NASA Tech Briefs

National Aeronautics and Space Administration

Fall 1985
Volume 9 Number 3

Lewis Research Center: A Multi-Faceted Approach to Technology Transfer

NASA

run America's in space:

by electromagnetic containerless undercooling. This has been demonstrated on Earth with a sphere of molten tungsten (melting point: 6,170°F). But we've discovered in GE research labs, the electromagnetic power needed to position spheres of molten metals on Earth makes their manufacturing cost prohibitive. In space, microgravity solves that problem.

What we learn in future shuttle flights will be the basis for work on the first permanent space station. We hope by then to be planning actual production of purer metals, stronger alloys, new crystals.

Growing gallium arsenide: a gold mine in space.

The benefits of gallium arsenide production in space — a potential 7,000% increase in yield, for example — are clearly astronomical. And the possibility of increasing computer chip capacities one hundredfold (and of making similar improvements in microwave and laser technologies) long ago led GE into gallium arsenide microelectronics research.

GE has prepared a concept study for NASA on automating production of gallium arsenide ingots in space. That study also addresses the feasibility of automating production of the ingots into finished and tested computer chips ready for use when they arrive on Earth.

Manufacturing products in space for use on Earth.

The part GE has already played in making it possible to manufacture space-made products for use on Earth is similar to the part we will play on the "producing" end of the permanent space station.

In 1978, we began basic development of the apparatus for manufacturing latex microspheres 1/2500 of an inch in diameter — the most perfectly uniform spheres ever made, and impossible to make on Earth (18,000 microspheres can fit on the head of a pin).

The apparatus GE designed and built worked successfully on all four 1982 and 1983 shuttle flights.

NASA has turned the latex microspheres over to the Bureau of Standards for packaging and sale.

So far, a university and various businesses in health and microscopy are interested in the first products manufactured in space.

Improving life on Earth by manufacturing in space.

By creating a space station designed to produce a diversity of products such as purer vaccines, new drugs, stronger self-lubricating metals, new alloys which cannot be made on Earth (400 have been identified so far), NASA will be helping to improve our life on Earth. The value of such work to all of us is incalculable.

General Electric has both experience and commitment. As one of the world's largest diversified manufacturers, with an annual R&D budget larger than those of many countries, we will build on GE experience with all the technology, ingenuity, and determination we have to make America's first permanent space station a productive national asset.

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Valley Forge, PA.

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NASA Tech Briefs

FALL 1985
Volume 9
Number 3

National Aeronautics and Space Administration

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Published by:
Associated Business Publications
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NASA Tech Briefs are provided by the National Aeronautics and Space Administration, Technology Transfer Division, Washington, DC:
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Special Features and Departments

ON THE FRONT COVER:
When the Jupiter-bound Galileo mission is launched from the Space Shuttle in May, 1986, its 15.7-foot diameter flexible antenna will unfurl in space. Tiny black spots on the antenna's mesh are calibration targets for measurements that are fed into a computer. The computer output will tell engineers where to change tension on the white cords to achieve the antenna's desired shape. The Galileo antenna will transmit and receive S- and X-band frequencies at a maximum data rate of 134 kilobits per second from Jupiter to Earth. At the top of the antenna's feed tower are components of the Galileo plasma wave experiment. The Galileo mission is managed by Jet Propulsion Laboratory. For more on JPL, see Mission Accomplished, page 195 this issue.

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Technical Section Thumb Index

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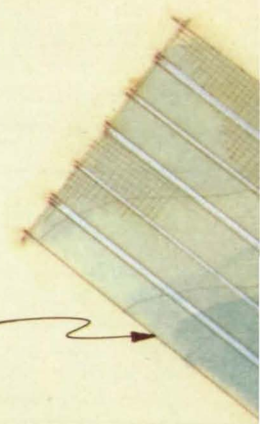
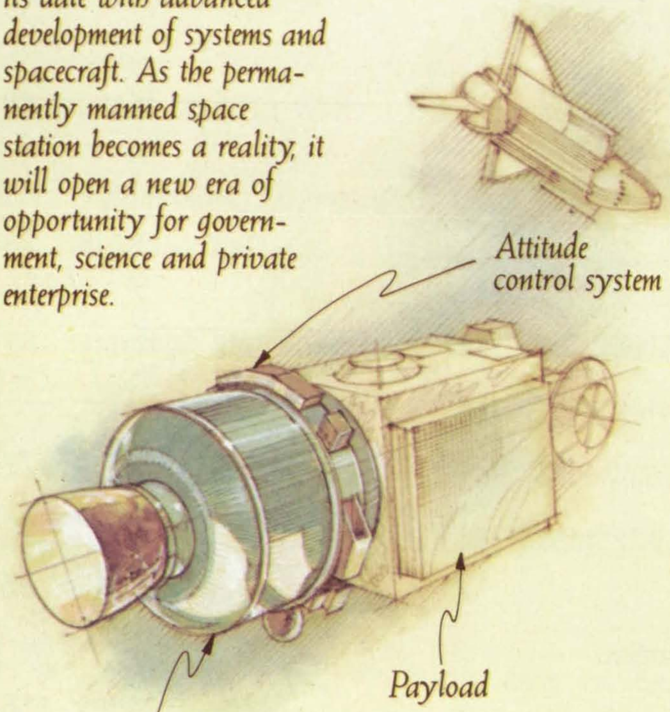
The next step: a space station that means business.

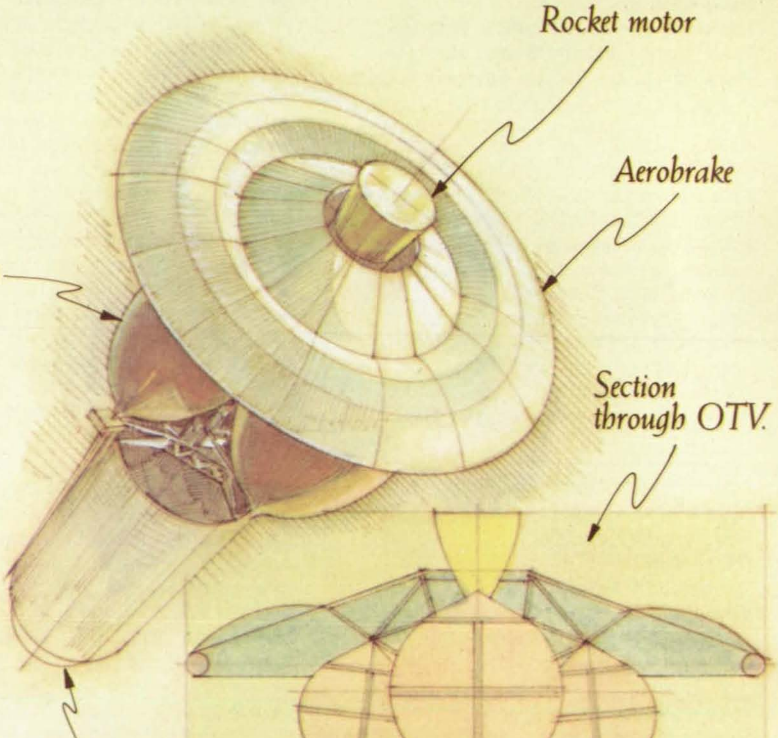
NASA has targeted the 1990's for deployment of a permanently manned space station. Martin Marietta is aiming to help NASA meet its date with advanced development of systems and spacecraft. As the permanently manned space station becomes a reality, it will open a new era of opportunity for government, science and private enterprise.





Transfer Orbit Stage (TOS)

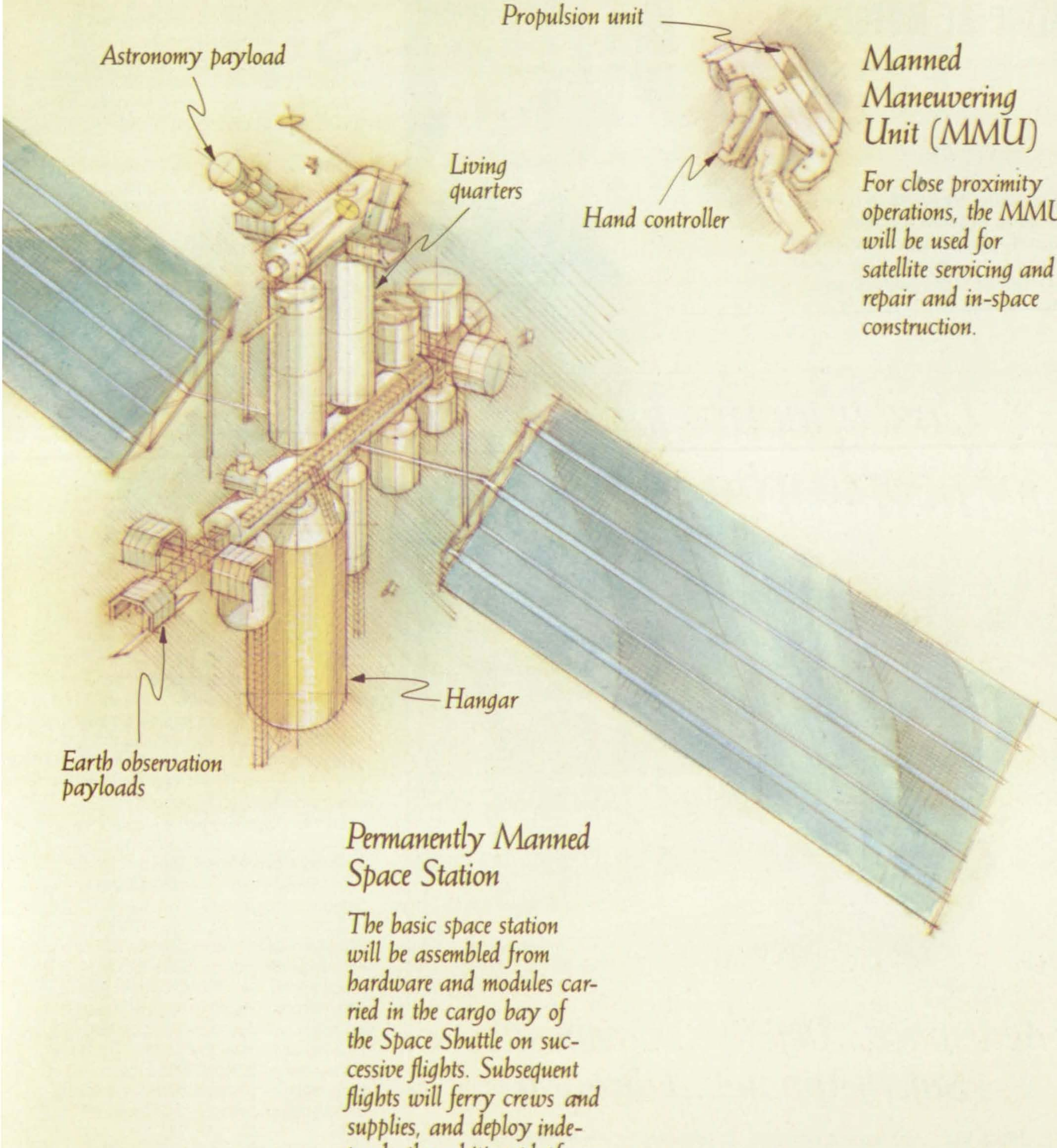
The TOS will boost spacecraft and payloads from the Shuttle's low Earth orbit to geosynchronous transfer orbit.



Orbital Transfer Vehicle (OTV)

The mission of this reusable vehicle is to boost spacecraft to high orbits, including the geosynchronous band. The OTV will fly 20 to 30 missions before refurbishment.

OUR COMMITMENT IS TOTAL. OUR CAPABILITIES



Manned Maneuvering Unit (MMU)

For close proximity operations, the MMU will be used for satellite servicing and repair and in-space construction.

Permanently Manned Space Station

The basic space station will be assembled from hardware and modules carried in the cargo bay of the Space Shuttle on successive flights. Subsequent flights will ferry crews and supplies, and deploy independently orbiting platforms.

MARTIN MARIETTA

Martin Marietta Aerospace
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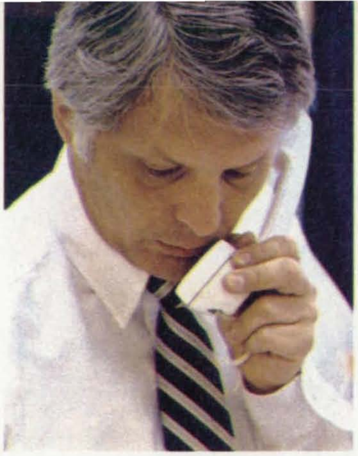
ARE PROVEN. OUR MISSION IS SUCCESS.

Editorial Notebook

In this issue, *NASA Tech Briefs* is pleased to present a guest editorial—a message from Joseph R. Wright, Jr., Deputy Director of the Office of Management and Budget (OMB).



Stop a passerby on the street and ask what qualities best describe NASA. Chances are he or she will say, "pioneering," "ambitious," or "capable," and they would be right—for NASA is all of these. But NASA's reputation for leadership has not been confined just to technical achievement. Successful space exploration has been as much a management victory as a technological victory.

NASA's innovation in management areas is evidenced by the last two issues of *NASA Tech Briefs,* which now wears a bright new face. Not only were they issued in a more timely fashion and to an expanded audience, but not one penny was spent by the Federal Government to publish the magazines.

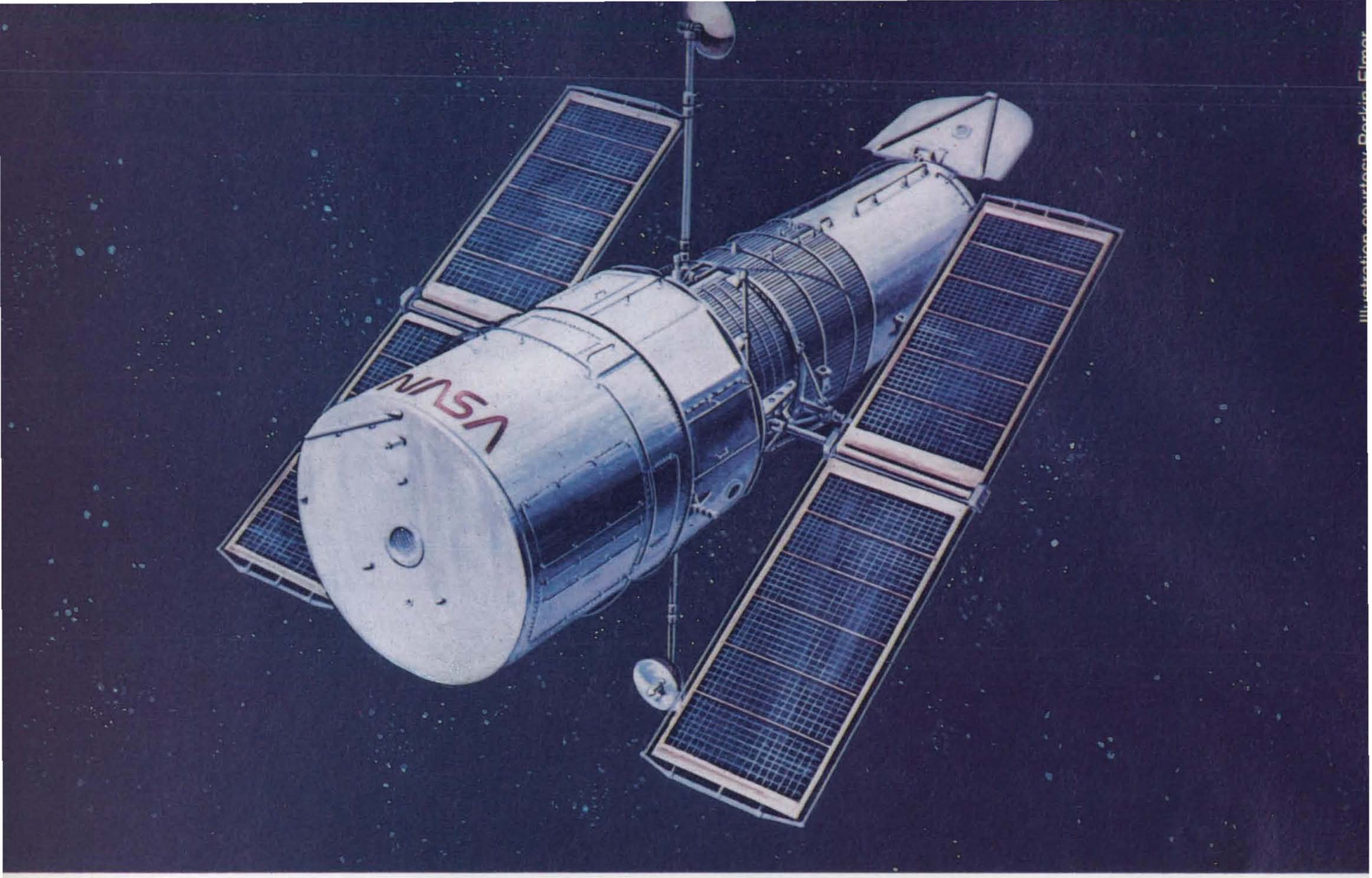
NASA's partnership with a private company to accomplish this is a small but concrete example of how this Administration is restoring balance between the public and private sectors—between what the Government either can do best or must do for national security reasons, and what the private sector can perform best.

As a result of our space exploration and development program, a bounty of technological innovations has been developed. Many are being spun off to the public and private sectors, benefitting nearly every facet of our lives. *Tech Briefs* was conceived to play a valuable role in sharing and augmenting the benefits of space technology—a role that is being enhanced as a result of the current contract arrangement.

Let me don my green eyeshade for a moment to note, from a Federal management point of view, why the *NASA Tech Briefs* arrangement is advantageous to taxpayers. First, it renders unnecessary the 75,000 circulation ceiling which OMB had imposed to help control printing costs to the Government. Lifting the lid allows wider dissemination of valuable information gained in the space exploration process, thus better fulfilling the original Congressional mandate. Now, with private sector publication, total qualified circulation of 300,000 is planned by the end of 1987.

Secondly, Uncle Sam is not only saving half a million dollars a year in printing costs, but also stands to begin collecting royalties after two years. Thirdly, subscribers are getting a higher quality product, with more color and better paper stock. One reader apparently wrote in suggesting a similar contractual arrangement for the *Congressional Record* in the hope it too could be made more readable! And fourth, printing back-ups have been eliminated so that the publication will arrive in readers' hands much quicker—so much quicker that some recipients actually received

(Continued on page 9)



NASA Hubble Space Telescope

Editorial Notebook

(Continued from page 6)

the Spring '85 private-sector issue before the Summer '84 Government-printed issue.

In diverse corners of Government, partnership with the private sector is more and more becoming the way of doing business. President Reagan remains firm in his belief that the road to sustained economic health is paved not with Government expansion, but by a growing, robust private sector that seeks and meets new challenges. This Administration is not giving lip-service to increased reliance on the private sector; it is demonstrating that it can work. For example, private travel agencies are serving Federal agencies' needs in more than 500 sites now—triple the number of 1980. As a result, Federal agencies were able to abolish 17 in-house travel offices in 1984, saving $1.2 million a year.

Federal loan officers are now "prescreening" loan applicants and contractors bidding on Federal projects, to eliminate individuals and firms that are poor credit risks. More than two million accounts from six Federal agencies are being shared with seven private-sector credit bureaus to build an information base on credit-worthiness which must be checked before a loan or contract is granted. Previously, Federal and private loan officers had no way to obtain from other Federal agencies the credit experience of applicants for financial assistance or contracts.

Other examples abound. In 1982 the National Consumer Cooperative Bank was turned over to the private sector, eliminating a $122.1 million taxpayer subsidy. The U.S. Department of Agriculture's burgeoning Crop Insurance program is now 70 percent provided by private insurers, as opposed to three percent in 1981. Within a year or two, all Federal crop insurance will be written by private companies.

The thread that runs throughout the President's privatization initiatives is confidence in the private sector to perform well at a competitive cost. We in Government are just beginning in earnest to harness the capabilities of the private sector for delivery of essential services to the public.

NASA Tech Briefs is just one periodical, and private publication of it is just one small step. But it's in the right direction. And who knows better than NASA that small, first steps can be enormously important over time. □

President Ronald Reagan greets Joseph R. Wright, Jr.

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gonna knock your socks off.

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Speed. The 4361 features a high-speed cache buffer. It has a separate floating-point processor to handle multiplication. And it executes the 70 most-used instructions in the hardware. No wonder the 4361 will turn in a Whetstone that will knock your.... You get the idea.

Precision and accuracy. The 4361 has advanced 32/64-bit architecture. It can handle 31-decimal-digit precision. And as for accuracy, IBM's high-accuracy arithmetic facility (ACRITH) includes 22 special floating-point instructions that process iterative calculations accurately. Or notify you if the accuracy you need can't be maintained.

Ease of use. The 4361 needs no pampering. Install it almost anywhere—in a corner of your office, for example. And the 4361 can run unattended, with no onsite DP specialist.

To make life easier yet, there's the IBM Engineering/Scientific Support System (E/S^3)—a consistent, menu-driven interface for interactive users. E/S^3 is rich in function and offers an open architecture so you can add applications easily. It handles graphics, text and data manipulation. And it supports a wide range of administrative applications.

Attachability. What would you like to attach to your IBM 4361? Lab instruments? Personal computers? ASCII-oriented devices? Are they Unibus-oriented? Or do they use any other serial digital interface? The 4361 welcomes them all. It attaches to IBM and non-IBM devices of all kinds.

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NASA News in Brief

"Made-In-Space" Label Premieres...

Billions of tiny polystyrene spheres, manufactured aboard the Space Shuttle Challenger, are currently being marketed in a cooperative venture linking NASA and the National Bureau of Standards (NBS). Commercial producers of finely-ground powder products, such as paint pigments, inks, toners, chemicals and cosmetics, are among the first customer for the space material.

Ernest Ambler of NBS says, "They will be used to improve the microscopic measurements made throughout the economy in electronics, medicine and other high technology areas," adding that the spheres are being offered by NBS as a standard reference material.

The space material has been packaged in 600 units that retail for $384 each. The units contain approximately 30 billion polystyrene spheres packed in water. Each sphere measures 10 micrometers, or 1/2500 of an inch, in diameter. Proceeds from the sales are shared equally by NASA and NBS.

The chemical process for manufacturing the spheres was developed for NASA by Lehigh University. The low-gravity environment of the Space Shuttle produces spheres which are uniform in shape and size, unlike those produced on Earth.

According to NASA administrator James M. Beggs, "This is the first of what we expect will be a long line of products to carry the made-in-space label."

Teacher In Space Announced...

Sharon Christa McAuliffe, a social studies teacher at Concord High School, Concord, New Hampshire, will venture out of the classroom and into space as part of NASA's Teacher in Space Project. Ms. McAuliffe, who's known as Chris, is scheduled to fly aboard the Space Shuttle mission in January, 1986.

She was selected in a process that began with 10,000 applications from elementary and secondary school teachers in all 50 states. From these, the Council of Chief State School Officers selected 114 nominees, 10 of whom became finalists.

The finalists traveled first to NASA's Johnson Space Center in Houston for medical evaluations and initial flight suitability testing, and then to Washington for interviews with the NASA Space Flight Participant Committee.

Barbara R. Morgan of McCall-Donnelly Elementary School, McCall, Idaho, was designated the back-up candidate.

Satellite Rescue...

The rescue of satellites has been in the news following the dramatic recovery of the stranded Palapa B-2 communications satellite by the crew of the Space Shuttle Discovery. Now a rescue *by* satellite is evening up that score. Thanks to COSPAS/SARSAT, an international satellite rescue system, skipper Jack Boye is alive and well in Princeton, New Jersey. Boye had been sailing his sloop "Dear America" from Miami to New York when its radio failed. Without the radio, Boye was unaware that what appeared to be a rainstorm was actually a dangerous low pressure system. The storm wrecked the sloop's electrical and electronic systems, before capsizing the boat. At this point, Boye activated a radio beacon to alert search and rescue authorities of his life-threatening situation.

An orbiting Russian search and rescue satellite received the distress signal and beamed it to the U.S. to alert rescue forces here. A Coast Guard aircraft located the sloop about 140 miles off Cape Henry, Virginia.

The COSPAS/SARSAT system consists of two U.S. and three Soviet satellites equipped with search and rescue signal receivers. Canada and France are the system's other major participants. To date, the system has been instrumental in the rescue of more than 400 persons, among them Boye who calls himself SARSAT's "hardiest and most thankful user."

In Other Satellite News...

The International Maritime Satellite Organizaton will launch two communications satellites from NASA's Space Shuttle—one in July 1988 and the other in mid-1989.

The satellites' spacecraft will be launched from a low-Earth orbit by the Space Shuttle. The spacecraft will be built by British Aerospace Corporation, and Hughes Aircraft will supply the communications payload. The PAM-D, a spin-stabilized upper stage rocket built by McDonnell Douglas will boost the satellite's spacecraft from low-Earth orbit into a geosynchronous transfer orbit.

The launch of these satellites will enhance the already extensive maritime satellite network, which services 43 member nations, including the United States.

Satellite to Meet Comet...

The International Ultraviolet Explorer (IUE) satellite has made its first observations of the comet Giacobini-Zinner, en route to their meeting on September 11, 1985.

The historic satellite-comet encounter, which will occur approximately 6,200 miles from the cometary nucleus and 44 million miles from Earth, will provide the first close look at the make-up and dynamics of a comet's tail.

The satellite's initial observations were made while the comet was approximately 87 million miles from Earth, on the inbound leg of its orbit between the Sun and Jupiter.

Course corrections for the satellite were determined from these initial observations, and implemented by IUE Mission Control at NASA's Goddard Space Flight Center.

The IUE spacecraft mission is a cooperative venture of the British Science Research Council, the European Space Agency and NASA. □

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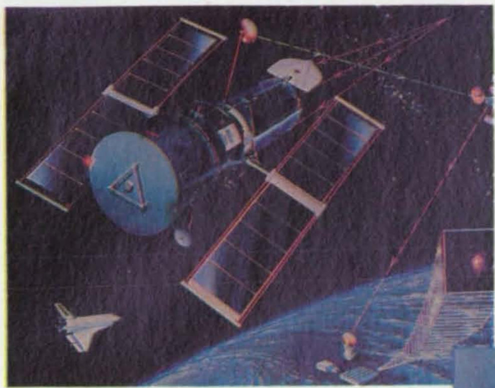

Zero Gravity Enterprises

That's the projected Gross National Product of U.S. business in space in just fifteen years, according to the Congressional Space Caucus.

$300 billion. . . and ten million new jobs for space construction, manufacturing, materials, medical products, metallurgy, and communications.

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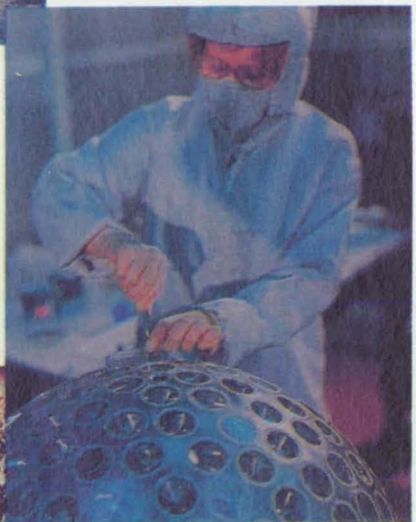

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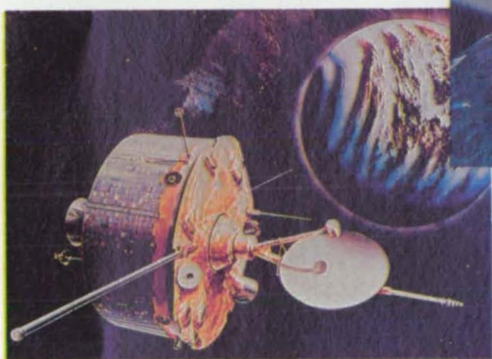

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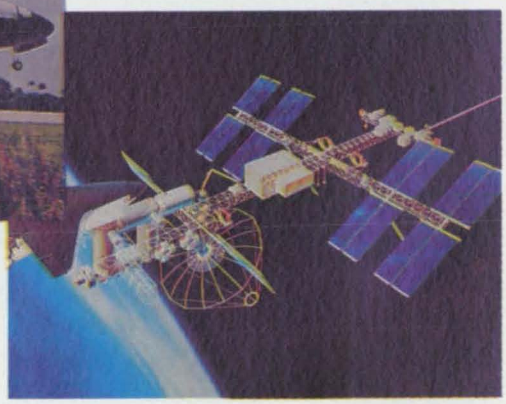

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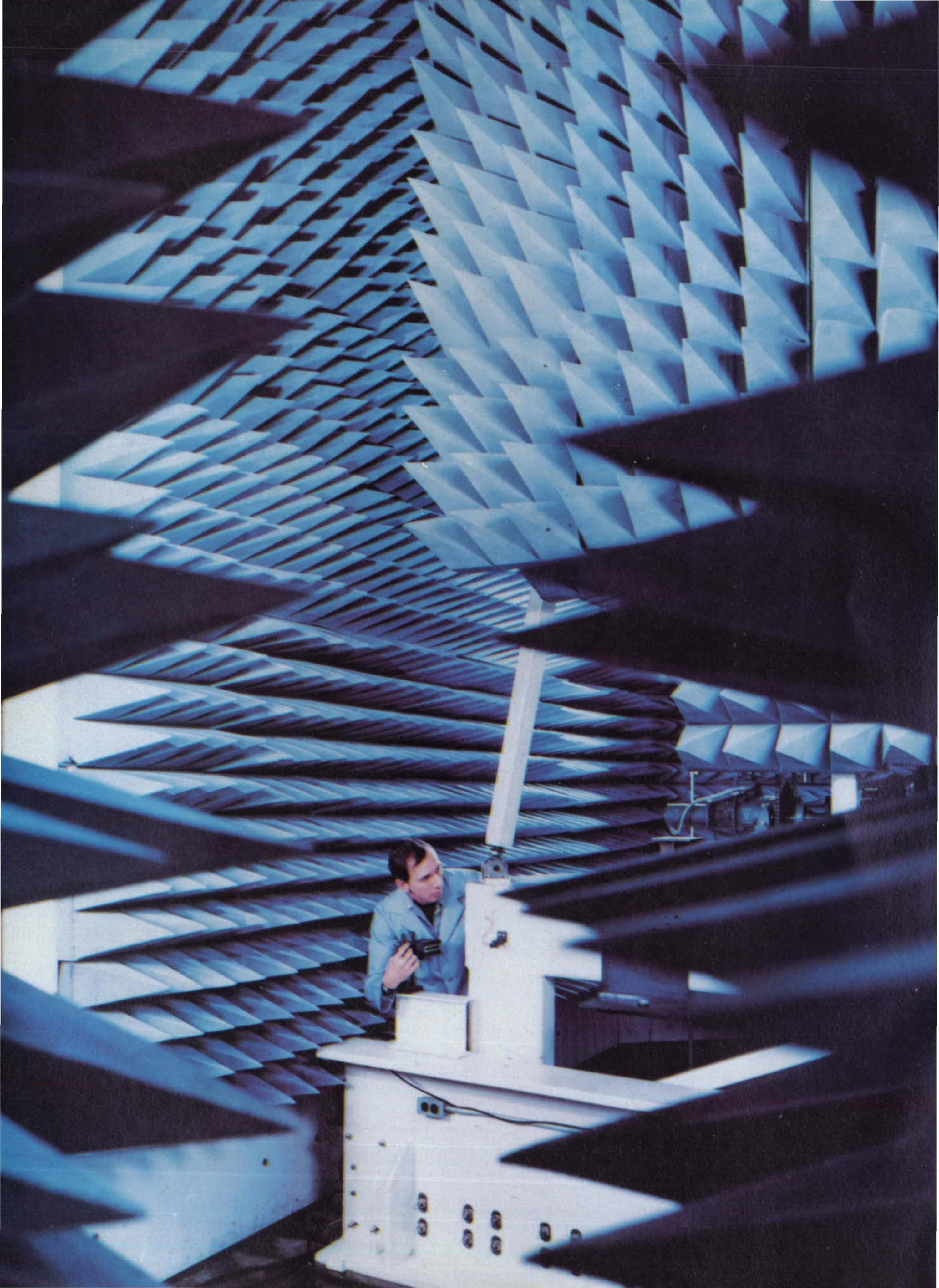
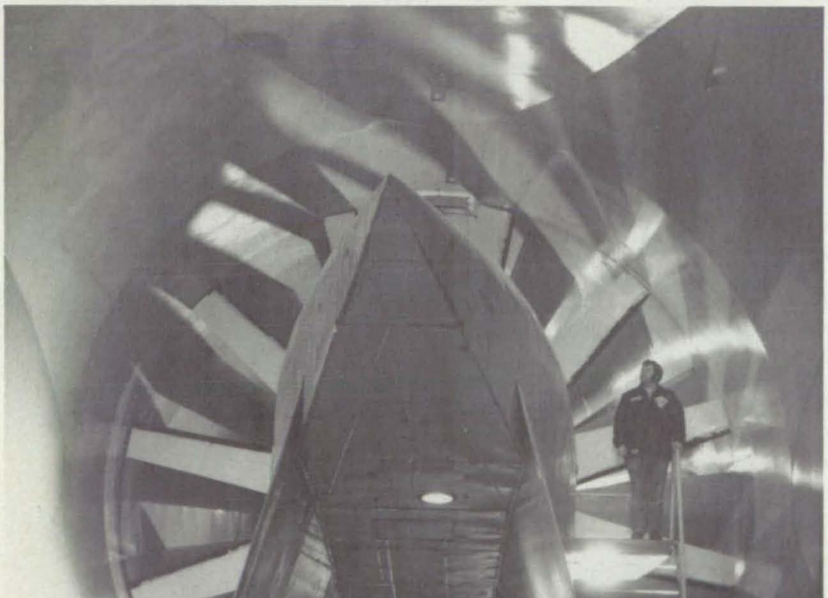


LEWIS—

NASA's Powerhouse Research Center

This is the third installment in a series profiling NASA's field research centers, and part of *NASA Tech Briefs'* effort to acquaint its readers with NASA itself, in addition to its technology transfer process.



CONTROLLED ENVIRONMENTS: At left, a technician adjusts a laser measuring device in Lewis' Near-field Antenna Test Facility. The foam cones on the walls absorb radio waves generated by the antenna, and prevent them from being reflected and measured twice. Above, the Lewis Icing Research Tunnel, the only facility of its kind, has been operating since 1944. During WWII, tests conducted there provided insight into aircraft icing problems.

On the eve of WWII, NASA's predecessor, the National Advisory Committee for Aeronautics (NACA) recommended that Congress allocate additional funds for new aeronautical research facilities. In addition to expanding the work then being done at Langley, the Committee recommended the construction of a new laboratory, and proposed a site in California's Santa Clara Valley. Ground was broken on December 20, 1939 for what would become the Ames Research Center.

Six months later, the Second World War had begun in Europe. Again, NACA approached Congress for additional funds, this time stressing the urgency of their request. There had been a considerable expansion of European aeronautical research facilities after WWI, so even at the outset it was clear that WWII would be as much an air war as it would a land or sea war. In June, 1940, Congress authorized the construction of the Aircraft Engine Research Laboratory. A site adjoining the Cleveland, Ohio, municipal airport was selected and ground was broken there on January 23, 1941. Before the year was out, the United States would declare war on the Axis powers, and its fledgling aeronautical research facilities would be operating under wartime pressures.

So begins the history of the Lewis Research Center, the third of the three NACA research centers that would become the nucleus of NASA in 1958 (for more on Langley and Ames, see *NASA Tech Briefs*, Spring 1985 and Summer 1985, respectively). From the outset, Lewis was designated NACA's power generation and propulsion research center, hence the original name Aircraft Engine Research Laboratory, which was changed in 1948 to honor Dr. George Lewis, NACA's director of aeronautical research from 1924-1947.

LEWIS

"Higher, Faster and Farther"

Throughout WWII and continuing into the early days of the jet age, the goals for Lewis were "higher, faster and farther." Its initial work involved investigating the problems of reciprocating or piston aircraft engines, and involved design modifications, engine cycle studies, new component development and research into fuels, lubricants and structural materials. Lewis researchers also contributed to the solution of engine-cooling problems for the B-29 aircraft and conducted research on icing problems.

Following the war, the laboratory was completely reorganized, although its designated research tasks—power and propulsion systems—remained the same. While the Berlin airlift of 1948 was accomplished with piston-engined transports left over from WWII, research into the various components of gas turbine jet engines had already begun at Lewis. Intelligence reports from Germany in the final days of the war contained design plans for jet-propelled aircraft, and these designs provided guidelines for the advance of U.S. aviation in the postwar period. Priorities included the development of aircraft capable of attaining higher speeds at higher altitudes. This was to be accomplished with turbojet and rocket engines, which would provide the necessary added thrust. The completion of the Altitude Wind Tunnel at Lewis in 1944 made the laboratory an ideal location for the development and early testing of American-built jet engines.

During the early 1950s, research at Lewis focused on the fundamentals of supersonic aerodynamics, especially as they related to the airflow into and through turbojet engines. Again, supporting basic and applied research into materials and components able to withstand the high temperatures necessary to the operation of turbojet engines was undertaken. Research into lubricants and fuels also furthered this effort.

In the mid-1950s, as public protest associated with the noise levels around city airports heightened, Lewis personnel undertook a quiet-engine research program, investigating air inlets, turbine blades and exhaust characteristics. Ultimately, their research focused on the axial flow compressor, which in turn led to the development of the turbofan engine, a much lighter and quieter jet engine.

Around the same time, Lewis researchers began investigating the possibility of using liquid hydrogen as a rocket fuel. While low-weight hydrogen promised attractive increases in thrust-per-kilogram when compared to other fuels, its reputation, left over from the Hindenburg disaster, as a dangerous and difficult to handle fuel impeded its acceptance. By 1957, however, Lewis researchers were successfully and routinely firing an 89-kilonewton-thrust engine using liquid hydrogen as fuel. The results of these tests advanced newly-formed NASA's plans to launch a lunar rocket, and in 1959 it was decided that the upper stages of that rocket would be fueled with liquid hydrogen.

Agenda for the Space Age

Just one week after NASA was organized in 1958, the go-ahead was given for Project Mercury, America's first manned spaceflight program. At Lewis, researchers continued their work

LEWIS RESEARCH CENTER:

At Home in Cleveland

Andrew Stofan, Lewis director; Harrison Allen Jr., deputy director, external affairs; James Burnett, director, external affairs; and Dan Soltis, TU officer.

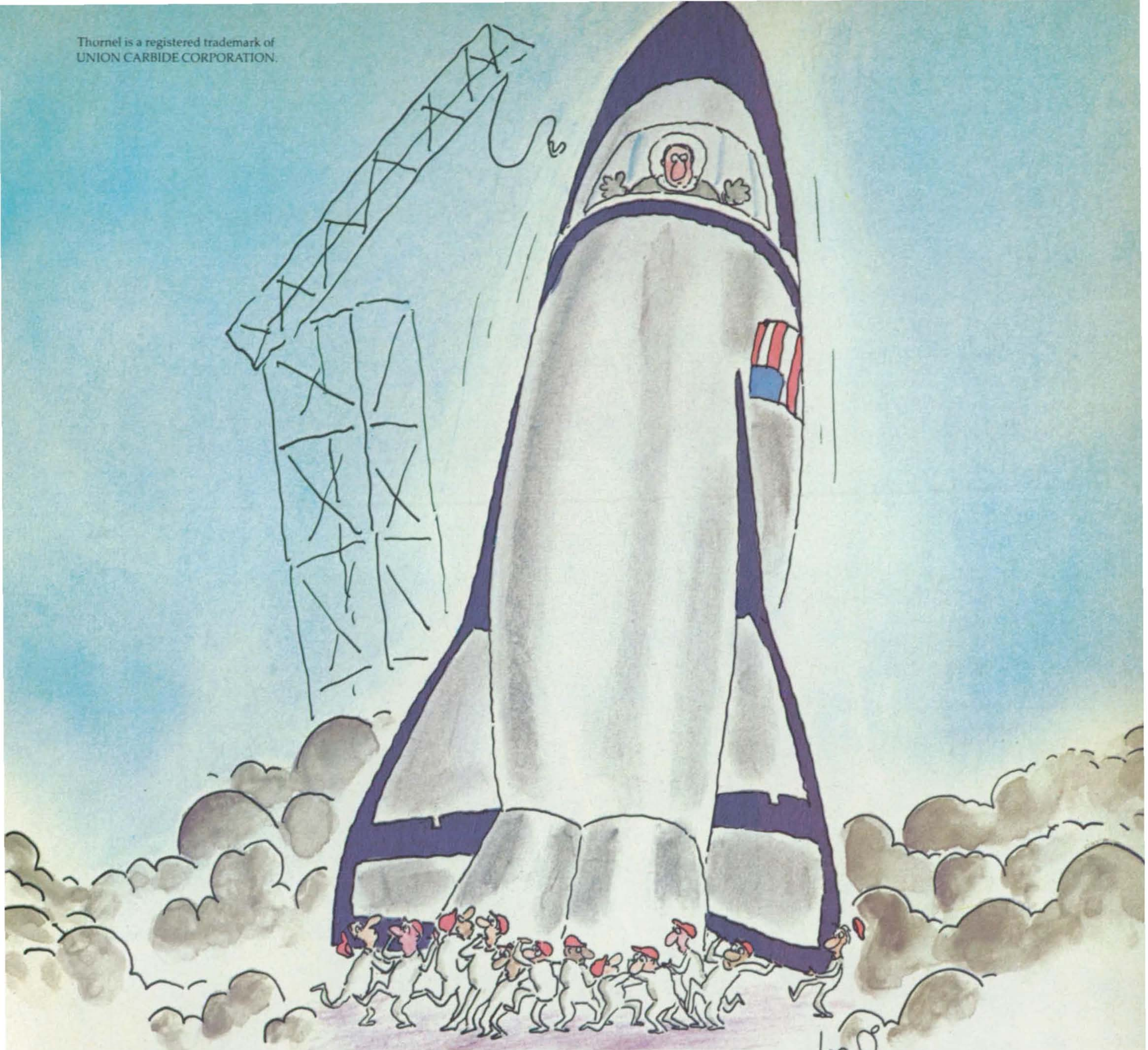
The relationship between Lewis Research Center and Cleveland- area industry has been long and fruitful. When NACA was selecting sites for its new aeronautical research facilities in the late '30s, the Cleveland Chamber of Commerce and local industry leaders—including Frederick Crawford, president of Thomas Products, later TRW—beckoned.

With the advent of NASA's Technology Utilization (TU) Program in the early 1960s, the relationship between Lewis and industry was strengthened. The TU office at Lewis is part of the External Affairs Department, a fact which emphasizes the Lewis commitment to dialogue with industry. At Lewis, the TU Office developed and implemented the concept of the NASA TU Conference. The first New Technology Conference was held at Lewis in 1964, and 400 industry leaders from the Cleveland area attended the briefing, which focused on selected aerospace technology. The conference was designed to transfer an awareness of new technology in a format that invited further inquiry. As word of the conference spread, more and more industry executives expressed their interest in attending. So while early conferences were designed to appeal to executives from many different industries, subsequent conferences were keyed to specific industries. In 1965, Lewis hosted a conference geared toward the petroleum industry, and in 1967 the conference addressed aerospace technology as it relates to industry and commerce. The latter conference was designed for small business owners in the Cleveland area and was supported by the Small Business Administration. Conferences for the electric power, ion plating, and gas industries followed.

In addition to the conferences, about 3000 annual inquiries are fielded by the Lewis TU Office. The TU Office staff also gives an average of 30 speeches per year, and people from the Lewis Speakers Bureau give an additional 280 speeches. The number of individual technical discussions between Lewis staff and industry representatives varies from year to year. Once the TU Office has arranged for the first meeting, direct contact for subsequent sessions is encouraged. This multi-faceted approach to technology transfer has helped generate a substantial and continuing dialogue between Lewis technical staff and industry representatives.

But business people are by no means the only beneficiaries of Lewis' Cleveland location. While Lewis does not include biomedical research among its programs, it has become involved in a number of Cleveland-area biomedical projects as part of its "good neighbor" policy. Among these are communications systems for surgical suites, the "fast neutron" cyclotron for cancer therapy, emergency medical service communications and dispatch systems, and battery packs for surgical instruments.

Lewis Research Center also undertakes cost-shared technology transfer projects in cooperation with outside organizations, most of which address a specific problem area, such as gearing or energy storage. And finally, Lewis contributes to technology transfer in a manner which needs no further explanation—you're holding it in your hands. □

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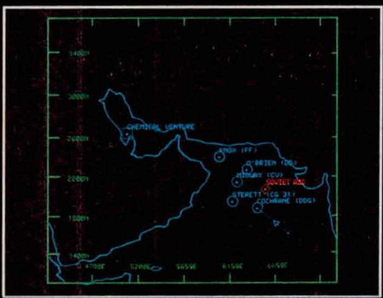

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on hydrogen-fueled upper stage rockets, the center's most important early contribution to the space program. Research conducted at Lewis' Rocket Engine Test Facility yielded the lightweight, regeneratively-cooled hydrogen engine. This research, in turn, led to the development of the J-2 engine for the Saturn rocket. A cluster of five hydrogen and liquid oxygen J-2 engines boosted the first Apollo spacecraft into an orbit of the Earth, and a single J-2 engine boosted the three-man spacecraft out of Earth orbit and into the lunar gravitational field.

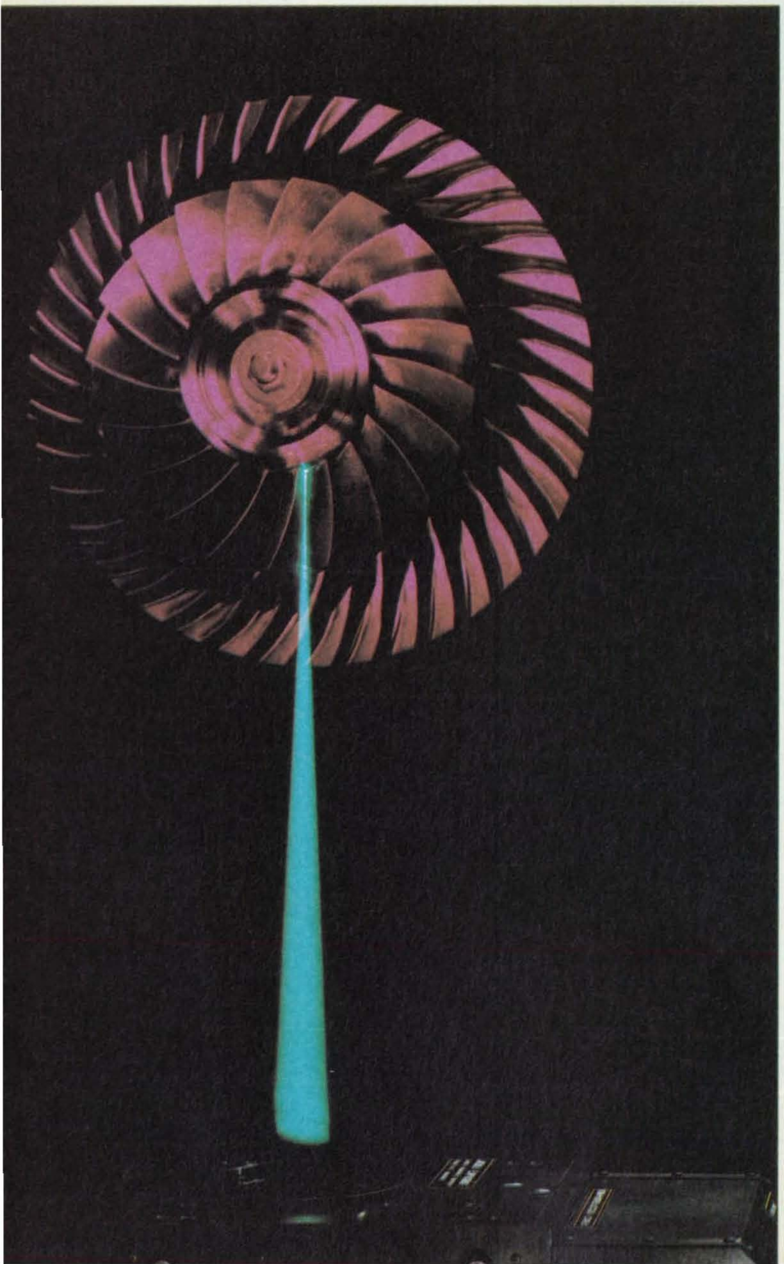
Hydrogen-fueled engine research at Lewis also yielded the RL-10 engine for the Centaur, a powerful upper stage launch rocket, which was used to boost communications and weather satellites, and the planetary exploration spacecraft, including those of the Voyager and Viking series. Even today, Lewis Research Center continues to manage the Centaur, and plans call for it to launch both the Galileo and Ulysses spacecraft from the orbiting Space Shuttle in May, 1986.

Down to Earth

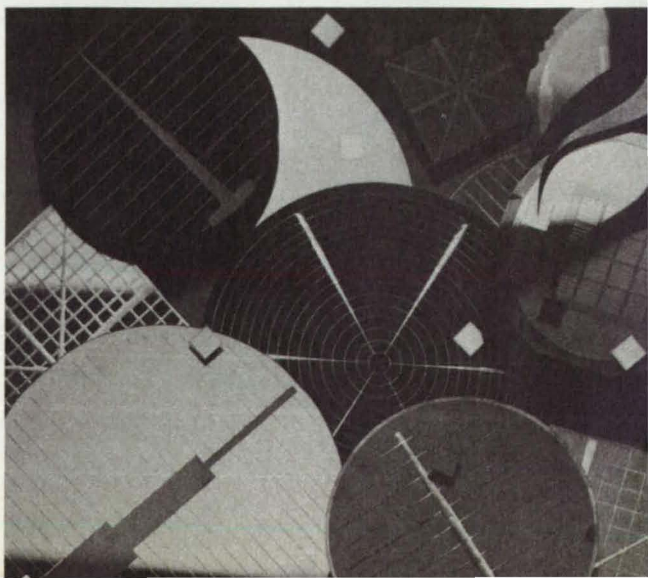
During the 1970s, the political and economic climate dictated a considerable reduction in NASA's budget. The remaining three Apollo missions were scratched, and other cutbacks were evident throughout the space program. At the same time, the Arab oil embargo forced the U.S. to begin considering alternatives to fossil fuels.

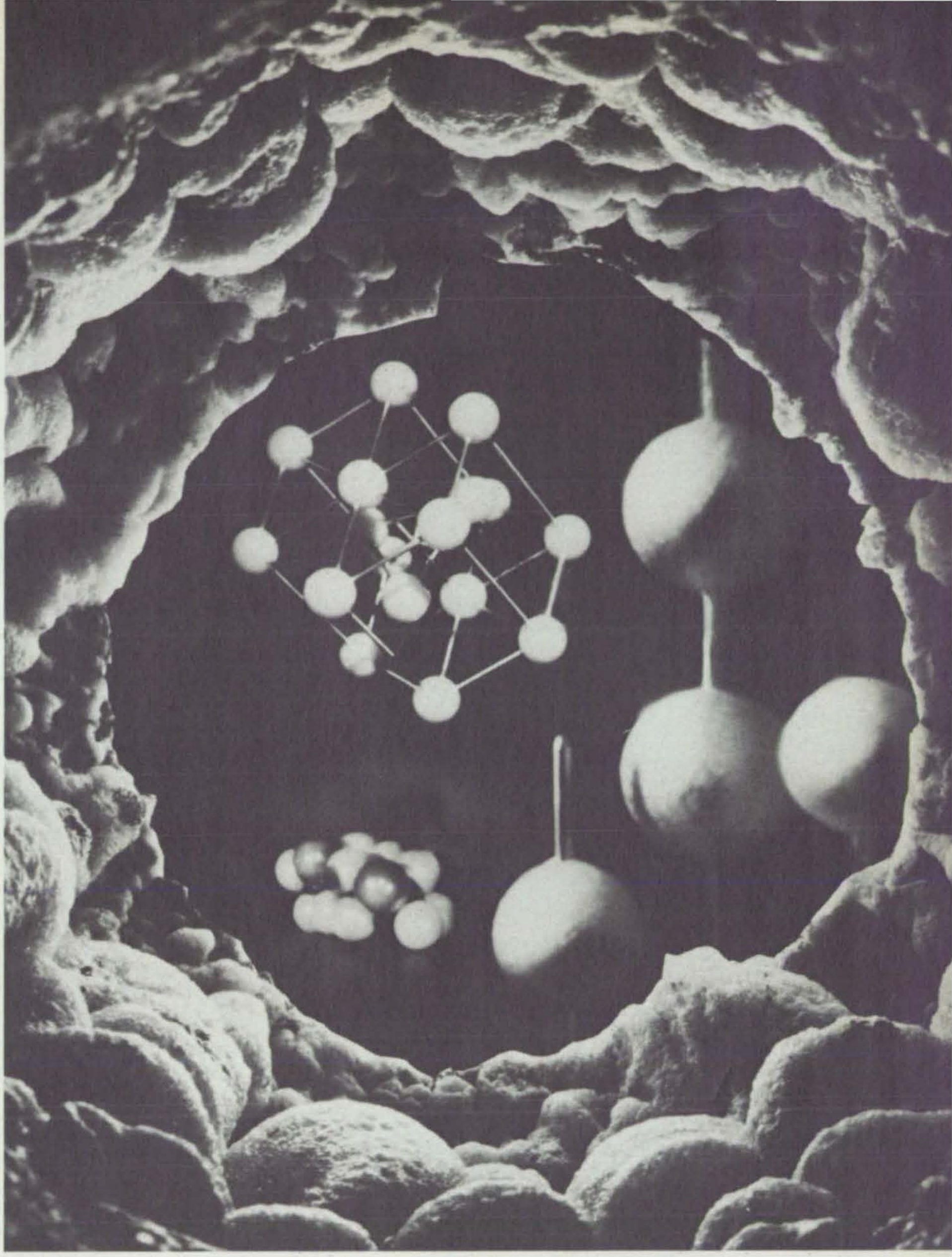
Working with the Department of Energy, Lewis Research Center personnel applied their technical expertise in energy systems to the problems of terrestrial power generation. Solar cells, originally developed to power satellites in space, were adapted for use in charging electrical batteries. This project ultimately resulted in the development of solar energy systems which are being used to supply the basic energy requirements—lighting, water pumping, refri-

The Mod-O wind turbine generator is located at Lewis' Plum Brook Station. Smoke tests reveal the true pattern of wind as it flows through the turbine blades.



