice of the synchronizing sequence affects the amount of time left in each frame to transmit data and the ability of the receiver to acquire synchronization and to lock. The suffixes and prefixes of the sequence are generally made unequal. It is also preferable to make the sequence contain both extremes of the PPM alphabet ($a_m = 0$, $a_n = M - 1$ for some m and n) so that a shifted version of the sequence

$$\{a_0 + c, a_1 + c, \ldots a_{L-1} + c\}$$

cannot occur in the transmitted data.

A synchronizing sequence detected by the receiver can be one of three types, (1) a true synchronizing sequence at the beginning of a frame, (2) a sequence of data that duplicates the synchronizing sequence, or (3) a signal corrupted by noise in such a way that the receiver recognizes it as a synchronizing sequence. The verification process ensures that only sequences of type (1) affect receiver synchronization.

The synchronizing scheme is intended primarily for use in optical communications, especially where received signals are weak. The scheme was tested in a PPM system of $M = 256$, $L = 2$, $A_{th} + R_{th} \leq 12$, $0 \leq N \leq 65{,}536$. The signals were fed to photomultipliers, which detected 2 to 3 photons per pulse. Measurements of the distribution of times to acquire synchronization agreed well with theoretical predictions.

This work was done by William K. Marshall of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 123 on the TSP Request Card.*
NPO-17033

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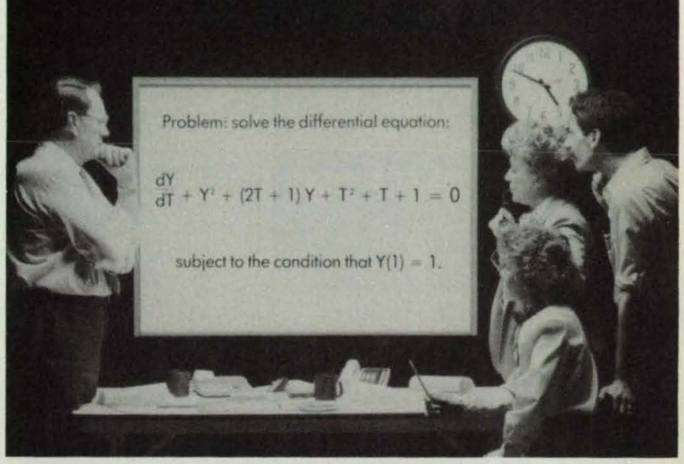

Symbolically. . .

(C1) DEPENDS(Y,T)$

(C2) DIFF (Y,T) + Y ^2 + (2*T + 1)*Y + T ^2 + T + 1;

(D2) $\frac{dY}{dT} + Y^2 + (2T + 1)Y + T^2 + T + 1$

(C3) SOLN:ODE(D2,Y,T);

(D3) $Y = -\frac{\%C\,T\,\%E^T - T - 1}{\%C\,\%E^T - 1}$

(C4) SOLVE(SUBST([Y = 1, T = 1],D3),%C),NUMER;

(D4) [%C = 0.5518192]

(C5) SPECIFIC_SOLN:SUBST(D4,SOLN);

(D5) $Y = -\frac{0.5518192\,T\,\%E^T - T - 1}{0.5518192\,\%E^T - 1}$

and Numerically.

```
(C6) FORTRAN(D5)$
      Y = -(0.5518192*T*EXP(T) - T - 1)
     1    /(0.5518192*EXP(T) - 1)
```

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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.

Simulation of Satellite Imagery From Aerial Imagery

High-resolution-image data are convolved with a point-spread function.

A report describes the use of higher-resolution-image data from aerial photographs or electronic scans of the ground to simulate the lower resolution images that would be obtained if the same area of the ground were viewed from an imaging system in orbit. The simulation technique is helpful in the analysis of data received from operating satellites and in the design of future satellite-borne imaging systems.

To simplify the calculations, the aerial image was treated as though it were not blurred, and all of the blurring was attributed to the low-resolution satellite imaging system. The point-spread (blurring) function of the low-resolution system was assumed to be a Gaussian function of two width parameters: one for the direction along the ground track (across the scan) and one across the ground track (along the scan) of the satellite.

The modulation transfer function (MTF) of the satellite imaging system was obtained from Fourier analysis of satellite imagery. Linear regressions were used to fit Gaussian curves to published plots of the logarithm of the MTF to the squares of the along-track and across-track spatial frequencies. The point-spread function was then computed as the inverse Fourier transforms of the fitted Gaussian curves in the spatial-frequency domain. For the Multispectral-Scanner (MSS) satellite data used, the Gaussian width parameters corresponded to half-maximum half widths of 36.1 m across the track and 40.1 m along the track: these seem reasonable in consideration of the 79-m field of view of the MSS.

The spatially-continuous Gaussian function was converted to a picture-element-weighting function having the same width parameters. The Gaussian filter was applied over a rectangular area large enough to contain all weights of maximum (center) value of 0.10 or greater; in this case, 7-by-7 picture elements. The normalizing constant was then recalculated for the rectangular area by taking the inverse of the sum of the Gaussian filter weights of all the picture elements in the rectangle.

The aerial images were taken in an airplane at an altitude of 65,000 ft (19.8 km), with an instrument having a 25-m instantaneous field of view and picture-element spacings of 17 m across the track and 22 m along the track. The data from these images were convolved with the Gaussian filter. The image was then resampled, using nearest-neighbor gray levels, to obtain picture elements of 57 m by 57 m, corresponding to those of the MSS.

In comparison with real MSS images of the same area, the simulated images seemed to have about the same resolution, but were slightly fuzzier because of the failure to account for the point-spread function of the aerial imaging system. The simulated images contained less noise than did the real images: noise could have been added, but was omitted because the noise characteristics of the two imaging systems are not well known.

This work was done by Christine A. Hlavka of **Ames Research Center**. *Further information may be found in NASA TM-86832 [N86-20934/NSP], "Simulation of Landsat Multispectral Scanner Spatial Resolution with Airborne Scanner Data."*

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

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center *[see page 14]**. Refer to ARC-11714.*

Nondynamic Tracking Using the Global Positioning System

The new technique can be used to track unmodeled movements.

A report describes a technique for using the Global Positioning System (GPS) to determine the position of a low Earth orbiter without the need for dynamic models. A differential observing strategy requires a GPS receiver on the user vehicle and a network of six ground receivers. The computationally efficient technique can deliver decimeter accuracy on orbits down to the lowest altitudes.

The new technique is a nondynamic long-arc strategy having the potential for accuracy of the best dynamic techniques while retaining much of the computational simplicity of the geometric techniques. In brief, one empirically constructs a continuous record of change in the position of the satellite by continuously tracking the phase of the GPS carrier signal. One then uses this record to map a long arc of pseudorange position solutions to a common

Circle Reader Action No. 342

epoch for averaging.

This is repeated at every point in time. Because there is no modeling of user dynamics, the benefits of long-term data averaging can be realized at the very lowest altitudes, and the solution process is simplified. This technique is a generalized form of the procedure known as smoothing pseudorange against the carrier. In this case, however, one smoothes the position obtained from multisatellite pseudorange against the change of position obtained from multisatellite carrier phase.

It can be shown that even in differential GPS applications, when the distances between receivers are sufficiently large, the limiting error is the (typically) few-meter error in GPS orbits. To achieve 10-cm accuracy for the TOPEX oceanographic satellite at an altitude of 1,334 km, it is therefore necessary to solve simultaneously for the GPS orbits and the user orbit. In addition to adjusting user position at every point in time, one adjusts the GPS states at epoch only, using the usual dynamic techniques. This is a relatively small complication, because at the high GPS altitude and over the few-hour data arcs used in this case, the GPS dynamics are easily modeled with high accuracy.

The major uncertainty in previous dynamic strategies for the determination of the TOPEX position from differential GPS data studies is the accuracy assumed for the dynamic models, particularly for the detailed model of the gravitational field of the Earth. By eliminating the need for such models, one eliminates the principal uncertainty but loses the information in those models and thereby introduces a greater dependence upon the performance of the receiver. Nondynamic tracking places a premium on both high-precision measurements and multiple GPS viewing capacity. In view of recent advances in the design of digital receivers, this may prove to be a favorable trade.

The computational load in the nondynamic approach is much reduced. Because none of the remaining error sources has any significant dependence on altitude, the predicted decimeter performance should be obtainable at even the lowest altitudes, where dynamic techniques degenerate to tens or hundreds of meters of error. So long as the onboard receiver retains lock on the GPS signals, it should even be possible to maintain this accuracy through any unpredictable or unmodellable satellite motion, including a maneuver.

While nondynamic tracking looks promising for some applications, dynamic tracking is needed in others. Without dynamics, the solution is strongly dependent on the observing geometry, which, with GPS, is much weaker radially than horizontally. TOPEX happens to be at an altitude for which, given the uncertainties in the gravity model, the ground network, and the characteristics of the flight receiver, the better strategy is not yet apparent.

This work was done by T. P. Yunck and Sien-Chong Wu of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 61 on the TSP Request Card. NPO-16926*

The Mark III VLBI System

Geodetic measurements have errors in the centimeter range.

A collection of three reports describes both the equipment and the results of some of the measurements taken with the Mark III very-long-baseline interferometry (VLBI) system. Using antennas at widely separated locations in the United States and Europe, the system yields such astrometric data as the celestial coordinates of distant radio sources within $\sim$ 3 ms of arc and such geodetic data as the relative positions of the antennas within $\sim$ 5 cm.

The signals, usually from extragalactic sources, are received in the frequency bands of 2.2 to 2.3 and 8.2 to 8.6 GHz. At each site, the Mark III system can handle the outputs of two independent receivers at intermediate frequencies of 100 to 500 MHz. The intermediate-frequency signals are routed through 14 separately controllable frequency converters to produce a total of 28 upper and lower sideband channels. Each channel is sampled at the Nyquist ratio, 4×10^6 per second. Only the sign (polarity) of a sample, represented by a single bit, is recorded to maximize signal-to-noise ratio per bit stored. A Honeywell 96 tape transport (or equivalent) outfitted with Mark III digital electronics is used to record each bit stream (augmented with timing information) on one of 28 parallel tracks. High-quality 650-Oe videotapes [9,200 ft long, 1 in. wide (2,760 m by 2.5 cm) recorded at 33,333 b/in. (13,123 b/cm) along each track] are now used exclusively to maintain an SNR about 12 dB higher than that obtained originally with standard instrumentation tape.

The Mark III system has demonstrated high accuracy over short baselines, where phase-delay measurements can be used; for example, it gives the relative horizontal and vertical position of the Haystack Observatory antennas within a few millimeters over a baseline having a horizontal component of about 1,239.4 m and a vertical component of 30.0 m. Over baselines longer than a few hundred kilometers, the accuracy is limited by the uncertainty in the tropospheric path delay to a level of a few centimeters. VLBI measurements of continental drift are contemporaneous, unlike geological measurements, which are literally averages over millions of years. VLBI baseline measurements spanning just 2 years determine relative plate velocities to an accuracy of 1 to 2 cm/yr, and this accuracy should increase at least linearly with time spanned by observations.

Advanced hardware, called Mark III A, has been developed to improve system performance and efficiency. It consists of "double speed" processor modules and "density upgrade" kits for the recorders. The latter increase the area density of recording more than an order of magnitude by reducing track width from the original value of 640 to 40 μm. The high SNR of the videotape now used compensates for loss of signal amplitude caused by narrowing of tracks. In addition, accurate narrow-track headstacks and a headstack-positioning subsystem had to be developed to make the density upgrade possible. Upgraded machines record a total of 336 tracks, 28 at a time in 12 passes, each lasting 800 seconds. Thus, one tape lasts almost 3 hours when recording at 56-MHz bandwidth (112 Mb/s) and holds about 10^{12} b. Advantage can readily be taken of the continued rapid advance of tape technology: Mark III A hardware has already been used to demonstrate 16 hours of recording at 128 Mb/s on a single reel of "digital video" tape [16 passes times 32 tracks at 50,000 b/in. (19,685 b/cm) using a 16-in. (40-cm) reel of ½-mil (0.01-mm) tape, 27,000 ft (8100 m) long] to meet the requirements of VLBA, the Very Long Baseline Array.

The original Mark III hardward and the III A subsystem upgrades were developed as part of the NASA Crustal Dynamics Project at the Haystack Observatory.

This work was done by A. E. E. Rogers, A. R. Whitney, J. I. Levine, E. F. Nesman, J. C. Webber, and H. F. Hinteregger of NEROC Haystack Observatory for **Goddard Space Flight Center.**

To obtain copies of the reports, "Very-Long Baseline Radio Interferometry: The Mark III System for Geodesy, Astrometry, and Aperture Synthesis," "The Density Upgrade: Mark III A (a Future Improvement of the Mark III VLBI System)," and "Precision Geodesy Using the Mark III Very-Long-Baseline Interferometer System," Circle 100 on the TSP Request Card. GSC-13028

Adaptive Control for Space-Station Joints

Input gain weighting is added to an existing adaptive-control algorithm.

A report discusses a concept for the adaptive control of rotations of various appended structures about joints on a space station, with suppression of vibrations in both the station and the appendages. The adaptive-control concept may be relevant to such terrestrial applications as the control of aircraft, the suppression of vibrations in large buildings, and robotics.

The control strategy is to apply, to the rotation actuators, the set of control signals that will cause all moving parts to follow the commanded trajectories as closely as possible. The previous version of the adaptive control loop includes an adaptive gain matrix that contains proportional and integral components, each of which includes an output-weighting matrix chosen by the designer. In the present version, input gain-weighting matrices are added to increase control efforts in specified locations at the designer's discretion.

An inner control loop is also introduced to suppress the instabilities that would otherwise arise from the zero-frequency rigid-body modes. By an appropriate choice of the inner-loop gain matrix, the rigid-body modes can be given nonzero frequencies and stabilized. Accurate knowledge of the system dynamics is not necessary for the design of the inner loop: the inner loop can be made robust by placing it only where the controllability of the rigid-body modes is the highest.

A computer simulation to test the new concept involved the use of an adaptive control algorithm in a space station having 19 degrees of freedom: namely, 12 vibrational and 7 rigid-body-rotational modes. The performance was analyzed in terms of the responses to various position and rate commands. In comparison with an algorithm without input weighting, the new algorithm showed improved performance with reduced control demand. The parts followed the commanded trajectories almost perfectly, and vibrations were suppressed in spite of the uncertainties in the mathematical model of the station and of the low order of the reference model in the control loop.

This work was done by Che-Hang Charles Ih, David S. Bayard, and Shyh Jong Wang of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Space Station Adaptive Payload Articulation Control," Circle 60 on the TSP Request Card.*
NPO-17063

Tests of Helicopter Control System

Advanced control systems are being developed for rotorcraft.

A report discusses aspects of the development of a multivariable, explicit-model-following control system for the CH-47B fly-by-wire helicopter. This project is part of a recent trend toward the use of highly-augmented, high-gain flight-control systems to assist the pilots of military helicopters in the performance of demanding tasks and to improve the handling qualities of the aircraft.

The CH-47B has been modified for research purposes to include full-authority, electrohydraulic, parallel actuators in each of the four control axes. These actuators act as the interface between the electronic control system and the basic CH-47B mechanical control system. An evaluation pilot is equipped with a longitudinal-and-lateral cyclic stick with a programmable force-feel system, conventional pedals, and a standard collective lever. Electrical control inputs from the evaluation pilot and measurements of the helicopter motions are processed in the onboard flight computers to produce the commands for the electrohydraulic actuators. The parallel arrangement of the electronic control system with the mechanical control system allows a safety pilot to monitor the electronic control system by following the motion of his controls since these controls are mechanically connected to the actuators.

The electronic control subsystem strives continuously to make the helicopter behave like a mathematical model that represents the desired helicopter dynamics. The commands from the pilot are fed to the model; the errors between the states of the model and the measured states of the helicopter are fed to the control subsystem that attempts to minimize the errors by generating control signals for the actuators.

The explicit model chosen for flight tests was a linear decoupled model in which the pilot commanded the pitch attitude with the longitudinal cyclic stick, the roll attitude with the lateral cyclic stick, the yaw rate with the pedals, and the vertical velocity with the collective lever. Because the tests revealed an unacceptable delay of about 0.4 s between the pilot's command and the aircraft response, the control algorithm was augmented with a feed-forward control law. Additional high-frequency roll-rate feedback was also required to reduce roll-control overshoot.

The modified control system gave high-bandwidth control and excellent performance in flight. The frequency and damping characteristics of the helicopter motions followed those of the model almost perfectly. The aircraft followed the model with a delay of about 200 ms.

This work was done by Kathryn B. Hilbert and J. Victor Lebacqz of **Ames Research Center** *and William S. Hindson of Stanford University. To obtain a copy of the report, "Flight Investigation of a Multivariable Model-Following Control System for Rotorcraft," Circle 148 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 14]. Refer to ARC-11761.

Physical Sciences

Compact Ho:YLF Laser

Longitudinal pumping by laser diodes increases efficiency.

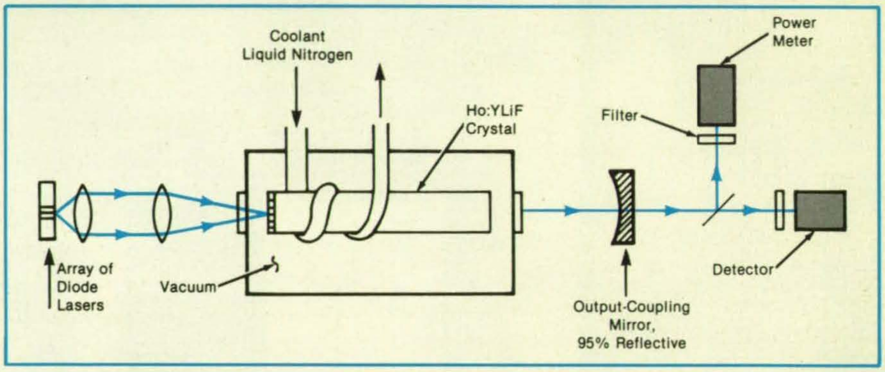
NASA's Jet Propulsion Laboratory, Pasadena, California

An improved holmium:yttrium lithium fluoride laser radiates as much as 56 mW of power at a wavelength of 2.1 μm. The new Ho:YLF laser is more compact and efficient than are older, more powerful devices of this type.

The design takes advantage of the efficiency of longitudinal pumping by a commercially available array of GaAlAs diode lasers (see figure). The array, mounted on a Peltier cooler in a vacuum, radiates up to 200 mW continuously at a wavelength tunable in the range of 784 to 794 nm.

The pump output is collimated and focused into the Ho:YLF crystal, which measures 0.5 by 0.5 by 1 cm. The crystal is sensitized with Er ions and Tm ions, which assist in the efficient transfer of energy following absorption of the pump radiation by the Er ions. The crystal is cooled to a temperature of 77 K to reduce the lasing threshold. At this temperature, the Ho:YLF absorption band around the wavelength of 800 nm is 6 nm wide and overlaps the 1-nm spectral width of the pump signal.

Both ends of the crystal are polished flat. The pumped end is coated for high transmittance at the pump wavelength and high reflectance at the output wavelength, while the output end is antireflection coated for the output wavelength. A plano-concave resonator is formed by the addition of an output-coupling mirror with a radius of curvature of 5 cm and a reflectance of 95 percent at the output wavelength.



The **Compact, Efficient Ho:YLF Laser** is based on recent successes in the use of diode lasers to pump other types of solid-state lasers.

With the pump wavelength tuned to 790 nm for maximum absorption and about 176 mW of pump power delivered to the Ho:YLF crystal, about 56 mW of output power is measured in the TEM_{00} mode. The lasing threshold input power is 7 mW, and the ratio of the increase in output optical power to the increase in input optical power is 0.33, which nearly equals the quantum efficiency of 0.38 for Ho:YLF under the given conditions. Ignoring the power consumed by the Peltier cooler, the electrical-to-optical conversion efficiency of the laser is 6.6 percent.

The laser output is highly sensitive to the alignment of the output-coupling mirror, the temperature of the crystal, and the pump wavelength. Changes that are likely to improve the performance include the elimination of the dewar window in the laser cavity, more-uniform cooling of the Ho:YLF crystal, proper matching of the modes of the pump to the laser cavity, optimization of the reflectivity of the output-coupling mirror, and variations in the concentrations of Ho and the sensitizers.

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

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 14]. Refer to NPO-17282.

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.

Evaporation and Ignition of Dense Fuel Sprays

A simple theoretical model makes useful predictions of trends.

A pair of reports presents a theoretical model of the evaporation and ignition of sprayed liquid fuel. The model was developed as part of research in the combustion of oil and liquid fuels derived from coal, tar sand, and shale in a furnace; this work may eventually contribute to an increase in the efficiency of combustion and a decrease in pollution generated by the burning of such fuels.