At left, a laser beam measures air velocity within the rotating blade of a centrifugal compressor, an aircraft engine component. Below, low-cost terrestrial silicon solar cells made by various commercial manufacturers. Lewis has been involved in solar energy research for over 20 years.





Molecular models are viewed through an ablative rocket engine nozzle. The nozzle's inside surface was melted during a combustion durability test. Ablative material acts as a sacrificial coolant. As a liner of the rocket chamber, it absorbs the heat generated by the engine and changes from a solid to a gas. The Apollo service module and the lunar module descent and ascent engines were lined with ablative material, which extends engine life and improves engine performance.

geration— of small villages in developing countries. Lewis Research Center, for the Agency for International Development, has implemented photovoltaic power systems around the world.

Other terrestrial energy-related research undertaken at Lewis Research Center includes the study of wind energy and the development of wind turbines, automotive propulsion systems—including the Stirling and more efficient gas turbine engines—and phosphoric acid fuel cells.

In 1978, NASA inaugurated its Energy Efficient Engine program and based it at Lewis. Since that time, researchers there have devised a number of new component technologies which, when combined, offer an estimated 15 percent reduction in aircraft engine specific fuel consumption.

Along the same lines, researchers at Lewis initiated and managed NASA's advanced turboprop program, which revives the concept of turbine propeller engines for purposes of fuel conservation. New propeller designs, incorporating the swept-tip concept, have been devised and initial tests show that multi-bladed, swept-tip, turbine-driven propellers can provide equivalent performance with an estimated fuel economy of 30 percent. (That could translate into billions of dollars per year in commercial transport fuel savings.) The system is currently undergoing ground tests and test flights are planned for 1987.

Present (and Future) Tense

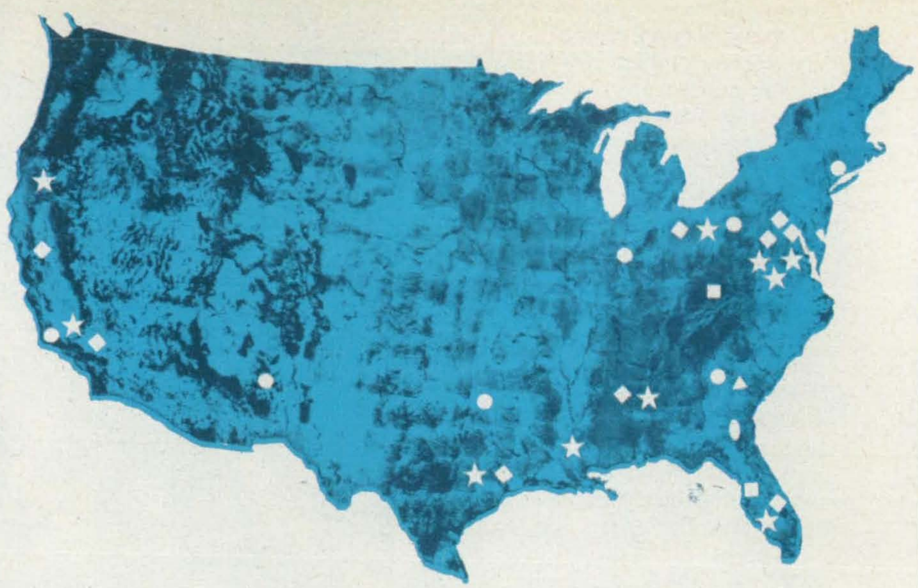
A renewed national interest in space exploration and development is one characteristic of the 1980s. For Lewis, this has meant a shift in emphasis from advancing the technology of propulsion systems to new space-related projects. Joining advanced turboprop research as a current Lewis priority is the design and development of power systems for the Space Station. Lewis researchers and their contractors are currently investigating both photovoltaic and thermal/rotating machinery systems for converting solar to electrical energy for the Space Station. The power systems work covers all facets of generating, storage, conditioning and distribution.

Besides playing a key role in the development of the Space Station, Lewis, NASA's lead center for satellite communications, research and technology programs, manages the Advanced Communications Technology Satellite (ACTS), the prototype for the next generation of communication satellites. It will be launched in the late '80s. ACTS programs focus on making efficient use of the geosynchronous orbit arc and frequency bands in the 30-gigahertz range. One of Lewis' goals in satellite communications is to build enough electronics in the actual satellite to minimize the size and complexity of ground base stations.

With a well-defined role in current and future space programs, the 4000 employees and support service contractors of Lewis Research Center have their work cut out for them. In Lewis' more than 100 buildings and 550 specialized research installations, scientists, engineers, technicians and their support staff are applying their expertise in advancing innovative high-technology concepts for use on Earth and in space.

In an overview as brief as this, it's impossible even to scratch the surface of the scientific accomplishments and contributions generated over the course of Lewis Research Center's more than forty year history. Just imagine what that means for historians of the 21st century! Well, at Lewis anyway, they'll be able to get a head start—for at Lewis, the future is already at hand. ☐

NASA Technology Utilization Services



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The Technology Utilization Officer
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Technical Support Packages (TSP's)
are prepared by the center TUO's. They provide further technical details for articles in NASA Tech Briefs. This additional material can help you evaluate and use NASA technology. You may receive most TSP's free of charge by using the TSP Request Card found at the back of this issue.

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Government and private industry in Florida and Kentucky can utilize the services of NASA's State Technology Applications Centers (STAC's). The STAC's differ from the Industrial Applications Centers described on page 21, primarily in that they are integrated into existing state technical assistance programs and serve only the host state, whereas the IAC's serve multistate regions.

Many data bases, including the NASA base and several commercial bases, are available for automatic data retrieval through the STAC's. Other services such as document retrieval and special searches are also provided. (Like the IAC's, the STAC's normally charge a fee for their services.)

To obtain information *about the services offered, write or call the STAC in your state [see above].*

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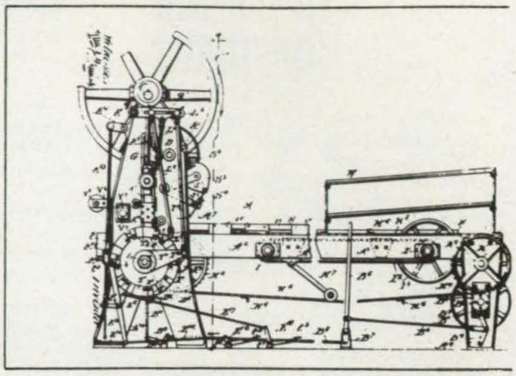

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APPLICATION TEAMS

Technology-matching and problem-solving assistance to public sector organizations

Application engineering projects
are conducted by NASA to help solve public-sector problems in such areas as safety, health, transportation, and environmental protection. Some application teams specialize in biomedical disciplines; others, in engineering and scientific problems. Staffed by professionals from various disciplines, these teams work with other Federal agencies and health organizations to identify critical problems amenable to solution by the application of existing NASA technology.

Public-sector organization
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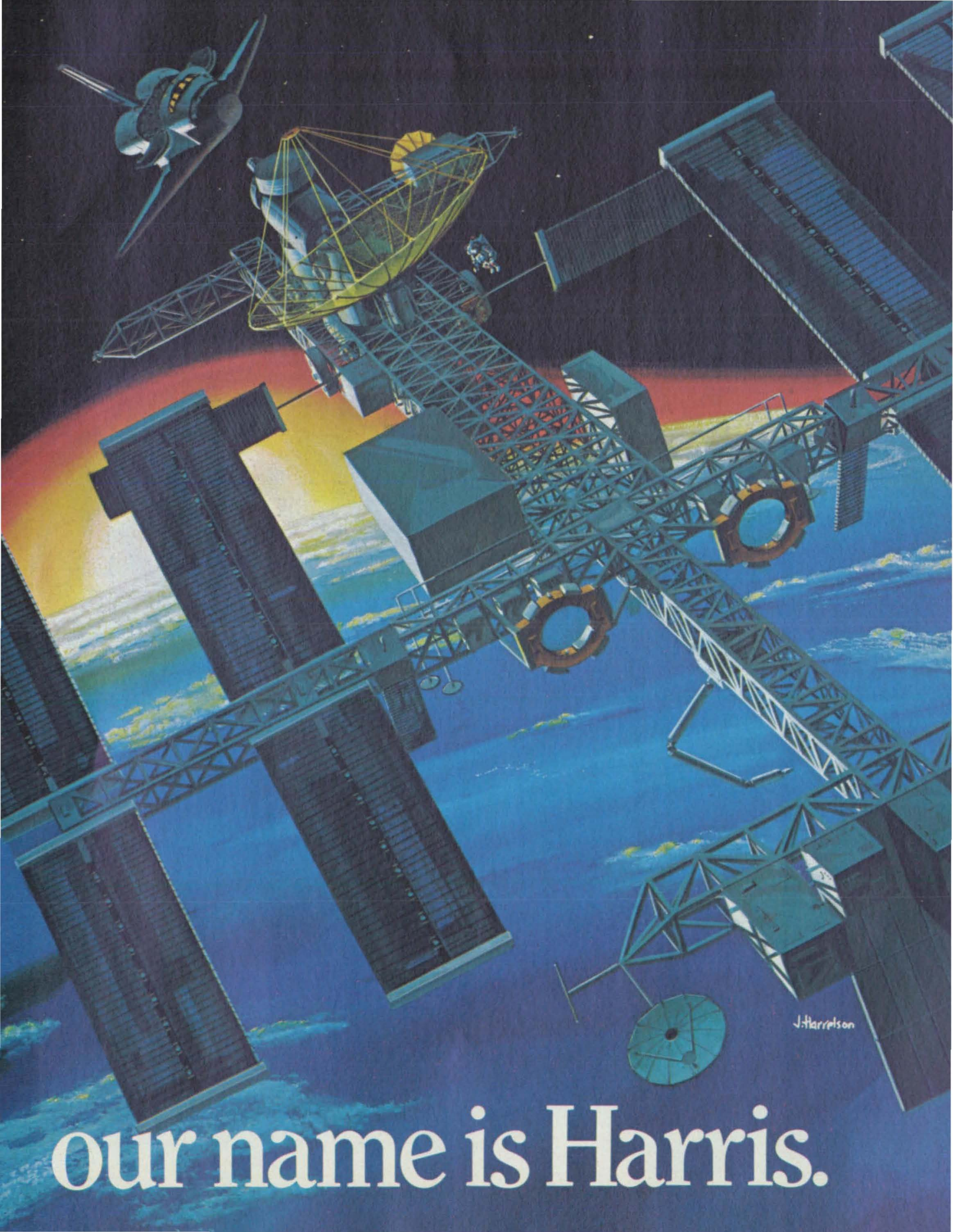
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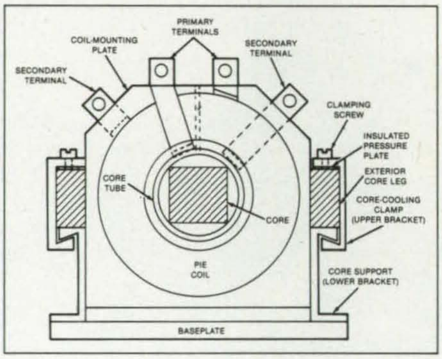
New Product Ideas

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 to the NASA Scientific and Technical Information Facility, Technology Utilization Office, P.O. Box 8757, BWI Airport, MD 21240 (see page 25). NASA's patent-licensing program to encourage commercial development is described on page 26.

High-Efficiency, Low-Weight Power Transformer

A high-efficiency (99.2 percent), high-power (25 kVA), but low-weight (6.95 lb) (3.16 kg) transformer is designed so that its mechanical structure also serves as the thermal paths for the conduction cooling of the core and windings. The transformer incorporates eight coil/plate assemblies. In each of these, the primary is bonded to one side of an aluminum mounting plate and the secondary to the opposite side, with insulation between plate and coil to control voltage breakdown. Each mounting plate is attached to an aluminum baseplate that is maintained at a specified temperature by external cooling. The individual primary and secondary coils can be connected in series/parallel combinations. Moreover, if a particular winding becomes inoperative, only the defective pie coil in that winding needs to be replaced.

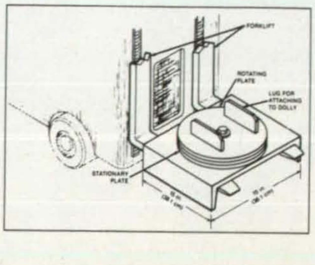
(See page 156.)



Forklift Swivel Dolly

An adapter enables a large dolly to be towed or pushed by a forklift and to swivel on the forklift on turns. Prevented by the adapter from slipping off the forks and damaging the loads, the dolly is maneuvered by the forklift in the way that trailers are maneuvered by tractors. The adapter includes a round steel plate with lugs that connect to the dolly (see figure). The plate is centered by a bolt and rotates on a large washer of almost the same diameter as that of the plate. The large washer is bolted to a round plate that rests on an inverted channel.

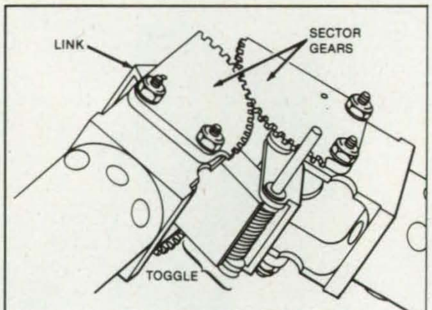
(See page 148.)



Toggle Hinge for Deployable Struts

Ensuring rigidity in portable bridges, masts, towers, platforms, and other deployable structures, a new toggle hinge eliminates the end play often encountered in conventional hinged structures. Positioned halfway along the length of a folding strut, the hinge allows the halves of the strut to pivot 180° about the center. With conventional hinges, the strut reaches its maximum length slightly before it is fully extended, and then it contracts by about 1 mm. Since the holes in the end pivots must be enlarged to accommodate the excess travel, the resulting structure is not rigid. In contrast, the toggle-hinged strut does not reach its maximum length until it is fully extended in the toggle or locked position. Thus there is no excess travel, and no allowance need be made in the end holes.

(See page 131.)

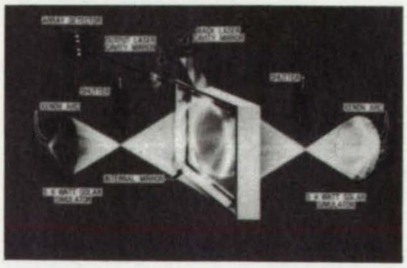


PARTIALLY FOLDED TOGGLE HINGE

Solar-Pumped Box Laser

A laser cavity that efficiently captures solar radiation allows long gain lengths at low solar concentrations. The cavity is stainless steel, with internal, high-reflectivity mirrors. In tests using solar simulators, its output reached approximately 300 mW for about 150 ms. With laser gain lengths of 60 cm (vs 10 cm maximum, previously), the new system allows lasing at a solar-simulator intensity of 150 Suns.

(See page 74.)

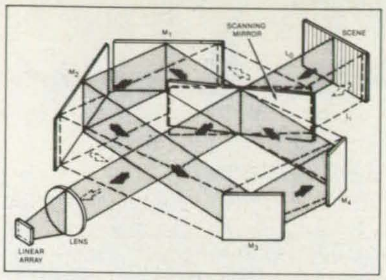


Optical Scanner for Linear Arrays

An optical scanner suited to photometric and radiometric applications and fully compatible with linear arrays instantane-

ously reads contiguous lines forming a scene or target in the object plane. The reading may be active or passive and the scans, continuous or discrete. The scans are essentially linear with scan angle and are symmetric about the axial ray. Focal error resulting from a curvature of the scan is within the Rayleigh limit. Except for the imaging lens, all the optical elements are plane mirrors, and the rotation of the scan mirror is the only motion required.

(See page 75.)



Phthalocyanine Tetraamine Epoxy-Curing Agents

Tough fire- and chemical-resistant epoxies are produced by using metal phthalocyanine tetraamines (MPT's) of copper, cobalt, or nickel as curing agents. Graphite-cloth laminates prepared from these epoxies have applications in airplanes, boats, cars, electrical insulation, chemical-processing tanks, and buildings. Since the new curing agents are soluble in aprotic solvents, it is now possible to use metal phthalocyanines to cure epoxy resins in a homogeneous reaction, yielding products superior to those in which the insoluble phthalocyanine carboxylic acids used as curing agents reacted heterogeneously and remained as discrete particles after curing. Because of the flame-retardant properties of the MPT curing agents, elastomers can be added to epoxy resins, to overcome brittleness and improve fracture toughness and impact strength, without rendering the resins flammable.

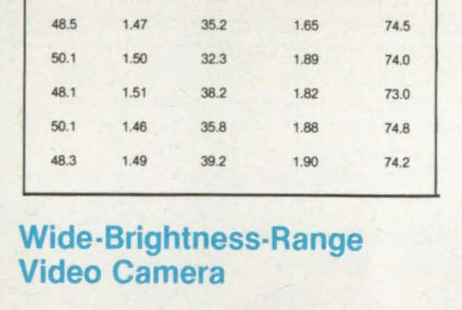
(See page 107.)

Limiting Oxygen Index	Specific Gravity	Percent Resin Content	Percent Moisture Absorption After 2 h Boiling in Water	Percent Char Yield in N_2, 800° C
50.3	1.46	34.6	1.51	75.0
48.5	1.47	35.2	1.65	74.5
50.1	1.50	32.3	1.89	74.0
48.1	1.51	38.2	1.82	73.0
50.1	1.46	35.8	1.88	74.8
48.3	1.49	39.2	1.90	74.2

Wide-Brightness-Range Video Camera

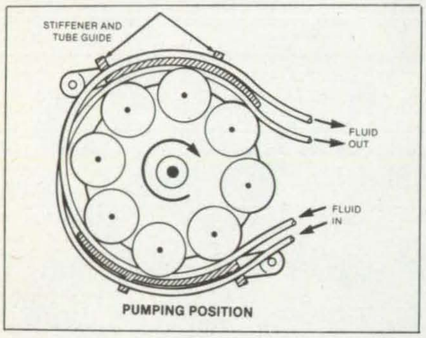
A new television camera views scenes containing extremes of light and dark without overexposing the light areas and underexposing the dark ones. By using a novel liquid-crystal light valve, the camera selectively attenuates the bright areas without affecting the dim areas. Using either a reflecting or transmitting liquid crystal, the camera views scenes containing brightness variations of up to 20,000:1.

(See page 52.)



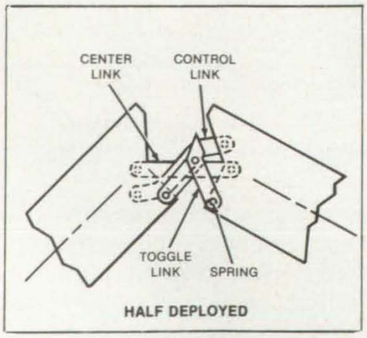
Lightweight, Switchable Peristaltic Pump

A proposed peristaltic pump moves liquids through 50 or more channels simultaneously. A special feature of the pump is that its pressure plates can be remotely set on either the idling or the operating position. In conventional peristaltic pumps, it is necessary to pre-position the plates for the operating mode. As a consequence, the elastic channels are pinched before operation and can acquire a deformation that reduces pumping efficiency. In the new design, it is unnecessary to open the pump housing to pre-position the plates.
(See page 148.)



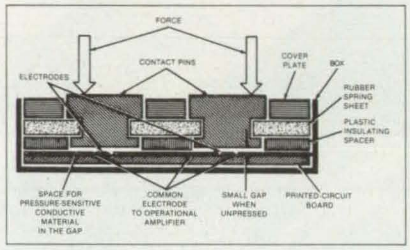
Bistable Articulated Joint

A new joint combines zero backlash, positive locking, and centerline pivoting. It could be used in tool handles, antenna booms, and other deployable structures. The joint has a four bar linkage. The two shafts, panels, or other items connected by the joint can swing through a 180° arc, making the joint useful in equipment that must fold compactly for storage. A torsion spring applies a torque that holds the joint in either its extended or folded position and eliminates play. The joint automatically locks in its extended position.
(See page 150.)



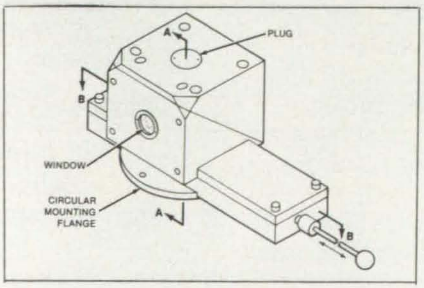
Touch Sensor for Robots

A touch sensor for robot hands provides information about the shape of a grasped object and the force exerted by the gripper on the object. Packaged in a small, rugged box that fits on the gripper pad, the touch sensor has projecting pins arranged in a regular matrix on one face of the box. The pins bear on individual circuit elements — each of which may be a switch that turns on when a pin is pushed or, alternatively, a variable resistor, the conductance of which increases with the force on the pin. The box protects the printed-circuit board and the pins from damage by overpressure and overtravel. It also shields the sensitive parts of the sensor from grease, dirt, fumes, and other contaminants.
(See page 46.)



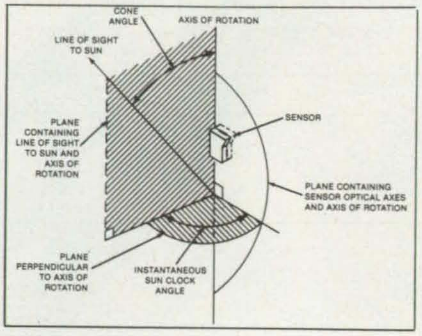
Optical Integrating Sphere for Vacuum Ultraviolet

An integrating sphere with a sliding sample holder allows radiometric measurements in the vacuum ultraviolet on four samples — without breaking the vacuum. The sphere mounts on a monochromator and is evacuated through the port that admits light from the monochromator. The interior surfaces of the integrating sphere and the walls inside the sample holder are coated with diffusely-reflecting white paint, which is highly reflective from 200 to 2,300 nm; with a suitable detector, fluorescence can be measured at any desired wavelength in that region. The cavity geometry and the diffuse radiation insures that, regardless of its initial spatial distribution, a nearly constant portion of the radiation emitted by the sample reaches the detector.
(See page 80.)



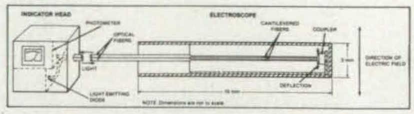
Sensor Tracks the Sun From Any Angle

Reflectors for solar concentrators could be guided by a sensor system that locates the Sun from any angle. The sensor generates error signals to point an object toward the Sun and follow its motion. At the heart of the sensor are three cadmium sulfide light detectors and a set of apertures that define the detector fields of view. The sensor contains no moving parts and needs only a few microwatts of power. Two sensing systems, required for redundancy in a NASA application, have a total mass of only 540 grams and a volume of only 550 cubic centimeters.
(See page 62.)



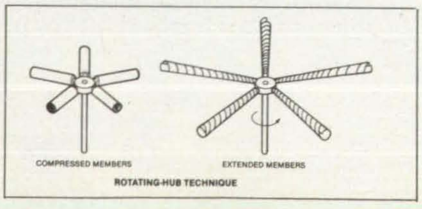
Fiber-Optic Electric-Field Meter

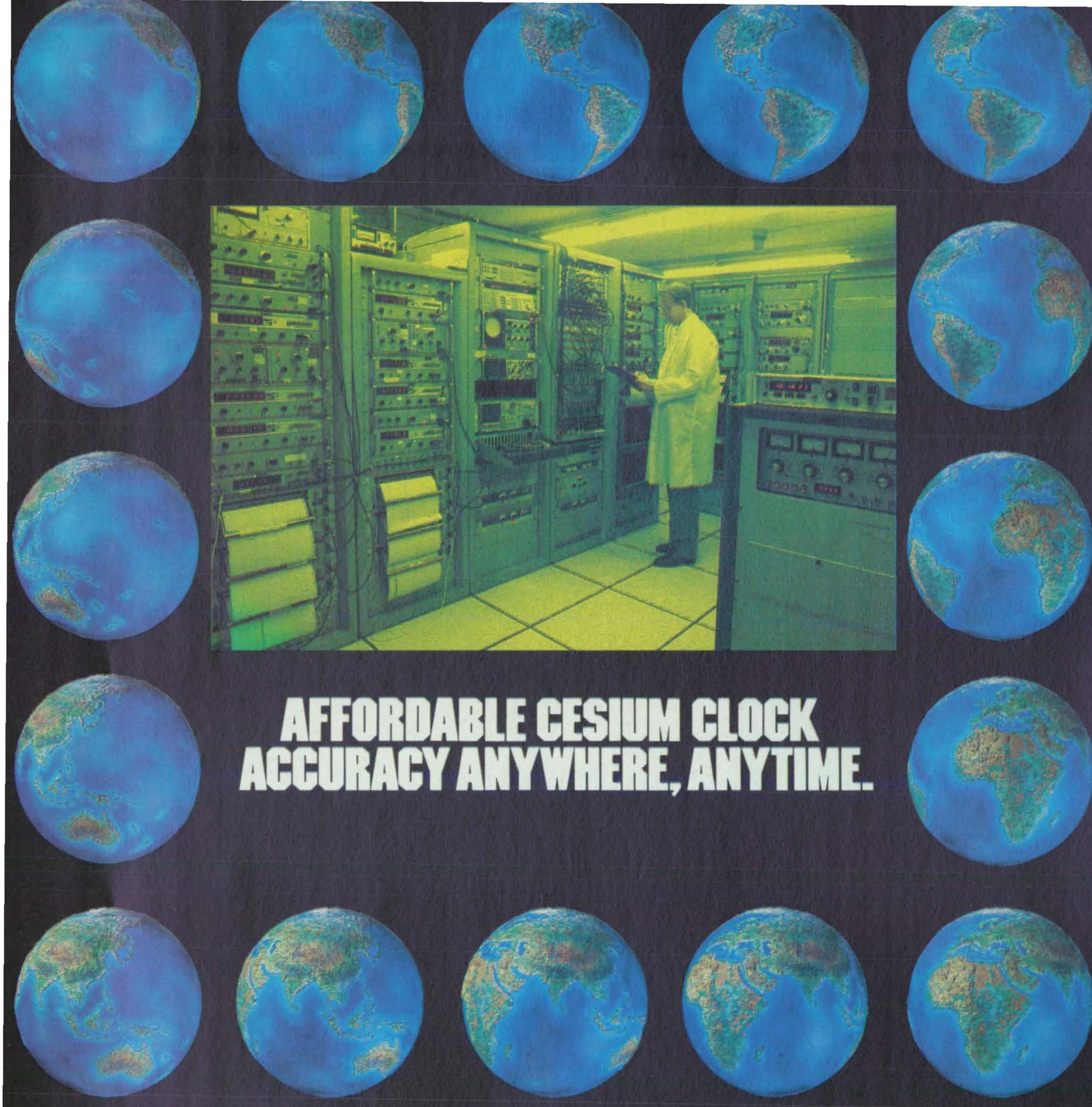
Containing mostly dielectric materials, a new sensor for measuring both ac and dc electric-field strength causes minimal disturbance to the field being measured. The sensor can be used to map fields in an electric power substation or under a high-voltage transmission line. It also can be used for laboratory measurements. The field strength is determined from the divergence of two cantilevered optical fibers, which form part of a path (completed by a coupler) to carry light from a light-emitting diode to a photometer. There are two versions of the sensor: One in which the fibers are coated with a conductive film and the other in which they are not.
(See page 39.)



Deployable Truss Member

Temporary structures could be constructed from telescoping rolls of sheet material that deploy to 24 times their stowed lengths. Initially rolled around a central core, the rolls could be deployed by centrifugal force (provided, for example, by a rotating hub) or by holding the outer perimeter of the rolled member and then applying an impulsive force to the core. It also may be possible to construct a "gun" that could "shoot" the core to the desired location.
(See page 124.)





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Circle Reader Action No. 354

Electronic Components and Circuits

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Polarizing Filter for Integrated Optics

An $LiNbO_3$ crystal is cut for maximum mode-filtering efficiency.

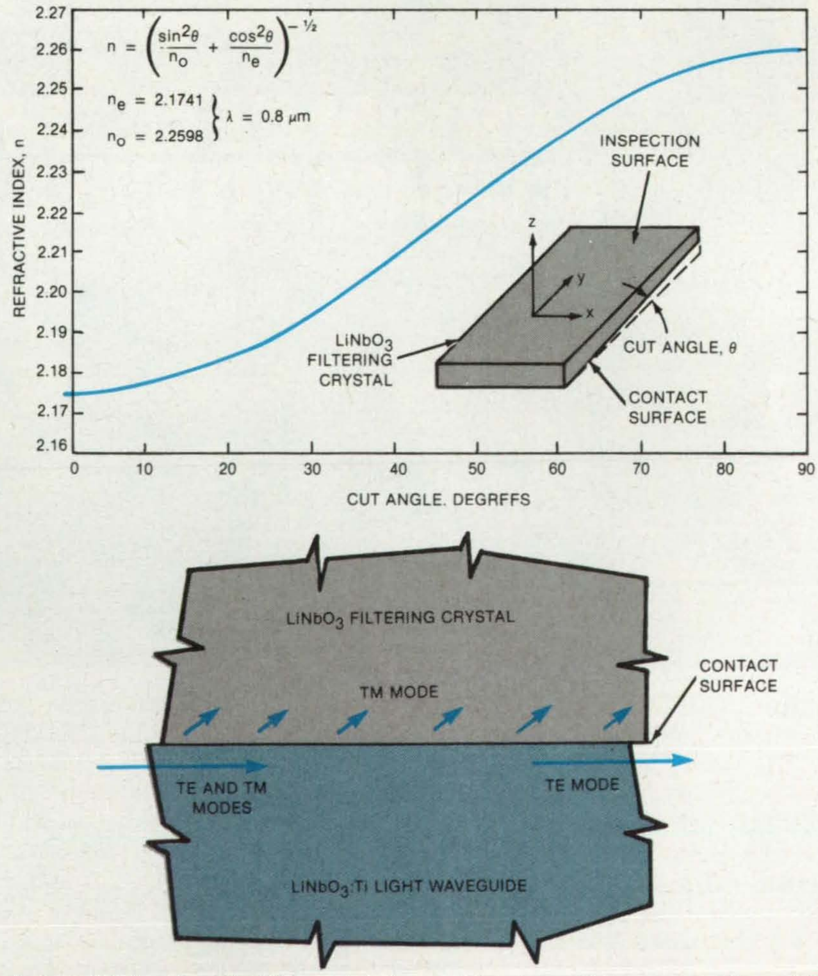
NASA's Jet Propulsion Laboratory, Pasadena, California

A polarizing filter for a titanium-doped lithium niobate light waveguide suppresses the transverse magnetic (TM) mode of light propagation while allowing the transverse electric (TE) mode to continue on its way. The filter — a lithium niobate crystal — is expected to find many applications in integrated optical circuits.

First, the filter crystal is cut at an angle at which its index of refraction matches or nearly matches that of the light waveguide for TM propagation (see figure). The filter is then pressed against the light waveguide. It will thus draw most of the TM light out of the light guide while the TE mode remains mostly within the light waveguide.

For demonstration purposes, a filter-crystal face was cut and polished at an angle of 20° with respect to the z face. When positioned on a light waveguide, the filter produced an attenuation of 30 dB for the TM mode and only about 1 dB for the TE mode. The TM attenuation would have been increased and that for the TE mode would have been decreased if the filter TM index had been more closely matched to that of the light waveguide.

This work was done by O. Glenn Ramer of Hughes Aircraft Co. and Willis C. Goss and Raymond Goldstein of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 72 on the TSP Request Card.*
NPO-16429



The **Index of Refraction** of a lithium niobate crystal varies with the angle of the cut. The angle is chosen to provide an index match for the TM mode and a mismatch for the TE mode in a $LiNbO_3$:Ti light waveguide that touches at the cut surface. Because of the match/mismatch pair, most of the TM radiation is drawn off into the crystal, while most of the TE radiation continues along the waveguide.

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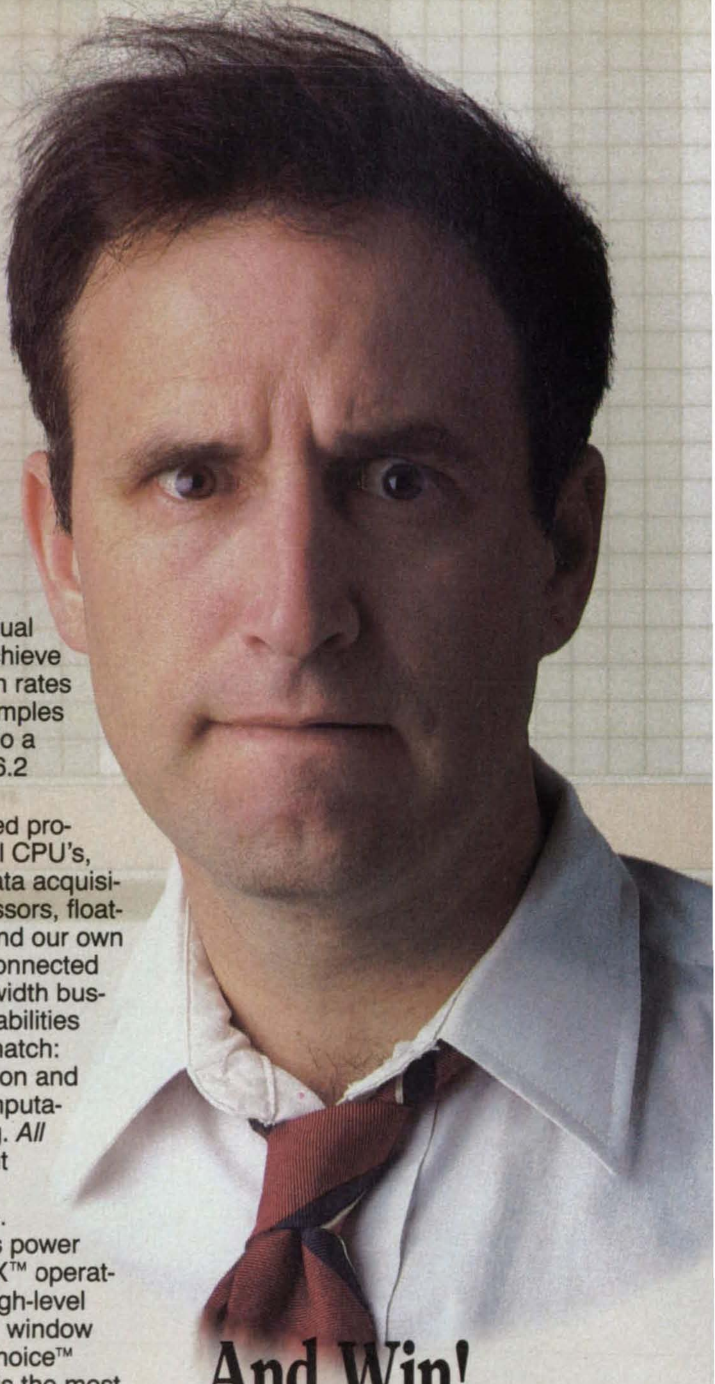

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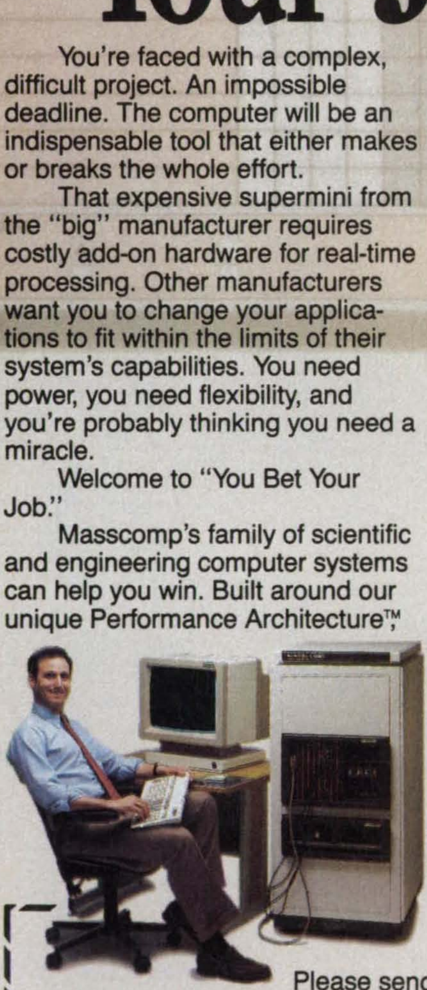

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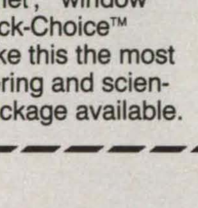

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Circle Reader Action No. 404

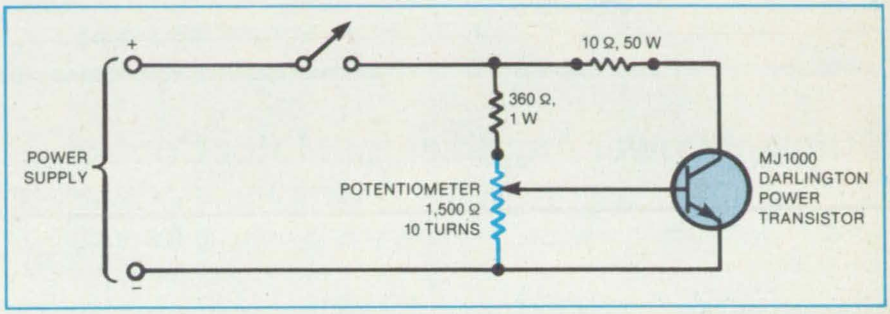
Smoothly Adjustable dc Load

A 10-turn potentiometer and a transistor are used instead of a rheostat.

Lyndon B. Johnson Space Center, Houston, Texas

A load circuit for testing dc power supplies can be adjusted without the momentary interruptions typical of rheostat loads. Load current passes through a power transistor and fixed resistor instead of through a wire-wound rheostat; it is therefore not subject to the interruptions that sometimes occur when a rheostat wiper skips from wire to wire during the adjustment of a load.

In the new circuit, originally developed to test power control circuits aboard the Space Shuttle orbiter, a potentiometer is used to adjust the bias of the power transistor and thereby adjust the load. There is very little load current in the potentiometer, however.



The **Basic Components of the Load Circuit** are a 10-ohm fixed resistor, a power transistor, and a 1,500-ohm precision potentiometer. The 360-ohm fixed resistor in series with the potentiometer limits the bias current to a safe level when the potentiometer is at its highest setting.

The dc power supply to be tested is connected to the input terminals of the load circuit, and the on/off switch of the load circuit is closed (see figure). The load is adjusted by turning the potentiometer knob. When the knob is turned fully counterclockwise, the transistor is biased off, and the load is nearly zero. When the potentiometer is turned fully clockwise, the transistor is fully on, and the load is at its maximum value. For a 10-ohm fixed load resistor and a typical 28-Vdc power supply, the maximum load current is 2.8 A. The maximum design load is limited by the power-dissipation ratings of the resistor and transistor selected for the circuit. Higher loads, of course, would be possible with components having higher ratings.

The components are standard, commercially available parts. They are mounted on the transistor heat sink, forming a compact package.

This work was done by Clement G. Patocka of Rockwell International Corp. for **Johnson Space Center.** *No further documentation is available.*
MSC-20853

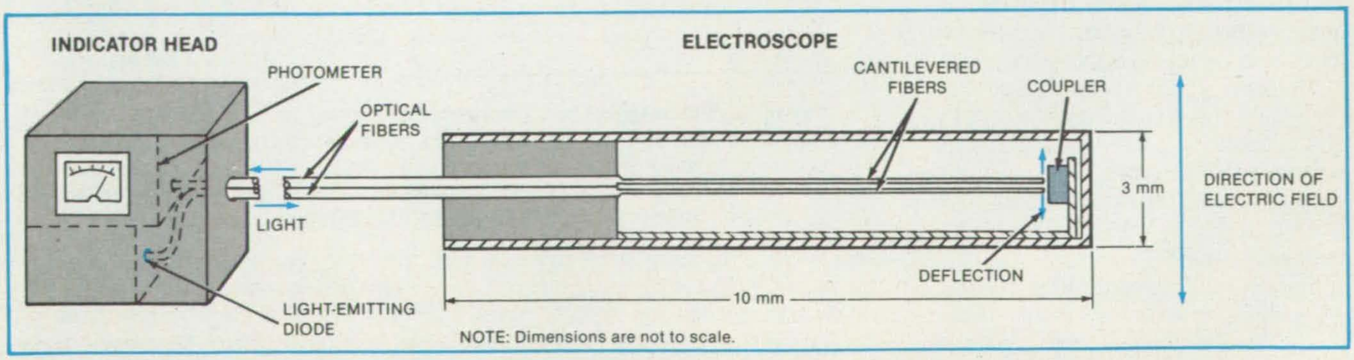
Fiber-Optic Electric-Field Meter

Dielectric construction causes minimal disturbance to the field being measured.

NASA's Jet Propulsion Laboratory, Pasadena, California

A new sensor for measuring electric-field strength does not greatly alter the field in which it is placed. The sensor can be used to map fields in an electric power substation or under a high-voltage transmission line. It can also be used for laboratory measurements.

Two parallel cantilevered optical fibers, each about 7 millimeters long, form part of a path to carry light from a light-emitting diode



Fused-Silica Fibers guide light from a source to a photometer. The light emerges from the tip of the source fiber, passes through a curved coupler, and enters the tip of the photometer fiber. The attenuation of the coupler changes with the distance between fiber tips.

to a photometer (see figure). The fibers are made of fused silica with a thin conductive coating.

The two fibers act as an electroscope; that is, they bend away from each other in response to the electric field. This bending occurs because one side of a fiber intercepts lines of force from the field while the other side is shielded from the field by the adjacent fiber. There is thus an unbalanced lateral force on each fiber proportional to the square of the field and to the area of the field intercepted by the fiber. The direction of the force on one fiber is opposite that on the other.

The free end of a fiber is coupled optically to the free end of the other by a lens assembly or by a curved light guide. The light guide attenuates the light passing through it from the one fiber to the other to a degree that varies with the distance between the free ends. The light intensity at the photometer thus varies as a predictable nonlinear function of this distance and of the field strength.

In a newer, all-dielectric version, there is no conductive coating on the fibers. Instead, one of the fibers is surrounded by dielectric field-shaping elements that create a strong field gradient. (A dielectric fiber experiences a force in an electric-field gradient).

With proper design, it should be possible to make the unit relatively insensitive to vibration and acceleration, since these effects bend both fibers in the same direction. The sensor responds as well to ac fields as to dc, since the fibers always deflect apart regardless of polarity of the field. An ac field thus appears to the instrument as a dc average with ripple superimposed.

This work was done by Alan R. Johnston of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 74 on the TSP Request Card.*
NPO-16435

Efficient Power Amplifier for Motor Control

Pulse-width-modulated amplifier supplies high current as efficiently as the low current needed for starting and running the motor.

Goddard Space Flight Center, Greenbelt, Maryland

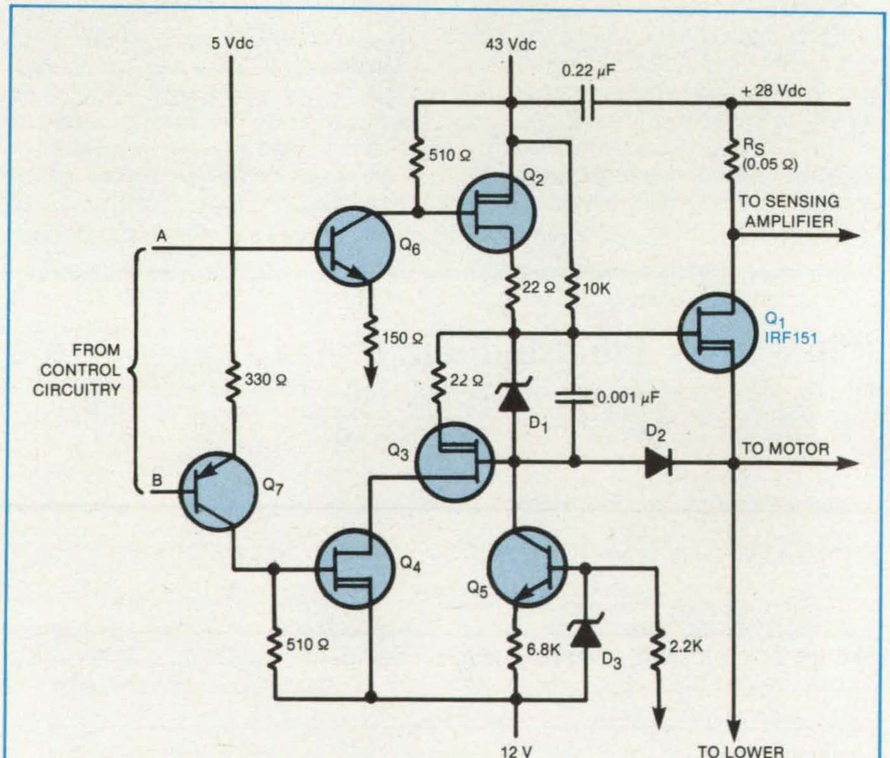
A pulse-width-modulated amplifier for controlling a motor produces a pulsed current with dc averages of 10 A for high torque and 1 A for sustaining torque. Operating from a 28-Vdc supply, the amplifier has an internal voltage drop of only 0.17 V. At the 1 A output level, the amplifier efficiency is 63 percent in contrast to only 11 percent for an equivalent linear amplifier.

The maximum torque and electrical power of the motor are required only briefly. Most of the time, the only power needed is that to overcome friction. Ordinary linear power amplifiers are not efficient at both extremes. When optimized to produce the high current needed to drive the motor during the high-torque period, they are inefficient during the low-current period because of their high internal resistances.

The low internal resistance of the pulse-width-modulated amplifier is achieved by using V-groove metal-oxide/semiconductor (VMOS) transistors in the output stages of the amplifier. Since VMOS devices are not available in p-channel form, n-channel transistors had to be used in both the upper and lower branches of the output-stage bridge.

The upper branch illustrates the principle of operation (see figure). Transistor Q_1 is the VMOS transistor. It has a saturation resistance of only 0.055 ohm. This low value in combination with the low resistance of the sensing resistor R_S makes the low internal resistance possible.

Transistor Q_1 is turned on when a 5-V signal is applied to terminals A and B. Transistor Q_6 is thereby turned on, and Q_7 is turned off. Transistor Q_6 then turns on Q_2, which ties the gate of Q_1 to the 43-V terminal adjacent to Q_2. This voltage, equal to the 28-V supply plus 15 V, is sufficient to turn on Q_1 rapidly without exceeding the maximum allowable voltage difference between the gate and source of the device.



One **Key to the Efficiency** of the motor-control amplifier is the V-channel metal-oxide/semiconductor transistor Q_1. This device has a low saturation resistance. However, it has a large gate input capacitance and a small margin between its turn-on voltage and maximum allowable gate-to-source voltage. The circuits for the output stages (one of which is shown here) overcome these limitations of the VMOS device.

Input A needs to be raised to 5 V only momentarily to turn Q_1 on. Transistor Q_1 remains on because it is tied to the 43-V terminal through a 10-kilohm resistor as long as Q_4 is off. Transistor Q_3 is always biased on by the current from Q_5 through diode D_1. However, there can be no current through

Q_3 as long as Q_4 is off.

When both terminals A and B are at 0 V, Q_7 is turned off. This turns on Q_4 to allow current through Q_3, which pulls the gate voltage on Q_1 down to zero quickly, thereby turning Q_1 off.

Transistors Q_2, Q_3, and Q_4 can carry currents of about 1 A. They can thus charge and discharge the large gate capacitance of Q_1 (about 4,000 pF) to turn Q_1 on and off quickly. Moreover, as soon as Q_1 is turned on or off, the current in the amplifier circuit becomes extremely low, ensuring low power dissipation.

The circuit that controls the power amplifier accepts analog feedback signals from a tachometer. The feedback is summed with the commanded velocity from a digital-to-analog converter and multiplied by an appropriate constant to produce a torque-command signal. The torque command is converted by a logic circuit to modulation of the pulse train that drives the motor-power amplifier. The logic circuit also selects a set of output switches to commutate the brushless dc motor in synchronism with the shaft motion as sensed via a shaft angle encoder.

This work was done by Richard J. Brown of the Navtrol Co. for **Goddard Space Flight Center.** *For further information, Circle 96 on the TSP Request Card.*
GSC-12807

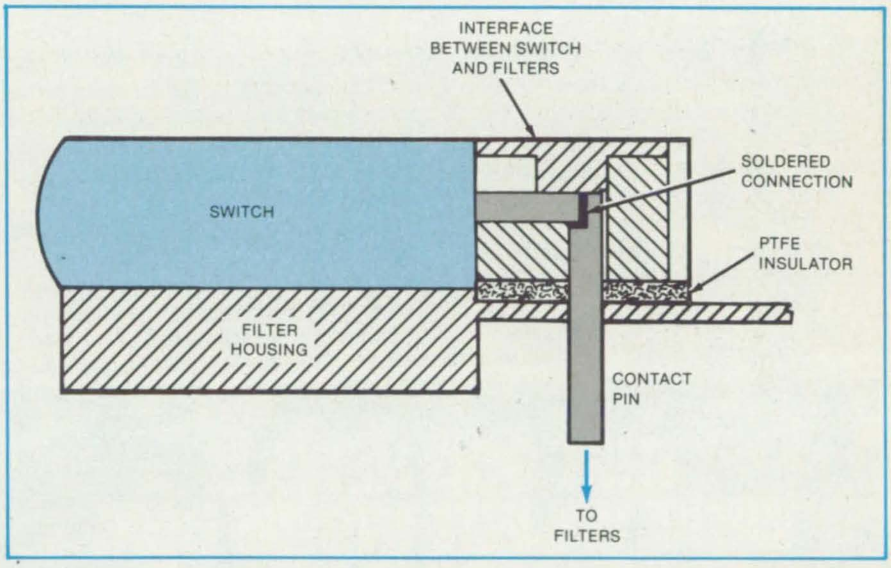
Plug-In RF Selector Switch

A short, direct link between switch and filters reduces signal loss.

Lyndon B. Johnson Space Center, Houston, Texas

A switch for selecting RF filters aboard the Space Shuttle orbiter saves space and weight, reduces the number of parts, and decreases signal loss. Previously, a signal was routed to the filters through connectors and cables. The new switch attaches directly to the filter housing, eliminating cables and connectors. As a result, the losses in the transmitter and receiver paths are reduced by about 0.4 dB.

The switch is mounted on the side of the filter housing (see figure) in such a way that the switch contact pin attaches to the filter contact pins. A soldered connection is made, and an interface is installed — for mechanical support — between the switch and filter housing. The switch is a single-pole/double-throw, with break-before-make magnetic latching, intended for switching RF signals from a common input to either of two outputs. The output selection is made by applying a 28-millisecond pulse of 22 to 37 volts dc to selected terminals. The magnetic actuator provides a latching force in excess of 2.45 N and is resistant to vibration and shock. It switches in less than 20 milliseconds.



Because Connectors and Cables Are Not Used, the RF path loss for a selected signal through the switch and filter is smaller than usual.

The impedance of the connection is 50 ohms, and the voltage standing-wave ratio is 1.02. The switch is designed to function for at least 12 years.