The mathematical model of the spray includes a moving spherical cluster of droplets of a single-component fuel. The droplets all have the same diameter and are uniformly distributed throughout the cluster. The droplets and the cluster all move together at the same velocity through the convective flow of air, evaporated fuel, and combustion products. Each droplet is considered to be surrounded by a fictitious sphere of influence; the ensemble of these closely packed spheres is the entire volume of the spray. The gas phase is considered to be quasi-steady with respect to the liquid phase. The temperature within a droplet is considered to be a function of time and of the radial position within the droplet. (Heat conduction is considered, and internal circulation is ignored.)

The temporal and spatial distribution of temperature within a droplet is represented by the classical equation for heat conduction, with an external boundary condition that relates the surface-normal temperature gradients to the rate of evaporation. Next, the difference between the flux of fuel molecules leaving and that striking the surface of the droplet is expressed in terms of the partial pressures of the molecular species, yielding an equation for the rate of evaporation as a function of the physical constants of the fuel and air, and of the temperature of the gas at the surface of the drop; this is a generalized, more realistic version of the Clausius-Clapeyron equation.

The evaporation of liquid from the drops in a quiescent flow is treated by applying conservation equations and the ideal-gas law to the spray volume. The evaporation rate in a convective flow is calculated from the rate for quiescent conditions, with modifications for the heat-transfer and viscous effects of the flow past each drop.

A critical parameter that affects evaporation is the relationship between the rates of evaporation with and without flow. Convective evaporation is modeled via a Reynolds-number correlation between the evaporation rates with and without convection. Unlike in all earlier versions of this model, which was valid only for nondilute sprays, the present model is inherently valid for both dense and dilute sprays. The penetration ratio is no longer used to calculate the evaporation rate. Instead, it becomes a diagnostic that radiates the evaporation regime of the spray.

The ignition criteria distinguish between diffusion-controlled and convection-controlled regimes. A Damköhler-number criterion is used to predict the ignition time in the diffusion-controlled regime. It is also used in the diffusive/convective regime, although its validity there is questionable.

According to calculations made with the model, dense and very dense sprays belong in the diffusive regime, and at ignition, a single flame is established around the entire droplet cluster. On the other hand, very dilute sprays and single-drop ignition fall in the convection-controlled regime. In the intermediate regime of dilute sprays, internal cluster flames are postulated at ignition. The boundaries between the various regimes are sensitive to the initial conditions and change as a function of time. By changing initial conditions, a spray can be made to ignite in a different regime. Ignition appears to be sensitive to the initial temperatures of the drops and of the surroundings, particularly at high temperatures.

This work was done by Josette Bellan and Kenneth G. Harstad of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain copies of the reports, "Analysis of Convective Evaporation of Dense and Dilute Sprays" and "Ignition of Non-Dilute Sprays in Convective Flows," Circle 162 on the TSP Request Card.*
NPO-16954

Ames Invention

(continued from page 34)

plane. The Navy has lost at least five F/A-18 engines and 25 Canada-22 engines in recent years due to shards of ice falling off the air intake into the engine, according to Navy sources. The military is also considering installing the deicer on its new V-22 tilt rotor aircraft, which presently carries 200 pounds of generators for deicing purposes alone. "The electro-expulsive system would reduce their power requirements for deicing from 50 kilowatts to 500 watts and save at least 180 pounds in the process," said Haslim. "That's another soldier they'll be able to add to the aircraft."

Once applied to the leading edge of helicopter rotors, the deicer will bolster NATO's stategic position in Western Europe, according to Haslim. "NATO helicopters would have the advantage of being able to fly in freezing weather to locate opposing forces," he explained. Currently, most helicopters are grounded in icing conditions because ice accumulation on the rotors causes excess vibrations and can result in crashes.

Other Applications

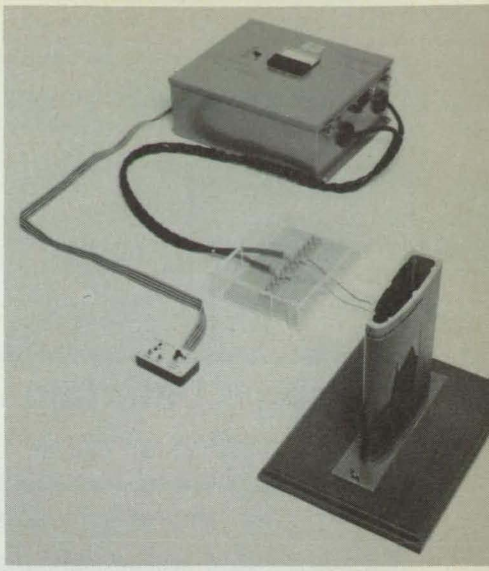
Haslim's invention could also be employed on ship superstructures, where ice removal is a difficult and dangerous task. "Right now some poor soul has to climb high up on the ship and knock ice off with a baseball bat," said Benjamin Lardiere, an aerospace engineer with Dataproducts New England, one of several companies vying to market the deicer. "This results in a lot of serious accidents. The NASA system would provide a safer, saner alternative."

The bakery and plastics industries may adapt the system as part of a mold release mechanism designed to speed up production lines. "Present mechanisms are slow and cumbersome," said Haslim. "You've got to pull the items out of the mold by hand. This new system would pop muffins or distributor caps from a mold in the blink of an eye."

Haslim also hopes to use the electro-expulsion concept to develop a self-pumping fluid tube for hydraulic systems. "By putting this system inside a hydraulic line," he said, " you could squeeze pulses of fluid through a tube at preset intervals and thereby eliminate the need for an external pump. This would improve not only performance but also safety. The external pump can be a dangerous single point of failure in a hydraulic system. If an aircraft's hydraulic pump fails, everything fails.

"This idea could be taken a step further to develop a synthetic artery that would improve the flow of blood to the heart," he added. "A self-pumping tube could be surgically implanted in the place of clogged arteries, taking a great strain off the heart and possibly saving the patient the agony of an artificial heart implant."

Haslim is working with a Stanford University medical engineer to develop the artery, but expects the research phase alone will take many years. "I'm confident we can make it happen," he said, adding, "I believe anything is possible if you really set your mind to it." □



This demonstration model of the NASA deicing system shows the elastomeric boot covering a wing model. The connecting power supply uses about 500 watts continuously for the entire system, versus about 2,300 watts per square foot for existing thermal deicers.

Problem Solver *(continued from page 34)*

me put it on their pumps. The Standard Oil Company got wind of the invention and came down to the station one day with a paper stating that all inventions by Standard employees belonged to the parent company. So I signed their paper and they paid me one dollar for my troubles." Haslim's pump lever has since been incorporated at gas stations the world over.

After serving in the Korean War as a Navy fighter pilot, Haslim worked for the Lockheed Missiles and Space Company and developed thermal systems for Gemini and Apollo spacecraft. In 1978 his career took a different turn when he joined the Helicopter Group at NASA's Ames Research Center and began designing advanced rotors. "I figured that after dealing with the complexities of spacecraft flight, working with helicopters would be a snap. Boy, did I ever have a rude awakening. I found out just how much I didn't know."

His present position as Program Manager for Ames' Advanced Plans and Programs Office allows Haslim the freedom to pursue pet projects like the electro-expulsive deicer. "I'm like a kid in a toy store," he said. "I'm free to let my imagination wander." Other inventions he is currently working on include a composite rescue boom for helicopters, a low-cost plastic resin aimed at replacing fiber glass on auto bodies, and filtered goggles that will help farmers spot crops in need of special care.

Haslim said he sees himself more as a problem solver than an inventor. "I look at something not being done effectively and I try to find a better way to do it. There are millions of cynics who will tell you why an idea won't work or why something can't be done. I try to rip down the artificial barriers they create. I make my own way." □

Ultrasonic Determination of Recrystallization

The state of recrystallization is easily identified.

Lewis Research Center, Cleveland, Ohio

The measurement of ultrasonic attenuation shows promise as a means of detecting recrystallization in a metal. The technique may be applicable to the real-time acoustic monitoring of thermomechanical treatments.

Cold working is a common method of strengthening metals. With increased cold work, strength increases up to a limit. The microstructure of the metal becomes increasingly distorted with increased work and exhibits high internal stresses. These residual stresses are detrimental to the final structure.

The reduction of stresses in the material is obtained by interrupting the cold-working process to anneal the material through a heating process. A repetitive process of mechanical work followed by subsequent annealing at the recrystallization temperature yields a material with optimum properties (small grains) and low residual stresses.

One complication in this thermomechanical treatment is that the recrystallization temperature varies with the amount of work in the material. Therefore, the recrystallization temperature must be determined at each step of the treatment for optimum results.

Several measurable characteristics of materials vary markedly during recrystallization. Four of the most-common measured characteristics are hardness, strength, ductility, and changes in the microstructure. These changes can be observed by mechanical testing and by metallographic, diffractive x-ray, and transmission-electron-microscopic examination. Measurements of strength, ductility, and microstructural variations generally require destructive tests. In addition, determinations of hardness, strength, ductility, and changes in microstructure may show wide scatter, depending on the techniques used.

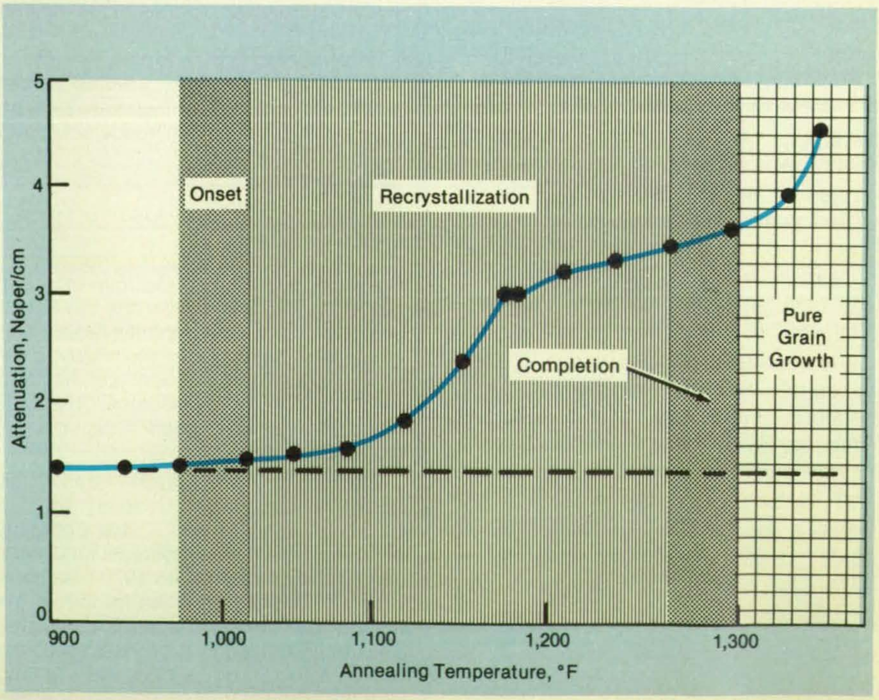
Ultrasonic attenuation was measured in cold-worked nickel 200 (99.5 + percent Ni) annealed at increasing temperatures. Localized variations in the density of dislocations, crystalline order, and volume percent of recrystallized phase were determined over the range of annealing temperatures by use of transmission electron microscopy, x-ray diffraction, and metallography.