This work was done by Andrew H. Hwon and Clinton F. Steidel of Transco Product Inc. for **Johnson Space Center.** *For further information, Circle 63 on the TSP Request Card.*
MSC-20572

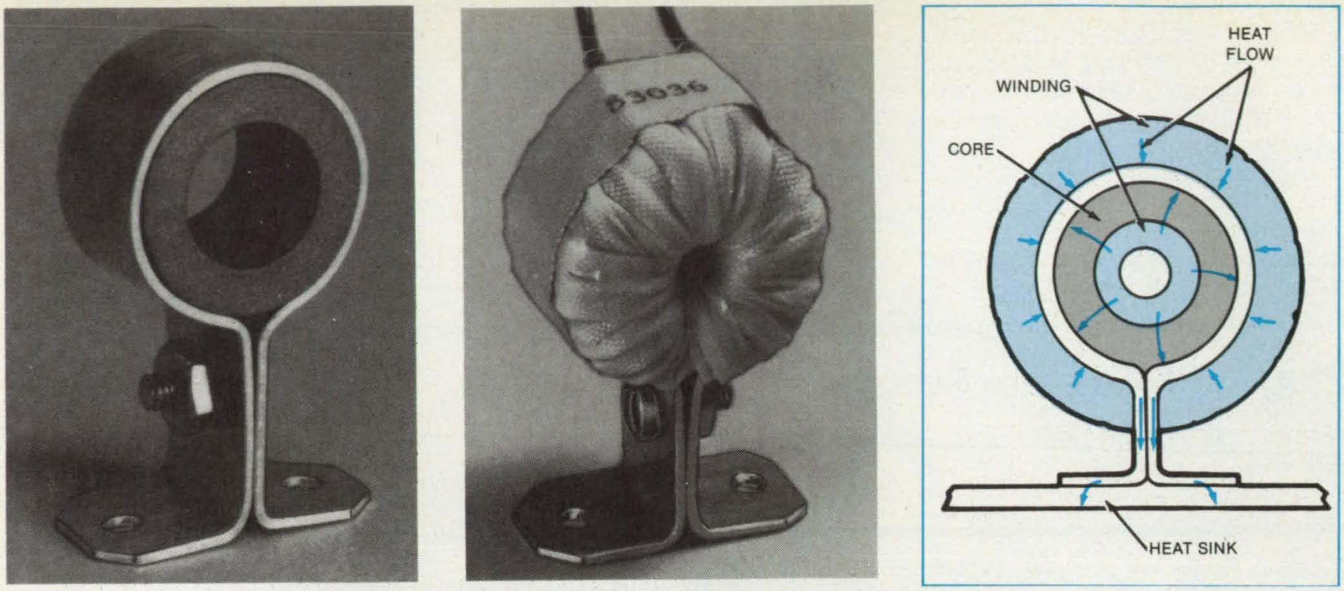
Removing Heat From Toroidal Inductors

A mounting bracket is adapted to prevent hotspots.

NASA's Jet Propulsion Laboratory, Pasadena, California

A bracket for mounting toroidal inductors has been adapted for removing heat as well as for providing support. The copper windings are wound around the bracket instead of directly on the core.

In a conventional toroidal inductor, the



The **Heat-Dissipating Mounting Bracket** encircles the hollow cylindrical magnetic core (left). The core can then be wrapped with a toroidal winding and encapsulated in the usual way (center). The bracket thus provides a direct path for heat to leave both the core and the windings (right).

magnetic core is nested within the windings. Substantial amounts of heat can be generated in the core; in fact, the region between core and windings is usually the hottest part of the component. There is no direct path for the heat to escape; it must be conducted through the windings to the surface and then dissipated through the surrounding air. Thus, excessive heat can easily build up in the unit, causing erratic performance or even failure.

The modified bracket is shaped so that it encircles the core in the space between core and windings (see figure). The bracket forms an efficient thermal conduction path and extracts heat not only from the core but from the windings as well.

The contoured heat-sink bracket can be used with tape cores (for example, Permalloy 80 or equivalent), with amorphous metal cores, such solid cores as those of ferrite, and powder cores (for example, iron or Moly-permalloy or equivalent). Its heat-removal efficiency is further improved if it is surrounded by a high-thermal-conductivity silicone compound.

This work was done by Colonel W. T. McLyman of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 12 on the TSP Request Card.*
NPO-16386

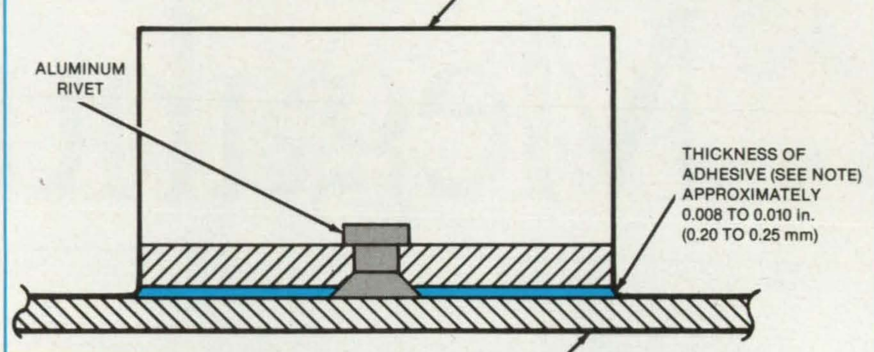
Attaching an Electrical Ground to an Aluminum Structure

Contact is made without screws or conductive adhesive.

Lyndon B. Johnson Space Center, Houston, Texas

A method for creating a low-resistance groundpath from electronic equipment to an aluminum supporting structure requires no drilling or other penetration of the structure. Originally developed for an electrical attachment in the Space Shuttle airlock, the method does not require the costly silver-filled adhesive used previously. The ground connection is light in weight, requires few parts, and is not subject to galvanic corrosion. It can be placed at any convenient location on the structure so that interference with adjacent parts can be avoided.

The new method uses an angle section with three protruding rivet heads held in firm contact with the structure (see figure) by an epoxy resin structural adhesive. The adhe-



NOTE: Use epoxy resin adhesive, type II, class I, FM 123-2, American Cyanamid Corp., Commerce, CA (or equivalent)

The **Countersunk Rivet Head** protrudes 0.010 in. (0.25 mm) below the aluminum bracket. A commercial epoxy structural adhesive fills the gap between the bracket and the facing sheet of the structure.

sive is cured while the bracket is clamped to the structure by vacuum bagging at a pressure of about 10 psi (70 kN/m^2).

The rivets are attached only to the angle brackets; they do not penetrate the facing sheet or the aluminum structure itself. Thus, there is no pressure leakage. To ensure good electrical contact and to avoid damage to the facing sheet, the periphery of the rivet head is rounded slightly.

The resistance of the ground connection is about 0.1 mΩ. This value is a major improvement over a previous connection employing metal ground straps attached to the structure by a conductive adhesive. The resistance for the latter connection was 600 mΩ. The longevity of the new low-resistance connection has not yet been tested.

This work was done by Kennard L. Billington of Rockwell International Corp. for **Johnson Space Center.** *No further documentation is available.*
MSC-20668

Touch Sensor for Robots

Sensor indicates where, and how firmly, a gripper has touched an object.

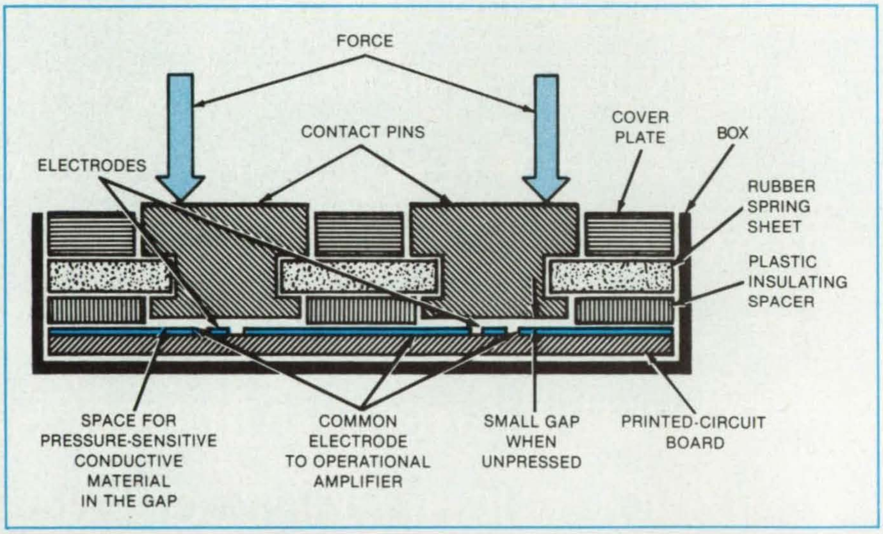
NASA's Jet Propulsion Laboratory, Pasadena, California

A touch sensor for robot hands provides information about the shape of a grasped object and the force exerted by the gripper on the object. Pins projecting from the sensor create electrical signals when pressed against the object.

The tactile sensor (see figure) is packaged in a small, rugged box that fits on the gripper pad. The projecting pins are arranged in a regular matrix on one face of the box. The inner ends of the pins bear on individual circuit elements. An element may be a switch that turns on when a pin is pushed and makes contact with it, or it may be a variable resistor, the conductance of which increases with the force on the pin.

The prototype box is milled from a solid slab of aluminum. In it rests a printed-circuit board carrying the switch electrodes (or pressure-sensitive resistors) and the common electrode. Insulating gaps separate the electrodes from the surrounding electrode plane. Covering the printed-circuit board is a plastic insulating spacer, which confines the pins laterally. On the spacer is a rubber spring sheet. The pins pass through the rubber sheet, which restores the pins to their normal positions when a tactile force is removed. Since the holes in the spring sheet are smaller than the heads and feet of the pins, the sheet confines the pins axially.

The sensing pins are electrically and mechanically separated from each other. The circuit for each pin is well defined and independent of the circuits for other pins; crosstalk is thus reduced to a minimum.



Two of the Many Contact Pins on a tactile sensor appear in this cross section. When a grasped object depresses a pin, it contacts the electrode under it, connecting the electrode to the common electrode. Alternatively, a pressure-sensitive conducting plastic may be inserted between the pin and the electrode and common electrode to give an output that varies with the force on the pin.

The rubber spring sheet provides an effective seal around each pin and around the box wall. The sensitive portions of the sensor are deep in the box, protected from the environment; grease, dirt, and fumes have little effect on these portions. Since the box bottom supports the printed-circuit board, the board and the pins are protected from damage by overpressure and overtravel.

This work was done by Howard C. Primus of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 2 on the TSP Request Card.*
NPO-16230

Books and Reports

These reports, studies, and 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.

Preventing Electrostatic-Discharge Damage to Electronics

Guidance for maintaining a static-free workplace

A booklet discusses the damage to electronic components caused by electrostatic discharges during assembly. Electrostatic discharges cause many electronic-equipment failures, with metal-oxide-semiconductor (MOS) devices being especially vulnerable. The booklet describes a procedure for setting up a static-free workplace for handling and assembling electronic components.


AFTER 35 YEARS AS HIS EMPLOYER, TELL HIM ABOUT DIRECT DEPOSIT AS A FRIEND.
Make sure the people who have given you so much through the years get everything they've got coming in the years ahead.
Direct Deposit lets your retiring employees send their Social Security straight to their checking or savings account. It's free, and it lets them enjoy the good life they deserve.
As an employer, send for a free Direct Deposit retirement planning kit today, and pass the information along...to a friend.
Write to—Direct Deposit (D1), U.S. Treasury, Annex 1, PB-1100, Washington, DC 20226.

The booklet emphasizes "level 2" protection, in which electrostatic voltages in excess of 20 volts are prevented from being applied to parts. In an introductory section, the booklet points out that electrostatic-discharge failures occur in the course of packaging, distributing, and testing components and cost manufacturers millions of dollars annually. Worse yet, from the standpoint of component users, it is possible for electrostatic discharge to cause latent failures. That is, it can cause damage that is not detectable by device or circuit tests, but emerges later as a failure.

The static-free workplace must be clearly identified and its entrance controlled. It is important to provide a grounded conductive floor. A means for grounding all personnel, whether they are assemblers or not, should be provided at the work-area entrance: A grounded doorknob or bar will serve the purpose. An ionized-air generator should bathe entering personnel and equipment with positive and negative ions, thereby neutralizing charges.

Work stations should have grounded conductive work surfaces. A ground bar should be available at each station for attaching the operator's conductive wrist straps and straps from instruments, tools, and soldering irons. All personnel must wear electrostatic-discharge-safe outer garments; for example, garments made of a polyester/cotton blend incorporating stainless-steel fibers. Conductive booties should be worn over shoes.

Ordinary plastics are prohibited in electrostatic-discharge-safe applications. However, plastics can be treated in several ways to increase their conductivities. For example, carbon particles can be incorporated into the bulk of a plastic to render it electrically conductive.

Hand coverings can present a problem. Conductive vinyl plastic gloves are available, but cause hands to perspire. Latex rubber finger cots are prohibited because of their propensity to generate static. Special antistatic finger cots are available. Nylon or cotton gloves can be used if treated with an antistatic agent.

The booklet recommends that an electrostatic-survey meter be kept at the workplace so that regular checks of antistatic provisions can be made. The booklet contains a checklist of items for weekly review. The checklist includes such questions as:

- Are chairs and stools all metal or do they have exposed nonconductive parts covered with conductive or static-dissipating material (surface resistance less than 10^{10} ohms per square) connected to the metal frame?
- Is the resistance to ground between 200,000 and 2 megohms?
- Are the electrical-equipment grounds intact?
- Is the work area free of untreated plastics and synthetic fabrics (ordinary vinyl bags and vinyl-jacketed notebooks, polystyrene bags and windows, polystyrene-foam cups and the like)?

As a final caution, the book notes that not every recommended step may be necessary, but leaving any one out will entail risk. It is surely more cost-effective to avoid risk than to repair failures.

This work was done by William S. Read, Paul C. Dozois, and James O. Lonborg of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the booklet, "Electrostatic Discharge Avoidance," Circle 70 on the TSP Request Card.*
NPO-15953

Single-Event-Upset Studies: A Compilation

Tests of latchup and bit flips in memory devices are evaluated.

A document summarizes 15 studies of single-event upsets covering 60 different types of semiconductor devices. Single-event upsets in integrated-circuit memory chips and related silicon charge-storage devices such as flip-flops, registers, microprocessors, counters, and bit slices are manifested as changes of state (bit flips) or as device latchup. A bit flip is a "soft error" — the device is not damaged, and the data can be rewritten in it. Latchup, however, is a potentially catastrophic failure in which large currents are likely to burn out the device and cause massive failure of system function.

An upset can arise from a variety of sources:

- A single ionizing particle such as a proton or heavier ion in galactic cosmic rays or solar flares;
- Protons trapped in belts around a planet;
- Alpha particles emitted by radioactive contaminants in electronic packages;
- Secondary cosmic rays (protons, neutrons, and mesons); or
- Neutrons, protons, and energetic photons from nuclear reactions.

The studies discussed in the document include the verification of basic reactions induced by heavy ions and protons and surveys of latchup and bit-flip susceptibility of several types of devices and device-fabrication technologies. These studies include tests of parts for future spacecraft systems.

One of the studies was important in establishing that cyclotron heavy-ion tests can be used to simulate cosmic-ray effects. Another study demonstrated the single-event upset mechanism for proton irradiation. Related later studies looked at single-event upset as a function of incident proton energy. Several tests were specifically designed to examine latchup, and others addressed the relative susceptibility of various medium-scale-integration families.

The document provides a brief overview of the tests, objectives, and conclusions of each study. It then summarizes the studies according to the categories of proton test data, latchup data, and heavy-ion bit-flip data.

This work was done by Donald K. Nichols, William E. Price, Carl J. Malone, and Lawrence S. Smith of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "Single Event Upset of Semiconductor Devices — A Summary of JPL Test Data," Circle 64 on the TSP Request Card.*
NPO-16362

Optimizing a Linear Array of Radiating Elements

Measurements are used in minimizing side-lobe levels.

EOPS empirically optimizes a linear array of radiating elements. The program directly addresses the problem of minimizing the maximum side-lobe level of fixed length, linear arrays of radiating elements under realistic "on-the-vehicle" conditions. It can be used for both electromagnetic and acoustic arrays.

Traditionally, antenna array design has been based on an analytic approach. Although this has led to many elegant closed-form solutions, it has often led to design methods that are limited by restrictive and unreasonable assumptions. EOPS, in contrast, is based on an algorithm in which an n-dimensional minimization method is applied to measured data of the individual elements in the array (thereby accounting for coupling and scattering between the antenna elements and the environment). EOPS calculates an "improved" set of element spacings. Measurements may then be taken on the new array and the procedure repeated until convergence occurs.

The EOPS program is written in FORTRAN IV for batch execution and has been implemented on a UNIVAC 1100 series computer with a central memory requirement of approximately 25k of 36-bit words. This program was developed in 1983.

This program was written by Stephen J. Blank of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 29 on the TSP Request Card.*
NPO-16352

Optimization of Antenna-Structure Design

Design constraints and optimality criterion are satisfied in the same procedure.

A conference paper describes the application of an optimality criterion to the design of a microwave dish antenna. For the purpose of this study, the overall design objective is to minimize the structural weight, subject to the design constraints that the antenna-pointing and microwave-path-length errors not exceed specified values.

The structure considered is a 34-m diameter ground-based antenna of the Deep Space Network. The analytical model of the structure contains about 1,145 nodes, 3,400 unconstrained displacement degrees of freedom, 3,900 rod members, and 90 plates. Path-length and pointing errors are caused by gravity and wind loadings; these are computed for a set of combinations of antenna elevation angle and wind direction known from previous work to impose the greatest demands on the structure.

If it is assumed that the structural weight is proportional to the volumes of the structural rods, optimization consists in minimizing the objective function

$$V = \sum_{i=1}^{N} L_i a_i$$

where L_i = the total length of all the members in the ith group of identical members and a_i = the cross-sectional area of a member in this group. The minimization is achieved by the method of Lagrange multipliers and optimality criteria applied through multiple iterations of the design.

Primary constraints are expressed by equations of the form

$$G_j = \sum_{i=1}^{N} \frac{F_{ij}L_i}{a_i} - C_j^* \leq 0 \qquad j = 1, 2, ..., k.$$

F_{ij} is a sensitivity coefficient such that the virtual work of the ith design variable for the jth constraint is given by $F_{ij}L_i/a_i$. C_j^* is a prespecified bound on the virtual work. It could represent, for example, the maximum allowable displacement in a given direction at a given node, in which case the virtual load is a unit load at that node in that direction.

Stress constraints for rod members can be converted to extension constraints, and the virtual-loading vector for a rod consists of a pair of colinear self-equilibrating loads applied at the opposite ends of a member. Antenna-path-length or pointing-error constraints are then expressed as particular virtual-loading vectors, with components at all nodes that support reflecting-surface panels. These vectors correspond to the antenna-surface displacements that give the corresponding path-length and pointing errors as calculated by geometric optics.

Structural members are selected from a table of commercially available cross-sectional shapes (for example, standard pipe or tubing sizes). The design is performed as though a continuous spectrum were available, but then the nearest available sizes that also meet the lower bound stress constraints are chosen. While this approach could theoretically lead to a nonoptimal selection, in practice the departure from optimality has been found not to be severe. Computer implementations of the design procedure have achieved significant performance improvements and low structural weights in as few as six iterations.

This work was done by Roy Levy of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the paper, "Optimization of Antenna Structure Design," Circle 8 on the TSP Request Card.*
NPO-16156

Connectors and Wiring for Cryogenic Temperatures

Thermal cycling and flex tests determine their suitability for the National Transonic Facility.

Tests performed at Langley Research Center to find connectors, cables, and other electrical components suitable for use in a cryogenic environment are described in the Technical Support Package referenced at the end of this article. In addition, several of these electrical cables have to flex under cryogenic conditions. The tests were necessary to qualify the materials for use in the National Transonic Facility (NTF), which operates at a temperature range from 175° to −300° F (353 to 89 K). The tests were based on a simulation of 10 years of trouble-free performance in the facility, equating to 100 temperature changes and 800 cold flex cycles each year. Very few "off the shelf" electrical components are qualified for these conditions, so the study included inquiries to about 45 manufacturers of products purported to qualify at cryogenic temperatures, and additional information was gathered from other NASA facilities and research agencies.

Two types of test apparatus were needed for the program: A thermal cycling machine to cycle components from +150° to −300° F (339 to 89 K) with temperature gradients approaching "real life" conditions of the NTF and a cable flex machine to flex cables during cryogenic and ambient temperature conditions. Both machines were fabricated in-house. The thermal cycle machine control system was automatic and provided for LN_2 level control, oven heat control, hot cycle [+70° to +150° F (294 to 339 K)], cold cycle [+70° to −300° F (294 to 89 K)], and full cycle [+150° to −300° F (339 to 89 K)]. The cable flex machine was used to flex electrical cables under cold and ambient conditions.

The electrical cables have to withstand cyclic stresses and, in certain areas of the facility, bending stresses under cold conditions [−300° F (89 K)]. Areas of failure would include breakage or shrinkage of cable jacket or conductor insulator and breakage of copper conductor or shielding material. Approximately 14 different varieties or cable configurations were tested. The results indicated, for example, that wrapped Kapton and Teflon are not acceptable for flexing, both having exhibited tearing during cold flexing. However, both are acceptable for cold temperatures in a nonflexing mode. Thermoplastic insulation and silicon rubber failed thermal cycling and are not recommended for use at cold temperatures. Extruded TFE Teflon passed thermal cycling and 1,000 cold flex tests. This type of insulation is not available as a jacket cable. Use of extruded TFE Teflon single conductors is recommended for both cold flexing and temperature changes. Irradiated Tefzel passed all aspects of the test program including 20,000 cold flex cycles, although small amounts of shrinkage were noted during thermal cycling. Both aluminum/Mylar and tinned-copper braided shield passed the test program. No failures occurred with the stranded copper conductors tested. Solid conductors are not recommended for flexing under any conditions.

Thermal cycling tests were conducted on electrical connectors, which have to maintain their insert material integrity. The pins or sockets must maintain reliable contact at all temperatures, and the shells must resist cracking. After exhaustive tests, MIL-C-5015 connectors with diallyl phthalate inserts were selected for use in the NTF. In addition to the two main test articles of cables and connectors, tests were conducted on solder, switches, nylon Ty-Raps, nylon and vinyl cable clamps, and cable-clamping material.

The approach and testing were relatively straightforward. A significant amount of useful information was obtained from this program on the suitability of a wide variety of electrical components for use under cryogenic conditions.

This work was done by Robert D. Turner of **Langley Research Center.** *For further information, Circle 13 on the TSP Request Card.*
LAR-13193

Electronic Systems

Hardware, Techniques, and Processes

Computer Programs

Wide-Brightness-Range Video Camera

Unit handles light and dark image areas without losing detail from either.

Marshall Space Flight Center, Alabama

A television camera selectively attenuates bright areas in a scene without affecting the dim areas. The camera can thus view scenes containing extremes of light and dark without overexposing the light areas and underexposing the dark ones.

The camera uses a liquid-crystal light valve for selective attenuation. Light from a scene is brought to a focus at the light valve (see figure). But first the light is passed through a polarizer and a polarization-selective beam splitter and is therefore linearly polarized when it arrives at the light valve. The light valve rotates the polarization of the incoming light 90° and reflects it to the selective beam splitter. Because the light now has the polarization in which the selective beam splitter reflects rather than transmits, the light is then reflected to the television camera or other video sensor.

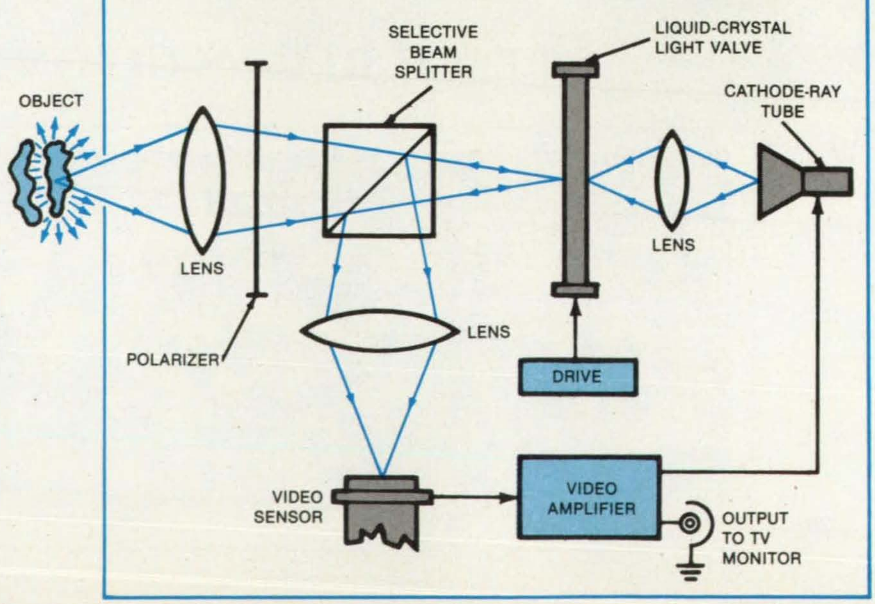
The sensor converts the light to an electrical video signal that is amplified and fed to a cathode-ray tube (CRT). The CRT converts the amplified signal into an image on its screen that duplicates the image on the video sensor. The CRT image is focused on the rear window of the liquid-crystal light valve. The light from this image alters the polarization properties of the liquid crystal; incoming light is polarized less than 90° if it impinges on a bright light-valve area. The effect is proportional to the brightness of the CRT image. The selective beam splitter therefore diverts proportionately less of the not-fully-rotated light to the video sensor.

Thus, light from bright objects produces a feedback signal through the sensor/CRT circuit and is thereby attenuated. The effect constitutes an optoelectronic automatic-gain-control feedback mechanism that tries to maintain a constant optical signal level at the sensor.

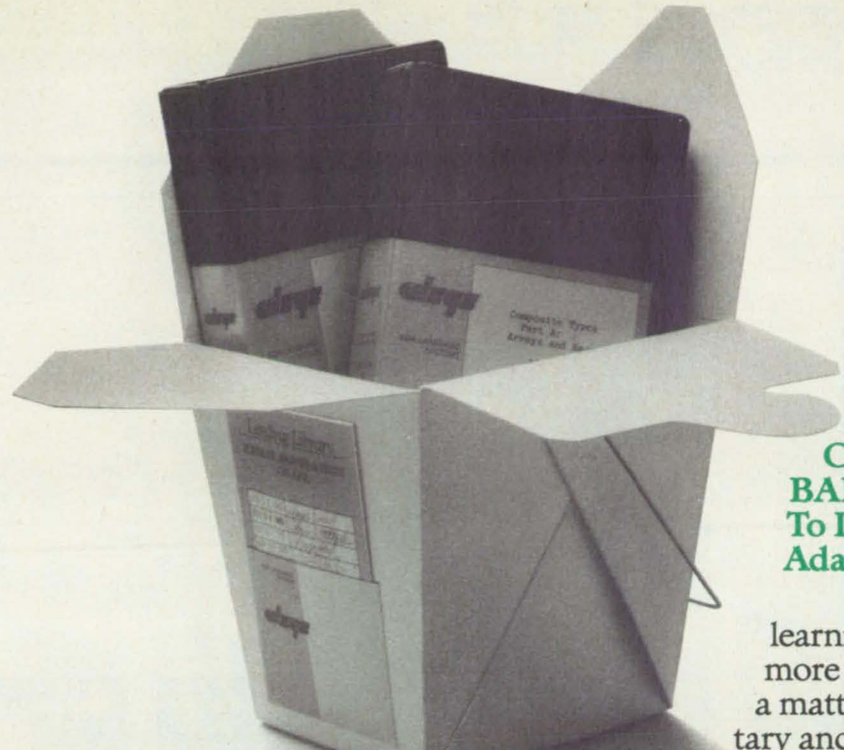
The dynamic range of the sensor alone is about 200:1. The attenuation range of the liquid-crystal light valve is about 100:1. Since the camera multiplies the range of the sensor by that of the light valve, it can view scenes containing brightness variations of 20,000:1.

An alternative version of the camera would use a transmitting light valve rather than a reflecting one and a transparent contact grid on the valve faces rather than a CRT image. The sensor image would be converted to control signals that would apply voltages to the liquid crystal, thereby altering its transmission properties in response to the image brightness.

This work was done by Glenn D. Craig of **Marshall Space Flight Center.** *For further information, Circle 10 on the TSP Request Card.* *MFS-25750*



The **Feedback Cathode-Ray Tube** locally alters reflection characteristics of a liquid-crystal light valve. This results in point-to-point optoelectronic automatic gain control to enable the viewing of both dark and very bright areas within a scene.



ADA TO GO

Programmers Borrow Company Tapes of ICHBIAH, BARNES & FIRTH Video Series To Learn Principles of Ada at Home

For many companies, learning to program in Ada is more than a matter of profits; it's a matter of survival in both military and commercial markets. And programmers are often willing to learn their parts at home.

One company has organized a lending library of ICHBIAH, BARNES & FIRTH ON ADA video tapes. An employee borrows a lesson, watches it at home, brings it back, borrows another. One in every four homes has a VCR. Borrowers mix Dynasty with Discriminants, Hill Street Blues with Rendezvous, hype and heroics with Types and Generics.

Dr. Jean Ichbiah, Principal Ada Designer.

That company knows that programming in Ada should not be taught routinely. Good programming in Ada first requires an understanding of architecture, grand concepts, sweeping ideas. Ada is a different *kind* of language. And if these principles are absorbed FIRST, programming becomes simpler, more intuitive, more efficient . . . a natural.

ICHBIAH, BARNES & FIRTH ON ADA is an authoritative 18-hour, 27-tape video course on these very principles, concepts, and ideas, with 1,200 graphics illustrating key points. Full transcriptions are included. The course is given by the Principal Designer of the Ada language itself (and two key members of his language design team). It is deservedly, the most popular and widely sold Ada video series in the industry.

It should be *everybody's* first introduction to Ada, whatever other Ada productions are planned for later.

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Circle Reader Action No. 341

Experimental Parallel-Processing Computer

A master processor supervises slave processors, each with its own memory.

NASA's Jet Propulsion Laboratory, Pasadena, California

A computer with parallel processing serves as an inexpensive tool for experimentation with parallel mathematical algorithms. The speed enhancement obtained depends on both the nature of the problem and the structure of the algorithm used. While the speed can be several times that achieved with a single processor, it will generally be less than the speed achieved with some algorithms by direct implementation in digital hardware. Unlike such hardware, the computer requires only a change of software to change algorithms.

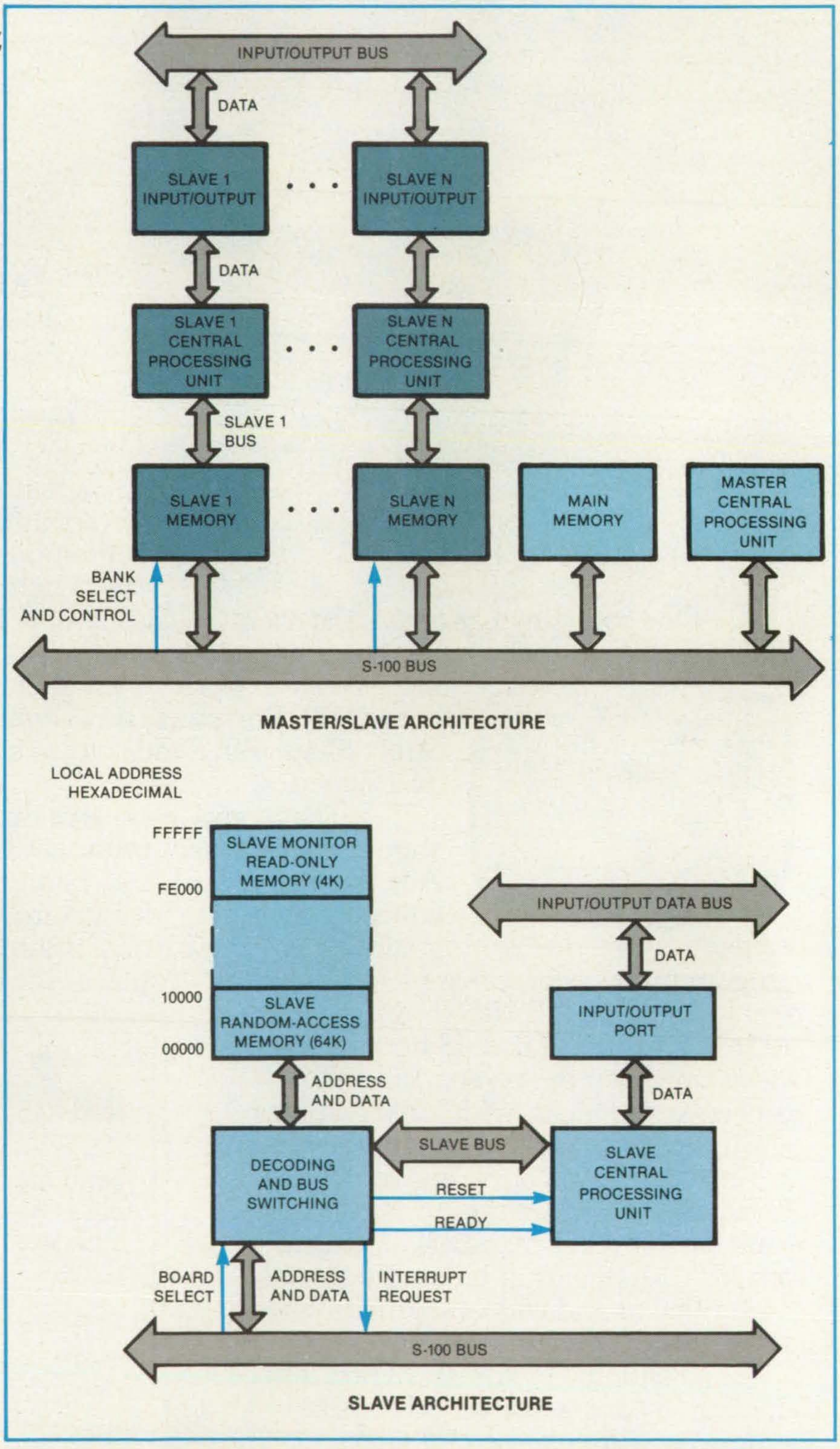
The architecture of the computer is shown in the figure. The computer uses the IEEE-696 (S-100) bus. The master processor and each slave processor have both an 8086 16-bit microprocessor and an 8087 numeric data coprocessor. The slave processors are designed so that they can be plugged into an existing computer with little or no modification to the computer.

Access to each slave memory can be obtained by both the master processor and the slave processor itself. A slave processor, however, cannot write to main memory or to another slave memory. However, all the slave processors can communicate with each other over the high-speed input/output data bus.

Each slave processor has a uniquely addressed control port connected to the S-100 bus. When the master controller sends the correct "select" code to one of the ports, the memory for that slave processor is enabled and connected to the S-100 bus, enabling the master processor to write to and read from that slave memory. At the same time, the "ready" line of that slave processor is held false, halting the slave processor.

When the master processor writes to a slave processor control-word address, the bus decoding circuitry causes the monitor program of the slave processor to restart: The slave then checks the three low-order bits of the control word, which tell which of seven entry points in the slave program should be used. The remaining 13 bits of the control word can be used as program flags for modifying program execution.

When the slave processor has completed its task, it generates an "interrupt" request to the master processor and waits for new data or instructions. The master controller can then unload the results from the slave memory and provide new data or



In this **Parallel-Processing Architecture**, the "bank select" and control signals determine which one, if any, of the N slave processor memories is accessible to the master processor at any given moment. When so selected, a slave memory operates as part of the master computer memory. When not selected, a slave memory operates independently of the main memory. The slave processors communicate with each other via the input/output bus.

instructions.

In a simplified version of the computer, each slave processor had 4k bytes of random-access memory for data and 4k bytes of read-only memory in which fixed programs were stored. The computer was used to perform selected steps of a structural-analysis problem involving matrices. An analysis of this problem showed that speedups of a factor of 4 could be achieved with as few as four slave processors in one structuring of the problem, but could also take as many as 20 slave processors in another structuring.

This work was done by James W. McGregor and Moktar A. Salama of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 82 on the TSP Request Card.*
NPO-16043

Fast Reed-Solomon Decoder

High speed is due to a high-radix Fermat transform.

NASA's Jet Propulsion Laboratory, Pasadena, California

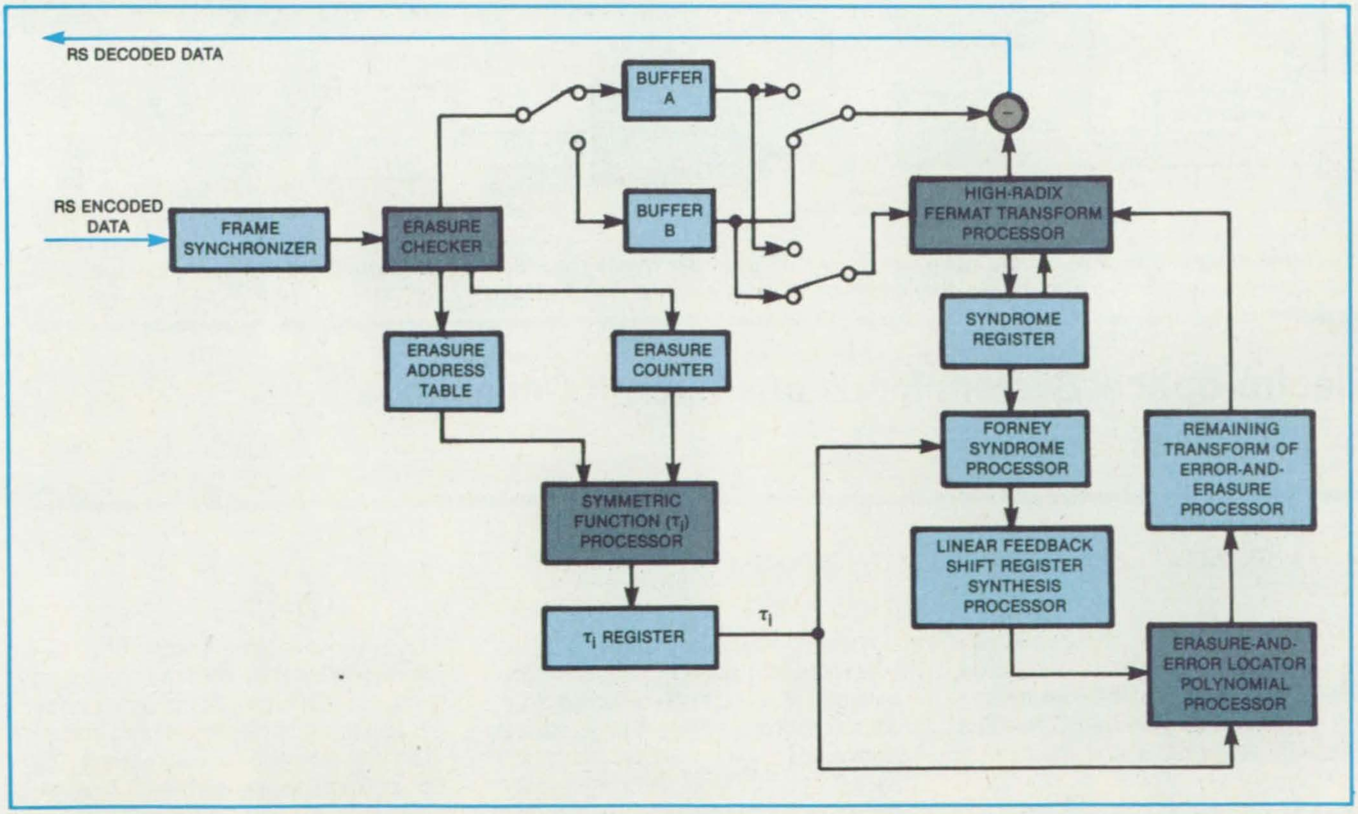
A high-speed decoder is intended for use with Reed-Solomon (RS) codes of long code length and high error-correcting capability. The design is based on an algorithm that includes a high-radix Fermat transform procedure, which is most efficient for high speeds. The RS code in question has a code-word length of 256 symbols, of which 224 are information symbols and 32 are redundant.

The overall decoding operation is based on the computation of the Forney syndrome from the received message and the use of a Berlekamp-Massey linear feedback shift register processor to compute the coefficients of the error-locator polynomial. Then an erasure-and-error-locator polynomial is computed. The error-and-erasure vector is calculated by a final high-radix transformation of this polynomial. The corrected message is obtained by subtracting the error-and-erasure vector from the received message.

The polynomial transforms are done with a fast transform over the Galois field $GF(F_n)$, where F_n is a Fermat prime. (In this case, $F_n = 257$.) The details of the transform operations are greatly facilitated by using an unconventional representation for the Galois field: Each number, $i = 0, 1, \ldots, F_{n-1}$, is represented by the conventional binary representation for $i - 1$, except that 0 is represented by the binary form of F_{n-1}.

A functional block diagram is shown in the figure. With the proper parallel-pipeline design of the processors shown, it is expected that the decoding speed will reach 100 megabits per second.

This work was done by Kuang Y. Liu of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 34 on the TSP Request Card.*
NPO-15867



This **Reed-Solomon Decoder** design implements a decoding algorithm that is particularly efficient for high-speed decoding of long, error-correcting RS codes.

Systolic VLSI Reed-Solomon Decoder

The conventional algorithm is modified to avoid calculating inverses.

NASA's Jet Propulsion Laboratory, Pasadena, California

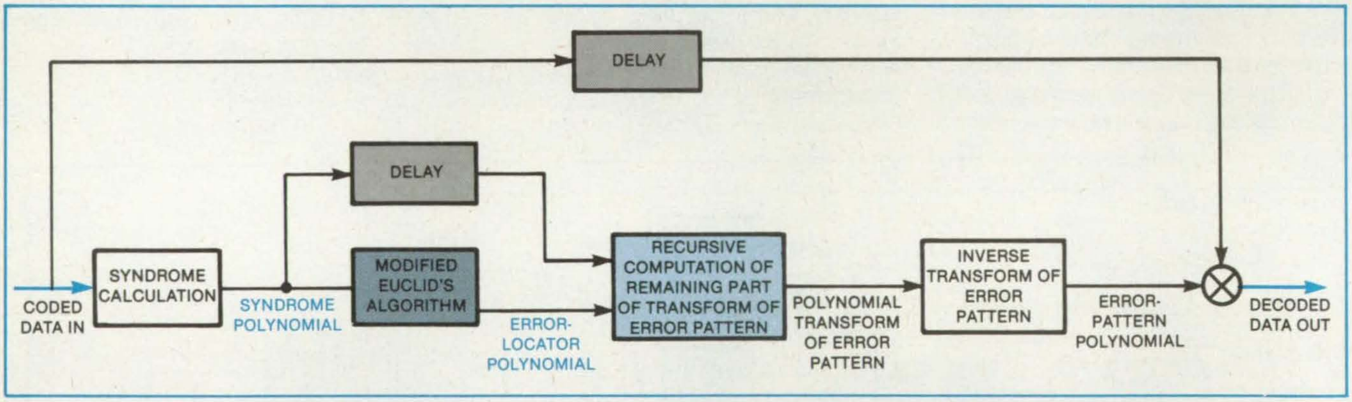
A decoder for digital communications would provide high-speed, pipelined Reed-Solomon (RS) error-correction decoding of data streams. The principal new feature of the proposed decoder is a modification of the Euclid greatest-common-divisor algorithm to avoid the need for time-consuming computations of the inverse of certain Galois-field quantities. The decoder architecture is suitable for implementation on very-large-scale integrated (VLSI) chips with negative-channel metal-oxide/silicon circuitry.

The pipeline circuit architecture used is also called "systolic" because the data are, in effect, pumped through the decoder in a stream — like blood through the heart. The error-corrupted data stream enters the decoder, and the corrected data stream leaves the decoder a bit at a time while decoding proceeds. The modified algorithm is used to calculate the error-locator polynomial from the syndrome polynomial in the second step of the decoding process (see figure). This method is faster than the Berlekamp-Massey and continued-fraction methods for computing the error-locator polynomial. Furthermore, the modularity of the Euclid algorithm makes it very attractive for VLSI implementation.

The encoder was developed as one component of the concatenated-coding scheme selected as standard for telemetry in future space missions by both NASA and the European Space Agency. In this scheme, the data are first encoded in a constraint-length-7, rate-1/2 convolutional code and then further encoded in an RS code in which 32 redundant bytes are added to each 223-byte block of the convolutionally encoded data.

The RS encoding step results in an effective increase of 2 dB in the signal-to-noise ratio for a decoded-bit error rate of 10^{-5}. Errors in up to 16 bytes per block can be corrected. The techniques used in the decoder will be of interest to communications engineers, coding theorists, and designers of hardware for such operations as fast Fourier transforms, fast polynomial calculations, and data encryption and decryption.

This work was done by Howard M. Shao, Trieu-Kie Truong, Leslie J. Deutsch, and Joseph H. Yuen of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 110 on the TSP Request Card. NPO-16383*



The **Proposed Reed-Solomon Decoder** improves on previous designs in that the modified Euclid's algorithm used to calculate the error-locator polynomial is well suited for implementation in VLSI circuitry and is very fast.

Electro-optical System Measures Aircraft Deflections

A digital system offers accuracy and convenience.

Ames Research Center, Moffett Field, California

In-flight deflections of aircraft surfaces are measured accurately over a wide range of airspeeds and attitudes by an electro-optical instrumentation system. Deflections caused by aerodynamic and acceleration forces are measured on wings, stabilizers, helicopter rotors, and other surfaces.

The electro-optical system replaces the 70-millimeter motor-driven camera previously used to observe deflections. As shown in the figure, its major components are optical targets attached to the deflecting structure, a control unit, receivers, target drivers, a telemetry unit, and a ground unit. The targets are infrared LED's in aerodynamically-shaped aluminum fixtures bonded to the aircraft surface. The system uses up to 48 targets and up to 6 receivers.

A driver turns on the target LED's sequentially for 5 milliseconds at a time, stepping through all 48 of them in 240 milliseconds. The sampling rate is therefore approximately four times per second for each target. The use of fewer targets can result in an increased sampling rate per target; e.g., one target can be sampled 200 times per second.


"I invest my time in high technology. I invest my money in U.S. Savings Bonds."
William L. Rasmussen
Honeywell, Inc.
William L. Rasmussen, one of the developers of the ring laser gyro, says: "I've tried many forms of investment and I'm satisfied I can't do better than U.S. Savings Bonds."
Just look at the facts. New competitive-rate U.S. Savings Bonds are the answer to sensible savings without risk. Today's Bonds pay higher market-based interest rates—the sky's the limit. And a guaranteed minimum return protects your investment. Bonds are exempt from state and local taxes, so the effective yield is even higher.
Best of all, Bonds are easy to buy —wherever you bank, or through the Payroll Savings Plan where you work. No fees or commissions. And no worries. So save time and money. Buy Bonds.
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UNITED STATES SAVINGS BONDS
A public service of this publication.

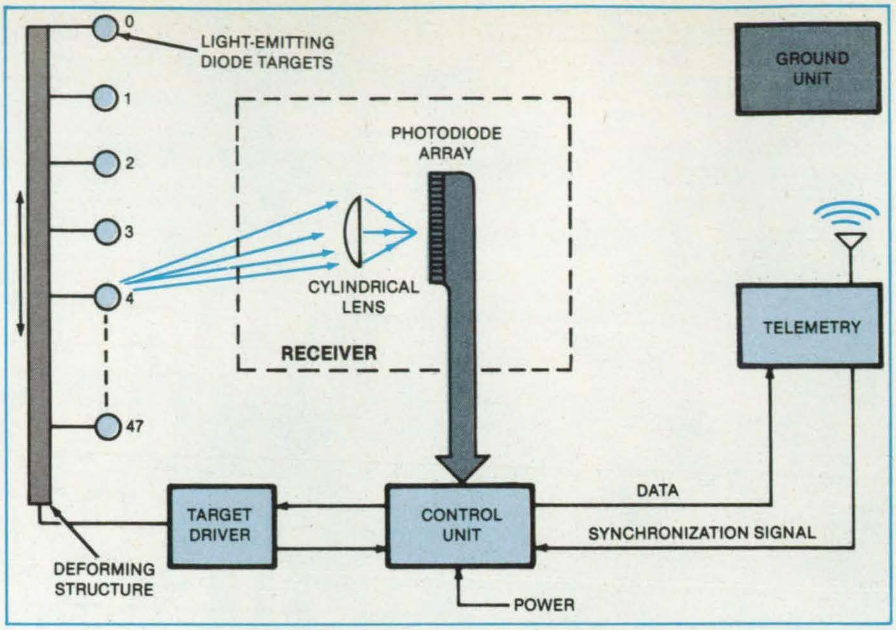
Light from the illuminated target is focused by a cylindrical lens to a line on the photodiode array at the lens focal plane. Motion of the target in a plane parallel to the lens axis does not change the position of the target image, but target deflection perpendicular to the axis and to the line of sight shifts the target image line along the diode array.

The receiver puts out an electrical signal proportional to the point at which the light impinges on the array. The control unit passes the signal data to a telemetry unit for transmission to the ground as a stream of two 10-bit words. One word identifies the target, and the other contains position information for that target. The ground unit records the telemetered data and displays them as deflection values at the target locations.

Motion in two dimensions can be measured by a system having two receivers with their axes perpendicular or parallel to each other, depending on the target distance. Similarly, three-dimensional motion could be measured by a system with three receivers. A three-dimensional capability would be useful not only for deflection measurements but also to provide position feedback for remote-manipulator or robotic feedback-control systems.

This work was done by Bob Fodale, Herbert R. Hampton, and Herbert R. Seymour of Grumman Aerospace Corp. and V. Michael DeAngelis of Dryden Flight Research Facility for **Ames Research Center.** *For further information, Circle 14 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 25]. Refer to ARC-11454.



The **Positions of Light-Emitting Diodes** on the deforming structure are measured in terms of image positions on a linear photodiode array.

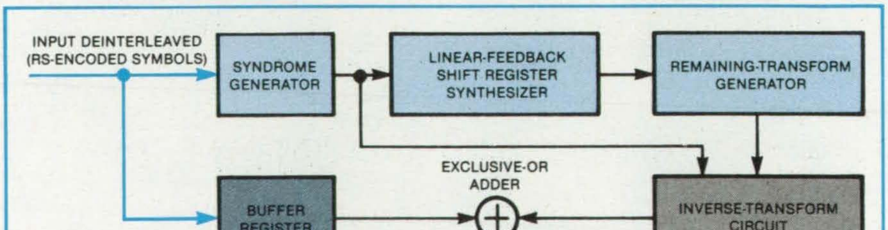
Modular VLSI Reed-Solomon Decoder

Features would include small size and high speed.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed Reed-Solomon (RS) decoder would be assembled from very-large-scale integrated-circuit (VLSI) building blocks. The decoder would exploit the recursive forms in RS decoding algorithms. It is meant to be used in conjunction with the RS encoders described in "VLSI Reed-Solomon Encoder" NPO-15470, page 130, *NASA Tech Briefs,* Vol. 7, No. 2 (Winter 1982).

RS codes are capable of correcting random or burst errors in telemetry and other data-communication signals. In the RS codes of interest here, the encoded data are transmitted in interleaved form in blocks of I code words. Within a block, I interleaved information words of $2^J - 1 - 2E$ information symbols each are transmitted first, followed by 2IE parity-check symbols in I groups of 2E symbols apiece. Within the information portion, every Ith symbol originates from the same preinterleaved data word. The original (preinterleaved) sequence is reassembled at the receiving



The **RS Decoder** (above) is one of four that are operated in a parallel pipeline (below) to achieve high-speed RS decoding. Switches A and B change positions at the code-word rate.

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Anyone could have used these 4,178 words. In the hands of William Shakespeare, they became *King Lear*.

All the writers of his day had the same elements to work with — the same words, forming the same language. But Shakespeare's talent was his ability to choose from all these elements and combine them flawlessly — in a unique organization of words.

At IBM Federal Systems Division we understand it takes the same basic talent to design and manage today's advanced complex systems. It's that special ability to take a myriad of separate pieces and make them work together — with precision.

And we're doing it.

For NASA's Space Shuttle we have designed a system to coordinate the individual operations of the most technologically advanced flying machine ever built.

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end. Decoding and error correction are performed on each reassembled RS code word of $2^J - 1 - 2E$ information symbols and 2E parity-check symbols.

The algorithms that decode and correct RS-coded data received with errors include calculations that can be performed independently for each symbol. This property makes it possible to distribute the computing among several identical chips in a "symbol-sliced" manner.

The VLSI architecture (see figure) has been specified for the essential functional blocks of the decoder, including:

- An eight-stage syndrome generator — a circuit that generates a signal indicative of the errors in a code word for an RS code of $E = 8$;
- A circuit to synthesize the linear-feedback-shift-register algorithm that determines the coefficients of the error-location polynomial from the syndrome;
- A remaining-transform generator — a circuit that calculates a polynomial transform of the error pattern for an RS code of $E = 8$; and
- An inverse-transform circuit that generates the error pattern from the syndrome-register and remaining-transform-generator outputs for an RS code of $2^J - 1 = 31$ and $E = 8$.

It is estimated that the proposed decoder could be fabricated on 200-by-200-mil (5-by-5-mm) complimentary metal-oxide-silicon chips if bit-serial transmission is used. The throughput would be around 3 Mb/s. Eight such chips plus about 40 discrete integrated circuits would be needed to construct the $2^J - 1 = 31$, $E = 8$ decoder. The total chip count would be about a tenth of that of a decoder of equal speed constructed entirely with discrete integrated circuits. Because of its small size and low power consumption, it may be advantageous to employ several such decoders in a parallel-processing scheme to increase decoding speed.

This work was done by Kuang Y. Liu of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 51 on the TSP Request Card.*
NPO-15837

"Speaking" Microcomputer

An electronic speech synthesizer replaces the cathode-ray tube.

Marshall Space Flight Center, Alabama

A microcomputer system developed for NASA allows a blind person to use a portable computer and to communicate with a remote mainframe computer. The system prepares data for transmission to the mainframe, translates data transmitted from the mainframe for its own use, and converts the data that would ordinarily be displayed on its video screen into synthesized speech.

A portable computer was modified by removing the cathode-ray-tube display and replacing it with a commercial electronic speech synthesizer. A slot in the microcomputer housing holds a modem for connection to the distant computer. A program was written to drive the speech synthesizer, and the CP/M operating system was modified to adapt the microcomputer to the synthesizer and the mainframe. The program is loaded into memory above the operating system and uses the CP/M BIOS vector table.