The exponent of the frequency dependence of the attenuation has been found to be a key variable that can be used to relate the ultrasonic attenuation to the thermal kinetics of the recrystallization process. The attenuation as function of frequency for thermomechanically-processed nickel 200 is shown in the figure. The onset and completion of the recrystallization process are easily identified and are indicated by the light shading. The state of the recrystallization process (the volume percent of the recrystallized phase) can be determined quantitatively from the attenuation data in the darker shaded region.

X-ray metallography and analysis by transmission electron microscopy individually cannot completely characterize the state of the recrystallization process. However, the ultrasonic attenuation, being extremely sensitive to the formation of small scatterers and having a wide dynamic range to large scatters, is a viable, nondestructive, and convenient method for characterizing the recrystallization process.

This work was done by Edward R. Generazio of **Lewis Research Center**. *Further information may be found in NASA TM-88855 [N87-10399/NSP], "Ultrasonic Determination of Recrystallization."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
LEW-14581



Starting With Work-Hardened Material, one can ultrasonically determine the effect of annealing, using the correlation between ultrasonic attenuation and temperature.

Computer Programs

COSMIC: Transferring NASA Software

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

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

If you don't find a program in this issue that meets your needs, call COSMIC directly for a free review of programs in your area of interest. You can also purchase the 1988 *COSMIC Software Catalog*, containing descriptions and ordering information for available software.

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Computer Programs

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

Electronic Components and Circuits

Distributed Architecture for Phased-Array Antennas

The effects of failures and changes in configuration can be simulated.

The Distributed Architecture for Phased Array Antennas (DISTAR) computer program is a simulation tool used to study the implementation of distributed phased-array equipment. DISTAR allows the placement of possibly-faulty transmitting/receiving modules (T/R's) at locations throughout the array. Variations in amplifiers and phase shifters may degrade the performance of an antenna, depending on environmental conditions and array architecture. DISTAR enables the antenna designer to examine the characteristics of an array and how they affect both the types and extents of antenna failures. General specifications for amplifier and phase-shifter tolerances can also be determined for various architectures.

The configuration of an array is assumed to be rectangular with optional staggering in the *x* or *y* direction. The array is divided into various subgroups both geometrically and electronically. Each T/R drives a subgroup of elemental radiators. Both hard and soft failures of the T/R amplifiers are modeled. A hard failure is catastrophic, as no power is transmitted to those elements controlled by the amplifier that failed. Soft, or noncatastrophic, failures are simulated by a modified Gaussian distribution.

Flat, warped, and parabolic arrays can be modeled. The user must supply the geometrical specifications of an array, the amplitude and phase for each row and column, and the locations of all T/R's. Specific or randomly chosen amplifiers may be deemed faulty. DISTAR puts out the normalized antenna gain patterns in the form of tables and two- or three-dimensional graphs.

DISTAR is written in FORTRAN 77 for interactive execution and has been implemented on a DEC VAX 11/780 computer operating under VMS 4.4 with a central-memory requirement of approximately 35K of 8-bit bytes (without graphics). DISTAR requires the commercial DISSPLA plot library for full graphics implementation. The program was developed in 1986.

This program was written by Shayla E. Davidson and Brian Bourgeois of **Johnson Space Center** *and R. P. Jedlicka and P. A. Henry of New Mexico State University. For further information, Circle 25 on the TSP Request Card.*
MSC-21236

Mechanics

Inverse Design of Simple, Unbranched Ducts

This program calculates the shape of the duct to obtain a desired flow field.

A computer program, DIN3D1, was developed for the inverse design of simple, unbranched ducts. The inputs from the user to the computer program are the velocity distributions for all the surfaces that make up a duct. These include the upstream and downstream velocity fields and the velocities along the streamlines that form the lateral boundaries of the duct. The output of the program contains the duct geometry and the complete flow field through the duct.

The program is based on the assumption of three-dimensional, steady, compressible, subsonic flow. The program implements a finite-difference solution of the governing equations for the flow-field velocities in a transformed space that has coordinates based on the velocity potential and two stream functions.

The program lets the user develop duct shapes with a predetermined velocity flow field. Thus, such undesirable flow conditions as boundary-layer separation, supersonic flow, choked flow, and shocks can be avoided. By the use of this program, it will be possible to produce high-performance duct designs with less effort than that required in the use of conventional techniques of analysis of the flows in ducts.

DIN3D1 is written in FORTRAN IV for use in IBM 370 systems.

This program was written by J. D. Stanitz of **Lewis Research Center**. *For further information, Circle 12 on the TSP Request Card.*
LEW-14420

Mathematics and Information Sciences

Semi-Markov Unreliability-Range Evaluator

Reconfigurable, fault-tolerant systems are modeled.

The semi-Markov unreliability-range evaluator (SURE) computer program is a software tool for the analysis of reliability of reconfigurable, fault-tolerant systems. The SURE program is based on a new method for computing the death-state probabilities of a semi-Markov model. Two features of a fault-tolerant system have traditionally made this task difficult: First, the use of sophisticated digital processors has led to complex reconfiguration strategies that result in large, complex models. Second, the recovery is many orders of magnitude faster than the fault-arrival process. This causes rapid growth in the error terms in numerical-integration algorithms.

The new mathematical theorem on which SURE is based provides a solution to both of these problems for systems with slow fault-arrival processes and fast system recovery (i.e., good fault-tolerant systems). Previous reliability-analysis software tools were applicable to only certain types of fault-tolerant systems.

The SURE program computes accurate upper and lower bounds on the probability of failure of a system. The bounds are algebraic in form and thus are efficiently automated in the program. The program does not assume any parametric form of the process of recovery of a fault-tolerant system. The SURE user defines the structure of the model of the system by enumerating all of the transitions in the model. The user must supply the mean and standard deviation for each recovery transition and the rate of failure for each failure transition.

There is no need for sophisticated data-fitting methods because means and standard deviations are easily obtained from experimental data. The program does not assume any special features of the fault-tolerant system undergoing analysis (e.g., does not assume that the rates of failure of spares are the same as those of active processors or that spares are assigned to a particular subsystem). A model-pruning technique has been included in the SURE program to facilitate the analysis of very large models that otherwise might require excessive computational resources.

SURE is written in PASCAL for interactive execution and has been implemented on a DEC VAX computer operating under VMS 4.1. Version 5.2 of SURE was released in 1987.

This program was written by Ricky W. Butler of **Langley Research Center**. *For further information, Circle 102 on the TSP Request Card.*
LAR-13789

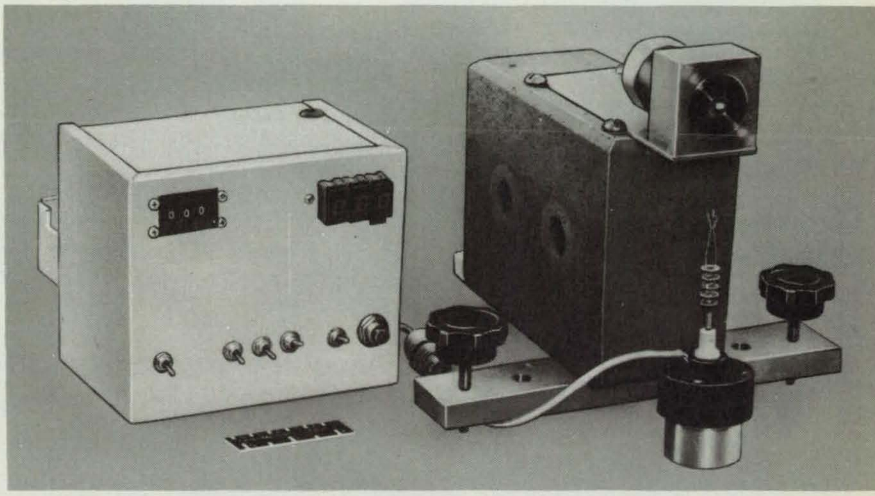
Miniature Remote Deadweight Calibrator

A microcomputer controls the calibration of a force transducer in a cryogenic chamber.

Langley Research Center, Hampton, Virginia

A miniature, computer-controlled deadweight calibrator was developed to calibrate remotely a force transducer located in a cryogenic chamber. When used with a microcomputer, the calibration system will automatically apply the deadweight loads to a skin-friction balance, record and reduce the data, and print out the results.

The system (see figure) includes a specially designed set of five interlocking 200-mg weights, a motorized weight-lifting platform, and a controller box that takes commands from a microcomputer on an IEEE interface. The computer is also used to record and reduce the calibration data and to control such other calibration parameters as the number of readings per data point and the number of calibration cycles. The lifting platform is a flat surface



The **Actuator Controller and Interlocking-Weight System** are key elements in the precise, automatic transducer calibrator.

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mounted on the vertically moving shaft of a commercial digital linear actuator.

A commercial driver for the actuator, modified and installed inside the system control box, serves as the interface between the controller and the linear actuator. The actuator controller, fabricated in-house, consists of a pulse counter with a three-digit light-emitting-diode display, a comparator circuit, and several gates and control switches.

The controller is operated in a manual mode during the setup procedure, in which the number of pulses required to move the platform to each weight-load position is determined. This information is used by the computer program to position the platform during the automatic calibration. The system is designed for a full-scale load of 1,000 mg. However, the concept can be extended to accommodate other full-scale load ranges.

This work was done by Frank H. Supplee, Jr., and Ping Tcheng of **Langley Research Center**. *For further information, Circle 26 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 14]. Refer to LAR-13564.

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.

Protecting Airplanes From Wind Shear

Improvements in flightpath displays may help pilots avoid crashes in downbursts.

A report presents the computer-simulated response of a large transport aircraft to downbursts of wind during takeoffs and landings. The simulation clearly demonstrates the benefits of increased available energy in the form of initial speed, initial altitude, or higher thrust-to-weight ratio. For example, the advantage of an increase of 10 kn (5.1 m/s) in speed can be equated to the advantage of about 130 ft (40 m) of altitude at takeoff and landing speeds.

The simulation was prompted by a crash in New Orleans in 1982 caused by downburst wind shear. The investigation that followed the crash called for studies of the ability of aircraft to penetrate and recover from wind shears and for development of sensor and guidance equipment on board aircraft to improve the chances of recovery.

The simulation showed that the higher thrust margins required of two-engine aircraft, as opposed to three- or four-engine planes, increase the tolerance of severe shear. The most successful procedures for flying through downburst shears involved flightpaths near the ground, sacrificing altitude for speed to increase endurance in the shear. Flying at fixed pitch attitude was found to be less successful but nevertheless is probably the most practical procedure with the flight-guidance displays currently available to pilots. The performance of an aircraft in a severe wind disturbance would be improved by displaying the flightpath so that it can be controlled directly and by simultaneously displaying information on the speed and altitude.

This work was done by Richard S. Bray of **Ames Research Center**. *To obtain a copy of the report, "Aircraft Performance in Downburst Wind Shear," Circle 93 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 14]. Refer to ARC-11801.

Rebound of Previously Compressed O-Ring

The behavior over a range of temperatures is analyzed.

A report presents a theoretical and experimental analysis of the relaxation characteristics of an O-ring of vinylidene fluoride/hexafluoropropylene copolymer of the same composition as that used in the solid rocket boosters on Space Shuttle flight 51-L. The study covers the range of temperatures from 10 to 120 °F (−12 to 49 °C).

The O-rings had a circular cross section, 0.28 in. (7.1 mm) in diameter. The O-rings were initially compressed 0.04 in. (1.0 mm) for 2 h by a flat plate. The equivalent stiffness for a 1-in. (2.54-cm) segment of the O-ring was 812.5 lb/in. (1.423×10^5 N/m). The relaxation data cover the interval from 0 to 1 s after removal of the compressive force. The magnitude of the initial rebound decreased from over 0.02 in. (0.5 mm) at 120 °F (49 °C) to essentially 0 at 25 °F (−4 °C) and below. The glass-transition temperature of the material is 10 °F (−12 °C).

The analysis indicates that two different mechanisms are involved in the response of the O-ring when a compressive force on the O-ring material is removed. When compressed, the material takes a set, which becomes the new short-term equilibrium position. During the first 2 to 3 ms after release, the rebound is dominated by overdamped elastic motion toward the short-term equilibrium position. After that, the response is dominated by a classic creep as the material relaxes toward its original shape.

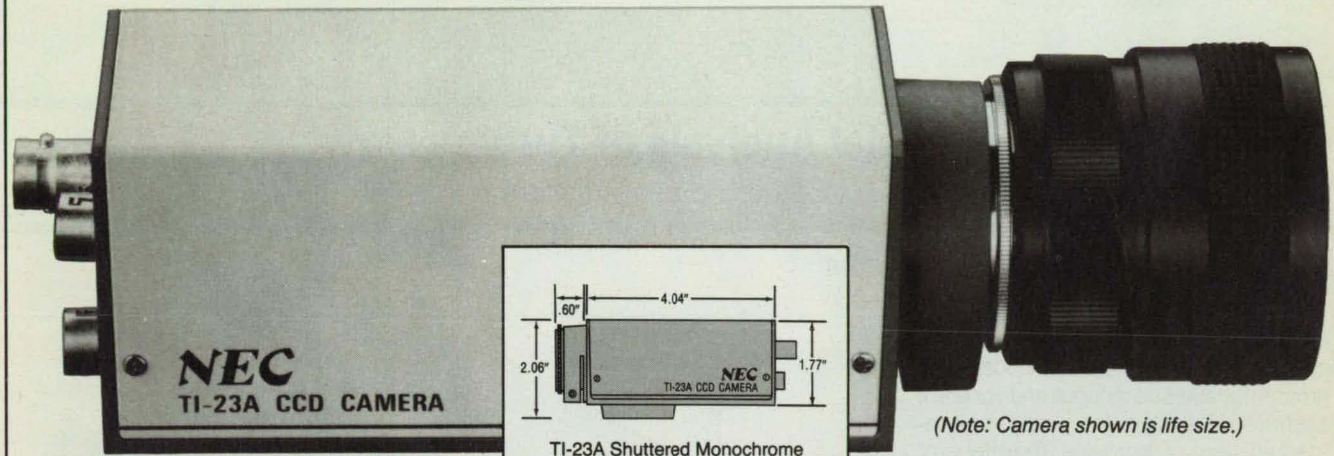
The set position, the initial response, and the final relaxation position all depend on both the temperature and the duration of the previous compression. The lower the temperature, the larger the set, the smaller the initial response, and the larger the difference between the initial position before compression and the final relaxation position.

The report presents a one-dimensional mathematical model of the response that provides for both the elastic response and the creep. The parameters of the model that depend on the temperature include the relaxation position after 2 min, the short-term equilibrium set position, the damping coefficient, and the creep-retardation factor. These parameters are represented by second-, fourth-, second-, and second-order power series in the temperature, respectively, fitted to experimental data. Graphs show the data and the fitted curves for each of these expressions. Other graphs show the measured displacement versus time during rebound and the corresponding curves from the model for various temperatures. The data and the curves from the model agree closely.

This work was done by Carleton J. Moore of **Marshall Space Flight Center**. *Further information may be found in NASA TM-86582 [N87-24985/NSP], "SRB O-Ring Free Response Analysis."*

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.
MFS-27186

Designed to Fit



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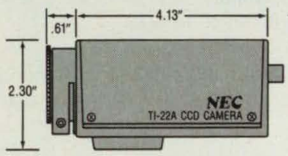
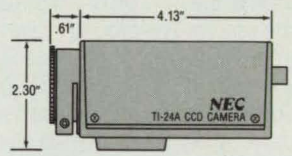
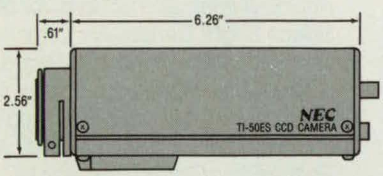


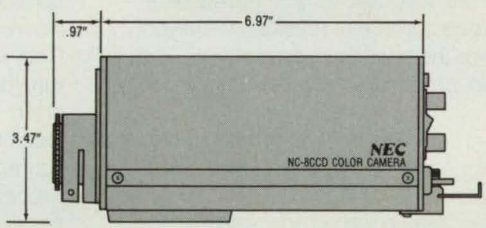
TI-22AII Monochrome
384(H)x490(V) pixels

TI-24A High-Resolution
Shuttered Monochrome
728(H)x493(V) pixels





TI-50ES High-Speed
Shuttered Monochrome
390(H)x493(V) pixels



NC-8 Low Light Color
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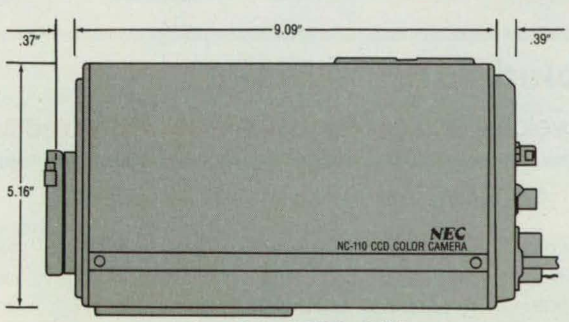

NC-110 Color, RGB Available
384(H)x490(V) pixels

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Circle Reader Action No. 369

Machinery

Hardware Techniques, and Processes

Quasi-Three-Dimensional Analysis of Turbine Flow

A computer program reduces computer time and treats multiple elements.

Marshall Space Flight Center, Alabama

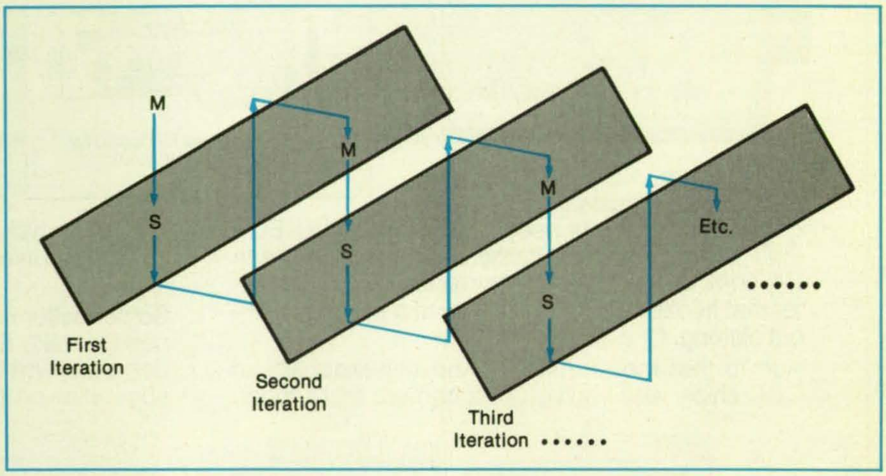
An improved design-analysis program for turbomachinery can be applied to multiple turbine elements simultaneously. The program enables continuous and coherent analyses rather than the previous piecemeal analyses of flow fields. The effects of upstream elements on downstream flow are thus taken into account automatically.

The quasi-three-dimensional program reduces the number of iterations needed to arrive at a final design and thus saves time and money. Moreover, the program can be restarted at several points in its execution sequence.

With its grid spacings tighter than those of older programs, the new program gives more accurate results. The program takes into account the behaviors of real gases, not just ideal gases.

The program consists of two parts. Meridional-plane analysis examines the flow from the hub to the tip surface. Streamline-surface-of-revolution analysis examines the flow from blade to blade. The analysis procedure follows these three steps:

1. Define station lines and run the meridional-plane analysis program for an annulus channel — one without blades. Let the leading and trailing edges be the station lines;
2. Insert one turbomachine element at a time, starting at the upstream end, and run the meridional-plane analysis program followed by the streamline-surface-of-revolution analysis program (see figure); and
3. Proceed to the next downstream assembly of elements and repeat step 2.



The **Flow About a Row of Turbine Blades** is computed by iteration of meridional-plane (M) and streamline-surface-of-revolution (S) analysis programs. The rectangular blade shape is schematic only.

This work was done by Wayne W. Hsu of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information, Circle 125 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-29280.

Designing Film-Cooled Turbine Disks

A technique would optimize weights and speeds of disks in film-cooled turbines.