The user gains access to the mainframe or operates the microcomputer from the microcomputer keyboard. The microcomputer numeric keypad is used to scroll up or down through the video memory or to resend any line in video memory to the speech synthesizer. The video memory buffer holds 32 lines of 128 characters each. It is filled in "wraparound" fashion: Any lines after line 32 are added to the beginning of the memory buffer, line 33 overwriting line 1, line 34 overwriting line 2, and so forth.

This work was done by Charles Mandy and Jimmy Annerton of The Boeing Co. for **Marshall Space Flight Center.** *For further information, Circle 56 on the TSP Request Card.*
MFS-25976

Sensor Tracks the Sun From Any Angle

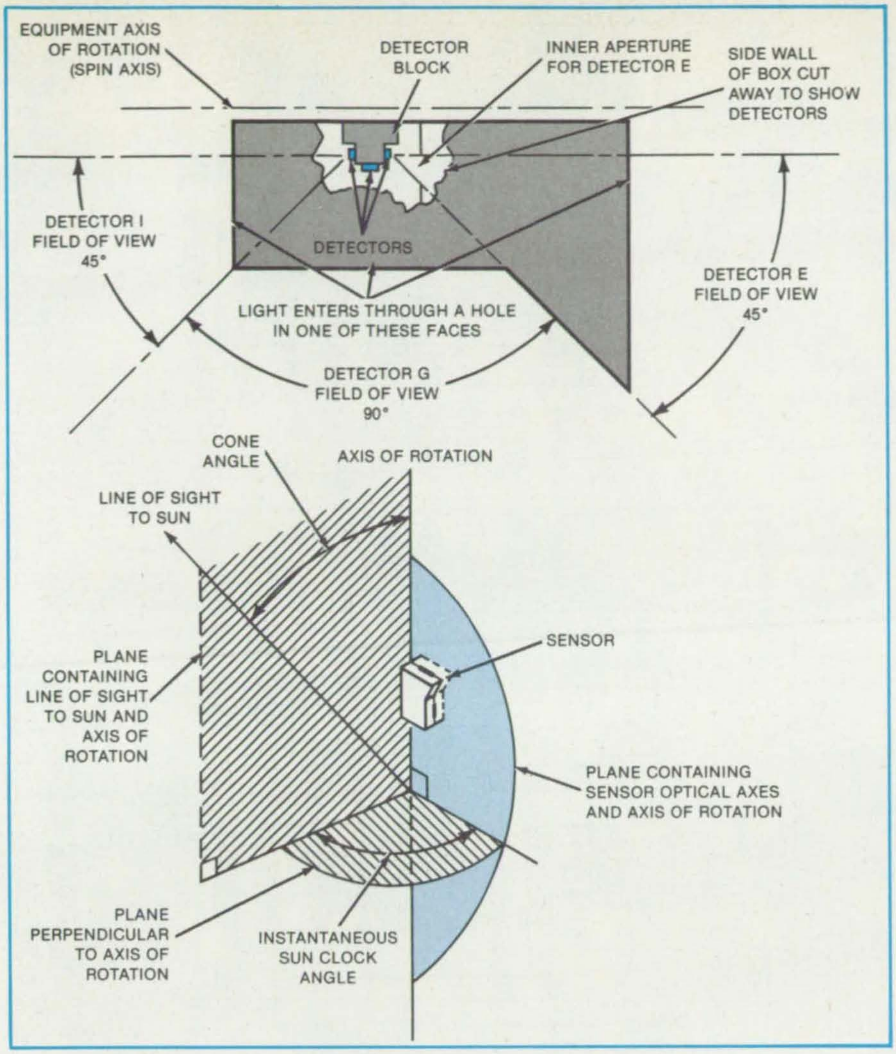
Three photodetectors cooperate to aline equipment toward the Sun.

NASA's Jet Propulsion Laboratory, Pasadena, California

A sensor system locates the Sun from any angle and generates error signals to point an object toward the Sun and follow its motion. The system was developed for orienting a newly launched spacecraft and directing its photovoltaic panels Sunward, regardless of the initial attitude of the spacecraft. The concept can be adapted to guide Sun-tracking reflectors for solar concentrators.

The heart of the sensor system is a detector box containing three identical cadmium sulfide light detectors and a set of apertures that define the detector fields of view (see figure). The detectors are placed on each of three faces of a block in the box and together cover a field of view of 180° in the plane that includes the equipment spin axis. As the equipment rotates, this plane rotates with it so that the field of view is swept through the total celestial sphere.

The most important signal output is from detector E. The outputs from detectors I and G are used only to orient the spacecraft so that it aims detector E approximately toward



The **Sun-Sensor System** includes three photodetectors, each with a separate field of view defined by a set of apertures. As the equipment rotates about the axis, the detectors put out time-varying signals that are processed by external electronics to determine the rotation rate and the direction to the Sun.

the Sun. Detector E provides enough signal resolution to bring the spacecraft rotation axis within 1° of the Sun; at the same time, detector E gives signals representing the instantaneous Sun clock angle, from which the rate of rotation can be determined. (The instantaneous Sun clock angle is the equipment-rotation angle between the plane containing the sensor optical axes and the plane containing both the axis of rotation and the line of sight to the Sun.) From the output of detector E, a digital signal processor computes the clock angle and the spacecraft rotation rate.

The sensor output signals have broad peaks spanning rotations of 10° to 20° as the cone angle approaches zero. By comparing the time for a given voltage level on one side of the peak with the time for the same level on the opposite side, the processor obtains the midpoint time. This midpoint is the instant at which the clock angle of the Sun is zero. By continuously keeping track of the lengths of the intervals between the times when the Sun clock angle is zero, the processor determines the rotation rate. The processor uses its calculations of the rotation rate and Sun clock angle to control thrusters that aline the rotation axis with the Sun.

The sensor system contains no moving parts and needs only a few microwatts of power. A redundant pair of sensing systems has a mass of only 540 grams and occupies a volume of only 550 cubic centimeters.

This work was done by Morris M. Birnbaum and Robert L. Bunker of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 71 on the TSP Request Card.*
NPO-16211

Interface Circuits for Self-Checking Microprocessors

Hardware faults are detected automatically during processing.

NASA's Jet Propulsion Laboratory, Pasadena, California

A fault-tolerant-microcomputer concept is based on enhancing a "simple" computer with redundancy and with self-checking logic circuits that detect hardware faults. This approach to fault-tolerant computing uses concepts previously described in "Fault-Tolerant Computer System" (NPO-14562), page 186, *NASA Tech Briefs,* Vol. 4, No. 2 (Summer 1979); "Finding Open Faults in CMOS Circuits" (NPO-15838), page 171, *NASA Tech Briefs,* Vol. 8, No. 2 (Winter 1983); and "Complementary-Logic Fault Detector" (NPO-15410), page 51, Vol. 9, No. 1 (Fall 1984).

The figure illustrates a 16-bit microcomputer in its "simple" form and in its enhanced, self-checking form. In the enhanced computer, two parity bits are added to each memory word as an error-detecting code: One parity bit as a check over odd and one as a check over even data bits. Data are therefore transferred on the data bus in 18-bit coded form. The address and control buses are also expanded to accommodate additional check bits.

The processor of the "simple" computer is replaced by a set of interface and checking logic (ICL) circuits and by two processors, one of which serves as the master central-processing unit and the other, which is redundant, serves as a check on the master. The ICL unit performs the following functions:

- Synchronizes the two processors and compares their outputs to detect faults;
- Checks signals on the address, data, and control buses for proper coding and removes the check bits before passing data uncoded to the processors;
- Encodes the uncoded processor outputs (if they agree) and transmits the output over the address and data buses; and

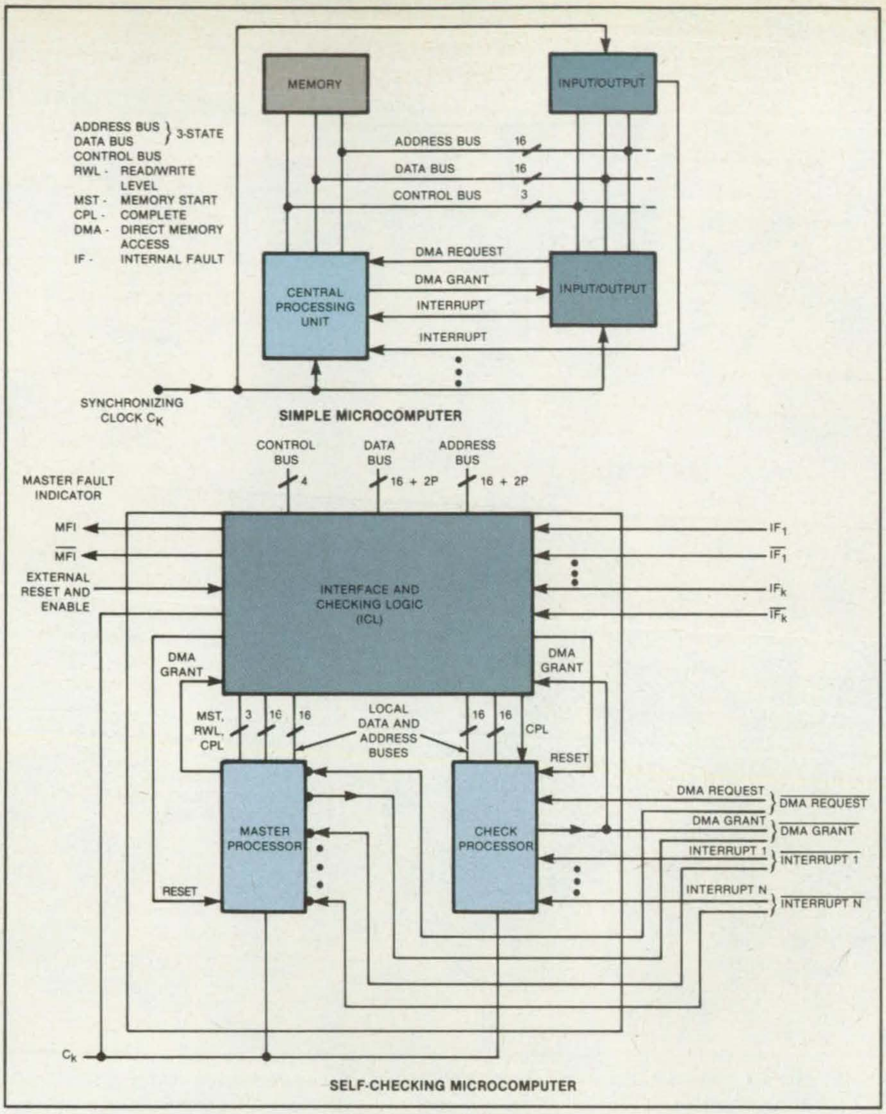
• Performs a variety of hardware fault checks, activating a master fault indicator when a fault has been detected.

The hardware fault checks include processor comparison, bus coding, detection of faults within the ICL unit itself, and receipt of internal fault signals from other modules in the computer. Upon detecting an error, the ICL attempts a rollback and restart by resetting the processors at a program-rollback location in memory. If a fault occurs again within a short interval, a permanent fault is suspected, and processing is stopped.

Each "direct-memory-access" and "interrupt" connection is made to each processor on separate wires, one in true form and one in complementary form. This provides redundancy as a check against a faulty connection, since each pair must take on the values (0,1) or (1,0) to be correct. If one signal of a pair is in error, a (0,0) or (1,1) input occurs, and this signals a fault.

This concept of self-checking complementary pairs (SCCP's) is employed throughout the ICL unit. The checking circuits all generate two-wire (0,1) or (1,0) outputs when everything is working properly. If a checker fails or if a fault occurs in the checker input, the checker output is (0,0) or (1,1), indicating a fault. The ICL elements include self-checking parity checkers, duplicate sequential circuits with SCCP outputs, and circuits that reduce two SCCP's to a single SCCP that gives the error output if either SCCP input is not complementary.

If a "stuck-at-zero" or "stuck-at-one" fault occurs in a reduction circuit, this too can usually be detected: A set of complementary inputs can be prescribed to "flush out" the fault by causing a noncomplementary output. Such reduction circuits can be connected in a tree to reduce an arbitrary number of SCCP's to a single SCCP that gives an alarm when a fault occurs anywhere in the computer.



Interface and Checking Logic and Redundant Processors confer on a 16-bit microcomputer the ability to check itself for hardware faults. The checking circuitry also checks itself.

This work was done by David A. Rennels and Ramamurti Chandramouli of Caltech for **NASA's Jet Propulsion Laboratory.**

For further information, Circle 35 on the TSP Request Card.
NPO-15700

Controllers for Flow-Field Survey Apparatus

Microcomputers control two- and three-dimensional survey systems.

Langley Research Center, Hampton, Virginia

The control systems of the flow-field survey apparatuses of the 22-Inch (56-centimeter) Hypersonic Helium Facility (two-dimensional) and the 20-Inch (51-centimeter) Mach 6 Tunnel (three-dimensional) at Langley Research Center have been equipped with a single-chip microcomputer and a single-board microcomputer, respectively, to drive probes at selected speeds and to perform other functions automatically. Flow-field measurements about models in wind tunnels are usually taken along paths perpendicular to the model longitudinal axis. For survey apparatuses that have individual switches for the directional drive motors, it is virtually impossible to drive the probe along a path between the right-angle directions by hand coordination of the switches. To overcome this problem, microcomputing devices were installed in the control circuits of the two systems and were programed to control the survey operations.

For the 22-Inch Hypersonic Helium Facility, the survey apparatus is only two-dimensional, and a single-chip microcomputer was sufficient to accomplish the desired control. The microcomputer was programed to read the settings of model angle of attack, traverse direction, and traverse speed and to compute and control the relative motor-drive rates through high-speed preset indexers to accomplish the desired traverse. The program also opens and closes circuits in the proper sequence to stop the probe drive when the probe contacts the model surface and to initiate data acquisition when the probe direction is reversed (away from the model surface).

For the 20-Inch Mach 6 Tunnel, the survey apparatus is three-dimensional and, because of the complexities, is served by a single-board microcomputer control system. The microcomputer is made up of a single-board computer, three multimodule boards used to perform floating-point math functions and serial input/output (I/O) functions, two expansion boards used to provide parallel I/O functions and analog output functions, and a system chassis with power supply. The three-axis survey system interfaces with the microcomputer through a limit chassis and an encoder interface/data splitter.

Each axis of the survey apparatus (X, Y, and Z) is equipped with a stepper motor, a translator, an absolute encoder, and limit switches. The stepper motor, translator, and limit-switch circuits are connected to the limit chassis that monitors the limit switches, displays their condition on the front of the control panel, and supplies this information to the microcomputer. The microcomputer processes the information from the limit chassis and from the control panel (pitch angle, roll angle, and survey rate) and, through a logic circuit in the limit chassis, sends pulses to the translators, which convert the pulses into the switching sequences needed to drive the stepper motors in the appropriate directions and at the proper rates to move the probe in the desired direction at the desired speed. Simultaneously, the encoder signals are transmitted to the encoder interface/data splitter, which conditions them for output — through independent buffer circuitry — to the microcomputer where they are translated to indicate on the control panel the probe position along each axis and then sent to the data-processing computer for printout.

Various modes of operation can be programed as the need arises. For example, the probe can be moved along each axis to a preset position, or through a fixed distance, or it can be driven along a path between the right-angle directions to a selected location or through a fixed distance along the path. Both of these control systems were fabricated relatively inexpensively from commercially available stock components.

This work was done by George C. Ashby, Jr., and Michael D. Vaccarelli of **Langley Research Center.** *For further information, Circle 97 on the TSP Request Card.*
LAR-13180

Fast VLSI Viterbi Decoder

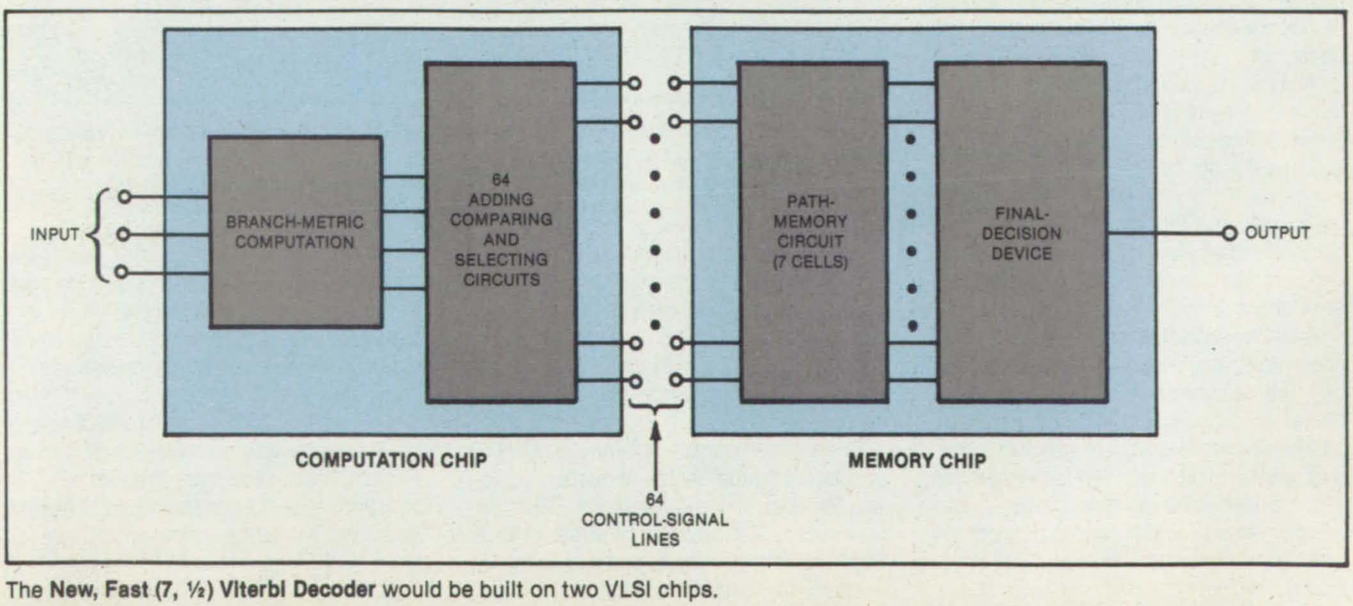
A new architecture implements a (7,½) decoder on two NMOS chips.

NASA's Jet Propulsion Laboratory, Pasadena, California

A fast Viterbi decoder with fully parallel, pipeline architecture would be implemented on two VLSI NMOS chips. The proposed decoder (see figure) would be used with the constraint-length-7, rate-½, convolutional error-correcting code widely used by NASA for deep-space telemetry data. With this (7,½) code, the bit stream contains 2 bits per original data bit, and the information about 1 data bit is distributed over 7 pairs of bits. The design principles of this decoder are also applicable to Viterbi codes of other lengths and rates.

The Viterbi algorithm entails a tree search among possible sequences of transmitted bits. The likelihood of each candidate sequence is computed in terms of the likelihood for each decoded received bit. The accumulated likelihood at each node of the tree is compared for the two paths (that is, the two sequences) entering that node. The path of lower likelihood is discarded. The retained paths are called "survivors."

A single-chip (7,½) decoder with the architecture used for previous (5,½) decoders would require about 10 times the VLSI chip area. However, three improve-



The **New, Fast (7, ½) Viterbi Decoder** would be built on two VLSI chips.

ments make it possible to fit the new decoder on two chips:

- A modified adding, comparing, and selecting structure is used to store the updated path metrics; it spends no time doing comparisons and subtractions in rescaling by the best-path metric: Instead, it uses a truncation procedure in which all fourth bits in the 4-bit metric registers are changed to "0" as soon as they become "1";
- A wiring structure is used that gradually increases the number of connection wires from one path-memory stage to another; by eliminating the processing of redundant features in the array of decoder states (hypothesized sequences) in the path memory, the decoder algorithm makes it possible to minimize the average wiring separation between adjacent memory stages, thereby reducing the required wiring area by about 60 percent; and
- A new, fully parallel pipeline architecture for tracking the survivor paths updates and stores all of the hypothesized information sequences simultaneously in a single clock cycle, thus permitting a higher data rate; the previous methods, called "register exchange" and "traceback," are slower and less efficient in the use of memory.

This work was done by Charles C. Wang of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 109 on the TSP Request Card.*
NPO-16365

Image Interpolation With Dedicated Digital Hardware

System interpolates 100 times as fast as a general-purpose computer.

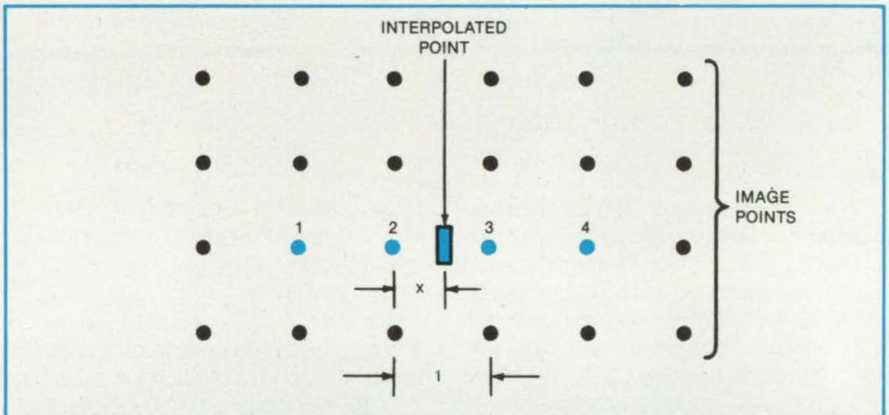
Goddard Space Flight Center, Greenbelt, Maryland

An algorithm for interpolating two-dimensional image data to change picture-element spacing has been implemented in dedicated digital hardware for high-speed execution. The interpolator calculates 5 × 10^6 interpolated picture-element values per second, 100 times as many as could be calculated by a general-purpose computer and 25 times as many as with a dedicated arithmetic and logic unit.

Image resampling occurs first along one image axis and then along the other, using two interpolation devices implemented in series. Each device performs a four-point interpolation of a serial picture-element data stream running along one axis of an image. Element spacing in the output image may be finer or coarser than in the input image, as desired.

A set of cubic convolution equations determines the weighting of the four original image points nearest the new image point. Casting the interpolation equation in the form shown in the figure reduces the number of required multiplications that cannot be handled by binary-digit shifts to three and reduces the number of nontrivial function evaluations to two.

A further simplification is achieved by approximating the equation shown in the figure: The calculation is divided into several pieces of differing significance. The 8-bit picture-element values are handled in two 4-bit groups: The four most significant bits and the four least significant bits. Results are carried only to the degree of precision required to maintain 8-bit accuracy in the final result.



$$P_O = f_1(D_1 - D_2) + f_4(D_4 - D_3) + \frac{2x - 1}{2}(D_3 - D_2) + ½(D_3 + D_2)$$

$$\text{WHERE } f_1 = -x(1-x)^2$$
$$f_4 = -(1-x)x^2$$

A **New Picture-Element Value, P_o** at position x, is given by a weighted sum of the values D_1 through D_4 of the four nearest original elements on the same line. The functions in the square brackets are evaluated by table lookup using x as a memory address.

High speed is achieved by using read-only memory as the function-storage medium and simply "looking up" the function value by using the argument value x as an address in memory. Such evaluation by table lookup is much faster than direct arithmetical calculation.

Tests show that interpolator accuracy is unaffected by the choice of element spacing. Variants of the interpolator could be constructed. For example, by suitably modifying the function values stored in memory, it would be possible to provide edge enhancement. The interpolator could be adapted to three-dimensional data by adding another stage of interpolation for the third axis. The number of input picture elements included in the interpolation equation could also be increased.

This work was done under the direction of Ray Hartenstein of **Goddard Space Flight Center**, *by Gordon Wagner of TCG, Inc., and Dave Simons and Jack Coulson of Ideas, Inc. For further information, Circle 95 on the TSP Request Card.*
GSC-12882

Laser Links for Instrumentation Systems

Laser links eliminate costly cables connecting sensors to data-collection centers.

Lyndon B. Johnson Space Center, Houston, Texas

A proposed data-transmission scheme uses laser-based communication systems instead of cables. Sensor data can be transmitted by semiconductor-diode lasers, which are effective over line-of-sight distances of up to several hundred meters.

The use of lasers instead of cables can simplify a number of installations. Stringing instrumentation cable can be expensive, time consuming, and difficult. In space stations, for instance, wiring must be routed along complex paths through the station structure. Similarly, a large terrestrial antenna array requires many lengths of cable up to a few hundred feet (about 100 meters) to connect a sensor from each antenna to a common receiver. Oil prospectors and geologists using acoustic and seismic equipment must lay similar lengths of cable for each sensor. Handling the cable, laying it over obstructions, and finding damaged sections are everyday problems. Field telephone installers face similar difficulties.

In the proposed system, an electronic circuit at each measurement site accepts the output of a sensor and amplifies or otherwise processes this signal to modulate the output beam of a semiconductor laser. If necessary, a lens system would collimate the modulated laser beam and direct it to a data-collection center such as an oil prospector's van. There, photodiodes would receive the laser signals and feed them to data recorders or displays. The laser transmitters and photodiode receivers would be general-purpose units that could be connected to a variety of sensors and recording and display equipment.

Such accessories as tripods would be provided to raise transmitters and receivers above ground cover and other obstructions. If a direct line of sight between a transmitter and the data collection center is not available, a laser relay unit could be used to route a signal indirectly.

This work was done by Paul S. Bailey of McDonnell Douglas Corp. for **Johnson Space Center.** *No further documentation is available.*
MSC-20863

Computer Programs

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

Cost and Performance Model for Photovoltaic Systems

It simulates performance, cost, and revenue streams of utility-connected power systems.

The lifetime cost and performance (LCP) model assists in the assessment of design options for photovoltaic systems. LCP is a simulation of the performance, cost, and revenue streams associated with photovoltaic power systems connected to an electric-utility grid.

LCP provides the user with substantial flexibility in specifying the technical and economic environment of an application. User-specified input parameters available to describe system characteristics include: Site climatic conditions, utility purchase and sellback rate structures, discount and escalation rates, construction timing, operation and maintenance activities, and lifetime of the system. Such details as array orientation and tilt angle, module and balance-of-system performance attributes, and the mode of utility interconnection are also user specified.

LCP assumes that the photovoltaic system is utility-grid interactive without dedicated electrical storage. In combination with a suitable economic model, LCP can provide an estimate of the expected net present worth of a system to a utility, a homeowner, or a third party. System value is based on the avoided cost of electricity supplied by the utility grid. LCP can also be used to perform sensitivity analyses to identify those system parameters having significant impact on net worth.

LCP simulation of system performance is site specific and follows a three-step procedure. First, the hourly power produced by the photovoltaic system is computed using the insolation and temperature profile for a selected year. Diurnal output variations in performance are explicitly modeled. For this step, it is assumed that there are no module failures or degradation.

Second, the monthly simulation is performed involving a month-to-month progression through the lifetime of the system. In this step, the effects on system performance of degradation, failure, dirt accumulation, and operations/maintenance efforts over time are used to compute the monthly power capability fraction. Component degradation and failure within the array can be described or evaluated as follows: User-input monthly array performance degradation based on empirical data, a simplified exponential decay model, or an externally supplied model of cell failures and array electrical design. The resulting monthly power capability fractions are applied to the hourly power matrix from the first step, giving the anticipated hourly energy output over the lifetime of the system.

In the third step, revenues are determined. For utility customer-owned systems, the photovoltaic energy output is compared with the owner's electricity demand for each hour. The amount of energy to be purchased from or sold to the utility grid and the resulting costs and revenues are then determined. For utility- or third-party-owned systems, revenues are based on energy output, electricity prices by time-of-day, and interconnection-related costs. Monthly expenditures for operation and maintenance are also calculated. LCP generates output reports pertaining to the performance of the photovoltaic system and system costs and revenues.

The LCP model has been implemented in Microsoft BASIC-80 for interactive execution on a Z80-based microcomputer operating under CP/M. This BASIC-80 implementation of the LCP model was developed in 1983.

This program was written by Chester S. Borden, Jeffery H. Smith, Michael C. Davisson, and Leonard J. Reiter of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 40 on the TSP Request Card.*
NPO-16404

Computer-Aided Reliability Estimation

A program models complex, redundant, fault-tolerant systems.

CARE III (Computer-Aided Reliability Estimation, Third Generation) helps estimate the reliability of complex, redundant, fault-tolerant systems. The program was specifically designed for the evaluation of fault-tolerant avionics systems. However, CARE III is general enough for use in the evaluation of other systems as well.

A key feature of CARE III is its ability to model very large systems that incorporate some form of system management strategy that controls hardware/software resources in the presence of multiple faults/errors (i.e., permanent, transient, or intermittent). The dominant cause of failure in ultrareliable systems is not usually the exhaustion of resources (i.e., redundancy) but rather the failure to detect and isolate a malfunctioning element before it has caused the system to take an erroneous action. Such failures are called coverage failures (imperfect fault handling). CARE III differs from its predecessors in, among other things, the attention given to coverage failure mechanisms.

System architectural characteristics that are modeled by CARE III include temporal and spatial redundancy to gain fault tolerance. Temporal redundancy is often used to recover from errors (e.g., transient errors) by "roll-ahead" or "rollback" techniques. The effects of these strategies can be accounted for in the fault-handling model (i.e., coverage model). Spatial redun-

dancy is accomplished by using hardware redundancy (i.e., replicated modules).

The analyst's definition of a module is dependent on the level of the reliability assessment. Two factors considered when defining a module are: (1) A hazard rate must be assignable and (2) the system must be able to manipulate modules. Manipulation involves module fault detection, module fault identification, and module reconfiguration (i.e., electrical or signal isolation). CARE III is able to predict system unreliability due to both module exhaustion and imperfect fault handling (coverage failure). The analyst can specify critically coupled faults so that double fault conditions are properly evaluated. To accommodate a popular system architecture that employs triads for fault masking and a number of spares for additional fault tolerance, CARE III can model a "spare flexing" system redundancy management strategy to minimize latent faults.

Reliability models tend to fall into two classes: Combinatorial and Markov. The method that CARE III uses is to represent the structure of interest as an inhomogeneous Markov model, with the different states distinguished only by the number of faults in each of the various stages of the system. The state-transition rates are separately determined using a coverage model to account for fault-state effects. The coverage model used in CARE III is based on semi-Markov techniques. The reliability model that CARE III addresses is a mixed-Markov process with an unmanageably large number of states. Assumptions about the relative size of the module failure rates and coverage parameters permit this detailed micromodel to be approximated by an inhomogeneous macro-Markov model with a reduced number of states. Replacing detailed information in the micromodel by probabilities of the corresponding events in the macromodels permits the separation of the model into a coverage model that needs to be solved only once and a fault-occurrence model that employs the coverage-model output.

CARE III consists of a set of computer programs. The CAREIN program checks and preprocesses the reliability model data, which includes stage (set of identification modules) data, fault-type data for each stage, the system fault tree, and any critical pairs fault trees. The COVRGE program generates the moments of the coverage functions. The reliability model is solved by the CARE 3 program using the files generated by CAREIN and COVRGE. The CARE 3 program computes the probability of system failure over time due to both hardware exhaustion and lack of system coverage. The resultant reliability functions can be plotted with the RELPLT program.

The programs are written in ANSI Standard FORTRAN 77 for batch execution and have been implemented on the VAX 11/700-series computers (VAX-11 FORTRAN compiler) and the CDC CYBER 170-series computers (CDC FORTRAN V compiler required 337K octal words of central-memory). The programs should be compatible with other computers that will compile ANSI Standard FORTRAN 77. The RELPLT program requires the commercial DISSPLA plot package. CARE III was last updated in 1985.

This program was written by Salvatore J. Bavuso of **Langley Research Center,** *Jack J. Stiffler and Lynn A. Bryant of Sequoia Systems, Inc., and Paul L. Petersen of Kentron International, Inc. For further information, Circle 81 on the TSP Request Card.*
LAR-13349

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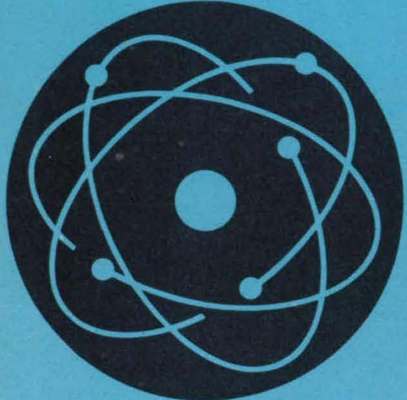
Physical Sciences



Hardware, Techniques, and Processes

Books and Reports

Computer Programs

Molecular-Beam Chopper and Four-Channel Amplifier

Near-simultaneous monitoring and digital averaging are possible for multiplexed mass-spectrometer outputs.

Langley Research Center, Hampton, Virginia

The molecular-beam chopper phase controller and timing interface diagramed in the figure is a subsystem of a four-stage, differentially pumped, modulated molecular-beam/mass spectrometer. This subsystem maintains accurate phase control and timing for repetitive signal averaging over several hours of operation.

The phase controller and timing interface maintains a prescribed and constant phase relationship between the molecular-beam chopper and four sequential analog mass controllers. Each analog output is chopped in half, and the sequence is repeated without loss of signal, allowing 100 percent real-time sampling efficiency. The subsystem also includes the required interfacing between the spectrometer and the digital processing oscilloscope/minicomputer. Thus, extensive signal averaging is possible so that relevant species ratios and sample statistics can be obtained from weak and very noisy signals.

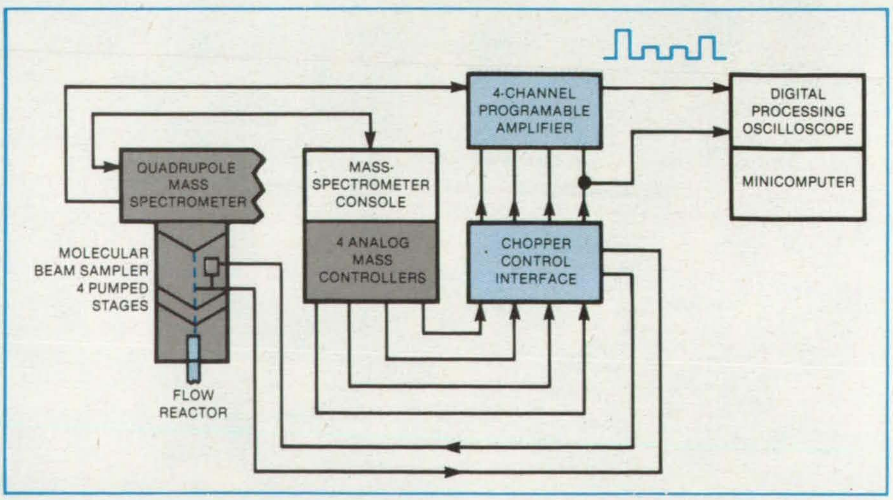
The four-channel programable amplifier controls signal gain and baseline shift over a wide range for each mass output. Gains for respective channels are set to optimize the overall detectability and signal-to-noise ratio, but are safely away from saturation limits.

The four-channel programable time-multiplexed amplifier allows the amplification and baseline shift to be selected independently for all four components of the time-multiplexed analog signals. Additionally, signal blanking is provided during mass spectrometer switching and settling time so that switching "spikes" and consequent modification of the oscilloscope autoscaling function can be avoided.

The system allows near-simultaneous monitoring of four masses with the capability for long-term digital averaging of the time-multiplexed, modulated molecular-beam analog outputs. The chopper synchronization allows extensive digital waveform averaging with substantial improvement in signal-to-noise ratio. The chopper modulation rate also permits 100 percent real-time sampling efficiency to be attained with near-maximum sampling/averaging rate.

This work was done by Billy R. Adams of Kentron International, Inc. for **Langley Research Center.** *For further information, Circle 105 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 25]. Refer to LAR-13174 and LAR-13175.



This **Chopper Phase Controller/Timing Interface and Four-Channel Programable Time-Multiplexed Amplifier** provide substantial improvements in attainable signal-to-noise ratio, detection limit, and accuracy of a molecular-beam/mass-spectrometer system.

Fourier-Transform Infrared Spectrometer

A solid interferometer would increase image strength at the detector.

NASA's Jet Propulsion Laboratory, Pasadena, California

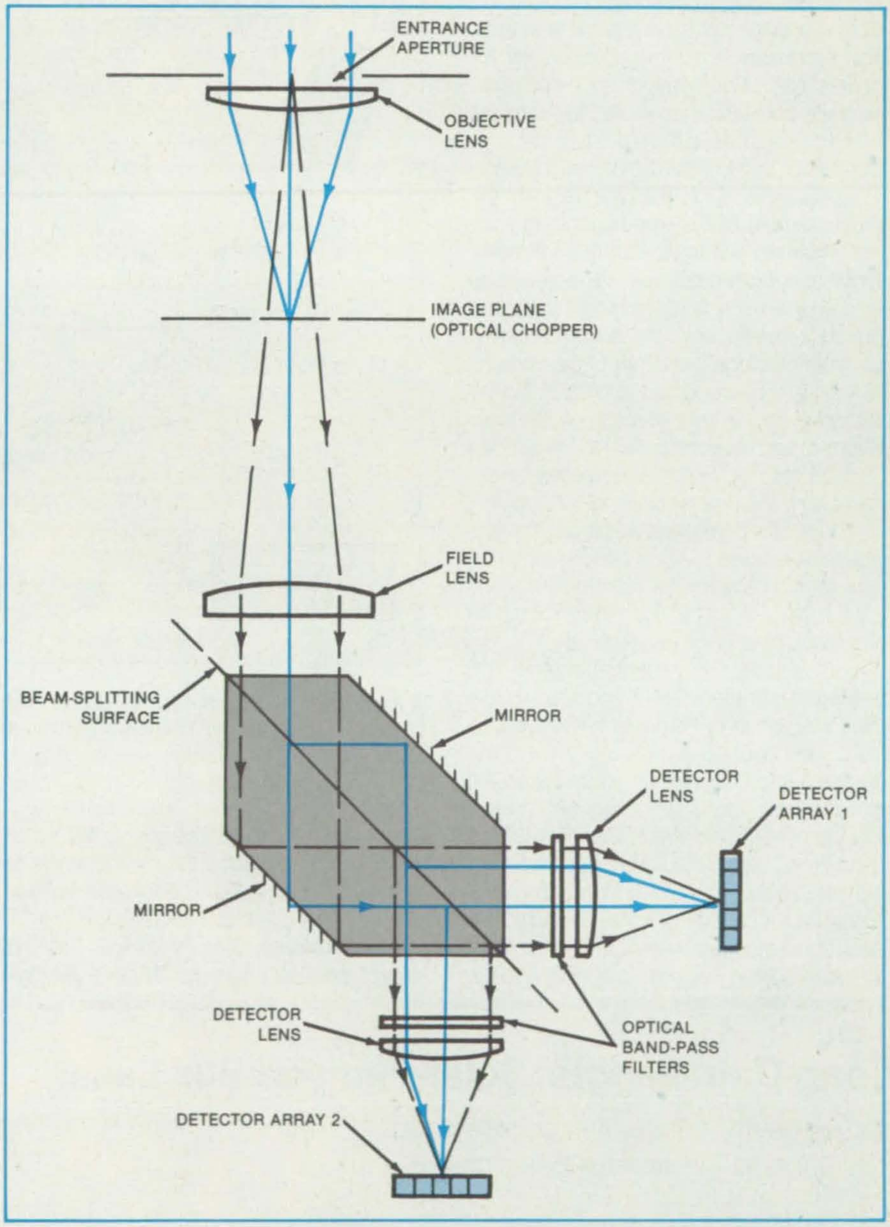
A proposed Fourier-transform spectrometer is expected to provide approximately a hundredfold increase in luminosity at the detector plane over that achievable with older instruments of this type. It could thus be used to analyze such weak sources as pollutants and other low-concentration substances in the atmosphere.

The spectrometer includes a Michelson interferometer (see figure). Light strikes a partially reflecting plate (beam splitter) at an angle at or near 45°. The light beams reflected and transmitted by the plate are both reflected back to the plate by mirrors, and the beams are recombined at the plate, interfering constructively or destructively depending on the wavelength of the light and the distances from the plate to the two mirrors. In the resulting interference fringe pattern formed on the detector arrays, the fringe position thus varies with wavelength.

In the new spectrometer, the interferometer is made of solid prism halves rather than air-spaced mirrors as in the customary design. The faces of the prism are the mirrors, and the interface between the prism halves is the partially reflecting plate. The use of a solid prism increases dimensional stability and increases luminosity by virtue of the smaller ray angles in the prism. (For infrared light, a prism of higher-refractive-index material such as germanium can be used instead of glass, and the increase in luminosity is on the order of magnitude of the refractive index.)

To produce interference fringes, the interferometer must have unequal path lengths between the beam-splitting surface and the two mirrors; therefore, the prism halves are of unequal thickness. Since the interferometer has two output beams, two detector arrays can be used to measure two different spectral regions. An optical filter in front of each detector array passes the appropriate spectral band to that array.

This work was done by Rudolf A. Schindler of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 65 on the TSP Request Card.* *NPO-16431*



The **Solid Interferometer** creates fringe patterns on two distinct arrays of light detectors, which may thus observe different wavelength bands. An objective lens focuses the scene on the image plane, which may contain an optical chopper. To make the instrument less susceptible to variations in the scene under observation, the field and detector lenses focus the entrance aperture, rather than the image, onto the detector array.

Contactless Calorimetry for Levitated Samples

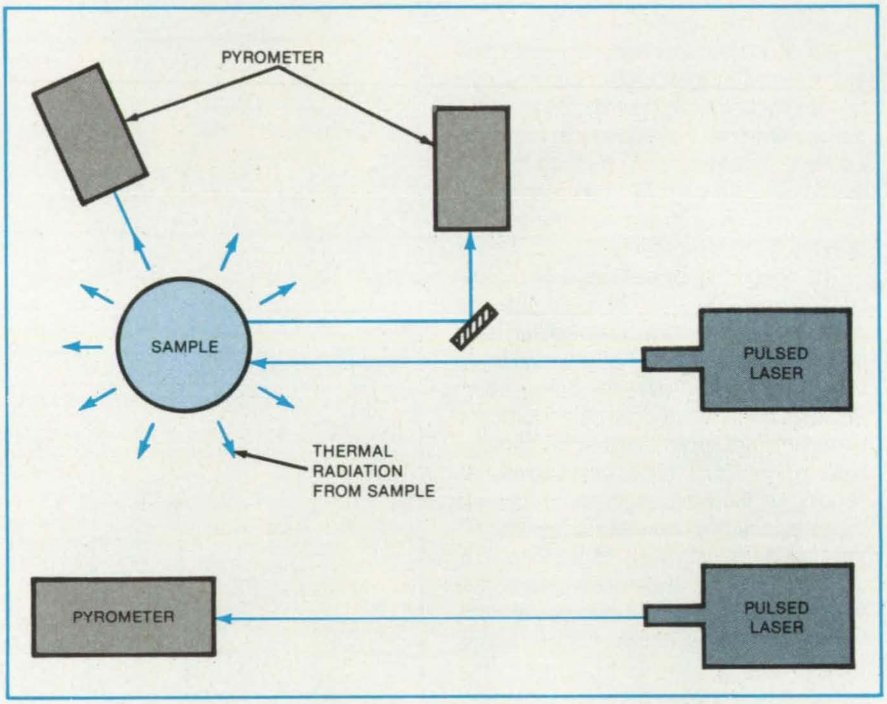
Radiative measurements would aid investigations of undercooling.

NASA's Jet Propulsion Laboratory, Pasadena, California

The temperature and specific heat of a hot sample would be measured with a pyrometer in a proposed experimental technique. The technique is intended especially for contactless calorimetry of such materials as undercooled molten alloys, the samples of which must be levitated to prevent contamination and premature crystallization.

Investigations of this type require the measurement of the time-dependent sample emissivity and temperature. In the new technique, both quantities are determined with a pyrometer. A pulsed laser is also required for the emissivity measurements. Pyrometer readings are taken of the sample, of the laser beam aimed directly at the pyrometer, and of the reflection of the laser beam aimed perpendicularly to the sample surface (see figure). The emissivity of the sample at the laser wavelength λ is calculated from the pyrometer readings. The relationship between the true sample temperature and the apparent temperature sensed by the pyrometer can be determined with the help of the Wien radiation law.

In the case of a spherical sample levitated electromagnetically and electrostatically in a vacuum, it is not necessary to correct for conductive or convective heat transfer, and it is possible to calculate the specific heat from a simple equation based on black-body radiation. The contactless calorimetry technique should enable data to be taken over the entire undercooling temperature range with only one sample. The technique should prove valuable in the study of undercooling because the difference in specific heat between the undercooled-liquid and crystalline phases at the same temperature provides the driving force to convert the metastable undercooled phase to the stable crystalline phase.



A **Pyrometer Measures** thermal radiation from the sample, the reflected laser beam, and the direct laser beam. These measurements are used to calculate the temperature and emissivity of the sample.

This work was done by Mark C. Lee and Won Dokko of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 69 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 25]. Refer to NPO-16448.

Long-Gain-Length, Solar-Pumped Box Laser

Laser cavity efficiently couples solar radiation to the laser mode volume.

Langley Research Center, Hampton, Virginia

A new laser cavity configuration efficiently couples solar radiation to the laser mode volume. C_3F_7I gas is optically pumped by two xenon-arc solar simulators, creating a population inversion and subsequent lasing from atomic iodine at 1.3 μm. The laser cavity is a stainless-steel box with internal, high-reflectivity mirrors that guide the laser mode volume through the optically excited C_3F_7I gas. Lasing output powers of approximately 300 mW have been achieved for durations of 150 ms.

Previous solar-pumped gas laser systems have been limited to laser gain lengths of less than 10 cm, requiring very high solar concentrations to achieve lasing. This new system allows lasing at substantially lower solar simulator intensities (150 Suns) and much longer laser gain lengths (60 cm).

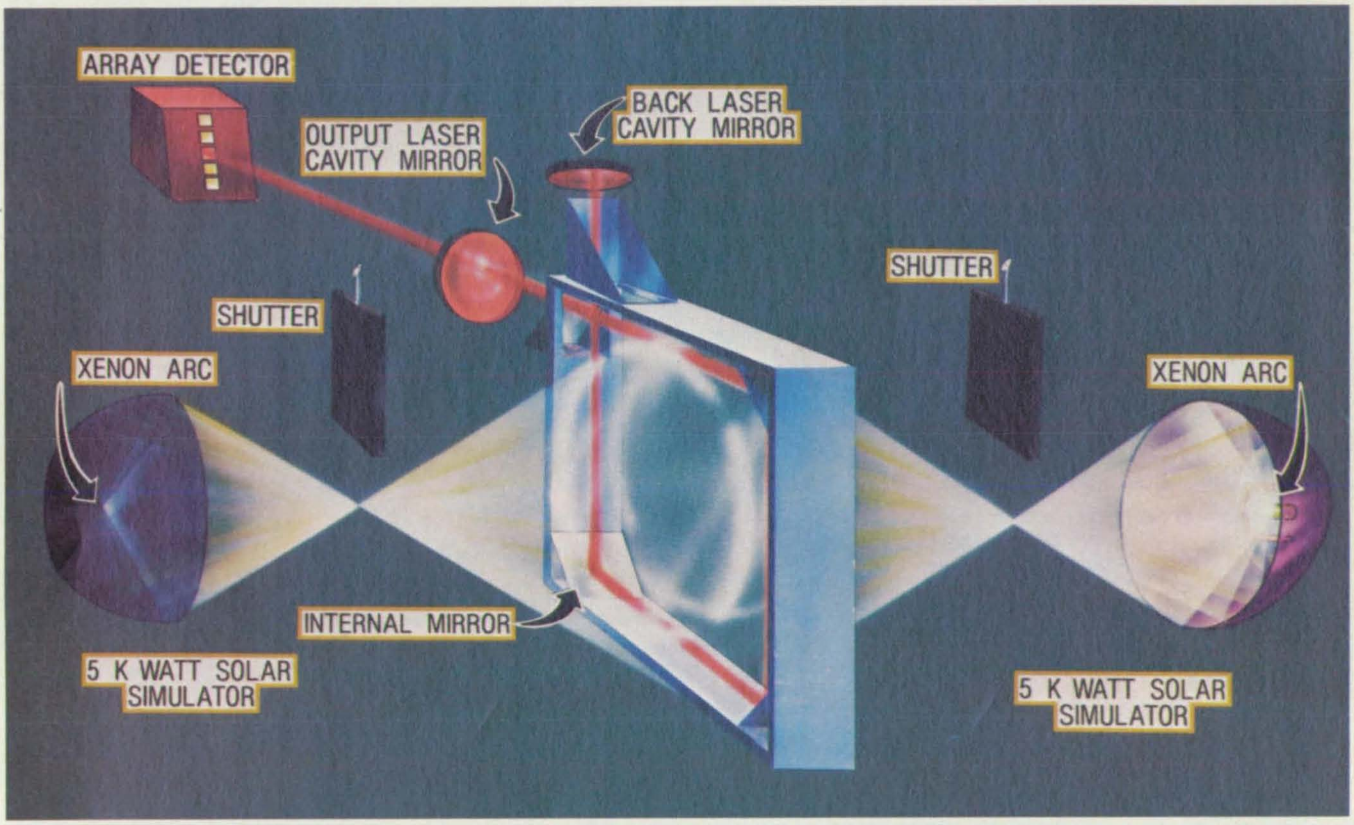
The laser was constructed using O-ring grooves to allow a vacuum seal with the quartz glass plates on each side of the stainless-steel laser frame. Brewster windows in the upper left-hand corner allow external laser cavity mirrors to be mounted and easily alined. The back cavity mirror has maximum reflectivity at 1.3 μm, and the output mirror has a reflectivity of either 97 or 85 percent.

In each of the three internal corners of the laser cavity are placed high-reflectivity dielectric mirrors. These mirrors allow the laser optical path (mode volume) to be alined with the incoming solar radiation pattern. The laser beam is detected by a germanium linear-array detector, which is used to resolve the laser beam profile. Two xenon solar simulators produce a maximum of 5 kW each of light. A mechanical shutter is used to allow rapid excitation of the laser cavity. The input simulator light is concentrated in the form of a doughnut, as seen in the figure.

The system allows long gain lengths at much lower solar concentrations, substantially increasing the practicality of solar pumping. The system was originally developed for studies of power transmission over long distances through space.

This work was done by Russell J. De Young of **Langley Research Center**. *No further documentation is available.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center *[see page 25]**. Refer to LAR-13256.*



This **High-Power Laser** was originally intended for long-distance power transmission in space.

Optical Scanner for Linear Arrays

Each frame in the object plane is projected onto a linear array in the image plane.

Goddard Space Flight Center, Greenbelt, Maryland

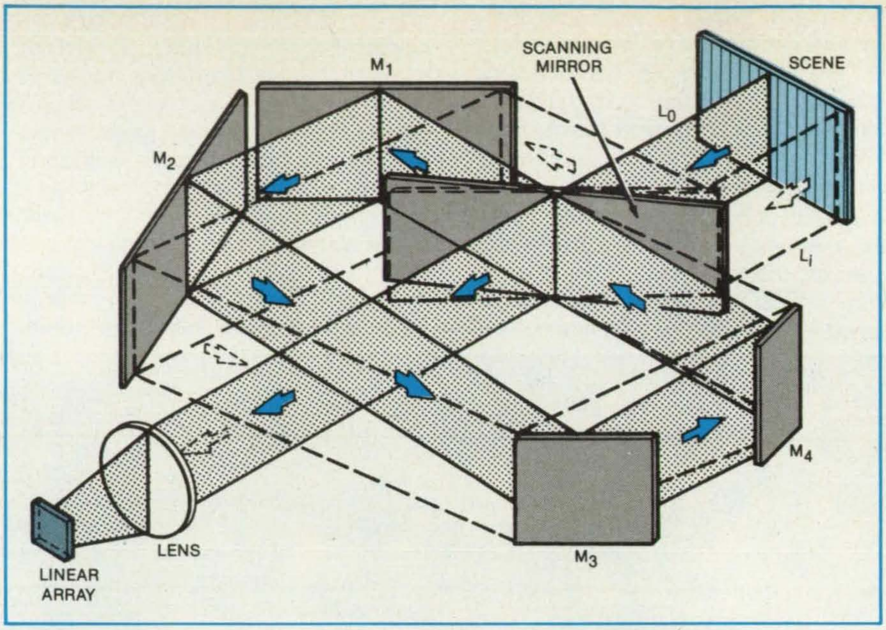
An optical scanner instantaneously reads contiguous lines forming a scene or target in the object plane. The reading may be active or passive and the scans, continuous or discrete. The scans are essentially linear with scan angle and are symmetric about the axial ray. A nominal focal error, resulting from a curvature of the scan, is well within the Rayleigh limit. The scanner was specifically designed to be fully compatible with the general requirements of linear arrays.

The essential elements of the optical system are shown in the figure. The corner mirrors M_1, M_2, M_3, and M_4 are perpendicularly oriented so that any ray incident on the front surface of the scan mirror will be directed by the corner mirrors along a parallelogramic path arriving at the back surface of the scan mirror where it will be reflected in a direction parallel to the incident ray. Except for the imaging lens, all the optical elements are plane mirrors. The rotation of the scan mirror is the only motion required.