Marshall Space Flight Center, Alabama

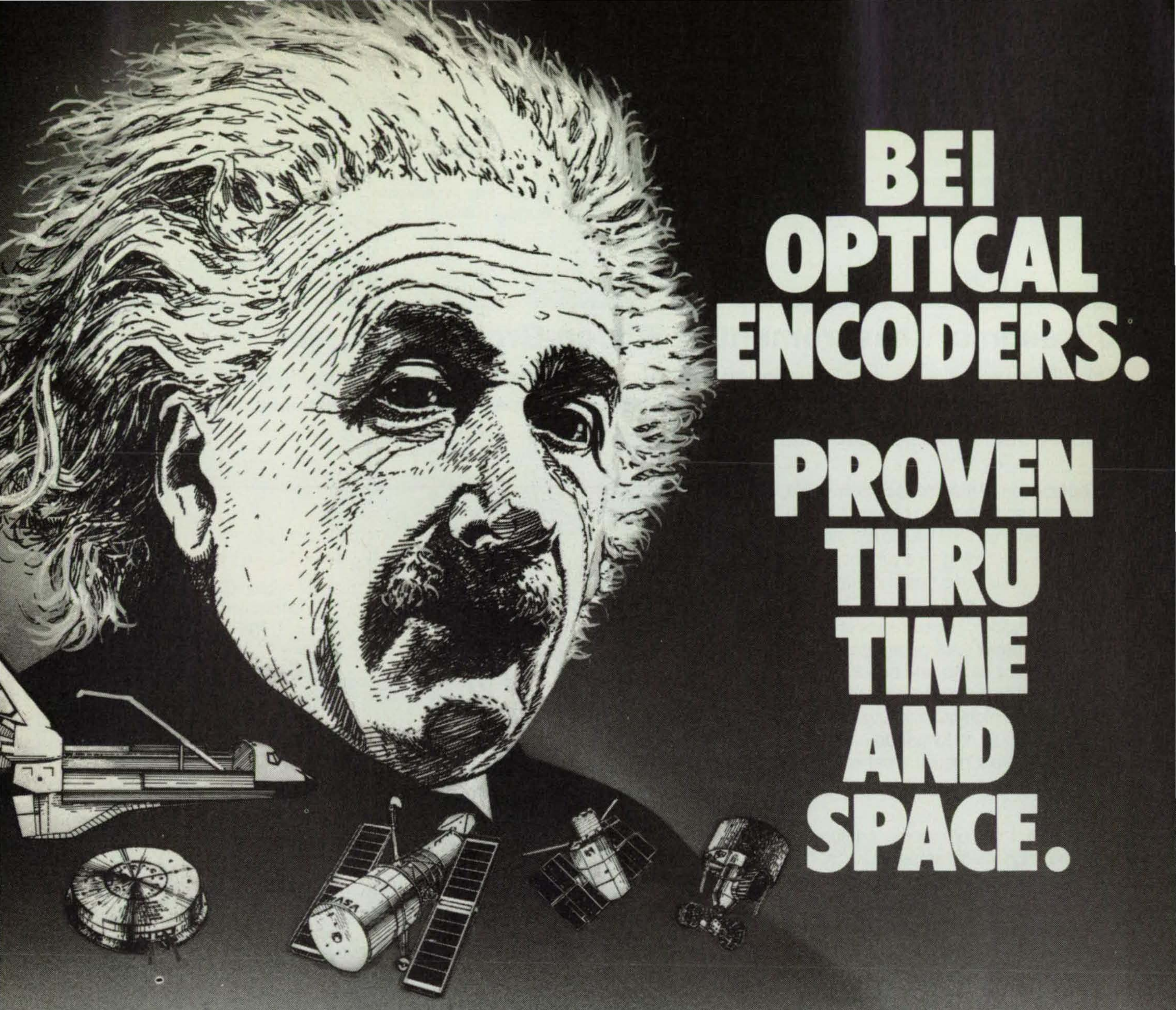
A proposed iterative approach to design would enable the shaping of turbine disks partly according to their temperature profiles. The method would balance the tangential stress in each disk with a measure of the temperature derived from film cooling as the film coolant travels radially outward from the source of coolant at the center of the disk. The rotor disk would be contoured to both the temperature profile and the ability of the disk material to withstand stress.

The method would provide an optimal match of power and efficiency with the thermal and structural properties of the turbine. It would avoid the extreme of low coolant flow, which gives rise to high temperatures in the disks and consequently unsafe operation, and of high coolant flow, which diminishes the performance of the turbine by diverting flow from the main power path.

Thus contoured or tapered, the disks would be relatively light in weight and could run at relatively high rim speeds approaching 2,000 ft/s (600 m/s). The new iterative approach would be suitable for the design of advanced stationary, aircraft, and rocket turbines.

This work was done by William R. Wagner 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-29287.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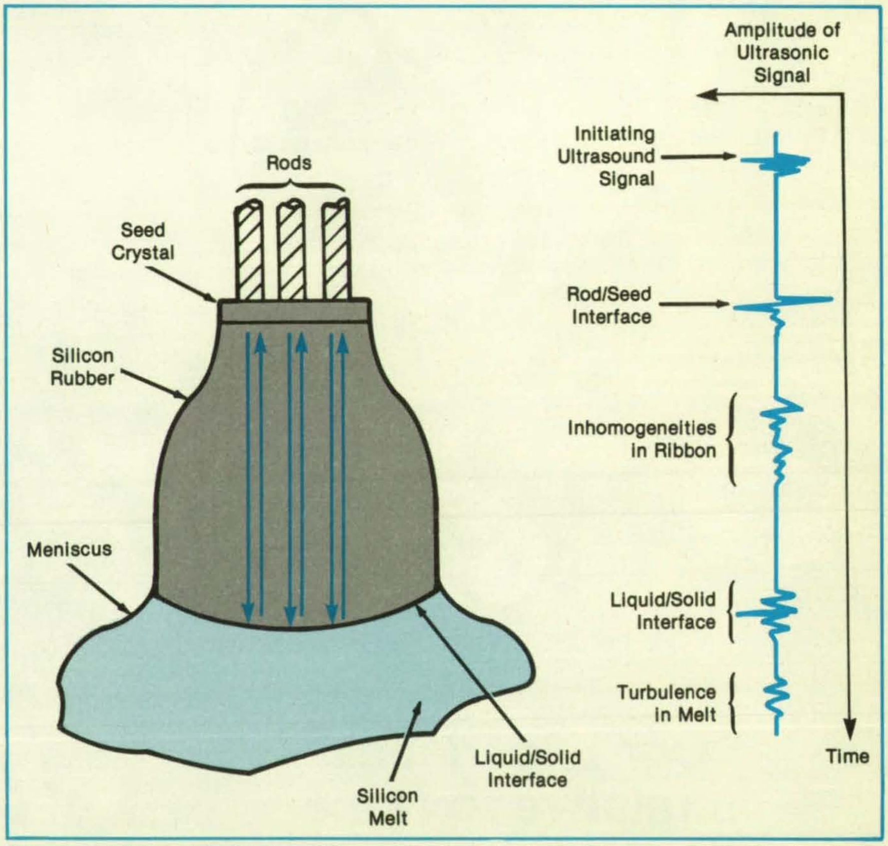
Ultrasonic Measurement of Silicon-Growth Interface

The difference in acoustic impedance between the liquid and solid would cause sonar reflections.

NASA's Jet Propulsion Laboratory, Pasadena, California

The position of the interface between a silicon melt and a growing ribbon of silicon can be measured with the aid of reflected ultrasound, according to a proposal. The reflections would also reveal characteristics of the ribbon and the melt. The data from the ultrasonic measurements would be used to control such parameters of the growth process as the rate of pull and the temperature of the melt, to promote fast production of high-quality single-crystal material. It would no longer be necessary to rely on indirect measurements to estimate the position of the liquid/solid interface.

To protect the ultrasonic equipment from the high melt temperature, buffer rods would be used to conduct the ultrasonic pulses to and from the silicon seed crystal. The seed would be immersed in the melt and withdrawn from it in the usual way, carrying a ribbon of single-crystal silicon with it. The ultrasonic pulses would be transmitted into the growing ribbon, then reflected from the features in the ribbon and melt back to the transducers (see figure). A sonarlike calculation based on the speed of sound in the medium and the elapsed times between transmission of a pulse and reception of its reflections would give the distances to the liquid/solid interface, inhomogeneities in the melt, and other features.



Ultrasound Pulses Would Travel Through Rods to a silicon ribbon growing by the dendritic-web process. The rods would return reflections of the pulses to the sonic transducers. The rods would isolate the transducers thermally, but not acoustically, from the hot silicon melt.

This work was done by Richard C. Heyser of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 131 on the TSP Request Card.*

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

Edward Ansell,
Director of Patents and Licensing
Mail Stop 301-6
California Institute of Technology
1207 East California Boulevard
Pasadena, CA 91125

Refer to NPO-17076, volume and number of this NASA Tech Briefs *issue, and the page number.*

Pyrotechnic Tubing Connector

A tool would form a mechanical seal at a joint without levers or hydraulic apparatus.

Lyndon B. Johnson Space Center, Houston, Texas

A proposed tool intended for use in outer space could be used on Earth by heavily garbed workers to join tubing in difficult environments. The tool, called Pyrotool, would be used with Lokring (or equivalent) fittings. Ordinarily, Lokring (or equivalent)

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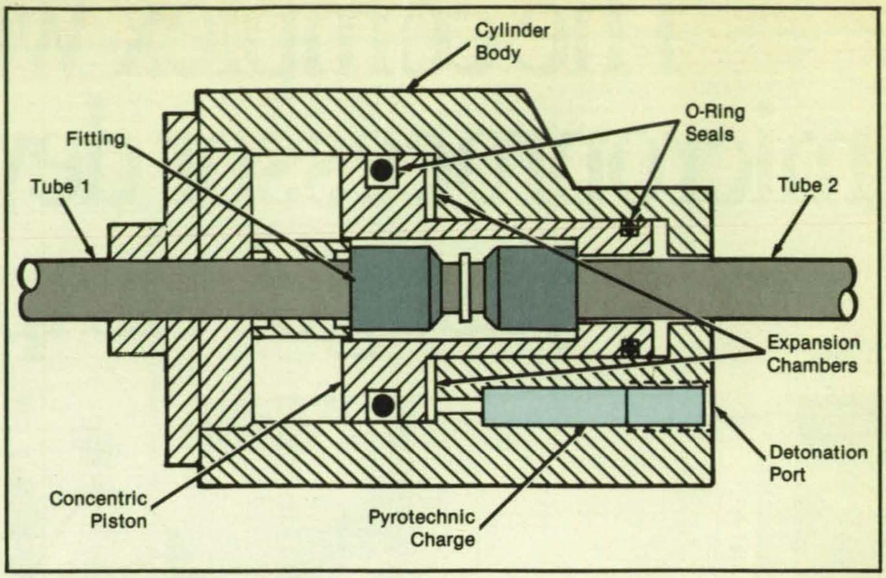
Circle Reader Action No. 612

fittings are slipped over the ends of the tubes to be joined and are compressed by a lever or by hydraulic pressure so that they form a leaktight connection.