Since the angle of incidence on the front and back surface of the scan mirror are equal, it follows that the incident and emergent rays must be parallel. Moreover, since each ray must pass through the center of the scan, there is a lateral shifting of frames so that each ray leaves the system collinear with the axial ray. Effectively then, the front surface of the scan mirror scans the object plane frame by frame while the back surface of the scan mirror descans each frame onto the image plane. All this indicates that each scan line could be identified with a particular scan angle.

The system has the following features, which are well suited to photometric and radiometric applications:

- The system only images rays in the paraxial region; consequently, radiometric errors such as the cos θ falloff are not a significant factor;
- Since the consecutive angles of a parallelogram are supplementary, the reflection losses for the corner mirrors should remain constant throughout the scan;
- Each pixel can only intercept that portion of the scattered light within its field of view; therefore, only a fraction of the light scattered by each optical surface will be collected;
- The scanner will accept plane reflecting or transmitting scenes or targets;
- The scanner can be used to measure the modulation transfer function (MTF) and the velocity-dependent MTF; and
- The scanner's ability to instantaneously register a line in the image plane with a focal error that is within the Rayleigh limit while scanning linearly is especially accommodating to linear arrays.



The **Optical System** and path followed by a fan of axial rays, L_0, and some arbitrary fan of rays, L_i, are shown.

This work was done by Mitchell W. Finkel of **Goddard Space Flight Center.** *For further information, Circle 66 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 commericial development should be addressed to the Patent Counsel, Goddard Space Flight Center [see page 25]. Refer to GSC-12897.

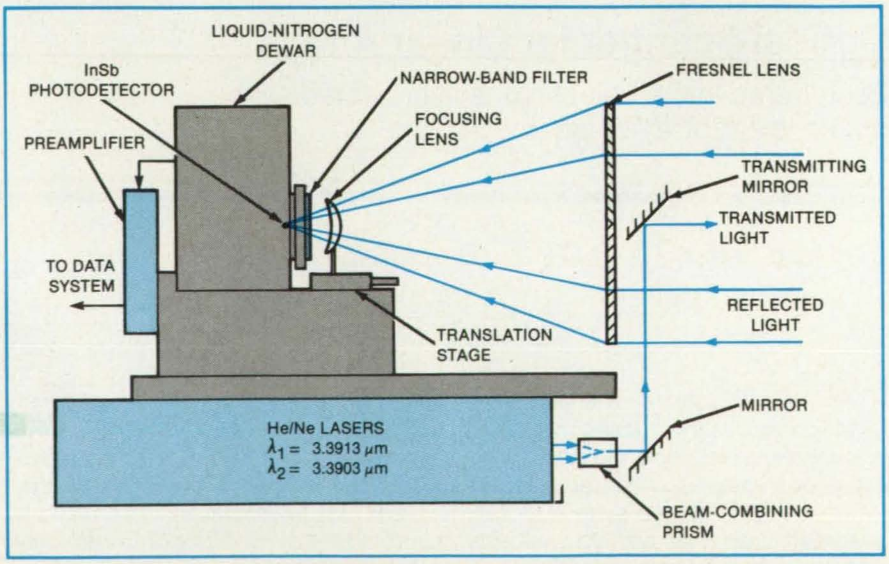
Methane Detector With Plastic Fresnel Lens

Easy-to-manufacture lens replaces a spherical mirror.

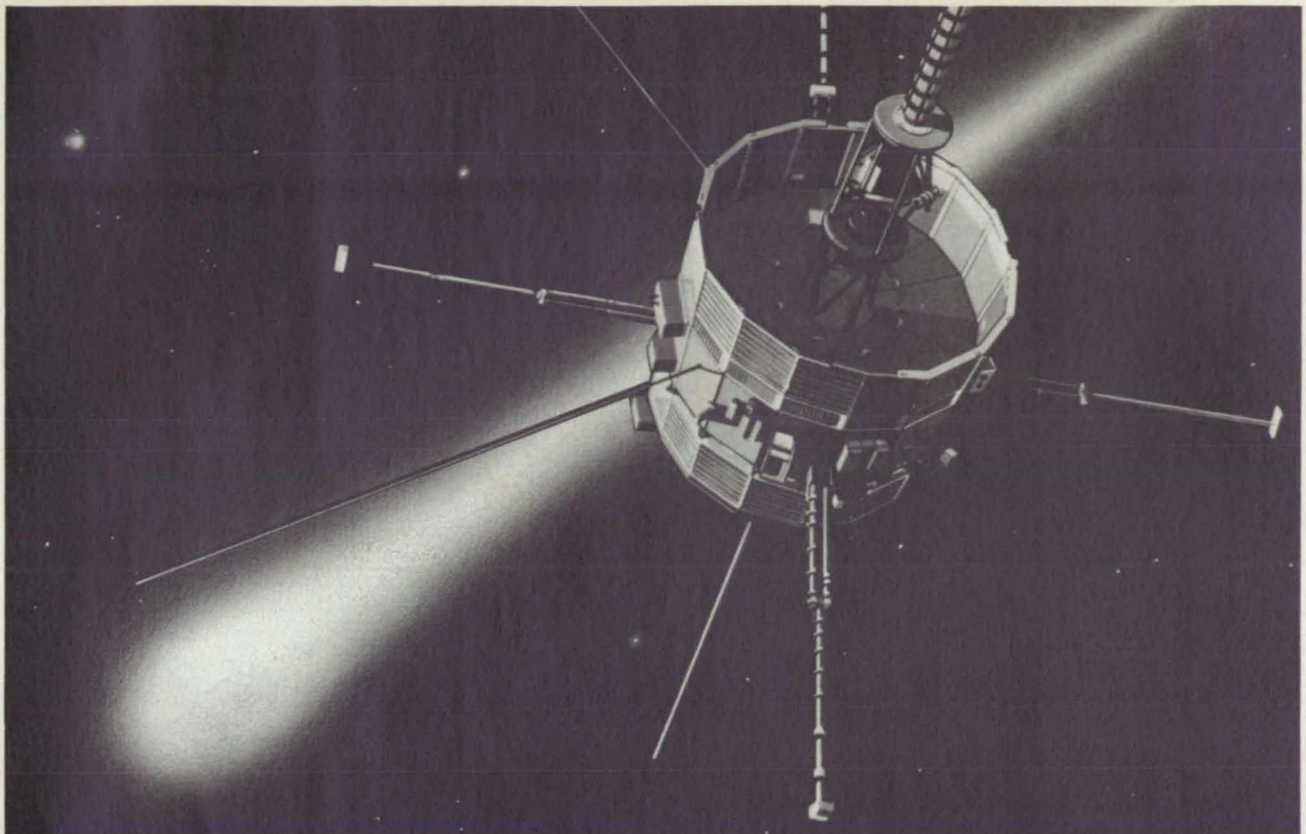
NASA's Jet Propulsion Laboratory, Pasadena, California

A laser detector for natural gas leaks has been modified by the substitution of a molded plastic lens for a spherical mirror. The detector sends laser pulses at wavelengths of 3.3913 μm and 3.3903 μm and measures the strength of the return pulses reflected by such features as buildings or hills. This has been described in "Detecting Methane Leaks" (NPO-15790), page 53, *NASA Tech Briefs,* Vol. 8, No. 1, Fall 1983. If methane is present in the air, the return pulses at 3.3913 μm are attenuated more than those of shorter wavelengths. By measuring the relative attenuation at the two wavelengths, the detector can be used to check for methane escaping from pipelines above or below ground and from landfill.

The modified Fresnel lens is 6 in. (15.2 cm) in diameter with 20 grooves per centimeter and a focal length of 22 cm at a wavelength of 3.4 μm. The lens is made of polychlorotrifluoroethylene; which was selected because, unlike ordinary hydrocarbon plastics, it does



Two Helium/Neon Lasers generate a light beam that is chopped and bounced off mirrors to illuminate a scene. The Fresnel lens concentrates the light reflected from the scene on the photovoltaic cell. A data system processes the cell signal to determine how much methane is in the air at the scene.



not absorb strongly at the approximately 3.4-μm laser wavelength. It is made by hot-pressing a 0.086-cm-thick sheet in a mold.

The primary components of the detector optical train are the Fresnel primary lens [manufactured by Lectric Lites, Co., Fort Worth, Texas (or equivalent)], a quartz focusing lens, a narrow-band optical filter, and an indium antimonide photovoltaic cell (see figure). The Fresnel lens collects reflected radiation from a relatively wide beam and concentrates it on the 1-mm-diameter photocell with the aid of the focusing lens. An interference filter suppresses background (solar plus thermal) radiation so that the photocell responds mainly to the laser light.

This work was done by William B. Grant of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 22 on the TSP Request Card.*
NPO-16284

Reflecting Slit for Imaging Spectrometer

A precise, high-quality reflecting surface serves as the slit.

NASA's Jet Propulsion Laboratory, Pasadena, California

An optical slit that reflects rather than transmits performs multiple functions for an imaging infrared spectrometer. It serves as a field reflector, field flattener, and entrance aperture for the instrument. The spectrometer is described in "Reflecting Schmidt/Littrow Prism Imaging Spectrometer" (NPO-15801), page 481, *NASA Tech Briefs,* Vol. 8, No. 4 (Summer 1984). The reflecting slit is a narrow strip of spherical reflecting surface, with intersecting spherical reflecting side surfaces that reject radiation originating outside the slit region (see Figure 1).

The precision of the slit geometry is crucial in the optical system; when viewed along the slit optical axis, the slit edges must appear straight, parallel, and free of defects. A dense material with a high modulus of elasticity is needed to achieve the required surface quality and geometric precision in manufacturing. Tungsten carbide meets the requirements and was chosen as the material for the substrate.

The slit is formed in a series of machining operations. First, the substrate is roughly shaped by a 4-in. (10.2-cm) diamond wheel on a milling machine, and clamping slots are ground into the substrate on the same setup. The substrate then is lapped on the side surfaces of the slit while it is clamped by special holding fixtures (see Figure 2). With abrasive paper or cloth embedded with 30-μm diamond particles, the side surfaces are lapped alternately until a sharp ridge is formed on the substrate at the intersection of the side spherical surfaces. The slit surface then is lapped onto the substrate, thereby destroying the sharp peak of the ridge and replacing it with the slit surface and two new ridges that define the slit edges.

To reduce the surface porosity of the tungsten carbide, the slit and its sides are coated with a 0.1-mm-thick layer of tungsten carbide by chemical vapor deposition. The coating is polished in the holding fixtures with a paste containing 3-μm diamond particles on a Sn/Zn alloy lap.

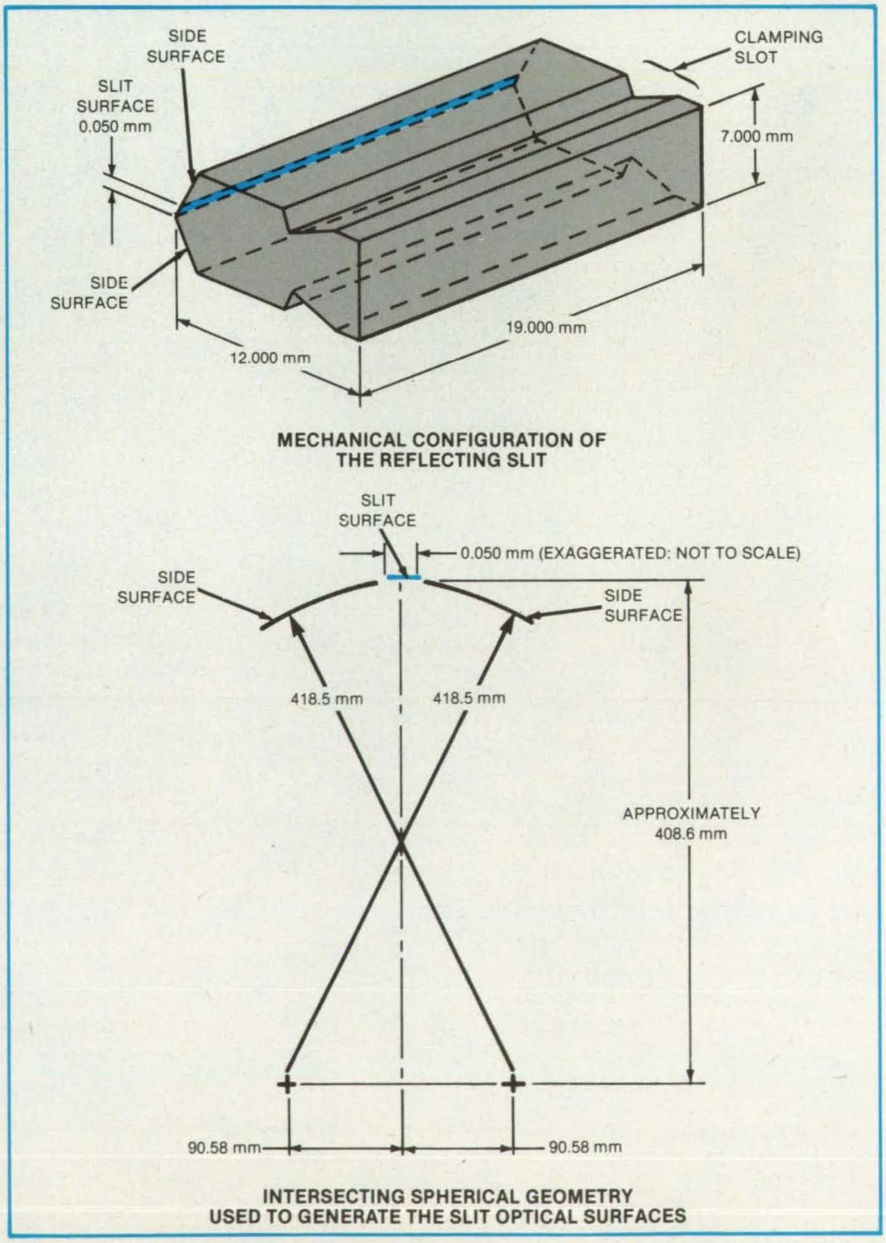


Figure 1. The **Reflecting Slit** is the middle one of three intersecting spherical reflecting surfaces. The two side surfaces reject light that falls outside the slit boundary.

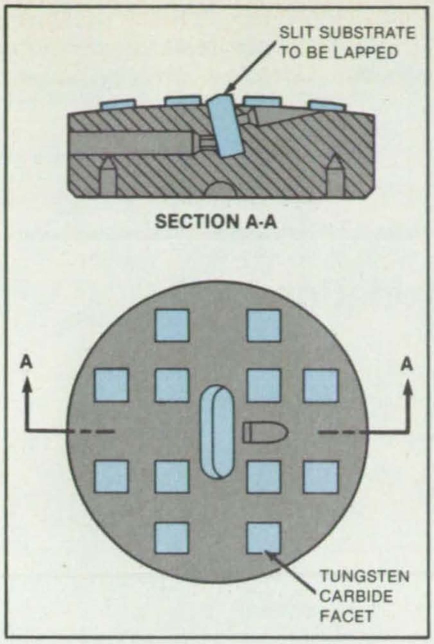


Figure 2. This **Clamping Fixture** holds the substrate while it is lapped to produce the spherical side surfaces. A similar holder is used to produce the slit surface, except that the substrate is held vertically instead of at a slant as it is here.

A variety of techniques have been used to check the quality of the slit thus prepared. Scanning electron microscopy, for example, showed a remarkable improvement in surface quality after chemical vapor deposition. Before coating, the substrate had a spongelike appearance. After coating and polishing, the few defects that remained were less than 1 μm in diameter.

A Foucault knife-edge test showed a good surface figure along the length of the slit. A two-beam interference microscope showed a curvature of about a quarter wavelength across the slit, but this amount of curvature is not expected to present a problem in the intended spectrometer application. The interference microscope also showed the edges of the slit to be well defined and smooth.

This work was done by Norman A. Page, Robert E. Parks, and John Michael Rodgers of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 85 on the TSP Request Card.*
NPO-16408

Laser Altimeter for Flight Simulator

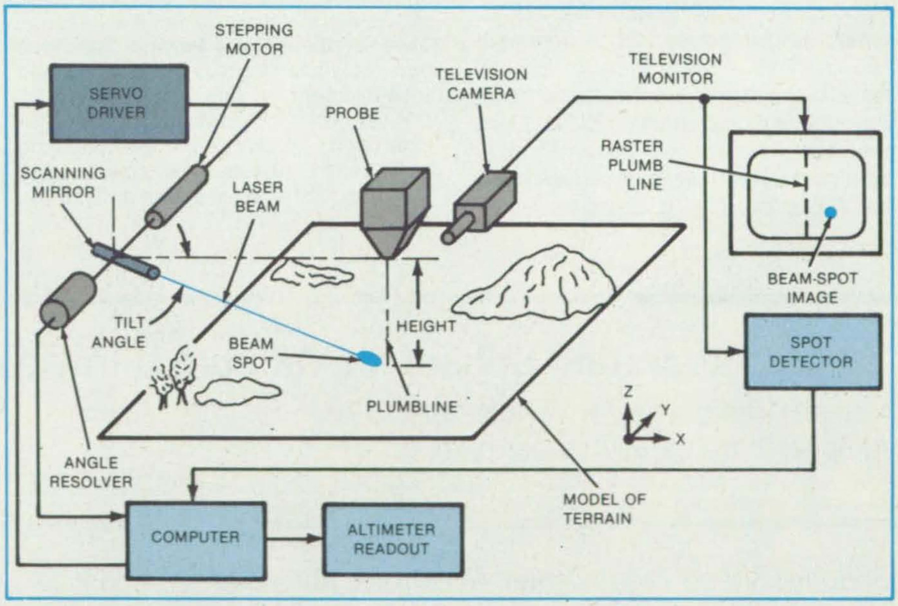
Height is found by triangulation.

Ames Research Center, Moffett Field, California

The height of a flight-simulator probe above a model of the terrain is measured by an automatic laser triangulation system. A laser beam originates from a pitchable mirror that is fixed with respect to the probe and moves with the probe. A feedback control subsystem keeps the laser beam pointed at the spot on the terrain directly below the probe through appropriate manipulation of the pitchable mirror. The height is then determined from the beam-pointing angle by simple trigonometry.

The aircraft is simulated by the probe, and the motion of the probe over the terrain model is a scaled-down version of the aircraft motion (see figure). Attached to the probe frame are a laser and four scanning mirrors (only one is shown) that are rotated by stepping motors to point the laser beam. The tilt of each scanning mirror (and therefore of the beam) is measured by an angle resolver and fed to the computer.

A television camera on the probe frame (or connected to the probe frame via imaging fiber optics) views the model of the terrain below the probe. The camera optics include a laser-band-pass filter to exclude stray light. The camera is oriented so that a raster line corresponds to the probe plumbline. The camera output is fed to a spot detector, the output of which is the raster-line number and displacement along the raster line of all elements of the laser spot on the terrain model.



An **Airplane Is Simulated by a Probe** that moves over a model of the terrain. The altitude of the airplane is scaled from the height of the probe above the model. This height is measured by triangulation of a laser beam aimed at the intersection of the model surface with the plumb line of the probe.

The spot-detector output is fed to the computer. If the raster-line numbers of the spot are not centered on the number of the plumb raster line, the computer generates an error signal. The error signal is sent to the servo driver, causing the stepping motor to turn in a direction that decreases the error. When the spot and plumb raster lines match, the angle-resolver output is fed to the computer. The output of the computer is the scaled aircraft height from a "lookup-table" memory of height versus tilt angle.

The system includes several scanning mirrors and at least two cameras because the path along a viewing or scanning line is sometimes obstructed by a building, mountain, or other feature of the model. The computer selects the camera or scanning mirror to be used at the moment. The output of the unused camera is blocked in the camera multiplexer while the unused laser beams are aimed away from the terrain model.

This work was done by Larry D. Webster of **Ames Research Center.** *For further information, Circle 57 on the TSP Request Card.*

This invention has been patented by NASA (U.S. Patent No. 4,391,514). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Ames Research Center [see page 25]. Refer to ARC-11312.

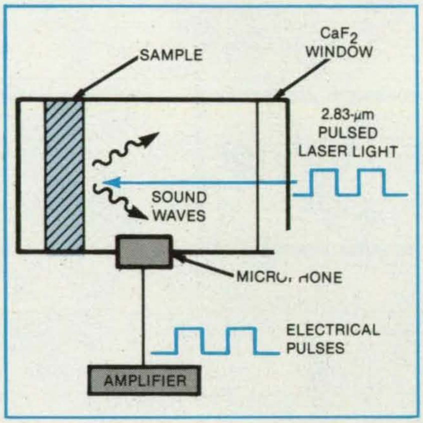
Laser Photoacoustic Technique Detects Photo-Oxidation

Traces of hydroxyl groups in polymers are detectable.

NASA's Jet Propulsion Laboratory, Pasadena, California

A laser photoacoustic instrument detects small amounts of oxidation in polymers. The instrument is used to evaluate the resistance to oxidation in Sunlight of polymer encapsulants for solar-cell arrays. With the instrument, researchers can monitor samples for the early stages of photo-oxidation and thus can study primary mechanisms of oxidation and degradation. The effects of these mechanisms would be masked during later stages.

A polymer sample, after exposure to Sunlight outdoors or to simulated Sunlight in an accelerated-testing chamber, is placed in a specially designed cell containing a sensitive condenser microphone (see figure). The sample is illuminated with a chopped 2.83-μm HF laser beam. The laser light absorbed by the sample is converted into heat. Bursts of heat corresponding to the chopped laser pulses flow from the sample to its surroundings. The heat bursts create pressure fluctuations (that is, sound waves) at the chopping frequency that are detected by the microphone.



Laser Irradiation of a Polymer Specimen generates sound waves that are detected by a microphone. Only light absorbed by the sample is converted to sound; light scattering — a serious problem in testing many solid materials by conventional spectroscopy — presents no difficulties.

The magnitude of the microphone output voltage increases with the portion of laser light absorbed, which in turn increases with the oxidation of the polymer. An increase in absorption of only 2.5×10^{-5} raises the microphone output by 1 μV. This sensitivity is more than 100 times as great as that of the best previously available measurement based on infrared absorption. In fact, whereas the infrared technique could not detect any oxidation in ethylene/methylacrylate with less than 10 hours of accelerated aging (equivalent to about 65 days of outdoor exposure), the laser photoacoustic technique provides an earlier indication.

This work was done by Ranty H. Liang, Daniel R. Coulter, and Amitava Gupta of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 99 on the TSP Request Card.*
NPO-16108

Optical Integrating Sphere for Vacuum Ultraviolet

A sliding sample holder permits four samples to be measured per pumpdown.

Goddard Space Flight Center, Greenbelt, Maryland

An optical integrating sphere with an integral sliding sample holder (see figure) saves time by allowing radiometric measurements to be made on each of four samples without breaking the vacuum. It is designed to operate with its interior evacuated so that dye samples can be illuminated with short-wavelength ultraviolet, which is strongly absorbed by air; it need not be evacuated when using longer wavelengths. The device mounts on a monochromator and is evacuated through the port that admits light from the monochromator.

The interior surfaces of the integrating sphere and the wells in the sample holder are sprayed with as many as 10 coats of a diffusely reflecting white paint, which is highly reflective from 200 to 2,300 nm. With a suitable detector, fluorescence radiation from a sample can be measured at any desired wavelength in that region. Because of the cavity geometry and diffuse reflection, a nearly constant portion of the radiation emitted by the sample reaches the detector, regardless of its initial spatial distribution.

The sample holder is a slide with four sample wells, each containing four locating posts. A disk-shaped sample is positioned between the posts and held in place with a retaining ring, which encircles the posts.

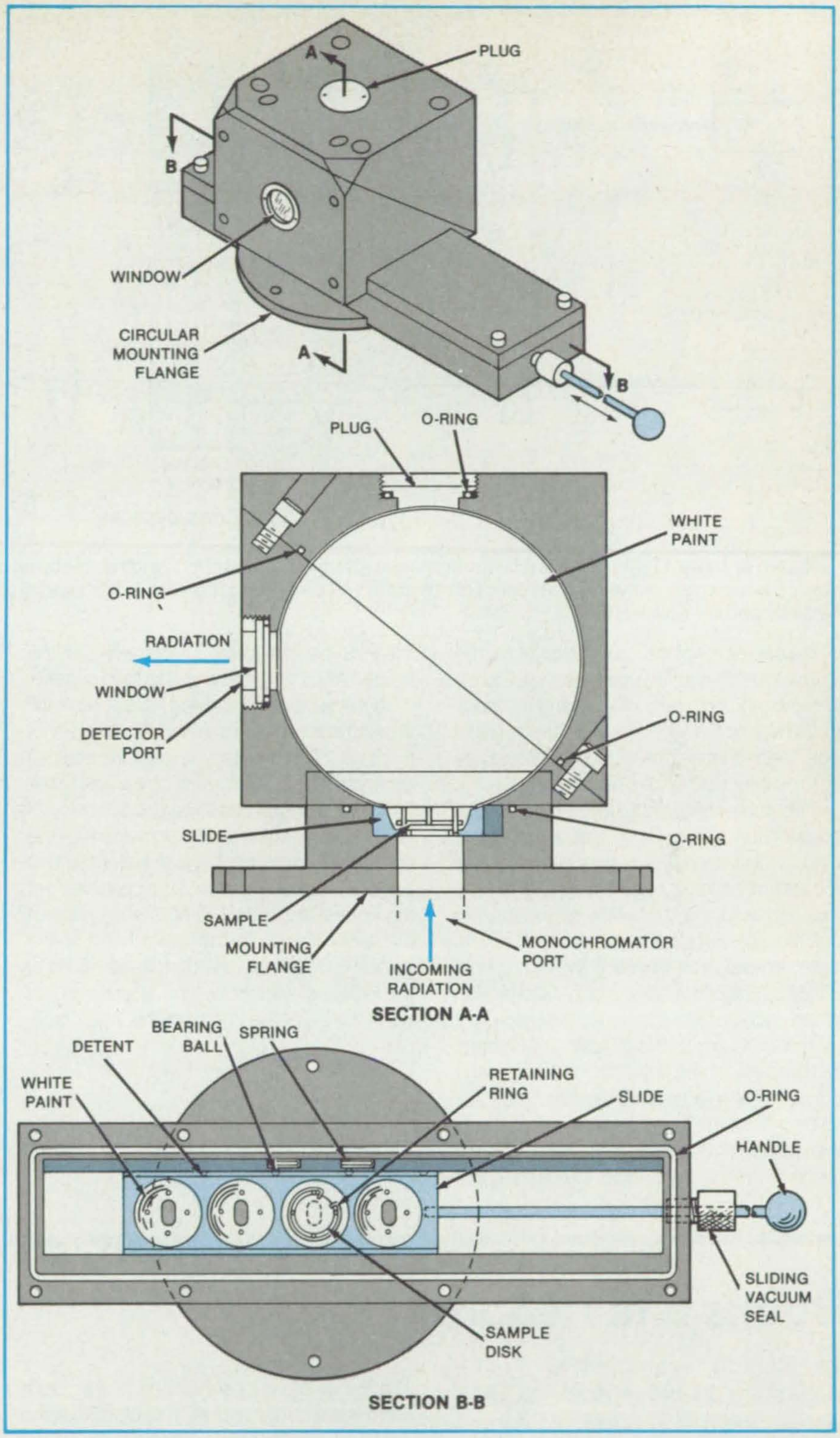
The slide is placed in a channel in the bottom of the assembly and connected to a sample-manipulation rod, which extends through a sliding vacuum seal to the exterior of the device. Spring-loaded bearing balls along one side of the slide register in detents to provide repeatable sample registration. After loading, the integrating sphere is then reassembled atop the slide channel.

In normal use, the detector is located at the exit port window on the side of the assembly, 90 degress from the sample. A second opening for a port is provided on the side opposite the sample.

The various joints and mating surfaces in the assembly are sealed with O-ring vacuum seals. The major components of the assembly are made of brass, although aluminum could be used throughout except for the sliding parts in the sample holder.

This work was done by Cyrus L. Butner of **Goddard Space Flight Center.** *For further information, Circle 53 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, Goddard Space Flight Center [see page 25]. Refer to GSC-12849.



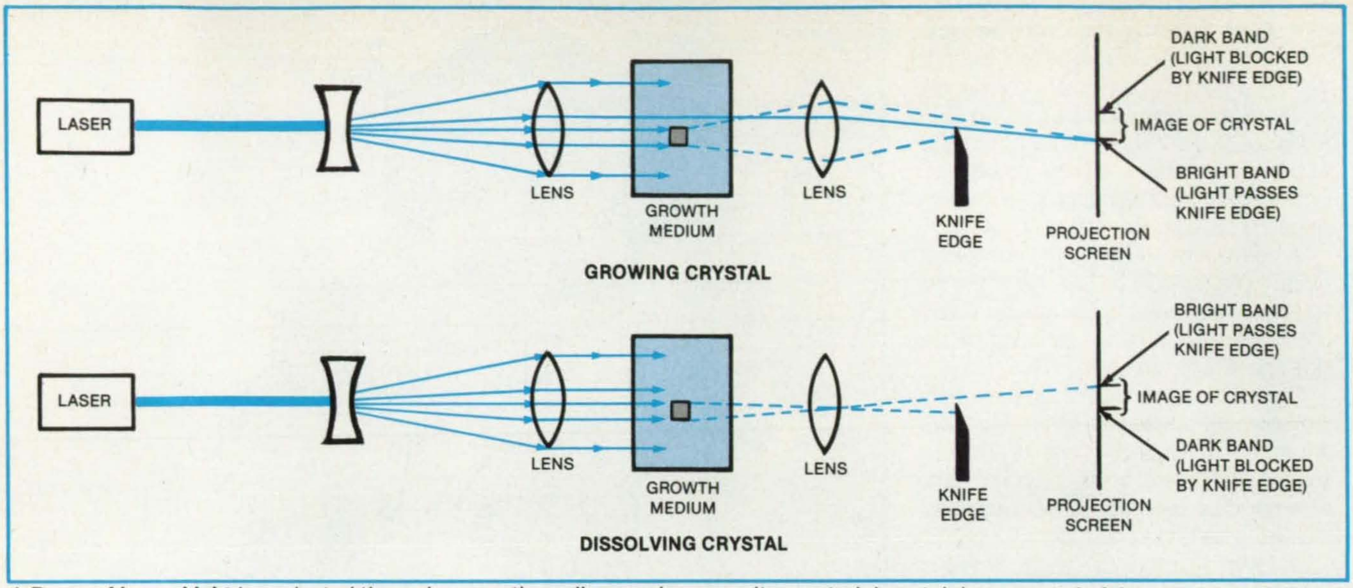
The **Multiple-Sample Vacuum Integrating Sphere** assembly (top) includes a circular mounting flange that bolts onto the monochromator exit port. The light from the monochromator enters through the sample holder at the bottom and exits to a detector via a port on one side. In the top view of the sample holder (bottom), the third sample well (which contains a sample) has been positioned over the entrance port. The handle is used to slide the sample holder from one detented position to another.

Laser Schlieren Crystal-Growth Imager

Refraction produces images with characteristic patterns representing growth or dissolution.

Marshall Space Flight Center, Alabama

A crystal can be observed as it grows from a melt with the aid of laser schlieren imaging. The observation method allows the



A **Beam of Laser Light** is projected through a growth medium such as a molten material containing a crystal of the same material, then over a knife edge, and onto a screen. This method will be used to monitor growth and dissolution of a triglycine sulfate crystal in microgravity aboard Spacelab III.

entire perimeter of the growing crystal to be inspected. Isolated crystal facets can be examined, and convection flows and temperature and concentration gradients are revealed. The method does not require contact with, or proximity to, the crystal.

The schlieren technique detects density gradients in a fluid. Collimated light passes through the crystal-growth medium and is focused on a knife edge. The image of the growth medium and crystal is projected onto a screen (see figure).

In general, light traveling through a nonuniform medium is refracted in the direction of an increasing refractive-index gradient (which is usually in the direction of increasing density). In the liquid around a growing crystal, material is continuously being absorbed from the liquid by the crystal. Thus, the density of the liquid increases with distance from the solid/liquid interface. Light traveling parallel to the interface is thus refracted away from the growing solid surface.

In the case of a dissolving crystal, material is being added to the solution. The density of the melt thus increases toward the dissolving crystal face. Light traveling parallel to the face is thus refracted toward the face.

Therefore, in the schlieren system of the figure, the growing crystal will create a bright band at the image of the upper face of the crystal and a dark band at the image of the lower face. On the other hand, if the crystal is dissolving, the dark band will be at the image of the upper face, and the bright band will be at the image of the lower face.

If the crystal is neither growing nor dissolving, only pale bands will appear. To examine the sides of the crystal instead of the top and bottom for growth or dissolution, one should rotate the knife edge by 90° around the optical axis. The relative positions of the light and dark bands can also be reversed by rotating the knife edge 180° around the optical axis from the present position.

This work was done by Robert B. Owen and Mary H. Johnston of **Marshall Space Flight Center.** *No further documentation is available.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 25]. Refer to MFS-28060.

Books and Reports

These reports, studies, and 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.

Calculating Atmospheric Effects in Satellite Imagery

The generation of image blur by light scattering is analyzed.

A report presents a detailed analysis of the atmospheric blurring inherent in photographs or other observations of the Earth from satellites or aircraft. This blurring is the result of scattering of radiation, which diffuses sharp image features by causing light from one part of a scene to fall on the image of an adjacent part. In contrast with earlier approaches to atmospheric optics, the one presented in this report is more accurate and versatile and is designed for use on minicomputers.

The 3-dimensional radiation-transfer problem is posed with two simplifying approximations: The properties of the atmosphere are taken to be horizontally (but not vertically) uniform, and the radiation is treated as unpolarized. However, the usual simplifying approximation of Lambertian scattering by the ground surface is not assumed. The theory thus provides for the anisotropic scattering of natural surfaces.

The derivation begins with an analysis of the downwelling and upwelling radiation fields. Integrodifferential equations that describe these fields include terms for diffuse ground reflection, direct atmospheric transmission, diffuse atmospheric scattering, and attenuation.

To break the radiation-transfer problem into tractable pieces, it is Fourier transformed. The resulting equation for each Fourier component of the radiation field is a one-dimensional variant of the classical equation of radiative transfer and is solved by an iterative technique.

An important element of the approach is the separation of the total intensity field into its direct and diffuse components. Since the atmosphere acts as a low-pass filter for image spatial frequencies, the diffuse field can be reconstructed with considerably fewer Fourier components than are required for the direct field. (Of course, the direct field retains the full spatial variability of the surface reflection properties.)

The spatial dependence of the diffuse intensity is obtained by performing the inverse Fourier transform on the Fourier components of the solution. The direct and total intensity fields are then reconstructed in the spatial domain using straightforward techniques.

The calculation provides both the upwelling and downwelling radiation intensities for a variety of off-nadir elevation and azimuth angles. Since the stratification of the atmosphere is taken into account, the results can be applied to both satellite and airborne observations. This analysis may eventually contribute to the development of atmospheric-correction algorithms.

This work was done by David J. Diner and John V. Martonchik of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "Atmospheric Transfer of Radiation Above an Inhomogeneous Non-Lambertian Reflective Ground: Part I: Theory and Fourier Transform Calculation Method," Circle 32 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of the technology described in this report should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 25]. Refer to NPO-16373.

Computer Programs

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

Algorithms for Coastal-Zone Color-Scanner Data

A set of algorithms extracts information from the satellite data.

Software for Nimbus-7 Coastal-Zone Color-Scanner (CZCS) derived products consists of a set of scientific algorithms for extracting information from CZCS-gathered data. This software uses the CZCS-generated Calibrated Radiance-Temperature (CRT) tape as input and outputs a computer-compatible tape and a film product.

The main functions of the CZCS derived products software are:

1. Flag all pixels of a scene as land, clouds, or water;
2. Determine the atmospheric effects due to such factors as Rayleigh scattering, ozone, and aerosol;
3. Calculate subsurface radiances for channels 1 through 3 after correcting the observed radiances for atmospheric attenuation;
4. Use the subsurface radiances to compute pigment concentration and the diffuse attenuation coefficient;
5. Produce a Calibrated Radiance Chlorophyll Sediment Temperature (CRCST) tape; and
6. Produce an image display tape.

The CRCST and image display tapes may be used for further analysis.

This software package also contains the CZCS Image Processing System (CIPS) and the Information and Production Control System (IPCS). These two systems are used by people at Goddard Space Flight Center to work with the raw analog data received from the Nimbus-7 satellite. It is not anticipated that these two systems will be of use outside the Goddard facility. However, a study of them may be informative to a user of the derived products software.

The CZCS derived products software is written in FORTRAN, MORTRAN (a structured FORTRAN), and OS Assembler. The system is tailored to the Goddard IBM 3081 running OS MVS and probably will require modification to adapt it to any other site. This software was developed in 1982.

This program was written by the Nimbus-7 Project Office for **Goddard Space Flight Center.** *For further information, Circle 37 on the TSP Request Card. GSC-12852*

Designing Eccentric Aperture Optical Systems

A model predicts the vector aberration of optical systems with tilted or decentered elements.

A computer program aids in the design of eccentric aperture optical systems by predicting the vector aberration that occurs in an optical system having tilted or decentered optical elements. In the fields of astronomy and remote sensing, there is an increasing tendency toward unobscured, all-reflecting optical systems necessitated by a trend toward imaging systems operating at ultraviolet and infrared wavelengths. The optical elements in these systems must be tilted or decentered. In general, this results in an optical system that has no axis of rotational symmetry; therefore, classical aberration theory is no longer applicable. The image also becomes anamorphic and keystone distorted due to the relative tilt between the object and the optical surfaces.

This computer program incorporates the vector theory of aberrations. Each optical surface contributes aberration of the same form as for a rotationally symmetric system, but the centers of the aberrations are not necessarily located at the center of the image. Two independent sets of aberrations are introduced by each surface: One by the base sphere of the surface, the other by the aspheric departure of the surface. These two sets of aberrations, along with those introduced by other optical surfaces, may be combined vectorially to yield the final behavior of the system.

This program is written in FORTRAN 77 for interactive or batch execution and has been implemented on a PRIME 700 series computer. The program was developed in 1983.

This program was written by John R. Rogers of the University of Arizona for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 39 on the TSP Request Card.*
NPO-16355

Materials

Hardware, Techniques, and Processes

Books and Reports

Trough Coating Solar Cells Without Spillover

New design prevents molten silicon from dropping off newly-coated ceramic substrates.

NASA's Jet Propulsion Laboratory, Pasadena, California

A problem with the trough coating of silicon on ceramic — the spillover of molten silicon — is overcome by a combination of redesigned heaters and tiltable trough. The modifications make it possible to coat virtually any length of ceramic with a film of solar-cell-grade silicon. Previously, the maximum length that could be coated before spillover occurred was 2 inches (5.1 cm).

Spillover occurs when, as a ceramic substrate is drawn over a trough containing molten silicon, the liquid semiconductor is drawn downstream of the trough before it solidifies (Figure 1). As the substrate continues its motion, the molten layer thickens until it eventually spills over and destroys the trough heater below.

So that the silicon layer would cool and solidify faster, the external heater was discarded, and the graphite trough holder itself was made an active resistance-heating element. In addition, the overhead substrate heater was shortened, shifting the peak-temperature zone upstream. The heating zone was thus terminated abruptly at the downstream edge of the trough (Figure 2).

Although the redesigned heaters made it possible to control the position of silicon solidification, they were not enough to eliminate the spillover problem. Accordingly, a motor-driven mechanism was added to the coating equipment; the mechanism allowed the coater to be tilted at various angles above the horizontal. Gravity could thus act to force an adhering blob of silicon back into the trough to prevent it from spilling over.

With the new heaters and tiltable coater, smooth, shiny silicon layers have been coated on mullite substrates measuring 5 by 55 by 0.1 cm, at a coating velocity of 0.06 cm/s. The coated layers were uniform over an area of 225 cm^2 and were approxi-

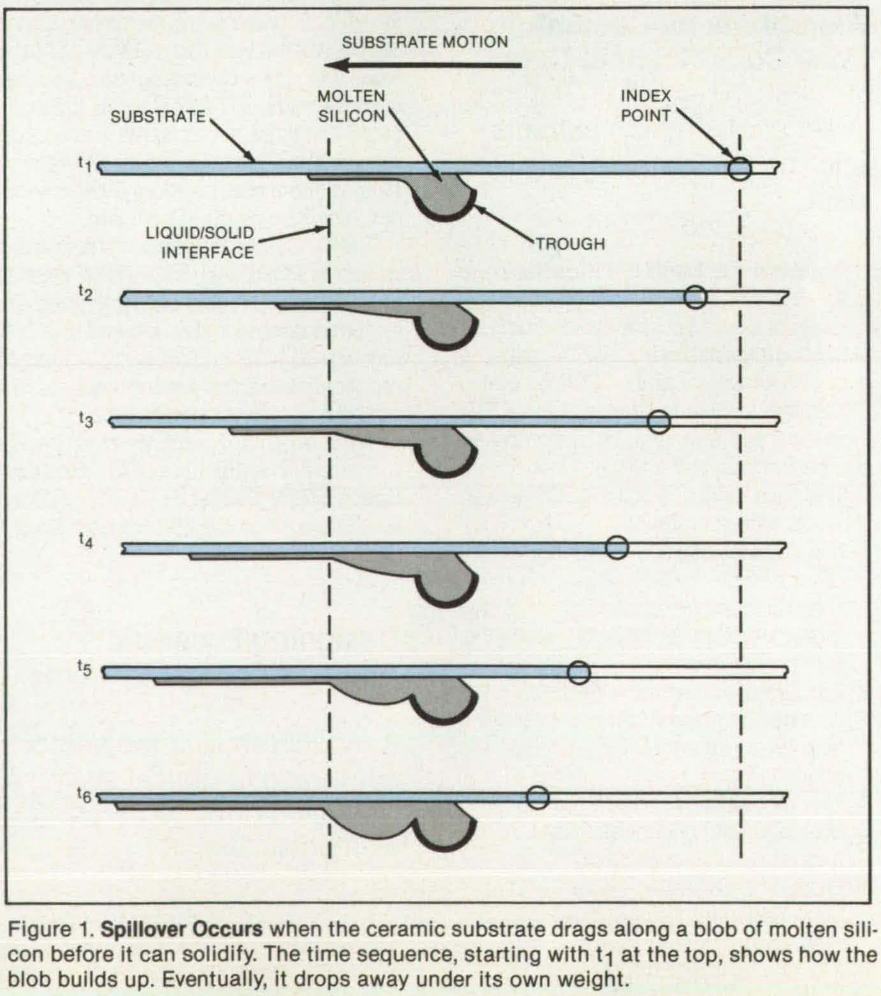


Figure 1. **Spillover Occurs** when the ceramic substrate drags along a blob of molten silicon before it can solidify. The time sequence, starting with t_1 at the top, shows how the blob builds up. Eventually, it drops away under its own weight.

mately 100 μm thick. The layers consisted of large columnar silicon grains virtually identical to those obtained by dip coating under similar growth conditions. Measured minority-carrier diffusion lengths were also similar to those for dip-coated silicon.

This work was done by J. Don Heaps of Honeywell Inc. for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 76 on the TSP Request Card.*
NPO-15313

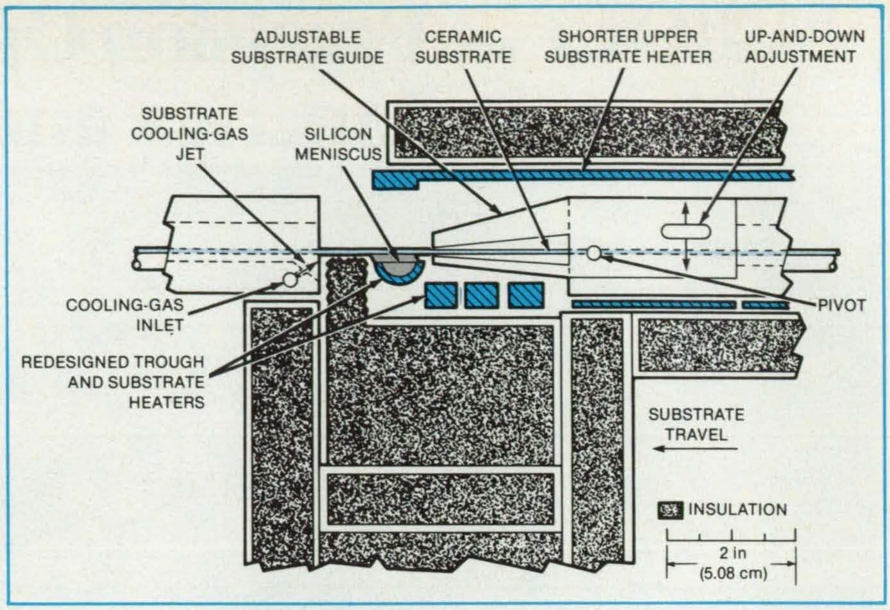


Figure 2. **Redesigned Heaters** include a shortened upper substrate heater (the previous one extended much farther to the left) and a trough heater that is now part of the trough support.

Reducing Stress-Corrosion Cracking in Bearing Alloys

The addition of noble metals may improve the properties of some stainless steels.

Marshall Space Flight Center, Alabama

The resistance to stress-corrosion cracking in some stainless-steel alloys may be increased by the addition of small amounts of noble metals. According to a proposal, 0.75 to 1.00 percent by weight of palladium or platinum added to the alloy melt may be sufficient to improve the properties of certain stainless steels so that they could be used in the manufacture of high-speed bearings.

Strong, hard stainless-steel alloys such as 440 C are possible choices as bearing materials for main shafts in high-speed turbopumps. However, alloy 440 C has poor resistance to stress-corrosion cracking and thus cannot safely be subjected to the type of interference fit required to hold an inner bearing race securely on a shaft. Experimental alloy CRB-7 is harder than 440 C and therefore is superior as a bearing material. Unfortunately, CRB-7 is even less resistant to stress-corrosion cracking than 440 C. The noble metal addition may raise the stress-corrosion-cracking threshold of both alloys.

This work was done by N. E. Paton, D. P. Dennies, and J. B. Lumsden III of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*

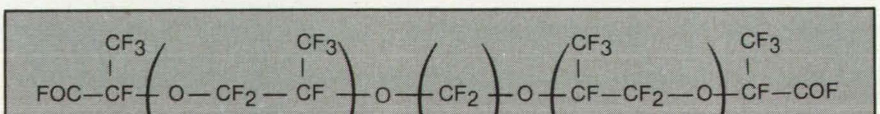
Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center *[see page 25].* *Refer to MFS-19948.*

Epoxy/Fluoroether Composites

Epoxies are toughened by copolymerization with elastomers.

Ames Research Center, Moffett Field, California

Composite materials made from unfilled and glass-fiber-reinforced epoxy are toughened by copolymerization with elastomeric prepolymers of perfluoroalkyl ether diacyl fluoride (EDAF). The improved properties are due to hydrogen bonding between the rubber phase and the epoxy matrix, plus the formation of rubberlike phase domains that molecularly interpenetrate with the epoxy



Perfluoroalkyl Ether Diacyl Fluoride is copolymerized with epoxy to impart increased toughness; m and n are integers, the sum of which is 5 or 6.

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matrix. With an optimum rubber content, particle size, and particle shape, the entire molecular structure is reinforced and toughened. The improved composites also show increased failure strength, stiffness, glass-transition temperature, and resistance to water.

In making a toughened composite by the new method, the EDAF (see figure) is copolymerized with an existing epoxy-resin prepolymer; for example, Epon-828 (or equivalent). This resin is a diglycidyl ether of bisphenol A (DGEBA). A suitable curing agent is 4,4′-diaminodiphenyl sulfone (DDS).

Preparation begins with the dissolution of the DGEBA in enough acetone or methyl ethyl ketone to obtain about 50 percent solids in the final mixture. EDAF is then added in the desired amounts (typically, 3 to 8 weight percent) and stirred for 15 minutes to prereact with the epoxy. The DDS is added and stirred until the solution becomes transparent.

The proportions of the three ingredients are selected stoichiometrically according to the requirement that the sum of the reactive functionalities of the DDS and EDAF must equal that of the DDS in the unmodified formulation (77 weight percent DGEBA, 23 weight percent DDS). The specific reactive functionalities of the three ingredients are, respectively: DGEBA, 185 g/equivalent; DDS, 124 g/equivalent; and EDAF, 725 g/equivalent.

To prevent the formation of voids, the ketones and other volatiles are removed by outgassing in a partial vacuum at a suitable temperature between ambient and 60° C. The resin is then cast in a mold or painted onto a sheet of woven glass fibers to form a preimpregnated sheet ("prepreg").

The casting is cured or the prepreg is partially cured to the required stiffness and tackiness by heating according to any of a variety of time/temperature schedules, with temperatures ranging from 80° to 150° C and times ranging from 5 minutes to 16 hours. Stacked prepregs are further heated under pressures up to 50 psi (340 kN/m^2) to form a unitary reinforced composite. The time/temperature and time/pressure schedule is chosen to give the best results for the given materials and workpiece design.

This work was done by Robert W. Rosser of **Ames Research Center** *and Mark S. Taylor of San Jose State University. For further information, Circle 80 on the TSP Request Card.*

This invention has been patented by NASA (U.S. Patent No. 4,410,682). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Ames Research Center [see page 25]. Refer to ARC-11418.

Imide Cyclotriphosphazene/Hexafluoroisopropylidene Polymers

Polymers have high thermal stability and high strength.

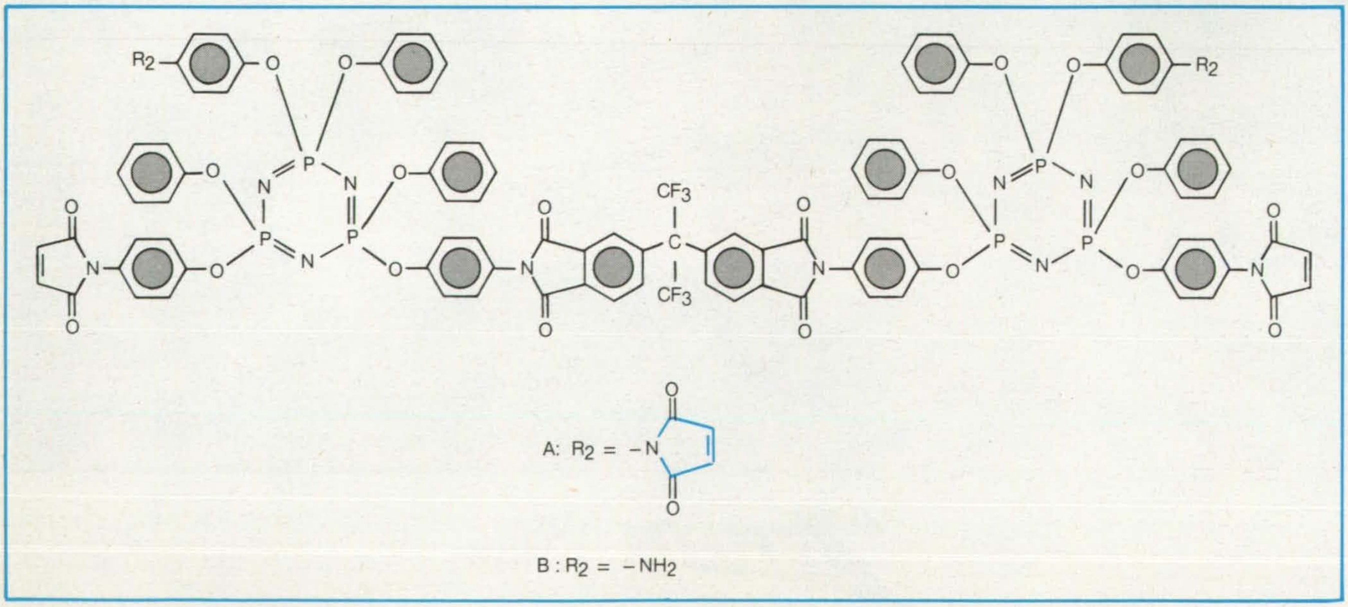
Ames Research Center, Moffett Field, California

Useful physical and chemical properties have been observed in compounds obtained by the thermally-induced melt polymerization of maleimido-phenoxy cyclotriphosphazenes linked through hexafluoroisopropylidene-diphthalimide groups. These polymers exhibit high strength, high thermal stability, and high char yields, and they appear to be excellent candidates for fabricating composite materials.

The structures of the polymer precursors are shown in the figure. In their synthesis, phenoxy and nitrophenoxy groups are added to the cyclic trimer hexachlorotriphosphazene. The resulting compound is reduced and reacted with maleic and hexafluoroisopropylidene-diphthalic anhydrides. The polymer precursor (compound A or B) is obtained by the thermal cyclic dehydration of the reaction products.

Compounds A and B are both soluble in acetone, methyl ethyl ketone (MEK), DMAC, THF, and some other solvents: This property is advantageous for the fabrication of void-free composites, preimpregnated laminates ("prepregs"), and adhesives.

The precursors are polymerized by heat-



These **Polymer Precursors** are used to prepare strong fire-resistant polymers. Each polymer is conveniently produced by heating its precursor to about 235° to 240° C.

ing. In a representative composite-fabrication process, graphite cloth is coated with a 50-percent solution of compound A in MEK or DMAC, then dried in air at 105° to 110° C for 5 to 10 minutes. The prepregs are stacked (four or eight plies) in a vacuum bag and pressed at 50 to 70 psi (340 to 480 kN/m^2) for 30 min at 170° C, then 1.5 h at 240° C, and then 15 min at 290° C. Slow cooling is preferred, holding for 10 min at 240° C, then holding for 30 min at 160° C. Laminates from compound A can also be made by hot melting.

The polymers of compound A are generally preferred because they are stable in air or nitrogen up to 375° C. They show char yields of 78 to 80 percent in N_2 at 800° C and of 60 to 68 percent in air at 700° C. Graphite-cloth laminates do not burn in pure oxygen, even when as hot as 300° C. The laminates show a flexural strength of 71×10^3 psi (4.9×10^8 N/m^2) and a modulus of 8.2×10^6 psi (5.7×10^{10} N/m^2), both of which are superior to those of many resins in current use.

This work was done by George M. Fohlen and John A. Parker of **Ames Research Center** *and Devendra Kumar of the National Research Council. For further information, Circle 79 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 25]. Refer to ARC-11428.

Measuring Carrier Lifetime in GaAs by Luminescence

Charge-carrier recombination is characterized without damage to samples.

NASA's Jet Propulsion Laboratory, Pasadena, California

Luminescence has been proposed as a nondestructive technique for measuring the Shockley-Read-Hall (SRH) recombination lifetime in GaAs. This lifetime, a measure of the longevity of minority carriers before capture by flaws with energy levels within the band gap, is the dominant lifetime governing the behavior of free charge carriers in GaAs.

The sample is irradiated, and luminescence escapes through the surface. The measurement requires no mechanical or electrical contact with the sample. No ohmic contacts or p/n junctions are needed. The sample therefore does not have to be scrapped after it has been tested.

A monochromatic light source with photon energy above the band-gap energy of GaAs (that is, above 1.43 eV) is modulated by a sinusoidal variation in intensity at a frequency of about 100 MHz and directed at a GaAs sample. The light generates excess free carriers in the sample. The carriers diffuse throughout the sample in density waves of the same frequency as the modulation frequency. As they diffuse, the carriers emit a characteristic luminescence that also fluctuates at the modulation frequency.

Because there is a lag between diffusion and the filling and emptying of recombination centers, the luminescence is shifted in phase with respect to the external light source. For a given modulation frequency, the phase shift varies with the carrier lifetime, surface recombination velocity, and other important parameters. The luminescence pulsations can be detected by a light sensor and compared with the modulating waveform to obtain the phase shift as a function of the modulating frequency. This function provides a measure of the SRH lifetime.

This work was done by Oldwig von Roos of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 90 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 25]. Refer to NPO-16337.

Resin Powder Slurry Process for Composite Fabrication

Water and isopropanol slurries are used for polyimide/graphite composites.

Langley Research Center, Hampton, Virginia

A potentially useful process for fabrication of fiber-reinforced resin-matrix composites is the powder slurry technique. The applicability of the technique has been demonstrated using powdered resin made from the thermoplastic polyimide LaRC/TPI (thermoplastic polyimide). Use of this process circumvents the need for such high-cost organic solvents as N-methylpyrrolidinone and diglyme (diglycol methyl ether).

Two basic slurries for the LaRC/TPI powder were investigated. An isopropyl alcohol/binder combination and a water/binder combination were used in conjunction with the polyimide powder to produce prepregs having 45 to 50 volume percent resin content. In preparing the prepreg, the graphite tow passes through the agitated slurry and spreads to accommodate infiltration of the fine polyimide powder. Then the impregnated tow is wound on a revolving drum, and the resulting prepreg is removed from the drum slightly wet to be air-dried.

With the isopropyl alcohol slurry, two binders were most effective: Camphor and methyl Cellosolve® (monomethyl ether of ethylene glycol). Upon molding the prepreg with the camphor additive, the resulting composite has a low void content. This may be the result of residual camphor acting as a flux for the molten resin, thus producing more resin flow and good fiber wetting. The methyl Cellosolve® additive produced a completely different type of prepreg; on drying, the residual Cellosolve® dissolved the resin powder coating to produce a stiff prepreg having the appearance of a solvent-applied resin coating. The advantage of this approach is that small amounts of solvent can be used while the fiber-wetting attributes of solvent-applied systems are achieved. In addition to these two additives, ethylene glycol and an acrylic binder were screened in the isopropyl alcohol system; in both cases, the prepregs were difficult to handle.

Water-based slurries have environmental, worker safety, and cost advantages over organic solvent systems. Therefore, the major effort was directed toward fabrication of LaRC/TPI/graphite prepregs from water slurries. Initially, by use of water with a sufficient amount of powder solvent added, adequate powder pickup was obtained, but the uniformity of powder dispersion was poor. This problem, due to poor wetting of the fiber by the water, was overcome by lowering the surface tension of the slurry with the addition of a surfactant. For the two powder solvents tested, ethyl Cellosolve® and diglyme, there was a different concentration level required to produce, on drying, sufficient powder retention without complete dissolution of the deposited powder. The ethyl Cellosolve® concentration was 23 percent, and the diglyme, 5.2 percent. In both cases, acceptable powder retention was obtained without completely dissolving the powder; however, lower concentrations of diglyme would probably be effective.

The resulting prepreg tapes in each case were heated in a forced draft oven at 200° C for 0.75 hour to convert the polyamic acid powder to polyimide. The resulting stiff sheets were cut to size and compression molded. The high-resin-content prepregs (≅ 78 volume percent) that were prepared gave low-void-content composites, while the low-resin-content prepregs (≅ 16 volume percent) were high in voids. Three factors appear to account for the void contents obtained: First, a high slurry viscosity could prevent powder infiltration during the winding process; second, shrinkage of the prepreg during imidization could produce tow separation; and third, air entrapment could prevent complete infiltration of the resin through the fiber tow during composite fabrication. The laminates were molded at a maximum temperature of 265° C, which does not produce a completely stabilized system. Slightly higher temperatures, e.g., 330° C, would be required to complete resin stabilization and to consolidate the laminates.

This work was done by Roscoe A. Pike of United Technologies Corp. for **Langley Research Center.** *For further information, Circle 43 on the TSP Request Card.*
LAR-13106

Water-Soluble Thermoplastic Polyimides

The conversion of resin powders to water solutions shows potential for making prepregs.

Langley Research Center, Hampton, Virginia

Several thermoplastic polyimide resins that show potential as matrix resins have been developed at Langley Research Center. A number of processes for composite fabrication have been evaluated, including powder processing, which involves the deposition of resin powder on graphite fiber from a nonresin-solvent slurry. Although the powder slurry approach is viable, the use of a solvent system is more amenable with current prepreg manufacturing methods. For example, conversion of the LaRC/TPI (thermoplastic polyimide) resin to a water-soluble form permits use of a solvent approach with a nonorganic solvent. Thus, solvents such as N-methylpyrrolidinone and diglyme (diglycol methyl ether) used in conventional polyimide systems can be eliminated. Uniform fiber wetting from an aqueous solution requires use of a surfactant to decrease the surface tension of the aqueous resin solution.

Water solutions of the LaRC/TPI powder were made by dissolving the processed powder in a dilute ammonium hydroxide solution at 60° to 65° C. The resulting dark-brown solutions were used to prepare LaRC/TPI/graphite prepregs. The fiber tow was drawn through the warm (60° to 65° C) solution and wound on a drum. In some cases, additional resin was applied by coating the wound prepreg with resin solution to achieve the desired fiber/resin ratios. No attempt was made at this time to determine the minimum amount of ammonium hydroxide required for resin solution. The aqueous resin solutions appear to have adequate shelf lives with no evidence of gelation or precipitation.

The LaRC/TPI/graphite fiber prepregs were molded under conditions similar to those used for powdered resin (265° C). In three cases, molding temperatures up to 285° C rather than 265° C were used to determine the effect on void content. In addition, several of the composites were molded using a vacuum bag combined with augmented pressure. No advantage was seen with either technique compared with the fabrication conditions at 265° C. The results show that the aqueous resin solutions produce composites having physical properties equivalent to those fabricated using the powder slurry technique.

It had been previously observed in powder composites that small amounts of camphor appear to influence the flow of the polyimide resin during the curing process. To determine if a similar effect occurred with the water-applied resin, the prepreg was coated with a dilute 5 weight percent solution of camphor before imidizing and molding. A 1.6 percent decrease in void content was obtained.

Selected specimens of the composites fabricated have been processed, under pressure, to 330° C to complete resin stabilization and consolidate the laminates. Additional compaction and flow were evidenced by a decrease in laminate thickness. This was achieved by applying a 500 psi (3.5 MPa) pressure at 100° C. The pressure was allowed to increase as the temperature rose from 100° to 330° C. The average final pressure was 1,300 psi (9 MPa), somewhat below the pressure used for initial laminate fabrication. Typical composite mechanical strengths are comparable to those reported for composites fabricated using the LaRC/TPI resin in organic solvents.

This work was done by Roscoe A. Pike of United Technologies Corp. for **Langley Research Center.** *For further information, Circle 42 on the TSP Request Card.*
LAR-13105

Magnetron Sputtering Deposits Corrosion-Resistant Alloy

Dense, amorphous, metallic film resists corrosion attack by acid.

NASA's Jet Propulsion Laboratory, Pasadena, California

Films of $Mo_{49}Ru_{33}B_{18}$ up to several microns thick have been deposited on glass, mica, and metallic substrates by magnetron sputtering. These coatings are thermally stable up to 800° C and are made corrosion resistant by the proper choice of sputtering deposition conditions. Protective, corrosion-resistant coatings of this kind could be applied to process equipment that comes in contact with aqueous, neutral, or acidic solutions in the chemical, petroleum, and paper industries, in wastewater treatment, and in heat exchangers.

In the sputter-deposition process, it is easier to deposit films of multicomponent alloys than it is in other processes, even when the constituents have different vapor pressures. The magnetron sputter-deposition technique is particularly advantageous because it offers high deposition rates, controllability, and ease of scaleup.

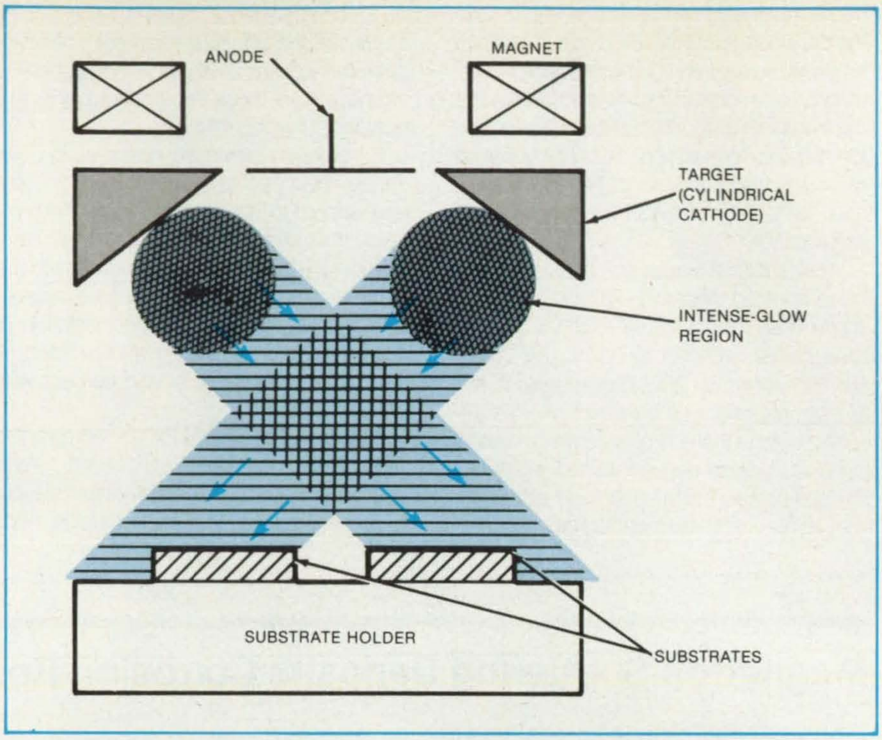
The source of the sputtered film is a target having the same composition as that desired of the film, formed by hot-pressing Mo, Ru, and B powders in the specified proportions. The target and substrates are mounted in a dc magnetron sputtering apparatus (see figure) and cooled by water to remain near ambient temperature during sputtering.

The sputtering chamber is evacuated by a hydrocarbon-free turbomolecular pump down to about 5 × 10^{-7} torr (~7 × 10^{-5} N/m^2). The chamber is flushed with dry argon (Ar), then dynamically maintained at the Ar pressure required for sputtering. A liquid-nitrogen trap in the sputtering chamber results in a pumping speed of 900 l/s (0.9 m^3/s). The substrate is placed about 15 cm from the target. The dc power applied to the target is about 500 W.

Before exposing the substrate to the sputtered flux, the target is preconditioned by sputtering at a constant rate to a depth of about 100 μm: This equilibrates the target with the sputtering environment, thereby assuring the same chemical composition throughout the thickness of the film to be deposited subsequently. Typical deposition rates are about 350 Å/min.

The process was tested with pure Ar, Ar/O_2 mixtures, and Ar/N_2 mixtures. Dense, amorphous, metallic films with smooth surfaces were produced at an Ar pressure of ~5 μm (0.7 N/m^2). At higher pressures, the films exhibited rough surfaces with underlying columnar structures. The use of Ar/O_2 mixtures gave rise to rough surfaces, voids, cracks, and other imperfections. Films deposited in Ar/N_2 were somewhat better, but still showed a columnar structure and were not equal in quality to those deposited in pure Ar.

The columns and structural imperfections make available large surface areas that are vulnerable to chemical attack. The smooth surface finish and absence of internal structure obtained with low-pressure Ar are necessary for corrosion resistance. Potentiodynamic tests of the films in H_2SO_4 showed that they have corrosion resistance superior to that of Mo. Potentiostatic polarization tests in HCl showed that the corrosion resistance of these films is greater than that of an alloy with the same chemical composition produced by rapid quenching.



Direct Current Magnetron Sputtering deposits films of target material on the substrates. Dense, amorphous films of high corrosion resistance are obtained by a proper choice of the target material, gas pressure, and gas composition.

This work was done by Satish K. Khanna, Anilkumar P. Thakoor, and Roger M. Williams of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 15 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 25].* *Refer to NPO-15928.*

Calculating Charge Transport in Semiconductors

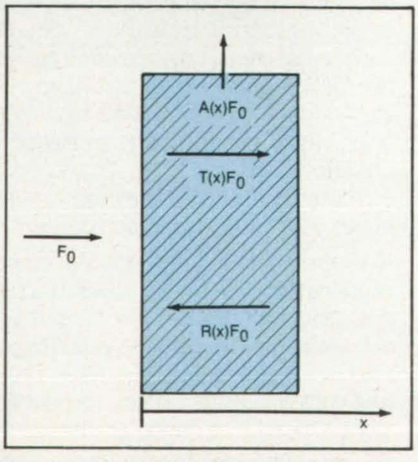
An easy-to-use flux method applies to very-high-speed transport.

Langley Research Center, Hampton, Virginia

Conventional methods for the analysis of the high-field transport of excess charge carriers in semiconductors fail when the active transport region is small compared to the mean carrier scattering length. Consequently, these methods cannot be applied to transport through small regions or at high speed, such as in very-large-scale integration (VLSI) or very-high-speed integrated circuits (VHSIC).

An alternative method, called the flux method, is an improvement over conventional methods in that it is easy to use, and it applies in an operating regime not accessible to conventional macroscopic methods. The key concept of the flux method is that it follows the behavior of the particle flux rather than the concentration of the particles.

In a technique for characterizing the transport of a flux of isoenergetic particles moving in one dimension through a diffuse medium, the transport properties of the moving particles are defined in terms of functions that specify how an incident flux is apportioned into a transmitted and reflected flux by its interaction with the medium. The physical requirements of the transport process are expressed as functional equations that limit the transmitted and reflected fluxes. This method focuses on the transport properties of a finite element of material, while the usual starting point of transport



The **Functions R(x), T(x), and A(x)** represent the fractions of the incident flux that are reflected, transmitted, and absorbed as a result of interaction with the slab.

theory specifies the transport through an infinitesimal element. In this new approach, neither the transport medium nor the particles need be specified; instead, the macroscopic transport characteristics emerge as properties of the transport functions.

The technique involves accounting for the steady-state flux that emerges from a material slab when a beam of isoenergetic particles is incident on it. Part of the beam is transmitted through the slab in the direction of the incident flux. Other particles may scatter from the slab and, in one-dimensional transport, reverse their direction and emerge from the slab in a direction opposite to their entry. Thus, some of the incident beam is transmitted, and some is reflected. Furthermore, some particles may be absorbed by the medium and withdrawn from further transport. In a process complementary to absorption, particles in the incident beam may interact with the medium and stimulate the generation of still more particles to be transported. These generated particles may have velocities in the beam direction or opposite to it and so may contribute to both the transmitted flux and the reflected flux.

As illustrated in the figure, the transport processes in a finite slab can be described globally by three numbers normalized to the incident flux, giving the reflected fraction R of the incident beam, the transmitted fraction T of the incident beam, and the absorbed fraction A of the incident beam. Both R and T are positive but are not necessarily bound; A is positive if absorptive processes dominate and negative if stimulated-generation processes dominate.

By studying the generic properties of these transport functions, a set of coupled, parametric, functional equations is obtained. Solutions to these equations are found and the resulting transport properties exhibited in terms of two parameters. One of these is a fundamental transport parameter. As this parameter is varied, the reflection and transmission functions change to reflect a characteristic change in the microscopic processes responsible for the transport. The second parameter results from the scale invariance of the functional equations. A global approach is taken: The analysis of the transport process is carried out without reference to infinitesimals. As a result, this method is not subject to limitations that follow from a local or infinitesimal analysis.

This work was done by C. E. Byvik of **Langley Research Center,** *A. M. Buoncristiani of Christopher Newport College, and John Thomchick of Pennsylvania State University. For further information, Circle 62 on the TSP Request Card.*
LAR-13201

Damping Melt Convection With a Magnetic Field

Thermal and solutal convection is almost as effectively reduced as by zero gravity.

Marshall Space Flight Center, Alabama

The application of a 3-kG magnetic field has been found to reduce thermal and solutal convection in a Bi/MnBi melt in a Bridgman-Stockbarger (moving-vertical-thermal-gradient) furnace operating in the normal gravitational field. The resulting Bi/MnBi alloy samples had properties similar to those of samples grown under nearly zero gravity (see example in figure). This new convection-reducing technique should prove useful in growing more uniform, defect-free semiconductor materials from such other electrically conductive melts as GaAs, CdTe, and $HgCd_{1-x}Te$.

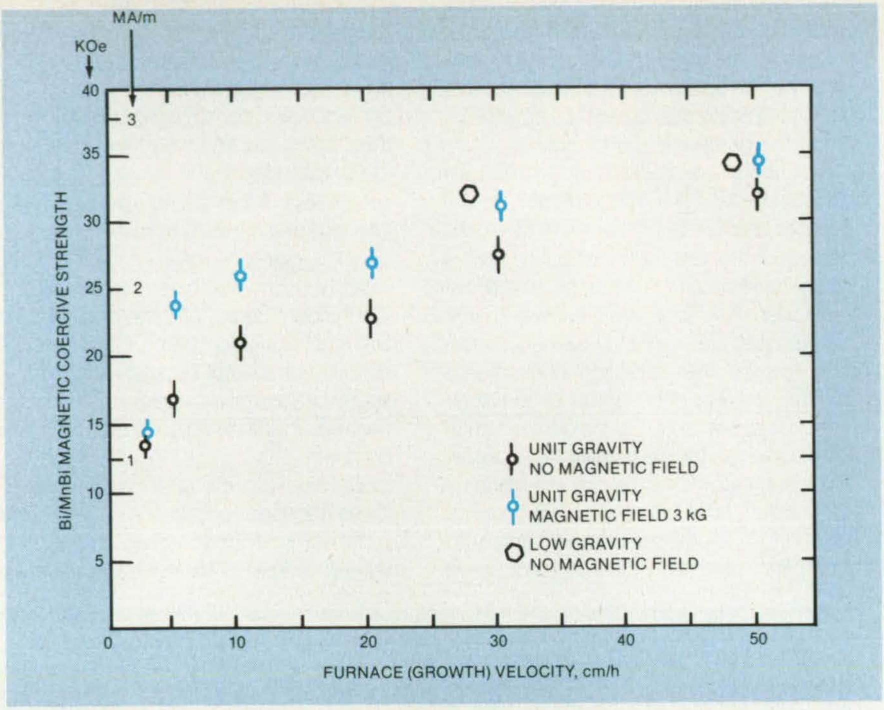
The samples (72 percent Mn by weight) were prepared in an evacuated high-purity quartz crucible by melting together commercially pure Mn (99.9 percent) and high-purity Bi (99.999 percent). The mixture was heated above 446° C for stoichiometric MnBi using radio-frequency induction heating and was stirred electromagnetically for 16 hours. During crystal growth in the furnace, a thermal gradient of 100° C/cm (corresponding to a 450° C hot-zone melt) and a 25° C cold zone were maintained. The hot zone was controlled by resistance heating and separated from the water-cooled chilling block of the cold zone by an insulated adiabatic zone.

The samples were directionally solidified upward in the furnace. After cooling, the resulting alloy cylinder consisted of rods of MnBi in a Bi matrix.

This vertical crystal-growing configuration is inherently lower in gravitationally induced convection than are horizontal crystal-growing arrangements. Nevertheless, samples grown in this furnace without a magnetic field showed smaller magnetic coercive strength and larger MnBi rod diameter and interrod spacing in the Bi matrix than did comparable samples grown in low gravity, implying that significant convection effects were still present.

The application of a magnetic field to an electrically conducting melt causes an inductive drag or magnetic "viscosity" for motion of the fluid across the magnetic-field lines. This drag dominates when the Hartmann number — the ratio of the magnetic viscous force to the ordinary viscous force — is much greater than 1.

With a 3-kG applied magnetic field, the Hartmann number in the Bi/MnBi melt was about 25. The resulting magnetic viscosity was apparently sufficient to suppress a large portion of the convection: When the samples were grown in the furnace with the magnetic field, they had magnetic and morphological properties similar to those of samples grown in gravitation ~10^{-4} that of the surface of the Earth. The figure shows the results for magnetic coercive strength; similar comparisons were made for solidification temperature, mean rod diameter, and mean interrod spacing.



Magnetic Coercive Strengths of eutectic Bi/MnBi samples grown with a 3-kG magnetic field applied to reduce convection (color) are similar to those observed in samples grown at low gravity. Samples grown in normal gravity without magnetic convection damping have lower magnetic coercive strengths.

This work was done by Ronald G. Pirich and Jerome L. DeCarlo of Grumman Aerospace Corp. for **Marshall Space Flight Center.** *For further information, Circle 102 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 25]. Refer to MFS-28040.

Purifying Water by Imbibition

Polymer beads would absorb organic compounds.

NASA's Jet Propulsion Laboratory, Pasadena, California

A concept for purifying water would use absorbent material rather than the usual adsorbent material to remove organic substances. In other words, the entire bulk of the material would be employed, not just the surface. The proposed purification process would use inexpensive equipment and low energy.

The absorbent material is methyl acrylate polymer. The material is cheap and can be regenerated simply by rinsing it with methanol or, even more simply, by allowing absorbed compounds to evaporate from it. Because it merely dissolves contaminants instead of forming chemical attachments to them, the polymer does not require large amounts of energy for regeneration.

The polymer is prepared as transparent beads 0.125 to 0.8 millimeter in diameter. The beads cost only about 60 cents per pound ($1.32 per kilogram, 1980 prices) and are thermally stable, insoluble in water, and can be reused many times.

In the new process, the beads would be placed in a column in which contaminated water flows over them. The beads would remove from the water such compounds as hydrocarbons, phenols, esters, higher alcohols, ketones, aldehydes, ethers, and halocarbons.

Calculations show that purification with the absorbent polymer would not be nearly as energy-intensive as with activated charcoal, a commonly used adsorbent. The energy consumed in regenerating a mass of activated charcoal would be about 14 times as great as that for regenerating the equivalent mass of the polymer with methanol and recycling the methanol by distillation. Another major saving would be realized in the energy required to prepare the polymer: Preparing activated charcoal consumes about 30 times as much energy as preparing the equivalent mass of the polymer beads.

This work was done by Emil A. Lawton of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 5 on the TSP Request Card.*
NPO-16419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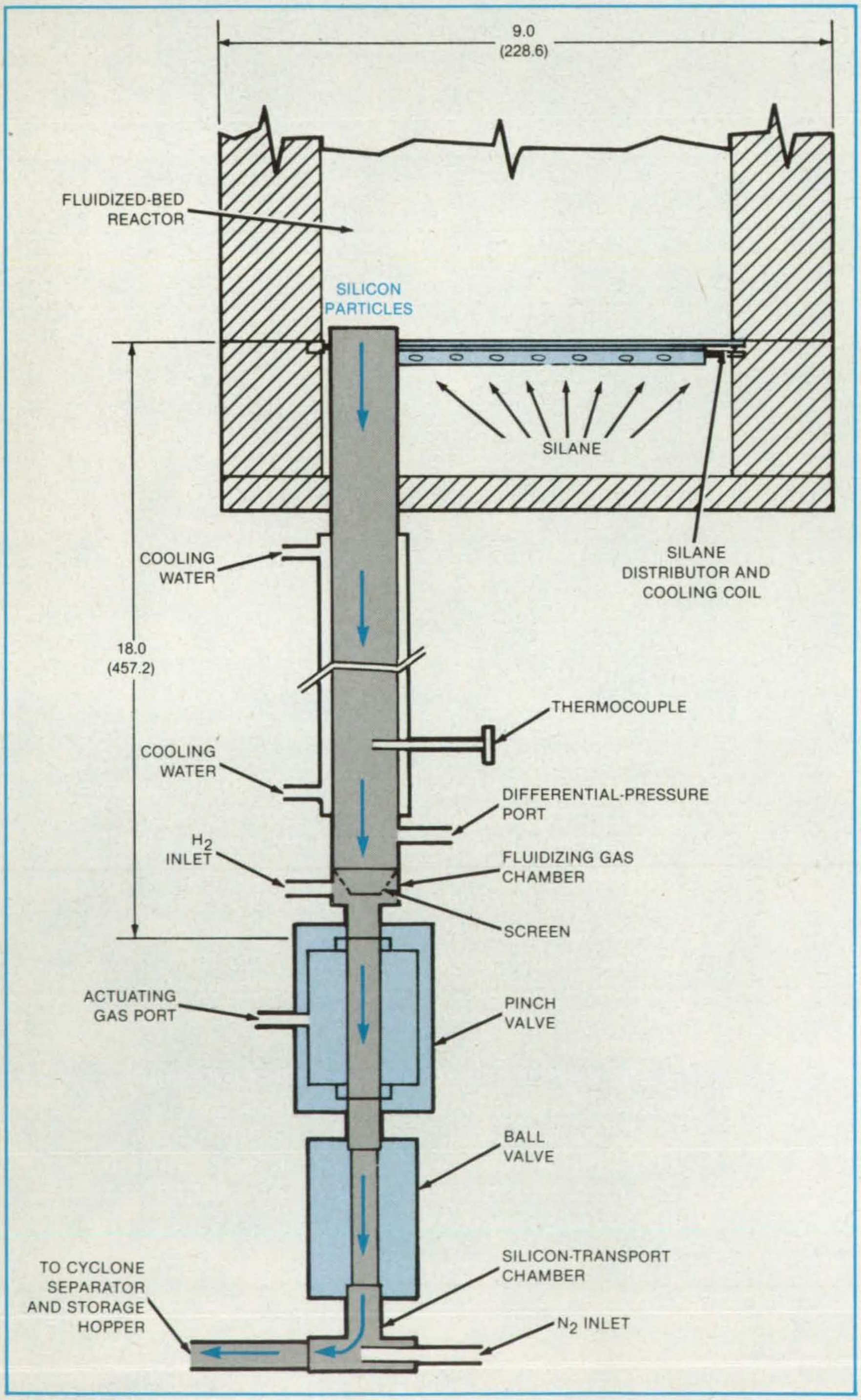
Extracting Silicon Product From Fluidized-Bed Reactors

Withdrawal tube encloses a second fluidized bed that extracts large particles.

NASA's Jet Propulsion Laboratory, Pasadena, California



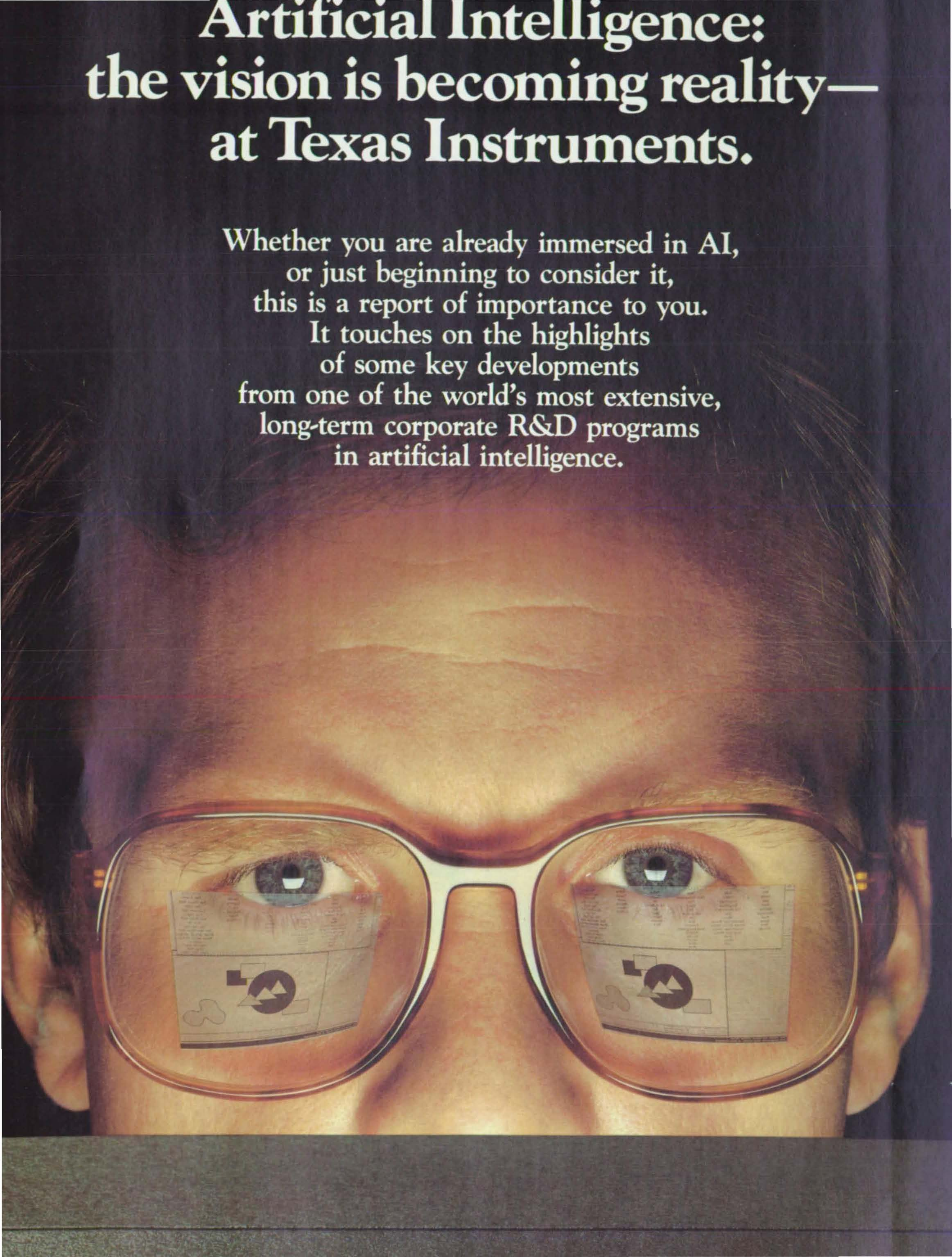
A **Withdrawal Tube** mounted to the base of a fluidized-bed reactor feeds large silicon particles to a storage hopper. The bed of particles in the tube is mildly fluidized by flowing hydrogen. Dimensions are in inches (millimeters).

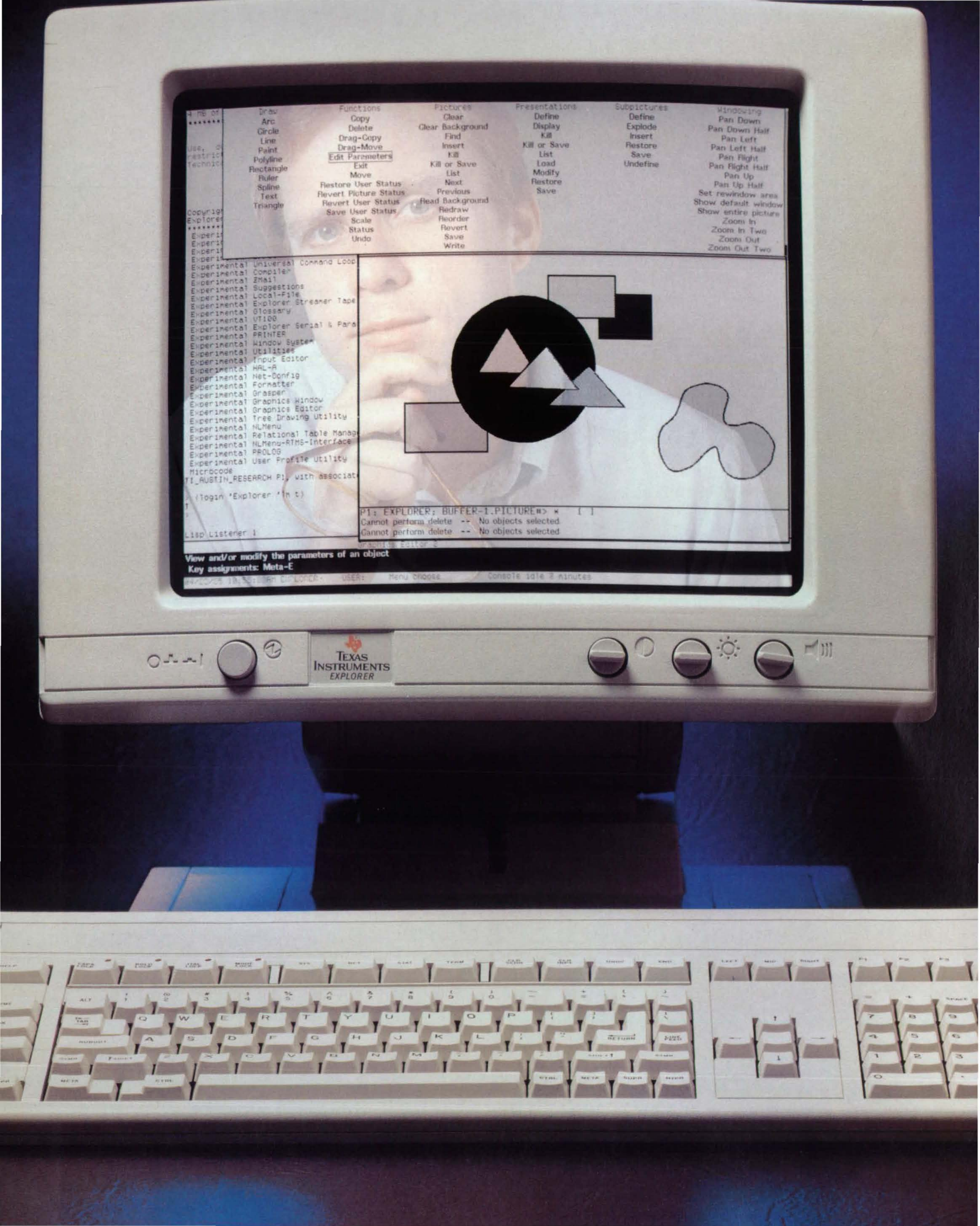
With the aid of a new scheme, silicon particles are continuously removed from the bottom of a fluidized-bed reactor when they have grown to a large size. In the reactor, silane (SiH_4) flows through a bed of small silicon seed particles at a temperature of 650° to 700° C. The silane decomposes into silicon vapor and hydrogen gas, and the vapor deposits as a solid on the seed particles. With the withdrawal system, the reactor can be operated continuously.

A withdrawal tube is placed at the bottom of the reactor (see figure). Particles falling into the tube from the reactor encounter a mildly fluidized bed of silicon particles, independent of the reactor bed. Hydrogen gas flows through the withdrawal tube to fluidize the bed of particles in the tube and to prevent silane from entering it from the reactor. Water flowing through a jacket on the tube cools the hot particles.

Larger particles work their way to the bottom of the tube. There, an electronically controlled, gas-actuated pinch valve opens for 1 second at 10- to 15-second intervals to allow these particles to drop out of the tube. The particles are then carried by flowing nitrogen gas to a cyclone separator and storage hopper.

This work was done by George C. Hsu, Naresh K. Rohatgi, and Andrew D. Morrison of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 84 on the TSP Request Card.*
NPO-16385


Artificial Intelligence: the vision is becoming reality— at Texas Instruments.
Whether you are already immersed in AI, or just beginning to consider it, this is a report of importance to you. It touches on the highlights of some key developments from one of the world's most extensive, long-term corporate R&D programs in artificial intelligence.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Experimental Compiler
Experimental EMail
Experimental Suggestions
Experimental Local-File
Experimental Explorer Streamer Tape
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Experimental VT100
Experimental PRINTER
Experimental Window System
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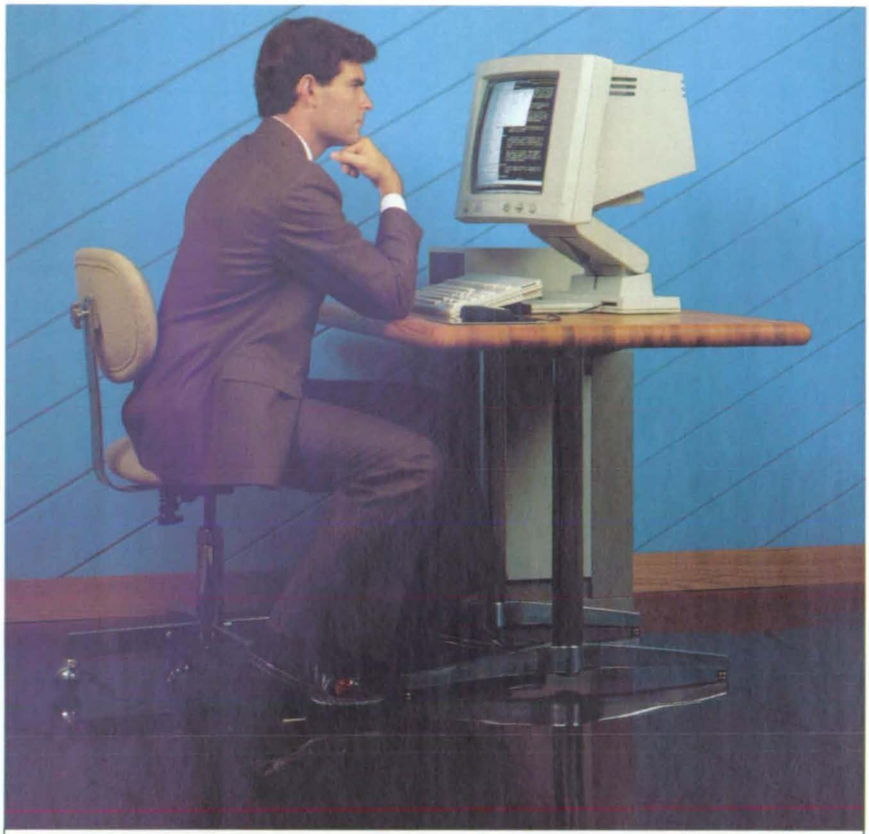
Artificial intelligence is an emerging set of technologies whose goal is to enable computers to solve problems traditionally thought to require human intelligence or capabilities.

Key to these next generation systems is a significant new approach to computer programming known as symbolic processing. Conventional computer programs require precise sequences of mathematical steps carried out in a prestructured manner. Symbolic processing works with ideas and knowledge rather than numbers, analogous to the way humans reason with knowledge they possess.

Conventional computers experience many shortcomings in areas where symbolic processing systems have proven especially effective: dealing with complex problems, interpreting information, using "rules of thumb" gained by experience, and handling uncertain or incomplete information.



The Explorer system represents an important advancement in providing exploratory programming and rapid prototyping capabilities for faster development of AI applications.

SYMBOLIC vs.	ARITHMETIC
Qualitative	Quantitative
Logical	Numerical
Inferential	Computational

People conceptualize ideas in symbolic terms rather than numbers. Symbolic processing computers manipulate information and knowledge in much the same way.

Symbolic processing, combined with other AI technologies—natural language, speech recognition and synthesis, computer vision—promises to open new dimensions in the way computers serve people. Using AI, computers can now be applied to the broader range of problem solving and decision making that people continually face in the real world.

At TI we're making AI work for you—now.

The transition from basic research to useful products is a commitment at Texas Instruments. We're concentrating not only on fundamental AI research, but on developing and marketing useful products that take full advantage of our experience. Today, TI has a number of products that are a direct result of this commitment.

The TI Explorer™ system. Solving problems beyond the reach of traditional computing.

The Explorer system from Texas Instruments uses a new computer architecture especially designed for AI applications. It executes the language of artificial intelligence, LISP (List Processing). Programmer-friendly ease-of-use features promote rapid productivity for new users.

In contrast to conventional computers, which are designed for numerical data processing, the Explorer system is designed for the efficient processing of symbols and concepts, which represent real-world objects, their properties and relationships, and "chunks" of knowledge.

Until recently, symbolic processing systems were large, expensive computers that required special environments. This limited their use primarily to research laboratories. But, using its advanced semiconductor capability, TI has set a new standard for symbolic processing computers. The Explorer system's compact design, advanced user console, and powerful software packages now make it possible to move artificial intelligence solutions out of the laboratory and into the workplace.

For the company working on AI development, or for the organization just beginning to evaluate it, The Explorer system from Texas Instruments is a "must" consideration.

Bringing AI technology to personal computing.

Making technology affordable and accessible to more people is a prime mission at Texas Instruments. In putting AI research to practical use, TI has developed a number of new capabilities for personal computers that are making artificial intelligence applications available to everyone who needs them.

The Personal Consultant™— expert system development tools for personal computers.

The Personal Consultant software package from TI lets you develop and run expert systems on a TI Professional Computer or other personal computer.

Expert systems are computer programs designed to simulate the reasoning processes of human experts in a particular field—in effect, a computerized consultant. It asks a series of questions, and applies rules used by human experts to analyze the answers and make recommendations.

With Personal Consultant software, you can even ask for *help*, inquire *why* you were asked a particular question by the computer, or *how* the system reached its conclusion.

The economies offered by Personal Consultant make adaptation of this advanced technology practical for business and industry today, allowing the expansion of expert systems development and applications to a much greater degree than was affordable up to this time.

Arborist™—powerful decision-analysis software.

Arborist software illustrates the application of AI techniques to solve conventional problems. A combination of LISP processing language, multiple window displays, graphic representation of data, and plain English commands breaks through old barriers to make decision-tree problem solving techniques available to anyone who needs to make better and faster decisions.

Available as a direct result of TI research in artificial intelligence, this new software makes a versatile professional productivity tool easy-to-use and affordable on economical personal computers.

◀ *The Explorer computer system for high-performance symbolic processing.*

Natural language software— helping PCs use plain English.

A leader in the development of natural language interfaces, Texas Instruments developed NaturalLink™ software to allow people to communicate with computers in everyday English sentences, rather than in more traditional computer commands.

Invented in TI's Artificial Intelligence Research Laboratory, NaturalLink packages are available now to provide simplified access to many of today's most popular commercial PC software packages. These include word processing, spreadsheet, database, and graphics programs—programs that impact the majority of personal and business computing needs.

System developers may also build natural language interfaces for their own applications by using the TI NaturalLink Technology Package.

Computers that speak— and respond to the human voice.

Back in 1978, TI brought a major breakthrough in synthesized speech to the fingertips of children in practical, affordable, *talking* learning aids that spawned a whole new generation of electronic products.

With the emergence of personal computers, Texas Instruments has applied advanced speech technologies to PCs with the TI-Speech™ system. This innovation brings together our latest developments in both voice recognition and voice synthesis. The TI-Speech system permits users to verbally enter commands in the computer and provides sophisticated telephone management functions. It makes using a computer easier. And for some hands-busy applications, or for some handicapped individuals, it makes computerization possible.

The Business-Pro™ computer combines advanced personal computing power with capabilities for artificial intelligence applications.

At TI we're using AI today ...for tomorrow.

TI has made an extensive commitment to the application of AI technology for in-house productivity and to solve customer problems. We began our R&D efforts in 1978 and are leading the way in bringing practical, cost-effective AI products to market.

As an established world leader in the research and development of symbolic processing computers, expert systems, and natural language and speech processing, TI is now utilizing the benefits of these efforts. We've discovered new ways to apply AI solutions to improve our own productivity—to speed and improve the development process for advanced VLSI semiconductors, to increase the productivity of automated production systems, to enhance the effectiveness of vital defense systems, to analyze seismic data more accurately for more effective oil exploration, and to develop software that provides better, more timely management information.

The results of these efforts, and our own experience, is bringing thoroughly tested AI products to the marketplace and making them available to an ever increasing number of disciplines.

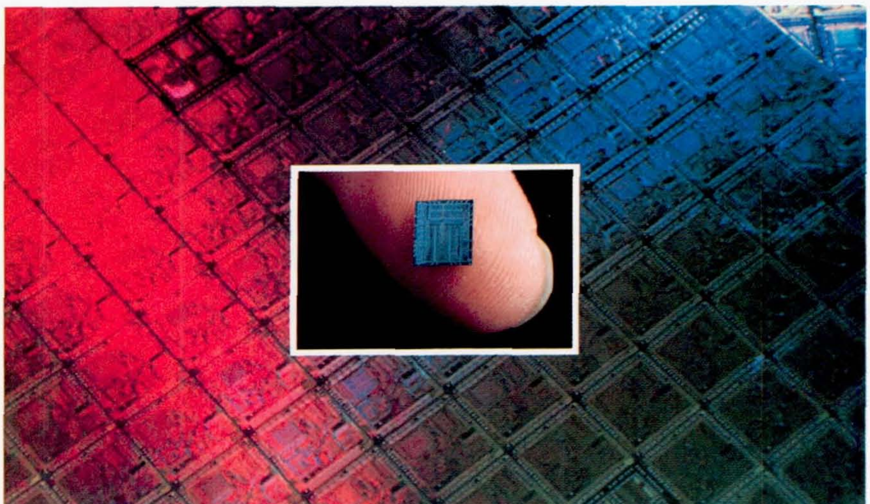
Expert systems, natural language processing, and speech recognition have been applied to fields ranging from genetic engineering to financial management to education. Symbolic processing computers such as Explorer are being used to perform tasks once thought to be solely the province of human experts: planning space missions, diagnosing machinery failures, designing control systems for chemical processing plants.

Texas Instruments dedication to research in artificial intelligence has made significant contributions to this exciting new field. As one of the world's largest technology companies, TI has the resources and commitment necessary to continue its leadership role in the development and production of reliable new products which capitalize on the results of artificial intelligence research.

The next generation of symbolic processing has already begun at TI.

One such program currently underway at Texas Instruments is the development of a LISP processor on a single chip. As part of the Strategic Computing Program of the Defense Advanced Research Projects Agency, this microprocessor is designed to provide up to 10 times the power of symbolic processors previously available.

This new chip will lead the way to many new commercial applications of artificial intelligence. When you link your AI development work to TI, you know you will stay at the leading edge of this fast developing technology—a potentially critical factor in competitive strategies for tomorrow.



A new single-chip LISP processor, being developed by Texas Instruments, will have 10 times the power of previously available symbolic processors.

TI's worldwide support and quality products help you make the most of AI technology.

To make artificial intelligence a practical reality takes more than product innovation. Texas Instruments already has a worldwide support system to provide technical assistance and follow-through. It's a total program of training, documentation, engineering support, and field service designed to provide you with the assistance needed to take maximum advantage of advanced AI technologies.

And for value, TI's exacting design and manufacturing standards enable us to deliver a higher quality product, a more reliable product, with greater functionality and at lower cost than would otherwise be possible.

Explore the promise of AI with TI.

- A proven track record for innovation in new technologies.
- An extensive, long-term R&D effort in artificial intelligence and the resources and commitment to sustain it.
- A leadership role in AI research applied to practical, affordable products—commercially available now—with new products under development.
- Consider TI's one-of-a-kind credentials in artificial intelligence. Whether you are just beginning to think about this new wave of computing technology or already have a program in place, Texas Instruments can help you lead the way.

For more information.

If you would like to know more about the exciting new developments in AI at TI, write to us at Texas Instruments, P.O. Box 809063, Dept. DEE02, Dallas, TX 75380-9063 and we'll send you additional information.

Discover new dimensions in computing with the Explorer symbolic processing system.

From the company that pioneered the transistor radio, integrated circuit, electronic calculator, integrated-circuit computer, computer-on-a-chip, microprocessor, and synthetic speech.

Once again, Texas Instruments is pioneering an important new technology and bringing it within your reach through a practical, problem-solving product at an affordable price. The Explorer computer system will play a vital role both in extending the boundaries of knowledge and in delivering the products emerging from artificial intelligence research.

A closer look at the Explorer system.

The Explorer system is an advanced computer system designed for high-performance symbolic processing. The Explorer is ideally suited for the development and execution of software that employs artificial intelligence techniques to help solve complex application problems.

The LISP environment.

The system features one of the most productive software development environments available today. The software is based on Common LISP to promote portability and consistency of software applications among different LISP machines. The Explorer also provides high-level extensions to LISP, including Flavors—an object-oriented programming facility.

Unique software.

In addition to the standard LISP machine environment, Texas Instruments provides a number of unique software packages as a standard part of the system software. The Command Interface Toolkit provides standard interfaces to the system. The Suggestions Menu System helps novices rapidly learn the Explorer environment. The Glossary Utility offers online definitions of terms. These packages greatly reduce the time it takes a new user to become productive on the Explorer system.

Advanced hardware.

The Explorer hardware supports high-speed symbolic processing through a number of advanced architectural features. These include a tagged architecture for run-time data typing, bit-field hardware for manipulating complex data structures, hardware assisted memory management (garbage collection), and a 128M byte virtual address space. In addition, physical memory can be expanded to 16M bytes and disk storage can expand to 1120M bytes unformatted (896M bytes formatted).

Explorer, Personal Consultant, Arborist, NaturalLink, TI-Speech, and Business-Pro are trademarks of Texas Instruments Incorporated.

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TEXAS INSTRUMENTS

Creating useful products and services for you.

DEAZ040

Producing Silicon Carbide for Semiconductor Devices

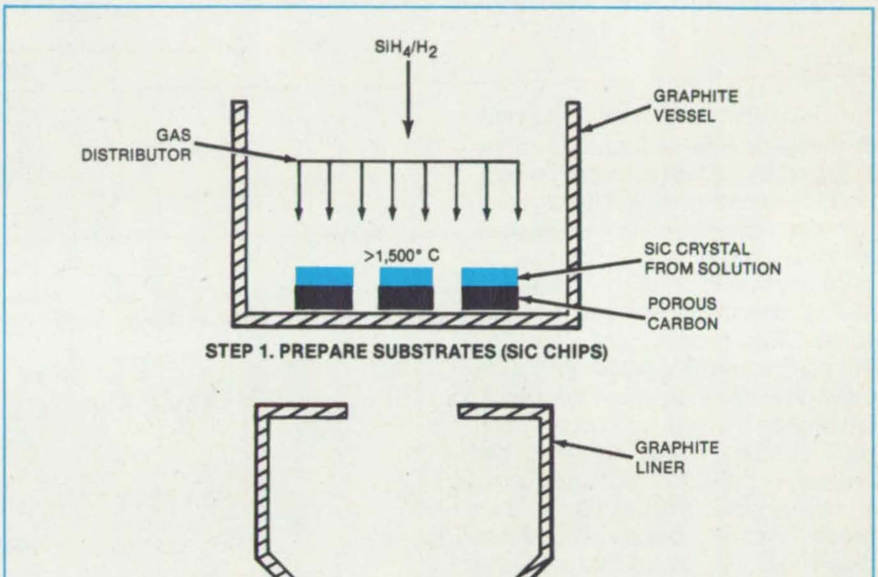
Two new processes should make single-crystal material at relatively high rates.

NASA's Jet Propulsion Laboratory, Pasadena, California

Two processes have been proposed for the production of SiC crystals for eventual use in semiconductors operating at temperatures as high as 900° C. Until now, there has been no practical process for growing single SiC crystals of sufficient size, purity, and perfection. Available processes have been batch, rather than continuous, operations and have tended to be energy-intensive, high-temperature, low-yield, contamination-prone techniques.

In one of the processes, chips of SiC would be placed in a bed of smaller SiC particles through which H_2 gas flows at a rate sufficient to cause mild bubbling of the particles. A reactant such as CH_3SiCl_3 or a SiH_4/CH_4 mixture would be introduced into the H_2 stream while the bed is heated to 1,200° C by resistive or capacitive heating. A layer of SiC should build up on the chips and particles, both of which are considered products. The thickness of the SiC deposit depends on the time the chips and particles are allowed to reside in the bed. If only the chips are heated, but not the bed particles, the deposition will be primarily on the chips.

The thickness of the deposited material will tend to be uniform because of the uniformity of the temperature in the bed and because the bouncing particles will smooth out newly grown material. A high deposition rate is expected — greater than 1 μm/min of SiC — and the production rate will therefore be high. The energy consumption of the process will be relatively low, since fluidized-bed particles lose much less heat by radiation than do high-temperature rods or isolated substrates. The process would be continuous, and the bed particles could be withdrawn frpm the bed at intervals.