The Pyrotool (see figure) would employ a pyrotechnic charge to compress the fittings. It would include a piston and cylinder containing the fittings and would be preattached to the end of a tube section. The user would insert the mating tube in the tool and fitting and would detonate the charge by mechanical or electrical means. The burning charge would generate pressure on the piston face, driving the piston toward the mating tube so that it compresses the fitting, thereby joining the tube ends.

The joining process would be completely contained and would create no debris. Once used, the tool would remain on the joined tubes.

This work was done by Thomas J. Graves and Robert A. Yang of **Johnson Space Center**. *For further information, Circle 15 on the TSP Request Card.*
MSC-21262



The **Piston Slides in the Cylinder** when pushed by gas from a detonating pyrotechnic charge. The impulse of the piston compresses the fittings, sealing them around the butting ends of the tubes.

Continuous Production of Refractory Microballoons

A continuous process would have economic and quality advantages over batch processes.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed continuous process for the direct production of microballoons from molten refractory materials has several advantages over the conventional batch techniques:

- The cost is lower.
- Microballoons can be produced with more uniform size and shape in large-quantity production.
- A wider range of sizes and shapes can be specified for large-quantity production.
- Temperature cycling is eliminated, reducing the cost of energy, thermal fatigue, and the frequency of replacement of parts between heating cycles.

Microballoon products made by the continuous process could include inertial-confinement fusion targets, thermal insulators, lightweight composites, impact absorbers, and containers for hazardous materials.

The general process is depicted schematically in Figure 1. Figure 2 illustrates in more detail the design of a version in which the microballoons are formed in a hollow jet. This version imposes the most formidable high-temperature design limitations and is the one most widely tested.

Melting and refining occur in a controlled-atmosphere vessel above a drop tower. The atmosphere is tailored for individual applications to influence the melt-chemistry and cooling characteristics of the freely falling microballoons. Within a single crucible, three induction heating coils and a common graphite susceptor independently heat the melting, refining, and nozzle/orifice regions. Temperature control is maintained in these three regions via thermocouples and furnace controllers. A rare metal, glass, or ceramic inner liner is used to contain the refractory melt.

A mechanism of rollers and packing glands feeds a polished rod of the raw material into the system. As it passes through the susceptor, the rod melts from radiant heat. The feed mechanism is connected to a melt-level controller consisting of a differential-pressure transducer and a ceramic tube immersed in the melt. The controller varies the raw-material feed rate and the pressure of the controlled atmosphere to maintain constant hydrostatic pressure, thereby assuring that an equal volume of liquid is issued to each microballoon.

Continuous melt refining is carried out in two stages:

1. Dissolved gas is flushed out with an inert gas, which is fed into the melt through a conventional bubbler. This step is necessary to control the chemistry of the melt and to minimize orifice clogging by such contaminants as oxides and nitrides. With molten metals, such dissolved gases as hydrogen could cause unwanted porosity

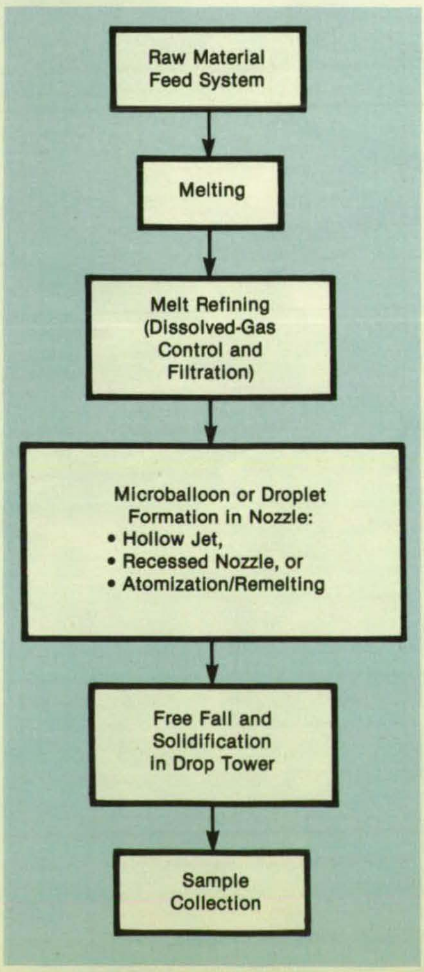
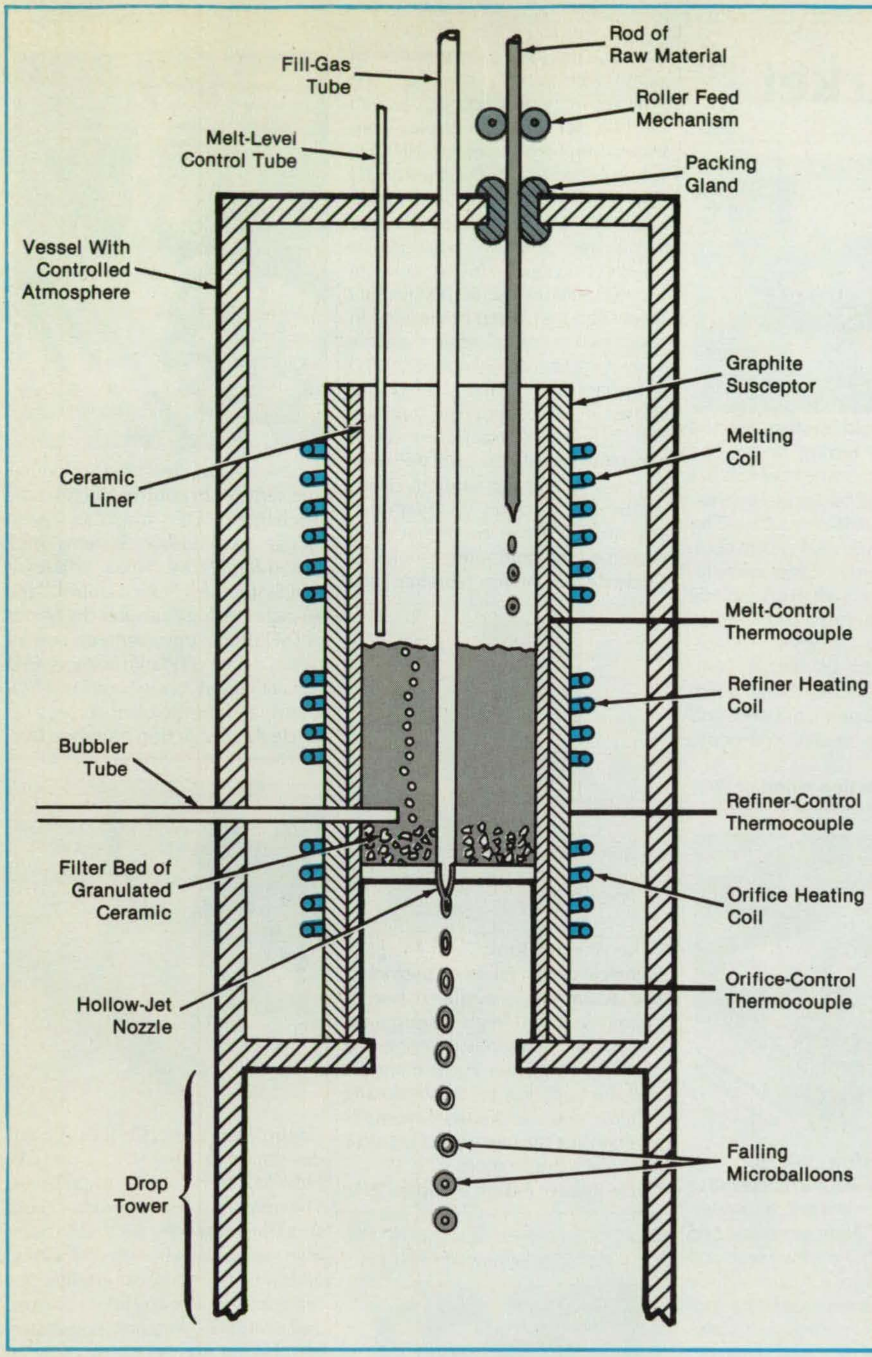


Figure 1. The **Continuous Process** is expected to produce high-quality microballoons at relatively low cost.



in the solidified microballoons. On the other hand, atomization/remelting processes rely on sensitively controlled levels of dissolved gas to form porosity upon solidification.

2. The melt is filtered by such conventional filters as glass or ceramic fiber meshes, monolithic porous ceramics, or granulated filter beds.

The lower end of the crucible is designed to accommodate a variety of nozzles for a variety of microballoon-generation techniques, using standard press fit or threading methods. Gas is introduced to the orifice through a ceramic or noble-metal tube passing along the axis of the crucible.

After issuing from the nozzle orifice, the microballoons solidify by cooling in the drop tower. As in conventional batch processes, the drop tower has a controlled atmosphere, and its temperature profile is adjusted to meet specific applications.

This work was done by Christopher H. Schilling, Mark C. Lee, and Taylor G. Wang of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 13 on the TSP Request Card.*

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

Edward Ansell,
Director of Patents and Licensing
Mail Stop 301-6
California Institute of Technology
1207 East California Boulevard
Pasadena, CA 91125

Refer to NPO-16679, volume and number of this NASA Tech Briefs *issue, and the page number.*

Figure 2. **Continuous Hollow-Jet Process will produce microballoons of refractory metal.**

Automatic Inspection During Machining

Machine tools can inspect their work under numerical control.

Marshall Space Flight Center, Alabama

In an experimental manufacturing process, a numerically-controlled machine tool is temporarily converted into an inspection machine by installing electronic touch probes and specially-developed numerical-control software. The software drives the probes in paths to and on newly machined parts and collects data on the dimensions of the parts.