A **Combination of New Processes** can produce silicon carbide chips containing epitaxial layers. Chips of SiC are first grown on porous carbon matrices. The chips are then placed in the fluidized bed, where an additional layer of SiC grows on them.

The other process employs crystallization from a molten mixture of silicon and carbon. It has been demonstrated in the laboratory. Silane is heated so that it decomposes into fine silicon powder. The powder is diffused into a porous carbon matrix, which is kept at a temperature above 1,500° C. A melt of silicon and carbon forms in the porous medium, and a SiC platelet crystallizes from the melt. The remaining carbon matrix is removed by etching or by heat treatment in oxygen.

With this process, no crucible is needed, and the contamination that might thus be introduced is avoided. The reaction temperature is moderate compared to that of previous processes and can be produced by a simple graphite resistance heater at low current. As in the first process, the growth rate of SiC is about 1 μm/min.

The proposed processes can be combined to yield a complete process (see figure). The liquid crystallization process can be used to make SiC particles or chips for the fluidized-bed process.

This work was done by George C. Hsu and Naresh K. Rohatgi of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 31 on the TSP Request Card.*
NPO-16391

Synthesis of Metal Phthalocyanine Sheet Polymers

New polymers are usable at temperatures up to 600° C.

Ames Research Center, Moffett Field, California

A new method for synthesizing metal phthalocyanine tetracarboxylic acids (MPTCA's) yields a high purity end product. In addition, high-purity metal phthalocyanine sheet polymers have been synthesized from these compounds.

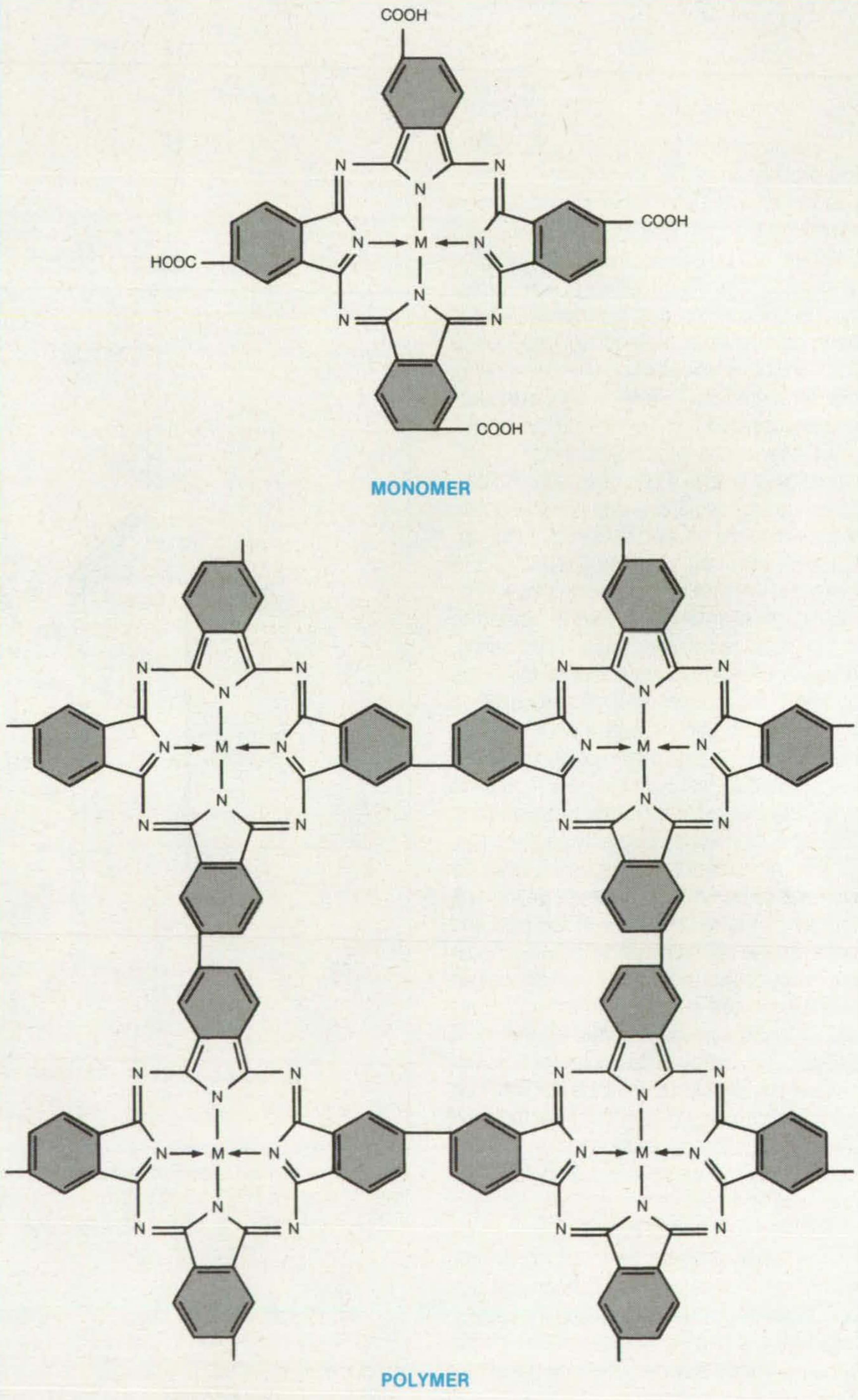
The synthesis of pure copper (II) $4,4',4'',4'''$-phthalocyanine tetracarboxylic acid (CuPTCA) involves many steps. The starting ingredients are copper (II) soluble pentahydrate, trimellitic anhydride, ammonium chloride, ammonium molybdate, urea, and nitrobenzene. These ingredients are slowly heated, then held at 185° C for 4 hours. The deeply-colored solid product is then washed in methanol, boiled in a solution of HCl and NaCl, and filtered. The product is next treated with a solution of NaOH and NaCl, treated with a solution of HCl, centrifuged, and dissolved in a solution of NaOH. Finally, the acid is precipitated from solution by HCl, centrifuged, dissolved and precipitated again, washed, and dried. MPTCA's of cobalt and nickel were also prepared using similar procedures.

In one polymerization method, the MPTCA monomer was heated to 450° C for 1 hour in a vacuum of 10^{-5} to 10^{-6} torr (10^{-3} to 10^{-4} N/m^2). The monomer was also successfully polymerized by heating for 1 hour at 450° to 500° C in a current of nitrogen.

The structures of both the monomers and the polymers are shown in the figure. All have a deep-blue-to-purple metallic luster, depending on the metal at the core of the molecule. The polymers are soluble in concentrated sulfuric acid, concentrated hydrochloric acid, chlorosulfuric acid, and trimethyl sulfonic acid. The threshold temperature for major polymer decomposition in air is above 450° C. The polymers exhibit char yields in nitrogen of approximately 90 percent at 800° C.

The monomers should be useful in the preparation of other polymers, paint pigments, inks, and coatings. The sheet polymers may be useful as solid lubricants (in the manner of graphite and molybdenum disulfide). The electrical conductivities of the polymers (which are higher than those of both the corresponding monomers and previous phthalocyanine polymers) range from 3.2×10^{-10} to 2.3×10^{-3} (ohm-cm)$^{-1}$.

This work was done by Bappaliage N.



A **Metal $4,4',4'',4'''$ – Tetracarboxylic Phthalocyanine** monomer can be formed into a sheet polymer by heating. The units of the polymer are linked in a manner similar to phenyl-group linkages in biphenyl: The conjugation extends throughout the macromolecule, thereby increasing the delocalization of the π – electrons. This increases the conductivity and thermal stability of the polymer.

Achar, George M. Fohlen, and John A. Parker of **Ames Research Center.** *For further information, Circle 78 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 25]. Refer to ARC-11405.

Predicting the Cyclic Response of High-Temperature Materials

Estimates of the stress/strain response are simplified.

Lewis Research Center, Cleveland, Ohio

A simplified analytical procedure for estimating the local stress/strain response in a high-temperature structural component has been developed. The simplified procedure relies on the assumption that local inelastic response in a high-temperature structure is constrained by the surrounding elastic material. The mechanical strain/temperature history can then be approximated with a linear elastic analysis. The procedure further assumes that the local response is composed of elastic, time-independent plastic, and creep components. A conventional yield surface concept is used to determine the onset of plastic action. At all other times within a loading cycle, the nonlinear differential equation is used to predict an incremental history recognizing the elastic and creep response. Short-time (primary) creep data are used in the creep model development.

The procedure was evaluated using results from thermomechanical cycle tests of uniaxial, strain-controlled Hastelloy X specimens. Hastelloy X was selected because of prior structural analysis and material model development conducted under two previous NASA contracts. Accurate prediction of the thermomechanical cycles was considered to be verification of the cyclic response model.

For comparison, simulations of Hastelloy X specimen tests were made with two existing Hastelloy X material behavior models: A classical time-independent plasticity and creep model and a unified time-dependent plasticity model. The classical plasticity and creep model assumes decomposition of the response into uncoupled plasticity and creep components. The unified time-dependent model considers inelastic response as a continuous function of stress and several state variables that recognize loading history.

The simplified procedure was developed recognizing characteristics of both material models. The time-independent yield surface concept was used to define discrete yield points, while a unified equation predicted integrated elastic and creep response. This method assumes that the local mechanical strain and temperature history can be defined by linear elastic analysis. The actual stress response is then determined by considering the nonlinearity produced by time-independent plasticity and time-dependent creep. Comparisons of the predicted results for the thermomechanical cycles showed the simplified procedure to be of comparable accuracy with the two other models.

This work was done by Vito Moreno of United Technologies Corp. for **Lewis Research Center.** *Further information may be found in NASA CR-168100 [N83-21390/NSP], "Development of a Simplified Analytical Method for Representing Material Cyclic Response" [$11.50]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
LEW-14032

Process for Nonequilibrium Ternary Alloys

Chemical reduction and hot pressing would create a variety of alloys.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed metallurgical process would yield amorphous ternary alloys of any of a range of desired compositions. Unlike conventional casting methods, the new process may produce homogenous alloys even when the proportions of the constituent metals are not those that can exist in equilibrium at the solidification temperature.

The process takes place in two steps. First, salts of the constituent metals are mixed together (the weights of the salts in the mixture should be those that will give the desired weight ratios of metals in the final alloy). The mixture is then heated in a hydrogen atmosphere. The hydrogen reduces the salts to the elemental metals in the form of intimately mixed submicron-size particles. Next, the particles are compressed and heated to form a dense, noncrystalline solid.

Iodides of nickel, copper, and iron, for example, can be processed to produce a nickel/copper/iron alloy of unusual strength and toughness: Such alloys are well suited to use in gas turbines and advanced engines. Similarly, aluminum/copper/iron alloys can be produced from the iodides of the metals.

This work was done by Ralph Lutwack of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 49 on the TSP Request Card.*
NPO-16226

Studying Crystal Growth With the Peltier Effect

Thermoelectric effects are measured to characterize the liquid/solid interface.

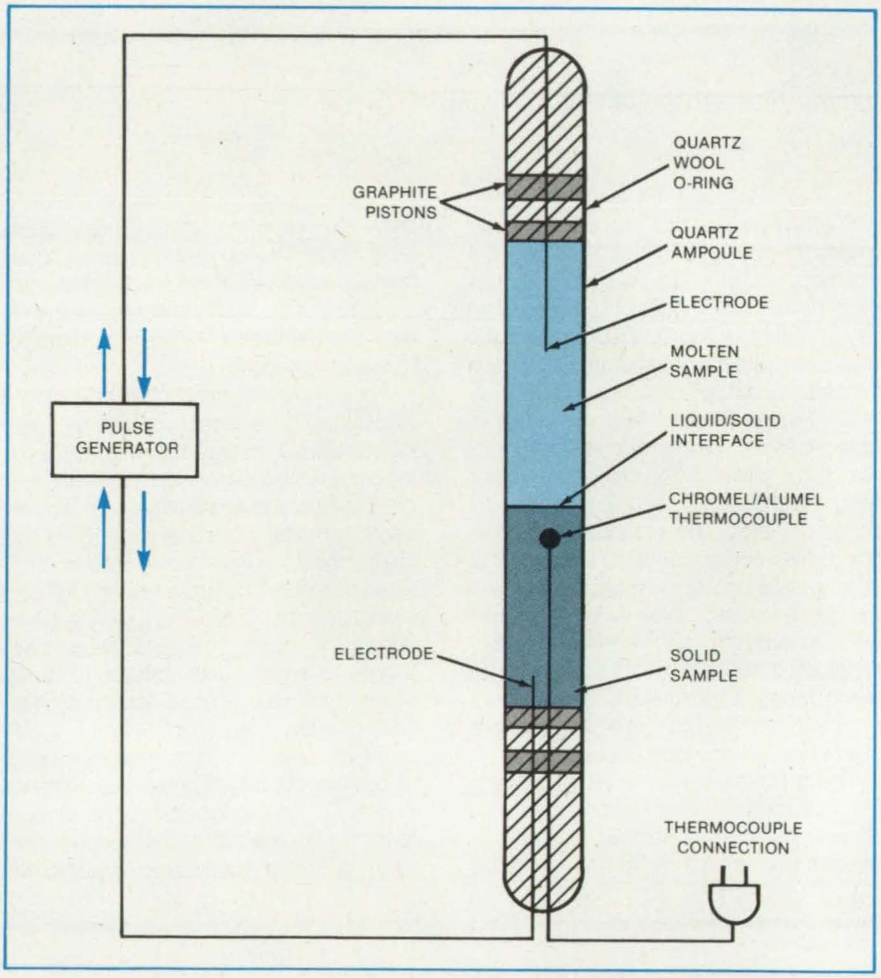
Marshall Space Flight Center, Alabama

Peltier interface demarcation (PID) has been shown to be useful as an aid in studying heat and mass transfer during the growth of crystals from molten material. (In the Peltier effect, which is the basis of PID, heat is evolved or absorbed at the junction of two dissimilar metals when an electric current flows across the junction. Whether heating or cooling takes place depends on the direction of the current.)

In PID, the two dissimilar "metals" are the solid and liquid phases of the same material. A current pulse is passed through a unidirectionally solidifying sample to create a rapid Peltier thermal disturbance at the liquid/solid interface.

This thermal transient causes a change in the interface velocity. Depending on the magnitude, sign, and duration of the current pulse, it may cause meltback or temporary cessation of growth. The disturbance, measured by a thermocouple stationed along the path of solidification at or near the interface, provides information about the position and shape of the interface.

In a series of experiments to demonstrate PID, measurements were taken of thermal transients induced by Peltier pulsing in a eutectic mixture of Bi/MnBi. The measurements employed the Bridgman-Stockbarger method of directional solidification in a furnace: Samples were mounted vertically, and solidification proceeded from the bottom to the top. The Bi/MnBi samples, which were held in an ampoule (see figure), contained 0.72 weight percent manganese.



An **Ampoule of Bi/MnBi** was placed vertically in a furnace with a vertical thermal gradient. The thermocouple in the sample measured the thermal transients caused by electric current pulses along the sample.

To study the effects of current pulsing on the crystalline structure, the liquid/solid interface was allowed to advance at a rate of 3 centimeters per hour. The measurements of the thermal transients due to current pulsing were made with the furnace stationary. Data from the thermocouple were recorded continuously.

Theoretical calculations and analysis of the thermal transient data show contributions of heat fluxes created by the Thomson, Peltier, and Joule thermoelectric effects. Although the temperature changes almost instantaneously due to the Peltier and Thomson effects when the current is pulsed, the return to thermal equilibrium exhibits a characteristic decay time, in this case about 3 minutes. Decay times are important because they set limits on the pulse amplitude and frequency that can be used for PID without seriously disturbing the overall growth conditions during directional solidification.

An additional limitation on pulse amplitude is imposed by Joule heating: This is ordinary resistive heating, proportional to the square of the current, whereas the other two effects depend linearly on the current. At high currents, the Joule heating predominates over the Peltier and Thomson effects and introduces excessive thermal perturbation.

The Thomson effect is proportional to both the thermal gradient and the current density; it tends to be largest at the liquid/solid interface and can cause a substantial perturbation in the thermal profile. In order to realize the full benefit of PID, it will be necessary to develop the instrumental and analytical capabilities to separate the Peltier contribution to the thermal transients from those of Thomson and Joule contributions.

This work was done by David J. Larson, Jr., Bonnie Dressler, Robert P. Silberstein, and William J. Poit of Grumman Aerospace Corp. for **Marshall Space Flight Center.** *For further information, Circle 103 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 25]. Refer to MFS-28041.

Plasma-Sprayed Coatings on Porous Surfaces

Base-metal oxidation and hole blocking are reduced by a new process.

Lewis Research Center, Cleveland, Ohio

The need for combining the benefits of duplex thermal-barrier coatings with film cooling on gas-turbine vanes and blades has stimulated development of an improved method for plasma spraying these coatings. This method reduces blocking of the holes by the plasma-sprayed material and at the same time reduces base-metal oxidation during the coating operation.

Film cooling with bleed air combined with a ceramic thermal-barrier undercoat imposes a dual insulative barrier between the high-temperature combustion gases and air-cooled metal parts. These insulative barriers provide reduced metal temperatures, increased gas-turbine engine-cycle temperatures, or decreased coolant requirements. These features provide a potential for increased engine efficiency and power, reduced fuel consumption, use of less costly materials or construction procedures, and extended life and durability.

The improved coating process consists of mounting the bases of grit-blasted vanes or blades in a plenum chamber. Then, argon supplied at a pressure of about 80 psia flows through the plenum chamber and through the hollow interior of the vane or blade bases and the film-cooling holes previously fabricated in the hardware. While the argon flows out through the film-cooling holes, the hardware surface is coated. First it is coated with a bond coat, and then a ceramic coating is overlaid. The mass flow of the argon through the film-cooling holes is between 0.005 and 0.015 lb/s (0.002 and 0.007 kg/s).

The bond coats, selected from the MCrAlY alloy systems, are arc-plasma sprayed to a thickness of 0.002 to 0.004 in. (0.005 to 0.01 cm). This flow of inert gas reduces both blocking of the holes and base-metal oxidation during the coating operation. After spraying is complete, the ceramic surface is polished to a roughness of 1 to 3 micrometers rms and is ready for use.

This work was done by Curt H. Leibert of **Lewis Research Center.** *For further information, Circle 61 on the TSP Request Card.*

This invention has been patented by NASA (U.S. Patent No. 4,402,992). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Lewis Research Center [see page 25]. Refer to LEW-13450.

Phthalocyanine Tetraamine Epoxy-Curing Agents

Convenient soluble compounds yield heat-resistant epoxies.

Ames Research Center, Moffett Field, California

Material	Limiting Oxygen Index	Specific Gravity	Percent Resin Content	Percent Moisture Absorption After 2 h Boiling in Water	Percent Char Yield in N_2, 800° C	Tensile Strength kpsi (MN/m^2)	Flexural Strength kpsi (MN/m^2)	Modulus of Elasticity Mpsi (GN/m^2)	Dynamic Modulus Mpsi (GN/m^2)
Resin + CuPT + BF_3−MEA	50.3	1.46	34.6	1.51	75.0	58.36 (402.4)	61.5 (424)	6.90 (47.6)	—
Resin + CuPT + BF_3−MEA + CTBN	48.5	1.47	35.2	1.65	74.5	69.97 (482.4)	75.1 (518)	7.11 (49.0)	—
Resin + CoPT + BF_3−MEA	50.1	1.50	32.3	1.89	74.0	60.28 (415.6)	59.2 (408)	6.67 (46.0)	0.87 (6.0)
Resin + CoPT + BF_3−MEA + CTBN	48.1	1.51	38.2	1.82	73.0	68.52 (472.4)	73.3 (505)	7.32 (50.5)	2.32 (16.0)
Resin + NiPT + BF_3−MEA	50.1	1.46	35.8	1.88	74.8	58.09 (400.5)	64.4 (444)	7.02 (48.4)	—
Resin + NiPT + BF_3−MEA + CTBN	48.3	1.49	39.2	1.90	74.2	66.2 (456)	74.5 (514)	7.82 (53.9)	—

Properties of Laminates made with epoxies cured with metal phthalocyanine tetraamines of copper, cobalt, and nickel are shown here. With all three metals, the addition of carboxy-terminated butadiene acrylonitrile (CTBN) improves the mechanical properties of the cured resin. The resin used in these examples is an epoxidized phenolic novolak.

Tough fire- and chemical-resistant epoxies are produced by using metal-phthalocyanine tetraamines (MPT's) of copper, cobalt, or nickel as curing agents. The synthesis of MPT's is commercially realizable and gives pure compounds with almost 90-percent yield. The synthesis is applicable for metals with atomic radii of about 1.35 angstroms, including Cu, Co, Ni, Zn, Fe, Pt, Al, and V. The MPT's have a metallic luster and a deep greenish-black color.

The high char yields (74 to 75 percent at 800° C in nitrogen) and high limiting oxygen indexes (48.1 to 50.3) shown in the table and the high decomposition temperatures of the new polymers indicate higher thermal stability than had previously been observed in cured epoxy resins. Graphite-cloth laminates prepared from these epoxies have mechanical properties even better than those of current materials. This should extend their application in airplanes, boats, cars, electrical insulation, chemical-processing tanks, and buildings.

The new curing agents are soluble in such aprotic solvents as dimethyl sulfoxide, dimethyl acetamide, and dimethyl formamide. For the first time, this makes it possible to use metal phthalocyanines to cure epoxy resins in a homogeneous reaction. Previous epoxies cured with insoluble phthalocyanine carboxylic acids and copper phthalocyanine did not exhibit comparable chemical and thermal properties because the curing agents reacted heterogeneously and remained as discrete particles after curing.

By adding 0.5 to 1.0 part by weight of boron trifluoride monoethylamine per 100 parts by weight of resin, the curing reaction can be catalyzed so that curing occurs more rapidly and at a lower temperature, thus avoiding degradation of the epoxy resin. Infrared spectra, thermogravimetric analyses, and differential calorimetric analyses were used to establish the optimum curing schedule of 4 hours at 180° C followed by postcuring for 1 hour at 250° C.

Thermal stability increases with MPT concentration. The optimum MPT concentration is the stoichiometric amount or slightly less; i.e., two epoxy groups per amino group of the MPT.

The mechanical properties of the cured resin can be improved by adding from 3 to 5 parts per 100 parts resin of either carboxy- or amine-terminated butadiene acrylonitrile. Commonly, adding such elastomers to epoxy resins to overcome brittleness and improve fracture toughness and impact strength contributes to flammability. However, the MPT curing agents so greatly reduce the flammability of the resins that use of the elastomers in the amounts needed does not render the resins flammable.

This work was done by George M. Fohlen, B. N. Achar, and J. A. Parker of **Ames Research Center.** *For further information, Circle 77 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 25]. Refer to ARC-11424.

Improved Jet-Mill Silicon Grinder

A milling-and-sorting system would produce less waste.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed refinement in jet-mill grinding of silicon would reduce the proportion of unusable, overly ground particles. The purpose is to produce particles of silicon of 100 $\pm$ 25 μm size for use in fluidized-bed reactors. The particles serve as seeds for growth of silicon from vapor.

In an older jet-milling apparatus, a swirling flow of air is set up in an egg-shaped chamber. A hopper feeds silicon particles to the chamber. Carried around the chamber by the airflow, the particles collide with newly entering particles and break up. The product is contaminated by the chamber material during this action. As particles become small enough, they leave the chamber through an orifice.

The problem with this apparatus is that many particles are carried around and around, and thus continue to collide, even after they have broken down to the requisite size. These particles are then too small and cannot function properly in a fluidized bed.

In the new grinding apparatus, the particle separator is distinct from the collision chamber. A particle collides only once before it is sorted for size. If it is the proper size, it is extracted; if not, it is returned to the chamber for another collision.

Hoppers inject equal amounts of particles into two equal and opposing airstreams (see Figure 1). The particles collide

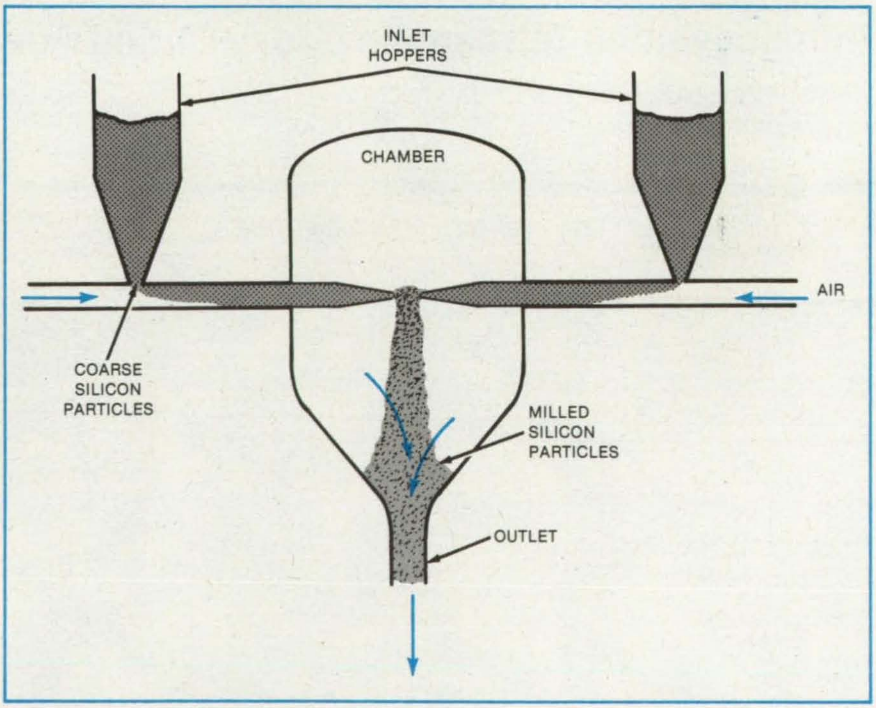


Figure 1. In a **Jet-Mill Grinder**, jets of air drive silicon particles into collisions that create fragments.

at high velocity. The collision products and uncollided particles fall out of the chamber and are immediately sorted. In the improved silicon-grinding system, several such jet mills would function cooperatively. Each mill would be designed for a specific range of

particle size and would have the proper airflow, nozzle size, and hopper-mouth size to ensure efficient feeding and the maximum number of collisions per pass. Since all grinding is particle to particle, contamination is minimized.

Particles can be sorted and extracted by any of a number of conventional devices — dry washers, cyclone graders and sorters, or wiffle tables, for example. Particles of the proper size would be routed immediately to the product outlet of the grinder. Larger size particles would be routed automatically to the appropriate jet mill (see Figure 2). The opportunity for excessive collisions and the consequent scrap output would therefore be reduced.

This work was done by Earl R. Collins, Jr., of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 4 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 25]. Refer to NPO-16336.

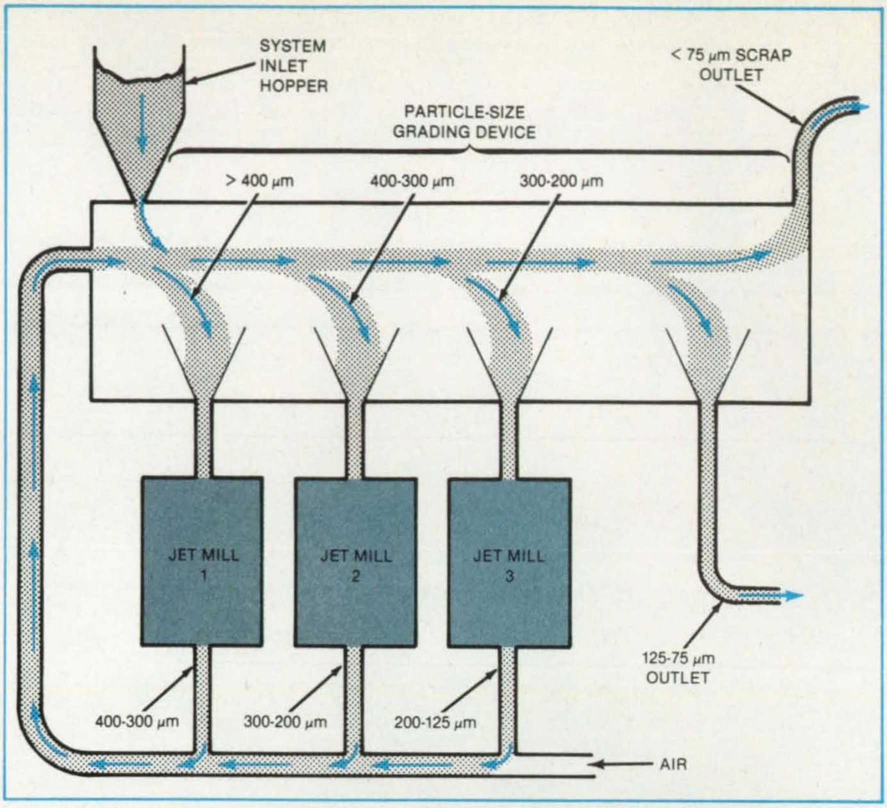


Figure 2. This **Grinding System** includes three jet-mill grinders, each designed for particles in a different size range. Particle-size sorters direct each silicon fragment to the appropriate grinder or to the outlet. Depending on the size of a fragment leaving one of the jet mills, it is either extracted from the grinding system or returned to one of the jet mills for another collision.

Measuring Thermal Diffusivity of Molten Semiconductors

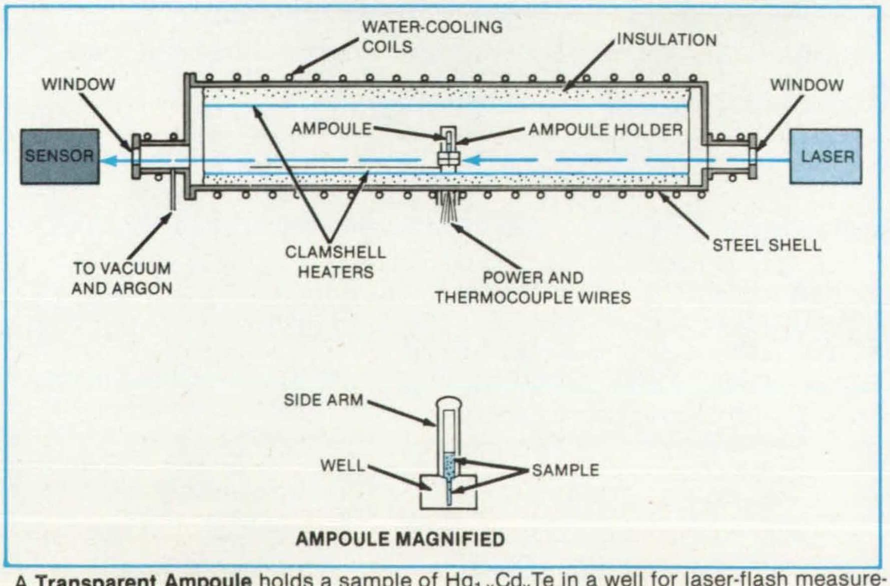
Test apparatus has an effective way of containing mercury cadmium telluride.

Marshall Space Flight Center, Alabama

The thermal diffusivity of molten and solid $Hg_{1-x}Cd_xTe$ is measured with the aid of a new apparatus. The knowledge gained from such measurements should help efforts to grow high-quality single crystals of this semiconductor for use in infrared detectors: Without knowledge of the thermal diffusivity, it is difficult to control the growth rate of the solid from the molten material.

The apparatus uses the laser-flash method, in which the front face of a small sample of the material is subjected to a burst of laser radiation, and the resulting temperature rise at the rear face is measured. From the timing and shape of the rise, the thermal diffusivity is calculated.

The problem in applying the laser-flash method to semiconductors above or slightly below their melting points is containing the liquid or soft material in a fixed geometry so that the laser can irradiate one face and an infrared detector can observe the other



A **Transparent Ampoule** holds a sample of $Hg_{1-x}Cd_xTe$ in a well for laser-flash measurements. The sample can be frozen and briefly boiled with no harm to the container.

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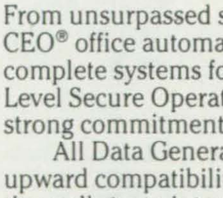

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face. With $Hg_{1-x}Cd_xTe$, the measurement is complicated by the high melting point (900° C), by the high vapor pressure of the mercury at that temperature [100 atm (10 MPa)], and by the tendency of its constituents to segregate across the liquid/solid interface.

The apparatus includes thick-walled ampoules of fused silica that hold the samples (see figure). An ampoule is transparent to the laser beam and can withstand the temperature and vapor pressure of molten $Hg_{1-x}Cd_xTe$. Each ampoule has a side arm through which the molten compound is introduced.

The filled ampoule is mounted in a furnace consisting of a steel tube containing clamshell heaters. The top and bottom heaters are controlled independently so that a vertical temperature gradient can be created in the ampoule. The sample can be frozen without damaging the ampoule by keeping a negative vertical temperature gradient during cooling. The ends of the tube are sealed off to minimize convection from the ampoule. The laser beam enters the tube through an optical window at one end, and the sensor monitors the sample through a window at the other end.

The liquid phase of $Hg_{1-x}Cd_xTe$ tends to be rich in Hg and denser than the solid phase in equilibrium with it. This tendency causes segregation during melting, the material in the side arm becoming rich in Cd. The segregation would remain after the entire sample turned to liquid. Diffusivity measurements would be inaccurate as a result. To eliminate segregation, the laser is fired several times at high power after the sample has melted. The liquid boils briefly, and the turbulence thus created homogenizes the melt.

Experiments with the apparatus show that the diffusivity of $Hg_{1-x}Cd_xTe$ decreases as x increases, at least up to values of about 0.3, and that the diffusivity of the molten material increases as the temperature increases. Repeated measurements were in close agreement.

This work was done by R. Crouch and L. Holland of **Marshall Space Flight Center** *and R. E. Taylor of Purdue University. For further information, Circle 88 on the TSP Request Card.*
MFS-28047

Melt-Pressed Films of Insoluble Semicrystalline Polymers

Induction heating is used for rapid heatup and cooldown of the polymer sample.

Langley Research Center, Hampton, Virginia

A technique known as "melt pressing" produces films from solid, insoluble, semicrystalline polymers in less than 5 minutes. The amount of crystallinity and possibly the final crystal structure of the film can be controlled in the process.

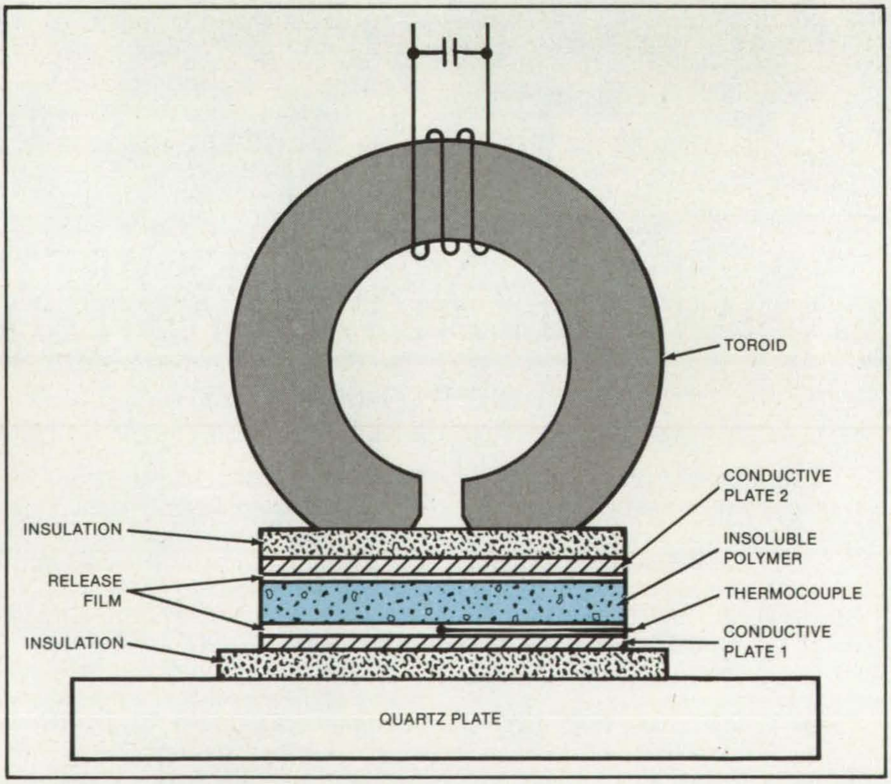
The melt press is illustrated in the figure. Induction heating, using a gapped toroidal core, melts the sample. The toroidal core and capacitor form a tuned circuit. Below the induction heating toroid is a layer of insulation that prevents heat transfer from the insoluble film to the induction heating apparatus.

The polymer samples from which films are to be formed are placed between sheets of high-temperature release film. Above and below these release films are conductive plates, which are rapidly heated by eddy currents generated by the induction-heating apparatus.

A thermocouple on the release-film side of conductive plate 1 and an automatic or manual control circuit adjust the input power to the toroid, thereby regulating film temperature and heating rate. Pressure is applied through the toroid unit by a hydraulic press.

A simple crease test on the resulting film serves as a screening device to determine whether a relatively high molecular weight polymer was synthesized. If the film is creasable, the polymer is of relatively high molecular weight. If the film is brittle, the polymer obtained from the synthesis is probably of low molecular weight.

Often, the final properties of semicrystalline polymers are determined by heatup and cooldown rates. The amount of crystallinity and possibly the final crystalline structure of polymers vary with the rate of heatup and cooldown. Normally, slower cooldown rates produce more ordered films. Therefore, in addition to producing films suitable for the crease test from insoluble polymeric materials in just minutes, this method permits the study of the effect rapid heatup and cooldown rates (not achievable with the typical electric press) have on semicrystalline poly-



The **Excitation Frequency of the Induction Heating Toroid** is determined by the resonant frequency of the toroid/capacitor tank circuit.

mer properties.

This work was done by James R. Tyeryar, Brian J. Jensen, and Robert L. Fox of **Langley Research Center.** *No further documentation is available.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 25]. Refer to LAR-13212.

Books and Reports

These reports, studies, and 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.

Protective Coatings for Metals

Resistance to marine air and acid is evaluated.

A report evaluates protective coatings for metal structures in seashore and acid-cloud environments. The evaluation is a result of a study of coating application characteristics, repair techniques, and field performance. Panels of carbon steel, aluminum alloy, and stainless steel were each covered with one of the following materials or material combinations:

- Single-component inorganic zinc coating,
- Two-component inorganic zinc coating,
- Epoxy/polyurethane topcoat on inorganic zinc primer,
- Manufacturer-recommended topcoat on inorganic zinc primer,
- Inorganic topcoat on inorganic zinc primer, and
- Urethane topcoat on epoxy primer.

Products from a variety of manufacturers were included in the study. Also included were factory-coated panels and industrial galvanized panels with and without topcoats.

The panels were placed on racks on a Florida beach, facing the ocean, about 100 feet (30 meters) from the mean-high-tide line. Some panels were splashed with a slurry of alumina particles in hydrochloric acid solution to simulate an acid cloud from rocket exhausts. Twenty-five such applications occurred during the 18 months of beach exposure. In addition, a group of panels was subjected to laboratory tests of adhesion and high-temperature resistance.

The report presents extensive tables and photographs of the results. The single-component inorganic zinc coatings performed poorly in the marine environment, while the two-component zinc coatings performed well. However, both types of coatings deteriorated under the simulated acid effluent.

For aluminum, one of the coatings was singled out as successful in the marine environment. All the coatings for aluminum failed in the acid effluent.

For stainless steel, several coatings were successful. These coatings will be further evaluated after 3 and 5 years of exposure.

In the laboratory, the majority of the coatings performed well in the normal adhesion tests and exhibited decreased adhesion after exposure to temperatures of 350° and 400° C. Among the topcoats, the polyurethanes withstood 100° C for 24 hours before showing signs of failure; the others endured 24 hours at 200° C.

This work was done by David J. Ruggieri and Anne P. Rowe of **Kennedy Space Center.** *To obtain a copy of the report, "Evaluation of Carbon Steel, Aluminum Alloy and Stainless Steel Protective Coating Systems After 18 Months of Seacoast Exposure," Circle 17 on the TSP Request Card.*
KSC-11308

Discoloration of Polyvinyl Butyral

Electric fields draw in metals that make this clear polymer yellow or brown.

A report presents results of a study of discoloration in polyvinyl butyral (PVB). PVB is widely used for encapsulating solar cells because it transmits Sunlight efficiently and has thermoplastic properties that suit it well to lamination with protective glass plates. However, clear PVB gradually turns a yellowish brown in simulated-aging tests and outdoor environmental tests. The discoloration severely reduces the solar-cell output.

Using the methods of modern analytical chemistry — transmission absorption, Fourier transform infrared absorption, atomic absorption spectroscopy, and scanning-electron microscopy — the study uncovered a major cause of yellowing. The clarity of PVB had been found to be affected by oxygen, moisture, heat, and light. However, the most severe discoloration is clearly associated with the migration of negative ions such as silver under the influence of an electric field. Moving from the solar-cell metalization into the PVB, the ions form organometallic compounds that show up as discoloration.

In the tests, the silver content was highest where a PVB film overlay a silver-containing conductor on a cell. Moreover, the most heavily discolored PVB regions contained 25 times as much silver as did the least discolored regions.

In experiments to simulate the suspected discoloration process, positive and negative 50-volt dc potentials were applied to metal electrodes separated by PVB while the specimen was heated to temperatures ranging from 60° to 95° C. The combination of electric field and heat accelerated discoloration, which was evident after only 3 days. A yellowish-brown region formed near the electrode containing silver when it was negative with respect to the other electrode. This tends to confirm that the discoloration is caused, at least in part, by the migration of negative silver ions into the PVB. The addition of moisture to the test produced even heavier discoloration.

This work was done by Quiesup Kim and Alex Shumka of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "Effects of Electric Field on Discoloration of Polyvinyl Butyral," Circle 6 on the TSP Request Card.*
NPO-16411

Tests of Zinc-Rich Anticorrosion Coatings

Some specimens are still in good condition after 10 years of exposure.

The condition of zinc-rich anticorrosion coatings after 10 years of exposure is discussed in a status report, which follows up on an 18-month study of anticorrosion coatings on steel that was started in 1971. Test panels with various coatings were mounted on racks on a beach and checked periodically. By the end of the 18-month study period, many panels had corroded badly and were removed, but panels that were in reasonably good condition were left at the site for further exposure.

In 1981, the remaining panels were removed to a materials-testing laboratory for identification, inspection, and disposition. Some of the original panels could not be located, however. In most cases, such panels were so badly rusted that they dropped out of the racks. Some with unreadable numbers fell apart as they were removed from the racks. Some had been removed for other uses.

Of the survivors, all of the panels with organic zinc-rich coatings were rusted over their entire surfaces and in various stages of exfoliation and advanced deterioration. Some of these panels had been in fairly good condition 3 years after they were first exposed.

Of the panels with inorganic zinc-rich coatings, only one was slightly rusted. These panels were in such good condition that they were returned to the beach for even more exposure.

An earlier report had concluded that a topcoat seemed to impair the performance of the zinc primers, as in fact it did in most cases. However, many topcoats on certain commercial primers are still in excellent condition. The successful topcoats include an assortment of mastics, epoxies, chlorinated rubbers, vinyls, acrylics, and polyurethanes.

This work was done by Joseph D. Morrison, William J. Paton, and Anne Rowe of **Kennedy Space Center.** *To obtain a copy of the report, "Status Report on Corrosion Performance of Zinc-Rich Coatings After 10 Years of Beach Exposure: Report IV on MTB 154-70," Circle 20 on the TSP Request Card.*
KSC-11309

Characterizing Semiconductor Alloys for Infrared Sensors

The mercury/cadmium/tellurium system is studied.

A report presents results of a continuing program aimed at characterizing mercury/cadmium/tellurium alloys and eventually developing improved methods of preparing the alloys for use as infrared sensors. Earlier developments in this program are described in "Growing Crystals for Infrared Detectors" (MFS-25786), page 136, *NASA Tech Briefs* Vol. 8, No. 1 (Fall 1983). The report discusses a pseudobinary HgTe/CdTe phase diagram, phase equilibria calculations, high-temperature-gradient directional solidification, and theoretical modeling of charge-carrier concentrations and electron mobilities. Appendixes cover electron scattering and the solution to the Boltzmann equation and document a computer program for the calculation of charge-carrier concentrations and electron mobilities.

Work covered by the report includes a series of differential thermal analysis (DTA) measurements of $Hg_{1-x}Cd_xTe$ alloy compositions with x varied from 0 to 1 in 0.1 increments. The liquidus and solidus temperatures deduced from the DTA data were used to establish the pseudobinary HgTe/CdTe phase diagram. The segregation coefficient of Cd was determined as a function of x and interface temperature.

Iterative phase-equilibrium calculations were performed according to the regular associated solution (RAS) theory, and a set of RAS parameters was obtained by simultaneously developing least-square fits to binary Hg/Te and Cd/Te and pseudobinary HgTe/CdTe diagrams. The RAS parameters were used to calculate the activities of Hg, Cd, and Te_2 and their partial pressures over pseudobinary melts.

Crystals with the composition $Hg_{0.8}Cd_{0.2}Te$ were grown by the Bridgman method at several constant furnace-translation rates from 0.0685 to 5.62 μm/s. Longitudinal compositional profiles were measured and compared with values calculated from different assumed HgTe/CdTe interdiffusion coefficients. Measurements of radial compositional variations suggested concave solid/liquid interfaces.

Theoretical models and computer programs specific to $Hg_{1-x}Cd_xTe$ were developed for calculations of charge-carrier concentrations, Hall coefficient, Fermi energy, and conduction-electron mobility as functions of composition, temperature, and of ionized-defect and neutral-defect concentrations. The model predictions for the temperature dependence of the electron concentration from 4.2 to 300 K agree well with the available data. The comparison of mobility calculations with experimental results indicates that longitudinal optical-phonon and defect scattering are the dominant mobility-limiting mechanisms.

This work was done by B. S. L. Lehoczky, F. R. Szofran, and B. G. Martin of McDonnell Douglas Research Laboratories for **Marshall Space Flight Center.** *Further information may be found in NASA CR-161598 [N81-20863/NSP], "Advanced Methods for Preparation and Characterization of Infrared Detector Materials, Part I" [$16]. A paper copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161. The report is also available on microfiche at no charge. To obtain a microfiche copy, Circle 7 on the TSP Request Card.*
MFS-27059

Life Sciences

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Books and Reports

Prosthetic Sphincter Controls Urination

A subcutaneous disk permits adjustment after the implantation.

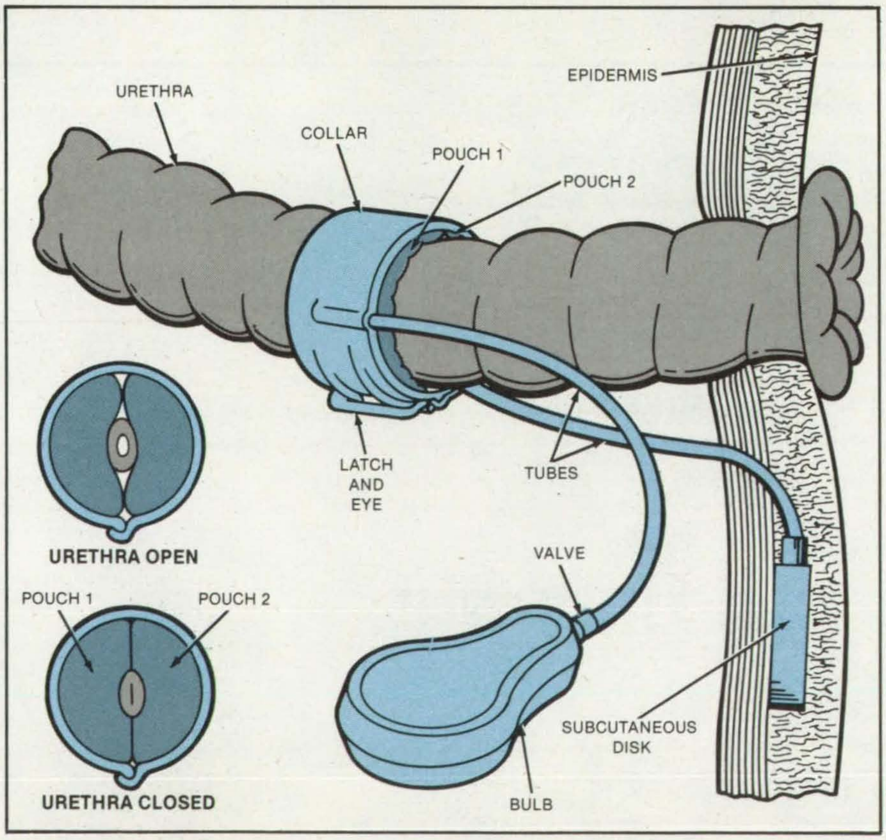
Marshall Space Flight Center, Alabama

People who have lost muscular control of the urinary canal through disease or injury may be aided by a prosthetic sphincter. Implanted so that it surrounds the uretha, the sphincter is deflated and inflated at will by the wearer to start and stop the urination. This sphincter differs from the previous models in that its operating pressure can be adjusted after the implantation to accommodate growth or atrophy of the urinary canal and to prevent tissue damage from excess pressure. The adjustable pressure also allows a sphincter of standard size to be used for a wide range of canal diameters. The principle can be adapted to other organs, such as the colon, ureter, or ileum.

The sphincter comprises a collar containing a pair of inflatable pouches. The collar encircles the urethra, with pouch 1 on one side of the urethra and pouch 2 on the opposite side (see figure). Pouch 1 is connected by a tube to a regulating relief valve on a bulb that serves as a pump and reservoir. Pouch 2 is connected by a tube to a hollow disk implanted just beneath the skin. The pouches and disk are filled with an aqueous saline solution containing an additive that is opaque to X-rays.

After the implantation, the pressure in pouch 2 is adjusted by a hypodermic needle injecting saline solution into the subcutaneous hollow disk so that the pouch loosely hugs half the circumference of the urethra. The wearer then pressurizes pouch 1 by squeezing the external bulb so that the pouch presses against the urethra and closes it off. The canal is kept closed by the pressure. To open the canal, the wearer opens a relief valve on the bulb.

The pressure in pouch 2 can be adjusted



The **Occluding Cuff** includes two chambers: One chamber, pouch 2, is permanently pressurized. The other chamber, pouch 1, is inflated and deflated by the wearer. As the cross sections show, when pouch 1 is deflated, the urethra is open; when pouch 1 is inflated, the urethra is closed.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repeatedly by adding saline solution to, or removing it from, the subcutaneous disk. Thus, changes in the urethra can be accommodated without allowing excessive pressure to be applied to the urethra or to pouch 1.

If the wearer inadvertently overpressurizes pouch 1, the regulator valve opens slightly and lets the excess fluid bleed back into the bulb. Similarly, if pouch 2 is overpressurized, the surfaces at which it contacts pouch 1 will transmit the overpressure to the relief valve. The valve will again operate and release solution from pouch 1 to relieve the excess pressure until the pressure in pouch 2 can be corrected.

The components of this sphincter are made from such biocompatible materials as medical-grade silicone rubber. The collar is reinforced so that it is stiff and resists outward forces from the pouches. A latch and eye hold the ends of the collar together so that it encircles the urethra. For more details about the construction and operation of the device, see "Prosthesis for Urinary Control" (MFS-27062) on page 121 of this issue.

This work was done by John B. Tenney, Jr., of Rochester General Hospital for **Marshall Space Flight Center.** *For further information, Circle 92 on the TSP Request Card.*

Title to this invention, covered by U.S. Patent No. 4,408,597, has been waived under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457(f)], to the Medical Engineering Corporation, Racine, Wisconsin.
MFS-25740

Enhancing Centrifugal Separation With Electrophoresis

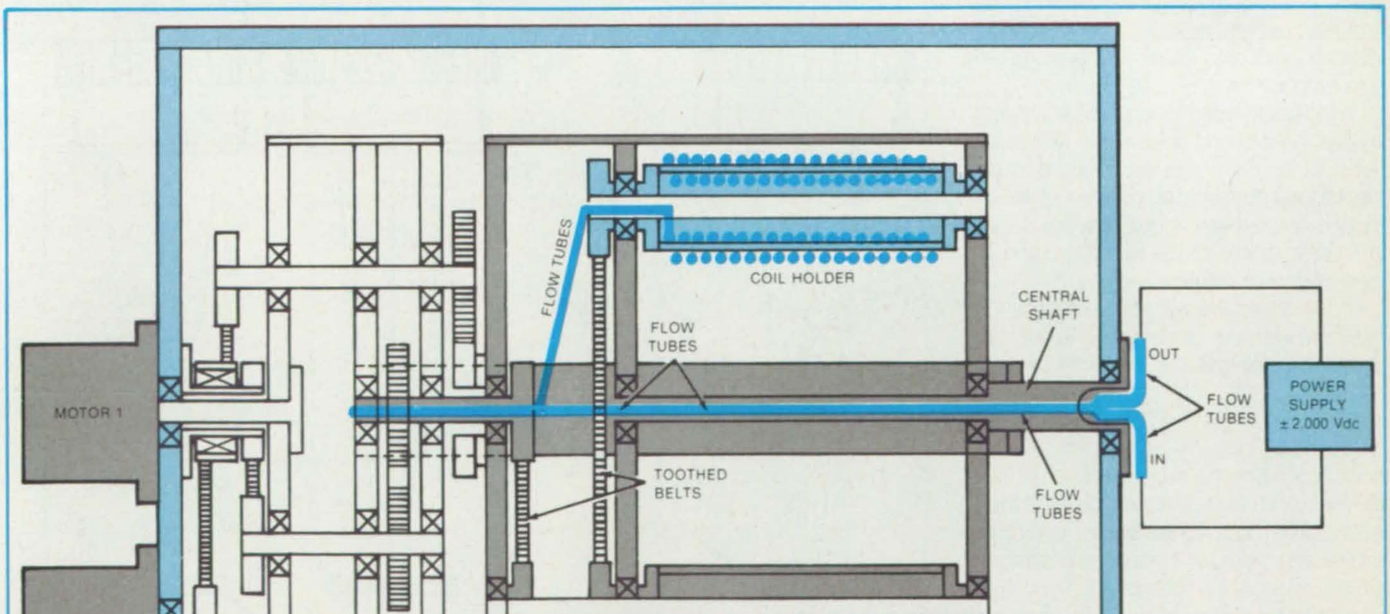
Biological cell separation is increased by applying a voltage to the separation column.