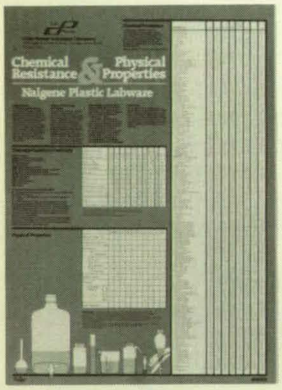
The conversion makes it unnecessary to remove the parts from the machine tools, set them up for inspection, and reset them on the machine tools for further processing. The probes and software can be used on three-, four-, and five-axis numerically-controlled machine tools like mills, vertical turret lathes, and jig borers.

Specifications documenting features to be measured and accuracies are developed for each type of machine. The numerical-control tapes for a given machine type are then checked to determine which of those features already on tape meet the criteria for inspection of the part on the machine. A numerical-control programmer then uses the available features to write an inspection tape. With new software, the machine tool machines a part, puts its cutters away, inserts the inspection probes to inspect the part, and reports results of the inspection immediately.

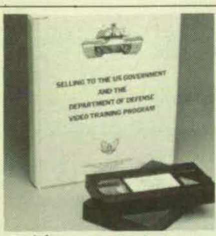
This work was done by Clyde L. Ransom of Rockwell International Corp. for **Marshall Space Flight Center**. *No further documentation is available.*
MFS-29362

New on the Market

The Series 10000™ family of **Personal Supercomputers™** from Apollo Computer Inc., Chelmsford, MA, puts supercomputer-class power at the fingertips of every user. The new computers are based on a PRISM (Parallel Reduced Instruction Set Multiprocessing) architecture featuring multiprocessing capabilities, parallel instruction single-cycle execution, new data flow compiler technology, and a 64-bit architecture. Designed for the office environment, Apollo's Personal Supercomputer family offers up to 128MB of main memory, 3 gigabytes of local mass storage, and a 128KB instruction cache and 64KB data cache to boost bandwidth.
Circle Reader Action Number 778.

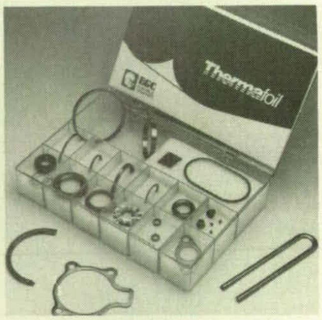


Cole-Parmer Instrument Co., Chicago, IL, is offering a free 20" by 28" **wall chart featuring a chemical resistance summary.** One section of the chart describes the effects of chemicals on plastics, and explains oxidation, depolymerization absorption, permeation dissolution and stress-cracking. Another section illustrates the chemical resistance of plastic resins.
Circle Reader Action Number 800.



A new **videotape training program** designed to help companies sell their products and services to the military market is now available from Federal Procurement Services, Rockford, IL. The two-hour tape comes with a 500 page training and reference manual that lists all major military and civilian buying locations. Federal Procurement Services also offers a videotape series on how to meet the government's stringent quality and paper work standards.
Circle Reader Action Number 792.

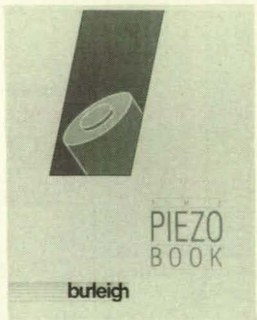
A new **handheld system** for the **nondestructive testing** of bonded metallic and composite materials has been introduced by Laser Technology Inc., Norristown, PA. The BONDSCAN inspection system combines an infrared video camera, memory unit, and built-in heat source to instantly capture and display material defects. Designed especially for evaluation of aircraft components, the BONDSCAN can rapidly detect delamination, unbonds and impact damage in any composite part.
Circle Reader Action Number 782.



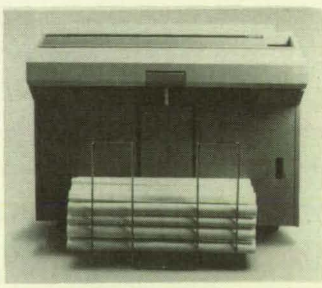
EGC Enterprises Inc., Mentor, OH, has developed a **seal and gasket kit** to assist design engineers in understanding how homogeneous and composite flexible graphite seals and gaskets can provide solutions to their fluid sealing problems. Each kit contains 18 sample products and a product guide that outlines the properties of flexible graphite. The kits are free to qualifying engineering departments.
Circle Reader Action Number 796.

Digital Equipment Corporation, Maynard, MA, has created an advanced version of its **VAX FORTRAN compiler** that allows application programmers to spread the execution of programs across multiple processors, thereby speeding job execution on VAX multiprocessor systems. The new software features directed decomposition, which enables an application developer to select parts of a program to run in parallel on different processors. This advance complements Digital's VMS Version 5 multiprocessing capability, which increases system throughput by executing several jobs at once.
Circle Reader Action Number 786.

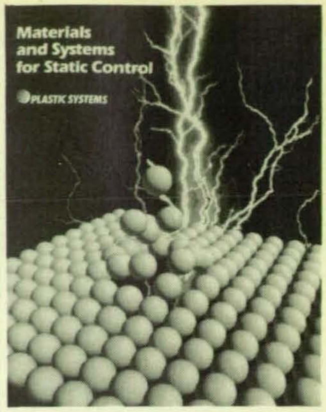
The 3D graphics performance of super workstations can now be achieved on personal computers with the **Nth 3D Engine™ display controller** from Nth Graphics, Austin, TX. When added to a PC/AT, the Nth 3D Engine produces a complete $13,000 CAD workstation that provides wire frame and shading functions at speeds previously found only in $50,000 stations. An 80,000-line 3D object can be rotated or zoomed in about two seconds, while the well-known "Teapot" model (1200 polygons) can be flat shaded and rotated in ¼ second. The standard Nth 3D Engine transforms 5,000 constant-shaded, 500-pixel polygons per second, and also supports conic, and bicubic structures along with text, any of which can be interactively picked on the computer screen.
Circle Reader Action Number 780.



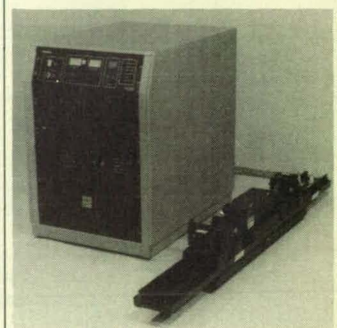
"The Piezo Book," a 14 page **technical design guide on piezoelectric actuators**, is available free of charge from Burleigh Instruments, Fishers, NY. The guide describes the properties of piezoelectric materials and their application to positioning systems, and also discusses methods for choosing the best type of actuator for a given application.
Circle Reader Action Number 794.



The world's first **wide format laser plotter** has been introduced by Versatec, Santa Clara, CA. The Versatec 8836 laser plotter draws at 400 points per inch resolution and produces quality plots at a constant speed of one inch per second. E-size (34"x 44") drawings can be plotted in under 70 seconds, while D-size (22"x34") drawings take less than a minute. Targeted at CAD users, the 8836 accepts industry-standard data formats such as Versatec Random Format and 906/907 pen plotter formats. Support for the HP-GL data formats is also available.
Circle Reader Action Number 790.



A new catalog describing products and services **to control electrostatic discharge** (ESD) is available free of charge from Plastic Systems Inc., Grand Rapids, MI. Titled "Materials and Systems for Static Control," the 48 page catalog illustrates the effects of ESD on the environment, and includes details on Plastic Systems' ESD consulting services, educational programs, and on-site plant surveys.
Circle Reader Action Number 784



Control Laser Corp., Orlando, FL, has developed a new family of **CW Nd:YAG lasers** called the 600 Series. The new lasers feature modular construction, easy-to-service subassemblies with plug-in boards and wiring, an innovative modular cooling system for fast water and filter changes, and a MOSFET switching power supply offering excellent pulse stability and extremely low ripple. Applications of the 600 Series include micromachining-scribing, engraving, trimming, soldering, drilling, and welding.
Circle Reader Action Number 788.

A **computerized diagnostic system** called "Charley" that can predict when machines need maintainance or repairs has been introduced by the General Motors Corp., Warren, MI. The cornerstone of the process is a knowledge base, known as an expert system, that emulates the human reasoning process. Using over 1,000 rules of vibration analysis, Charley examines the readings of a machine's vibration patterns to pinpoint such problems as unbalance, misalignment, structural weakness, and bearing wear or failure.
Circle Reader Action Number 798.

Subject Index

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NASA NEWS BRIEFS

NASA plans to issue a request for proposals (RFP) on June 29th for design and development of a Space Shuttle Advanced Solid Rocket Motor (ASRM). The motor will feature a segmented design to improve reliability and safety, and is expected to increase Shuttle payload by 12,000 pounds. NASA's estimated cost for the ASRM is just under $1 billion, including $300 million for construction of a production and testing facility.

Growth in trans-Pacific air travel would justify designing and building a new supersonic passenger airliner to be placed into service by the year 2010, according to results of an 18-month study sponsored by NASA's Langley Research Center. The supersonic transport envisioned in the study would cruise at two to three times the speed of sound and carry three times as many passengers as the Concorde.

A three-dimensional perspective display system has been developed by NASA's Ames Research Center to aid close-in spacecraft maneuvers. The computer-generated display can precisely depict a spacecraft's position relative to other vehicles and objects, allowing rapid, accurate monitoring and response. If placed aboard Space Station, the display would help in conducting maneuvers within one mile of the orbiting platform, according to Steven R. Ellis, the system's inventor.

The 25th anniversary of NASA's Technology Utilization Program will be spotlighted at Spinoff '88, the Thirteenth International Symposium on Technology Transfer and Annual Meeting of the Technology Transfer Society, to be held June 29-July 1 in Portland, OR. Other conference highlights include a report on technology transfer in the People's Republic of China and symposia on the commercialization of the Strategic Defense Initiative (SDI). For further information contact Richard Hampton, National Organizing Chairman, at (503) 244-3393. □

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HEADGEAR THAT HOLDS EVERYTHING AN ASTRONAUT NEEDS TO TACKLE SPACE MISSION PROBLEMS.

Keeping track of the millions of instructions needed to maintain a space station, monitor its systems and conduct research will be no easy task. But McDonnell Douglas space flight specialists have found a way to store massive amounts of data on computers linked to a miniature TV mounted on the astronaut's helmet. Detailed instructions needed to get the job done are instantly available at the touch of a button, leaving the astronaut free to move about the station and tackle intricate space mission tasks. Headgear data displays being developed by engineers at McDonnell Douglas–for spacecraft, aircraft and maintenance–save time and improve performance.

For more information, write:
Data Display, McDonnell Douglas,
Box 14526, St. Louis, MO 63178.

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