Marshall Space Flight Center, Alabama

The separation of biological cells by a coil-planet centrifuge is enhanced by electrophoresis. By itself, the coil-planet centrifuge offers a relatively gentle method of separating the cells under a low centrifugal force in a physiological medium that keeps the cells alive. With the addition of a voltage gradient to the separation column of the centrifuge, separation is still gentle but faster and more complete. Since the separation apparatus contains no rotary seal, the probability of leakage, contamination, corrosion, and short circuits is reduced.

The separation column is a coil-planet centrifuge that consists of a 19-meter-long tube of polytetrafluoroethylene wrapped in a 600-turn helix (see figure). After a sample has been injected into the tube, the coil is rotated slowly (at 5 revolutions per minute) about its axis while the frame in which the coil is mounted is turned about its own axis, the central shaft, providing an acceleration field 142 times that of gravitation.

An isotonic buffer solution flows through the tube at a constant rate of 11.1 milliliters per hour. A voltage gradient is applied through two electrodes fitted to the supply and collection ends of the tube; 2,000 volts dc between the electrodes yields a gradient of ± 1.053 volts per centimeter in the tube.



A **Coil-Planet Centrifuge** is augmented by electrophoresis to enhance the separation of cells or other small particles.

The electrophoresis-enhanced coil-planet centrifuge was used to separate human red blood cells from those of sheep. Since human erythrocytes are considerably larger than those of sheep — 87 cubic micrometers versus 32 cubic micrometers — the two can be readily distinguished during counting to determine the degree of separation. With no voltage, the peak concentration of the sheep cells preceded that of the human cells by about 6 minutes. With the positive voltage gradient, however, the interval between the peaks was 15 minutes. Interestingly, when polarity was reversed to the negative voltage gradient, the peaks were no longer separated in the tube.

At present, there is no sound explanation for the electrophoretic enhancement; in fact, theory predicts that the enhancement should be negligible. It may be that charge-related aggregation of particles and charge-related interaction between particles and the interior surface of the tube play a role. Regardless of the mechanism, it is clear that a voltage gradient does have an appreciable and positive effect on the quality of particle separation.

This work was done by Frederick Thomas Herrmann of **Marshall Space Flight Center.** *For further information, Circle 89 on the TSP Request Card.*
MFS-28053

Camera for Monitoring Vegetation

Video imaging offers advantages over photographic imaging.

NASA's Jet Propulsion Laboratory, Pasadena, California

A video camera uses solid-state imaging devices and light filters to bring out subtle spectral differences between healthy and stressed vegetation — differences not readily detectable with infrared film cameras. The camera employs two detector arrays. The images falling on them may come through a single lens or two separate lenses, but in either case through two different optical filters (see Figure 1). The same scene is thus imaged in two wavelength regions. The brightness data from each picture element are subtracted or divided to form an electronic image that is displayed on a cathode-ray tube (see Figure 2).

In the single-lens version, a beam splitter divides the entering beams into two equal parts, which then pass separately through the different filters and onto the two detector arrays. This version keeps lens costs low, ensures identical image formation, and allows easy use of zoom lenses.

In the alternative version, two separate cameras view the same scene through independent lens systems. There is more light available for each detector and less complexity in the optical layout.

Electronic circuitry adjusts the relative contributions of the two components. For example, the circuitry may subtract a fixed voltage from both signals before dividing or subtracting them, or it may apply different gain factors to each component. The output signal can be displayed as a gray-scale image or converted to a "false-color" image in which a different color corresponds to each shade of gray. In the final image, a stressed specimen will appear distinct from healthy neighboring vegetation either in brightness or color, even though its spectral variation is minor.

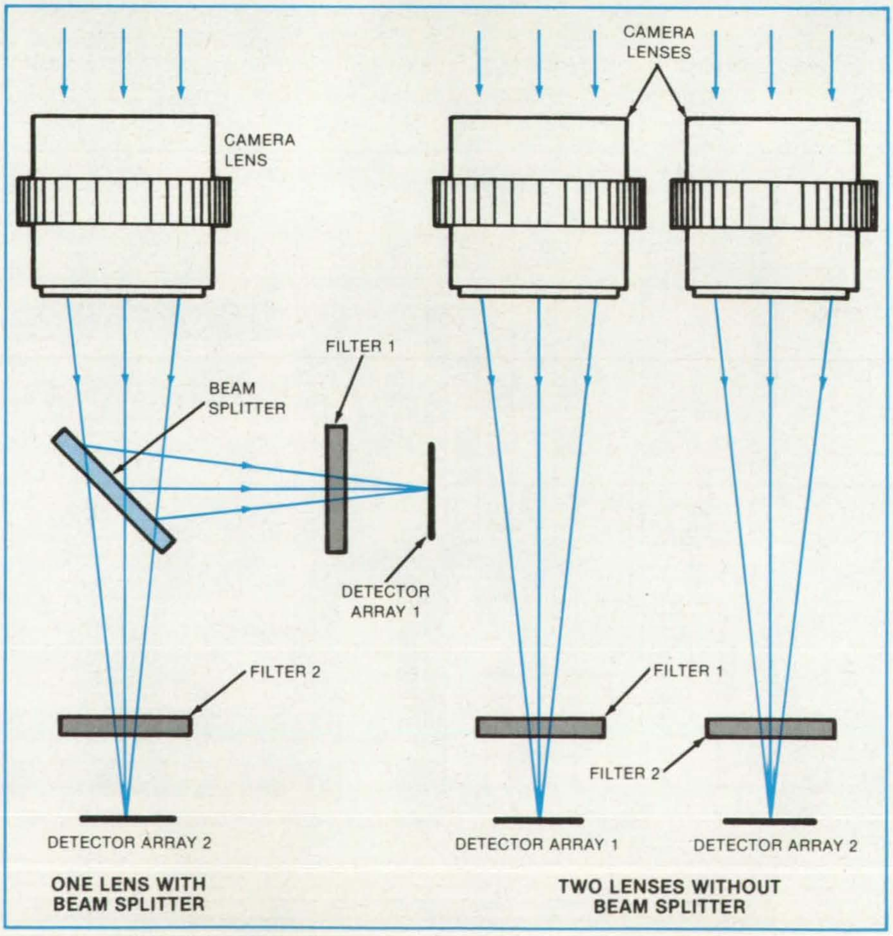


Figure 1. **Either of Two Optical Systems** can be used to implement the video camera.

The video camera offers several advantages over a photographic camera. Its silicon detector arrays are more sensitive to subtle infrared spectral differences than are infrared films. The wavelength range accessible to the solid-state detector is much wider than that of film, permitting greater flexibility in tailoring the system to the characteristics of different plant species. The video camera can be made small and easily portable. It eliminates the need for refrigeration of film before use, and it provides an instantaneous output with no delay for film development.

This work was done by Terry Z. Martin of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 1 on the TSP Request Card.*
NPO-16349

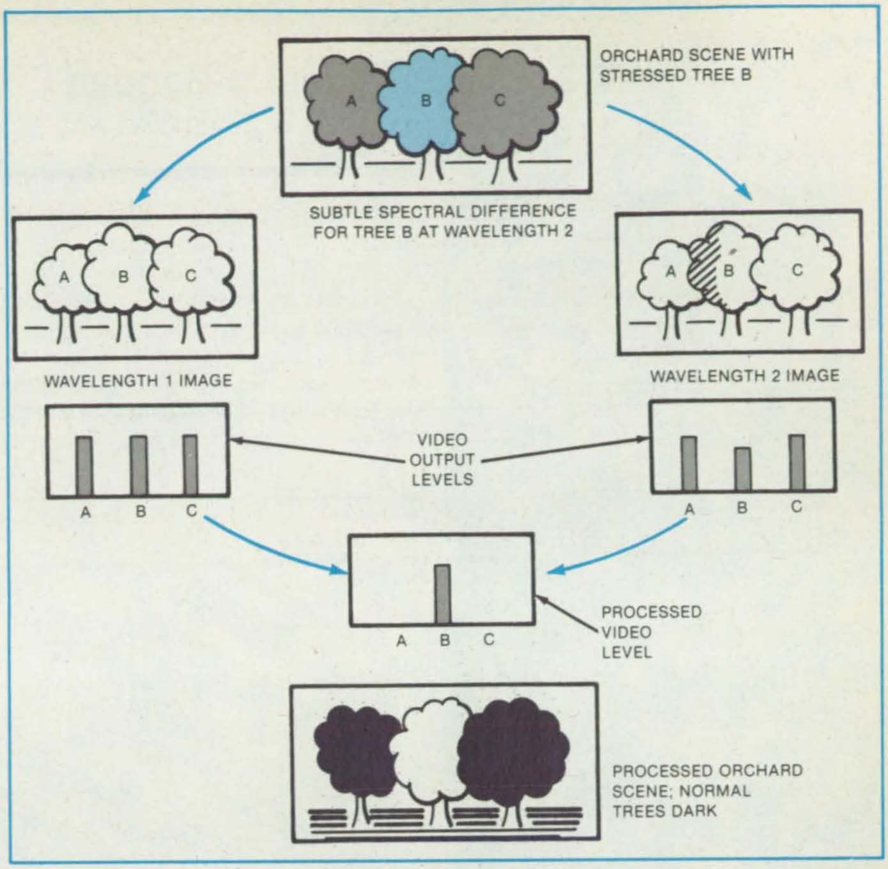


Figure 2. The **Video Camera Transforms** a small spectral difference in tree B into a major contrast in the final image. Sickly trees thus identified can be treated or removed. The imaging method can also be used for field crops. The video camera can be constructed from readily available components.

Books and Reports

These reports, studies, and 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.

Development of a Prosthesis for Urinary Control

Implantable device allows normal bladder function.

A new report describes the development and marketing of a prosthetic sphincter for urinary control. With the prosthetic device, patients void the bladder every 3 to 4 hours. The periodic voiding keeps the bladder muscles exercised and healthy and avoids bladder infections and kidney damage. The device has been tested successfully in laboratory animals. Clinical tests with humans are anticipated.

The device consists of a cuff, a septum, a valve, and a fluid reservoir. The flexing parts are made of silicone rubber. The cuff is implanted so that it surrounds the patient's urethra. The septum is self-sealing and can be penetrated many times by a hypodermic needle to allow adjustment of the pressure and volume of the cuff after it has been implanted.

The valve allows the patient to pressurize the cuff with fluid from the reservoir and to depressurize it. The valve is of the "press-to-relieve" type. Both the valve and reservoir are implanted where they can be pressed from the outside. The components are joined by silicone-rubber tubes.

Normally, the cuff is pressurized so that it is inflated and constricts the urethra. After the urine fills the bladder, the patient opens the valve, thus permitting the pressurizing fluid (a saline solution) to flow from the cuff to the reservoir. The cuff deflates, and its center passage opens. The urethra is now unrestricted, and urine passes out of the bladder.

When the bladder is empty, the patient squeezes the reservoir, which is in the form of a silicone-rubber bulb. This action forces saline solution into the cuff. The check/relief valve prevents flowback to the reservoir. Thus, the cuff is once again inflated and shuts off the urethra.

This work was done by John B. Tenney, Ronald Rabinowitz, Zygmunt Tomkiewicz, Howard N. Harrison, and David W. Rogers of Rochester General Hospital for **Marshall Space Flight Center.** *Further information may be found in NASA CR-170994 [N84-22168/NSP], "Development and Marketing of a Prosthetic Urinary Control Valve System" [$20.50]. A paper copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161. The report is also available on microfiche at no charge. To obtain a microfiche copy, Circle 87 on the TSP Request Card.* *MFS-27062*

Mechanics

Hardware, Techniques, and Processes

Books and Reports

Computer Programs

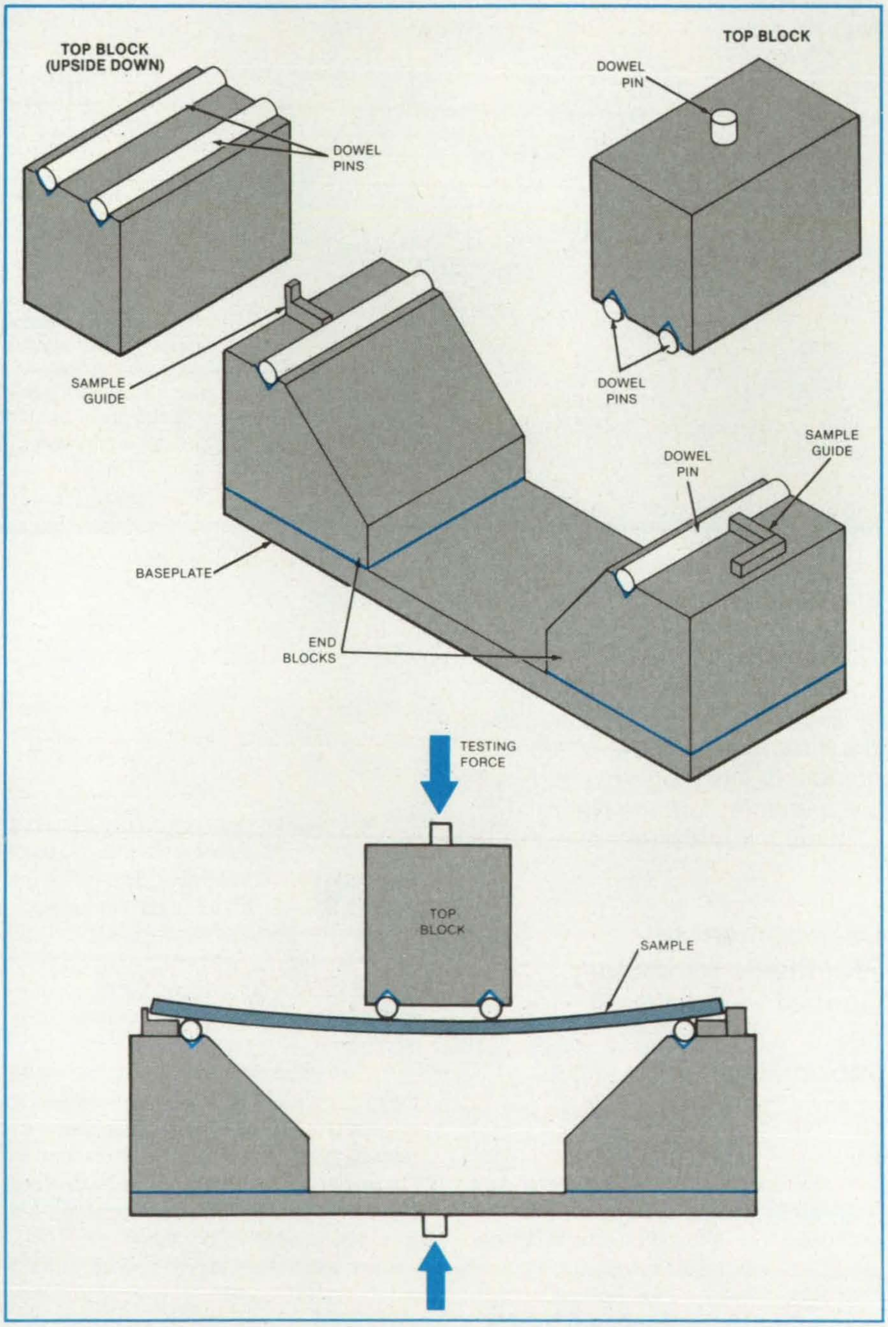
Adhesive-Bonded Fixture for Flexure Testing

Fixture is assembled with stock parts.

Marshall Space Flight Center, Alabama

A fixture for flexural tests of glass-fiber-reinforced epoxy rods ¼ in. (6.4 mm) in diameter is easy to fabricate. The little machining that is required can be done by the relatively unskilled. A standard version of the fixture, by contrast, requires high-quality machine-shop work by skilled artisans.

The fixture is built up with adhesive from simple building blocks. The fixture includes a sample support that holds the fiberglass/epoxy specimen and a top block that bears on the specimen (see figure). The top block



This **Flexural-Test Fixture** allows bending stress to be applied to a specimen rod while it holds the rod securely. The dowel pins, blocks, and plate that make up the fixture are joined by an adhesive. Color indicates adhesive layers.

and the end blocks of the sample support are machined from 2-in. (5.1-cm) cubes of aluminum.

A hole ¼ in. (6.4 mm) in diameter and ½ in. (12.7 mm) deep is drilled into one face of the top block. Inserted into this hole is a ¼-in.-diameter dowel pin ¾ in. (1.9 cm) long. The pin protrudes from the top of the block.

Bearing rods are attached to the bottom of the block. With a bandsaw, two parallel grooves are cut in the bottom surface to a depth of $^1/_{16}$ in. (0.16 cm). Dowel pins ¼ in. (6.35 mm) in diameter and 2 in. (50.8 mm) long are bonded to the grooves by a two-part structural adhesive with a recommended use-temperature range of −200° to +300° F (−130° to +150° C).

To fabricate the sample support, three parts must be prepared: Two end blocks and a baseplate. A corner is cut from each of the end-block pieces to form beveled edges. As with the top block, a groove is cut in each end block, and a dowel pin is bonded in the groove. The dowel pins act as bearing rods for the underside of the test specimen. Short strips of aluminum or other material are bonded to the blocks with the adhesive to position the specimen. The baseplate is cut from stock aluminum ½ in. (12.7 mm) thick; the plate measures 2 by 6 in. (5.1 by 15.2 cm). The two end blocks are bonded to the baseplate with the same adhesive used for the dowel pins. A dowel pin extends from the underside.

This work was done by Jonny M. Clemons, B. G. Penn, F. E. Ledbetter III, J. G. Daniels, and W. T. White of **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 25]. Refer to MFS-28051.

Damage-Free Relief-Valve Disassembly

A special tool extracts the valve nozzle without harming other parts.

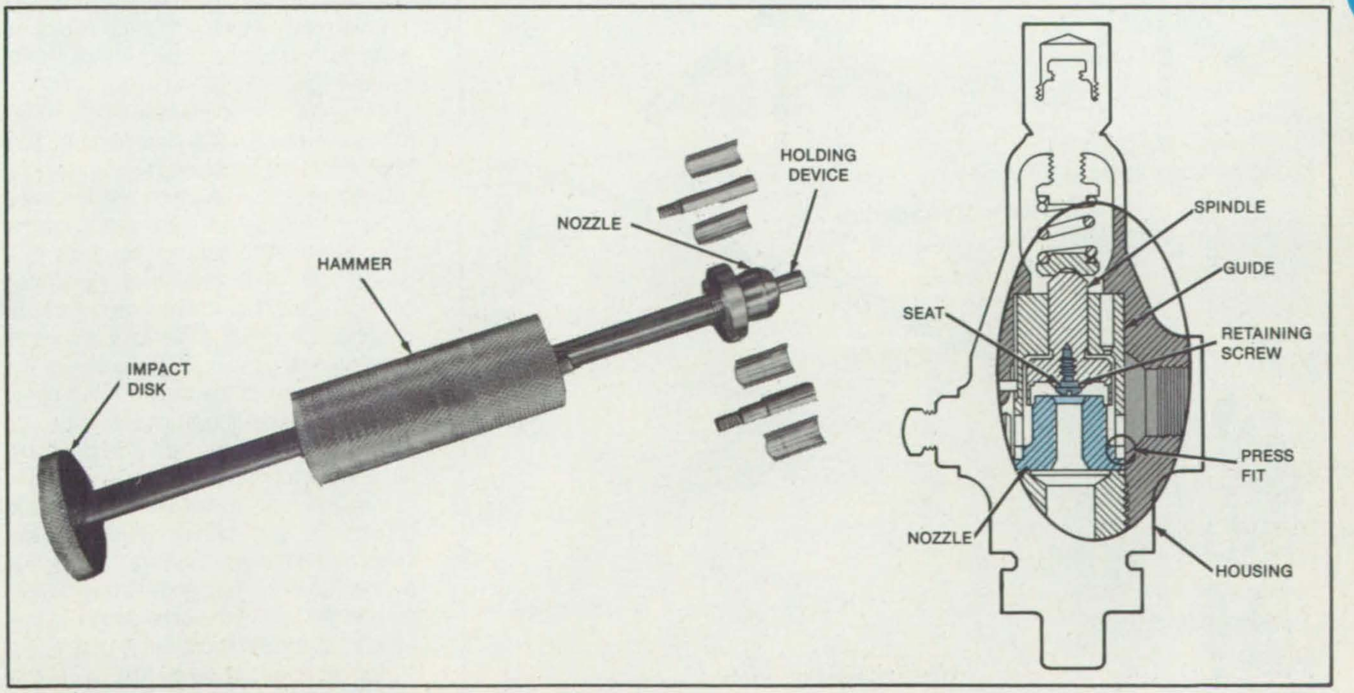
Marshall Space Flight Center, Alabama

A tool safely disassembles relief valves without damage to sensitive parts. Previously, reassembled valves failed because of damage inflicted on seat-retainer screws; the screwheads were being deformed by the procedure used to remove the valve nozzle. When the valve was later reassembled, the bent screwheads did not secure the valve seat reliably, and early failure resulted. Instead of striking the valve spindle against the nozzle, as in the older procedure, the new tool removes the nozzle directly. With minor modifications, the tool can be adapted to valves from different manufacturers.

The tool consists of an inside holding device and an inertia hammer (see figure). The user inserts the holding device in the bore of a relief-valve nozzle, tightens the tool to ensure a secure grip, and slides the hammer along the tool shaft so that it strikes an impact disk at the far end of the shaft. One or two sharp strokes are usually enough to remove the nozzle from the housing.

Standard adapters are provided with the tool for disassembly of valves with orifices 1/2, 3/8, 1/4, and 3/16 inch (1.27, 0.95, 0.64, and 0.48 centimeter, respectively) in diameter. Adapters can be fabricated readily for other sizes.

This work was done by Haynes Haselmaier of Pan Am World Services, Inc., for **Marshall Space Flight Center.** *For further information, Circle 46 on the TSP Request Card.*
MFS-28006



The **Relief-Valve Disassembly Tool** (left) is used to extract the valve nozzle from its housing (cross section, right). The holding device on the tool grips the nozzle. When the user strikes the hammer against the impact disk, the holding device pulls the nozzle from its press fit. Previously, the nozzle was dislodged by striking the spindle above it, but this practice often damaged the retaining screw.

Deployable Truss Member

A compact telescoping roll can extend 24 times its length.

Langley Research Center, Hampton, Virginia

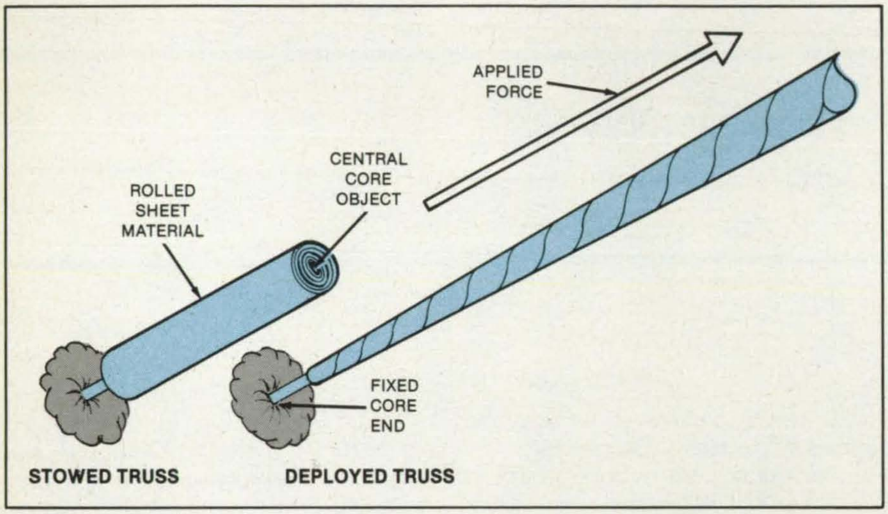


Figure 1. A **Compact Roll** telescopes into an extended truss member when force is applied.

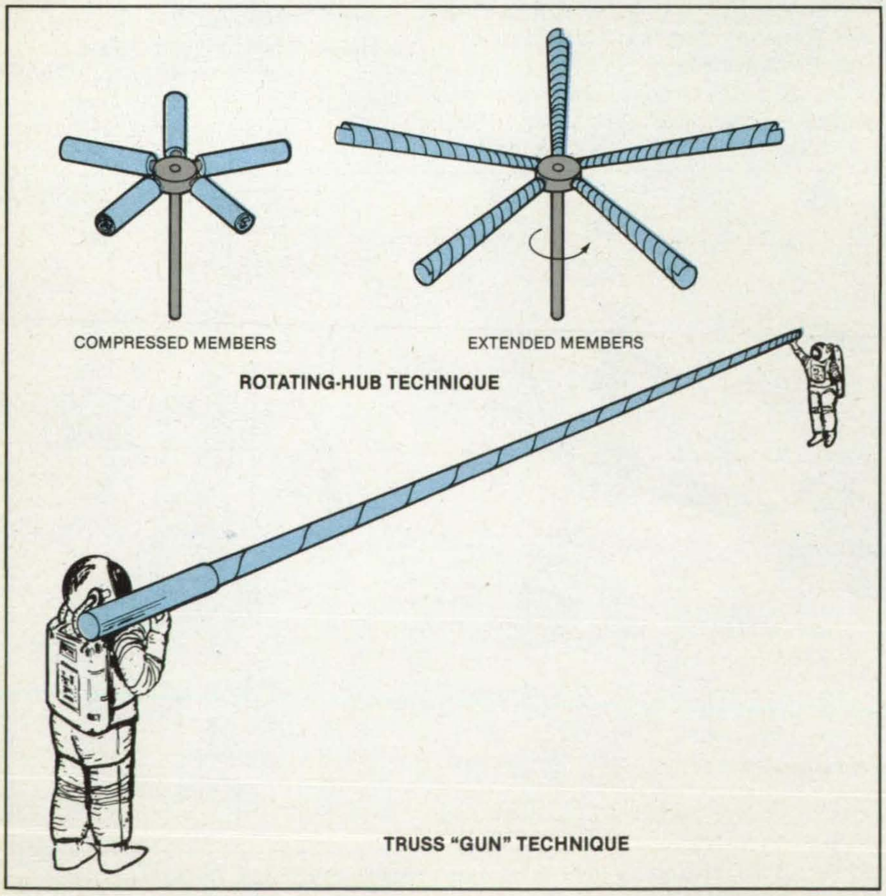


Figure 2. **Truss Members** would be deployed by various means, two of which are shown here.

A deployable truss-member concept has been developed that uses a telescoping roll of sheet material. There is a continuing need to develop compact, deployable truss members for structures that can be transported into space in large quantities by the Space Shuttle.

As shown in Figure 1, the truss member is initially constructed in its stowed state with appropriate sheet material rolled around a central core. For deployment in space, the truss can be extended by centrifugal force to form a cone. With both ends fastened to prevent unrolling, a rigid truss member can be formed.

Experience with a scaled-down model showed that a roll of waxed paper approximately 3/4 in. (1.9 cm) in diameter fastened to a 1/8-in. (0.3-cm) dowel core and 3 in. (7.6 cm) in length could easily extend to form a rigid cone 72 in. (1.8 m) long with a diameter varying from 1/8 to 3/4 in. Thus, at least a 24 to 1 extension ratio is possible, allowing very long truss members to be carried into space. This extension ratio can be controlled by the quantity of rolled material used. It may be necessary to apply a counterrotating torque to each end of the truss to tighten the coiled structure and make it rigid.

Compact truss members could be stowed vertically in the Shuttle cargo bay. They could be deployed by a number of techniques, some of which are illustrated in Figure 2. One technique would involve attaching several stowed members to a central hub. Centrifugal force, generated by rotating the hub, would extend the truss members. Another technique would involve fastening the outer perimeter of the rolled member to the inside of the cargo bay and then applying an impulsive force to the core object. The core object should have sufficient mass to extend the truss to its desired length. It may also be possible to construct a "gun" with which an astronaut might aim and propel the core object to the desired location. A second astronaut could receive the end of the extended truss and fasten it to the structure being built.

This work was done by Neal T. Frink of **Langley Research Center.** *No further documentation is available.*
LAR-13219

Elevated-Temperature Tensile-Testing of Foil-Gage Metals

System includes counterbalancing to offset the weight imposed by a mechanical extensometer.

Langley Research Center, Hampton, Virginia

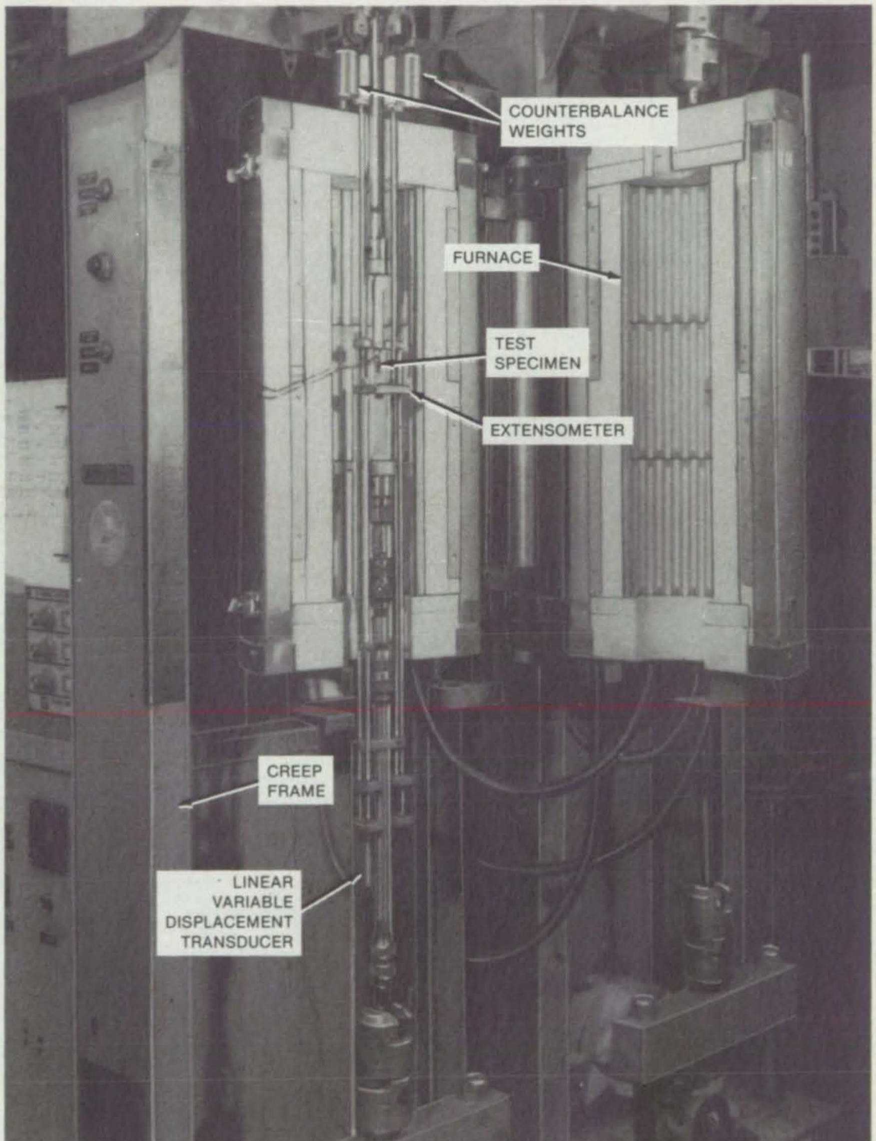
An automated system for measuring strain in metal foils at temperatures above 500° F (260° C) uses a mechanical extensometer and a displacement transducer. The system includes a counterbalance feature, which eliminates the weight contribution of the extensometer and reduces the grip pressure required for attachment to the specimen.

The system is shown in the figure. Four connecting rods used in the counterbalance system are attached to the top and bottom platens of the extensometer. They extend up through the furnace to ceramic insulators. The rods screw into threaded holes in the top platen. The bottom platen has extensions and threaded holes to allow positioning of the bottom rods at right angles to those on the top.

The ceramic insulators are connected by flexible wires through a pulley system to four weights. Each pair of weights offsets the weight contribution of half the mechanical extensometer and the attached transducer. The pulley system is suspended from a main support block, which is attached to the tensile test-machine frame by the back support plate. The main support block has adjustable features to allow correct positioning of the rods extending through the furnace top.

The ceramic-furnace top insulators have four narrow holes drilled through their length to allow clearance for the connector rods. To further reduce bending stresses induced in the specimen as a result of extensometer attachment, the grip inserts have a conical-tip/flat-edge design. Calibration of the extensometer at room temperature demonstrated the capability with this system of achieving class B-1 accuracy according to ASTM E83.

Mechanical techniques for strain measurement, such as the one just described, have advantages over optical and electrical-resistance methods primarily because mechanical extensometers can be used at elevated temperatures and can be attached easily to automated data-acquisition systems. Mechanical extensometers are also relatively inexpensive and readily available. The counterbalancing feature overcomes the two major difficulties in using extensometers with foil-gage specimens: (1) The weight of the extensometer and transducer represents a significant fraction of the total load applied to the specimen and may actually damage it; and (2) the grip pressure required for attachment of the extensometer to the specimens may induce bending stresses in foil-gage materials.



The **Counterbalance Uses Four Connecting Rods,** which are attached to both the top and bottom platens of the extensometer and four weights that can be adjusted to offset virtually all of the weight of the extensometer and transducer.

This work was done by Linda B. Blackburn and John R. Ellingsworth of **Langley Research Center.** *No further documentation is available.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 25]. Refer to LAR-13243.

Autopilot Servoactuator With Pressurized Detented Centering

A centering valve allows the use of a mechanical override in an autopilot mode.

Langley Research Center, Hampton, Virginia

Current commercial aircraft incorporate autopilot servoactuators on all three flight-control axes to stabilize the aircraft for optimum performance and to reduce pilot fatigue. Electrical signals from remote sensors control the autopilot servo to maintain the prescribed flight parameters that will result in the most efficient and safe operation of the aircraft. In some aircraft control systems, the design constraints may require the linkages to the autopilot servos to become fixed so that an alternate control system can function by reacting against it as a ground point.

One such application would be an aircraft with a fly-by-wire (FBW) control system that is augmented by a mechanical alternate control system. When the electrical FBW system is in effect, the aircraft must not receive commands from the mechanical system. A detent is required somewhere in the aircraft control system to provide an engagable hard point during FBW control mode selection or during failure conditions.

Under normal conditions for a FBW pitch-controlled aircraft with a mechanical backup system, a maximum rate electrical command may start to back-drive the pilot's control column when the elevator surface input forces reach some given value. This occurs when the mechanical feel force detent and gradient are insufficient to react these input forces, which may become significantly higher if required to clear or bypass a jammed surface actuator control valve.

An alternate system has been designed that incorporates centering valves into the four FBW servos, providing detents for reacting the mechanical system forces following a FBW shutdown. The required linkage hard point is incorporated directly into the autopilot servoactuator by the centering valve assembly shown in Figure 1. All components in this functional hydraulic schematic are usually present in contemporary aircraft flight-control-system autopilot servoactuators, with the exception of the centering valve.

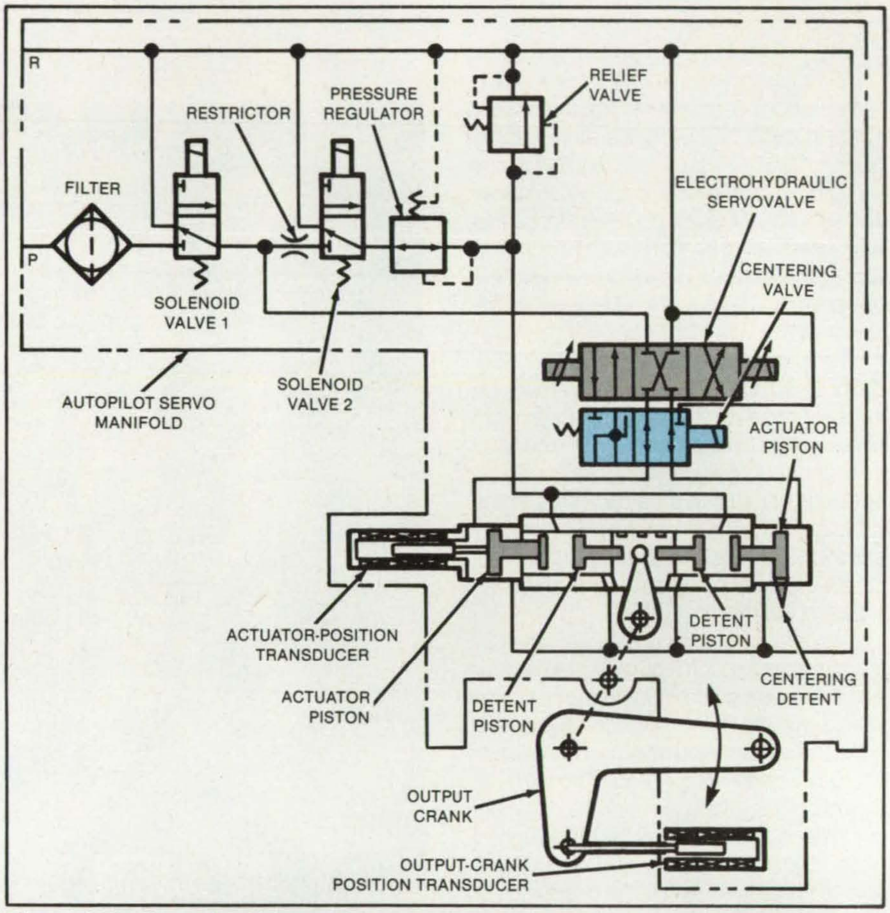


Figure 1. The **Centering Valve,** which serves as a hard-point linkage for mechanical system forces, is incorporated directly into the flight control system.

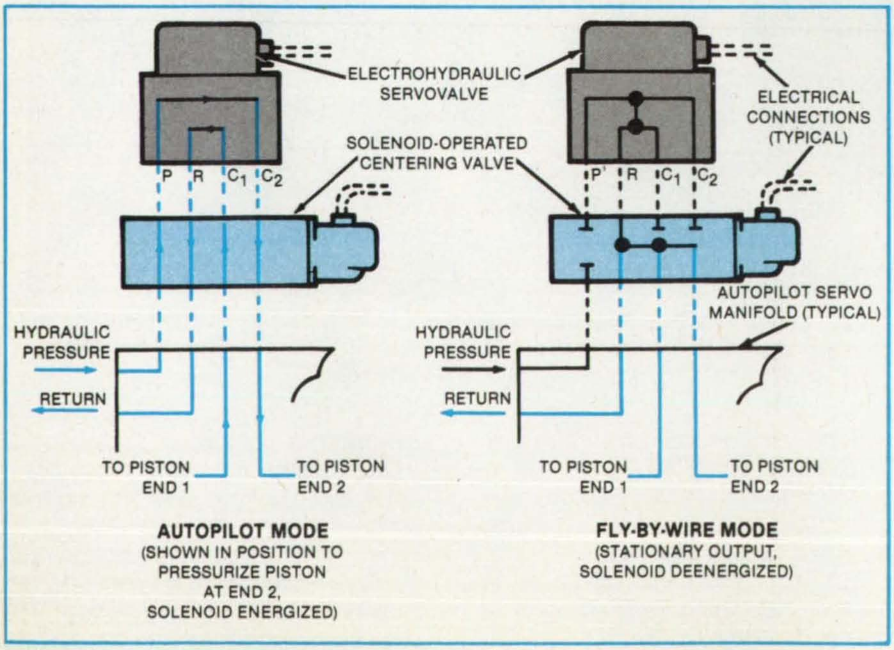


Figure 2. **Deenergizing the Solenoid** positions the centering valve when the fly-by-wire mode is selected.

During conventional autopilot operation, the output of the servo is controlled by electrical commands to the electrohydraulic servovalve via the various aerodynamic sensors in the aircraft. During this time, the electrical solenoid on the centering valve is energized to hold the position shown while the electrohydraulic servovalve oscillates between either of the two end positions shown. When the FBW mode is selected, the signal to the electrohydraulic servovalve commands it to hold the midstroke position, and the signal to the centering valve solenoid is removed, causing the valve to shift to its second position.

Figure 2 illustrates the two positions of the centering valve, showing the valve sandwiched between the electrohydraulic servovalve and the autopilot servo manifold. To produce the effect of the output shaft being fixed in the centered position during the FBW mode, the centering valve closes off the supply pressure at port "P" to the servo manifold while interconnecting both sides of the servoactuator piston to the return pressure cavity. Forces acting on both ends of the actuator piston are rapidly equalized and greatly reduced, driving the piston to the detent position. The centering valve is positioned by the action of deenergizing its electrical solenoid, accomplished when the pilot selects the FBW mode.

Because the pressure is equalized on both ends of the actuator piston, the centering detent provides the desired ground point reaction. The detent must be sufficiently high to react the back-driving loads in the control linkage. Therefore, the centering spring forces may be higher than those normally used in conventional autopilot servoactuators.

This work was done by John A. Aring of The Boeing Co. for **Langley Research Center.** *No further documentation is available.*
LAR-13185

Measuring Perimeters of Large Round Objects

Dimensions of tanks, rotors, and fuselages would be found accurately.

Marshall Space Flight Center, Alabama

The perimeters of large objects of approximately circular cross section can be determined indirectly through radius measurements by any of several proposed methods. The methods would reduce the errors introduced by a wheel moved around the perimeter and counting the wheel turns: Surface irregularities and variations in friction and contact pressure seriously affect the accuracy and repeatability of wheel measurements. Conceived for determining the dimensions of the Space Shuttle external tanks, the measurement concept may be applicable to such other large bodies as aircraft fuselages and generator rotors.

Each method is based on one of two fundamental approaches. In one approach, the object is rotated, and the radius from the axis of rotation to the edge in question is measured at fixed angular intervals. Applying the law of cosines to these measure-

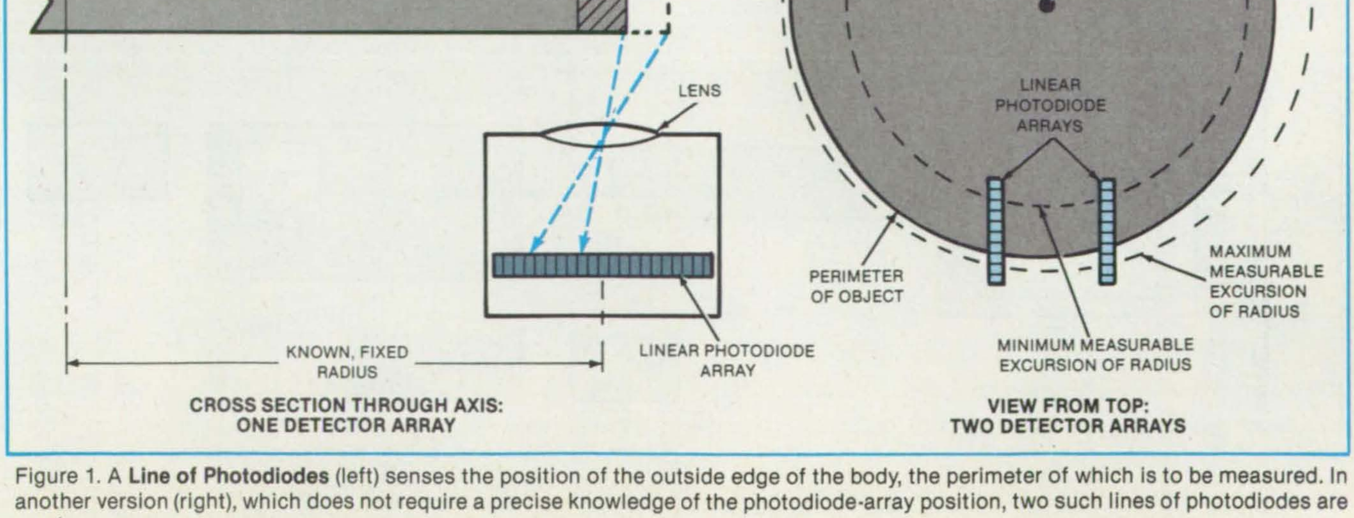


Figure 1. A **Line of Photodiodes** (left) senses the position of the outside edge of the body, the perimeter of which is to be measured. In another version (right), which does not require a precise knowledge of the photodiode-array position, two such lines of photodiodes are used.

ments, the arc subtended by each angular interval is estimated. The arcs of all the angular intervals in a complete rotation are added to obtain the circumference.

In the other approach, the radius is measured at small angular intervals — typically 1°. The average radius is computed from all the readings from a complete rotation and used to calculate the circumference. Of course, this approach does not work well for a highly fluted or scalloped edge.

In one proposed method, a lens is aimed at the edge of the body in cross section as a target to project the edge image on a line of photodiodes oriented radially (Figure 1, left). Electronic circuitry processes the signals from the array as the body is rotated about its axis and computes the radii and perimeter according to one of the two approaches.

In another method, the radius from the axis of rotation is measured by a linear gage in contact with the perimeter (Figure 2). In both this and the preceding method, the distance of the measuring equipment from the axis must be known precisely.

A variation of the optical method would not require precise positioning of the axis with respect to the array. Two linear arrays of photodiodes would be placed so that they both cover the maximum and minimum excursions of the body as it is rotated on a turntable (Figure 1, right). As the body is turned through 360° in small angular increments, the image of its edge is projected onto the arrays. From the changing positions of the image on the arrays and the spatial relationship of the arrays, electronic circuitry computes the increments of edge length and adds them to obtain the perimeter.

This work was done by Charles B. Dickinson of Martin Marietta Corp. for **Marshall Space Flight Center.** *For further information, Circle 106 on the TSP Request Card.*
MFS-28046

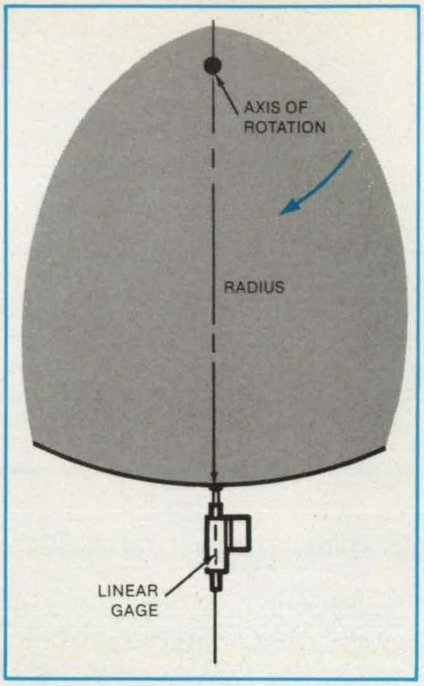


Figure 2. The **Distance From the Axis of Rotation to the Periphery** is measured by a linear gage in contact with the periphery.

Liquid-Level Monitor for Pressurized Vessels

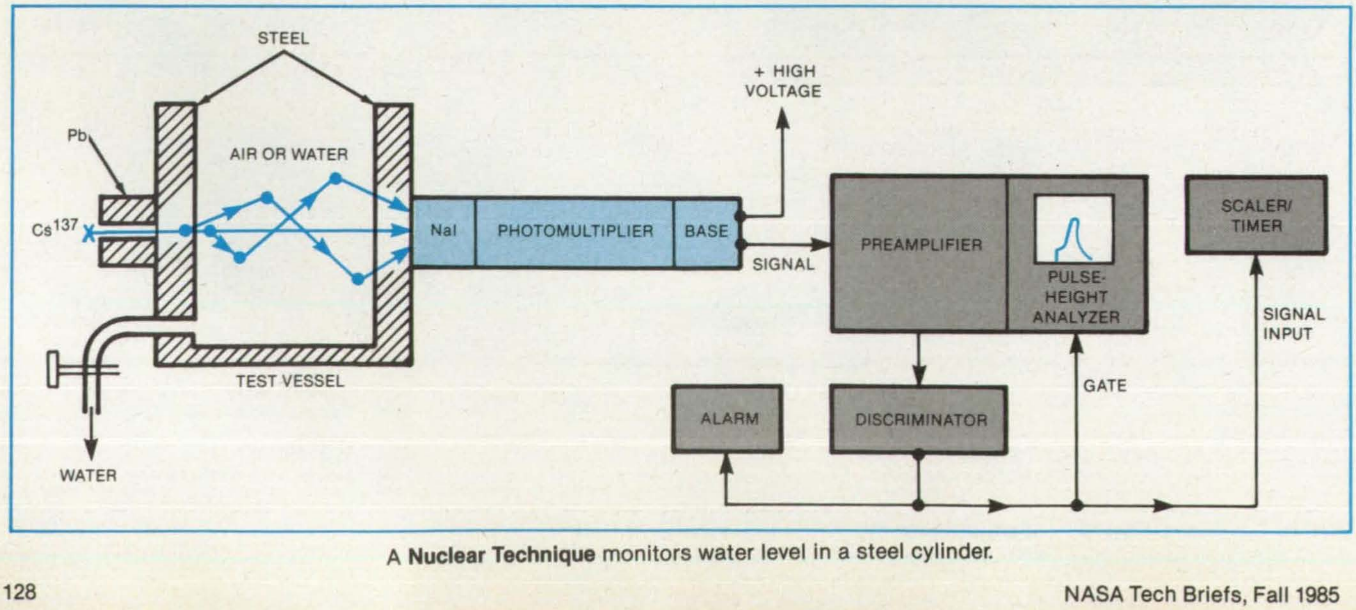
Gamma-ray attenuation indicates the presence or absence of liquid.

Langley Research Center, Hampton, Virginia

A technique for monitoring water levels in pressurized stainless-steel cylinders, based on the differences in gamma-ray attenuation coefficients in water and air, has been developed. A full-scale laboratory prototype system was constructed to test the technique.

Thermal probes in the Langley Research Center 8-ft (2.4-m), high-temperature wind tunnel are cooled by water stored in 30-ft (9-m) high, 16-in. (41-cm) diameter steel cylinders. The water level in the cylinders is initially monitored with a U-tube manometer.

Before the start of a run, high-pressure [about 408 atm (4.13×10^7 N/m^2)] air is introduced into the cylinders above the water level to force the cooling water through the multijacketed thermal probes. It was necessary to develop a technique that monitors



A **Nuclear Technique** monitors water level in a steel cylinder.

the presence of water at a critical height in the pressurized water reservoir, thus ensuring an adequate supply of cooling water for the duration of the test.

The prototype system for testing the technique is illustrated in the figure. A 10-μCi (nominal) Cs^{137} source emits the test gamma rays. The gamma rays transmitted through the pressure vessel are counted with a 2-in. (5.1-cm) diameter, 2-in. (5.1-cm) high NaI (Tl) crystal mounted on a high-gain photomultiplier, the output of which, after suitable amplification, is passed through a single-channel analyzer.

In laboratory tests, the counts were recorded for predetermined intervals for two discriminator settings, with and without water in the steel cylinder. The first discriminator setting of 200 keV was selected for counting all photons having energies above the photoelectric interaction energy limit. The registered counts reflect considerable impact of multiple scattering effects in the absorbers between the source and the detector. The second discriminator setting of 511 keV was selected to restrict the counts to photons that had suffered minimal scattering and, consequently, had lost minimal energy.

For the open-face, full-scale-model steel cylinder and Cs^{137} gamma-ray source used, the counting rates for air and water differ by a factor of 15.60 $\pm$ 0.60 for the 200 keV cutoff energy and by a factor of 17.24 $\pm$ 1.40 for the 511 keV cutoff energy. These results agree with the calculated values of 15.98 $\pm$ 1.50 and 17.68 $\pm$ 1.95, respectively. The values when the air is pressurized to 408.2 atm (4.136×10^7 N/m^2) are calculated to be 4.75 $\pm$ 0.51 and 5.01 $\pm$ 0.64, respectively. This large difference in counting rates clearly indicates a capability for detecting the presence or absence of water in the gamma-ray path in pressurized vessels.

This technique should be usable with liquids other than water, since the linear attenuation coefficients for intermediate-energy gamma rays in air are considerably lower than in the liquids. It should also be adaptable for the continuous monitoring of liquid levels in the reservoir systems and in underground storage tanks.

This work was done by Jag J. Singh and William T. Davis of **Langley Research Center** *and Gerald H. Mall of Computer Sciences Corp. Further information may be found in NASA TM-85651 [N83-33844/NSP], "Development of a Nuclear Technique for Monitoring Water Levels in Pressurized Vessels" [$8.50]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
LAR-13208

Measuring Metal Thickness With an Electric Probe

A four-point probe requires access from one side only.

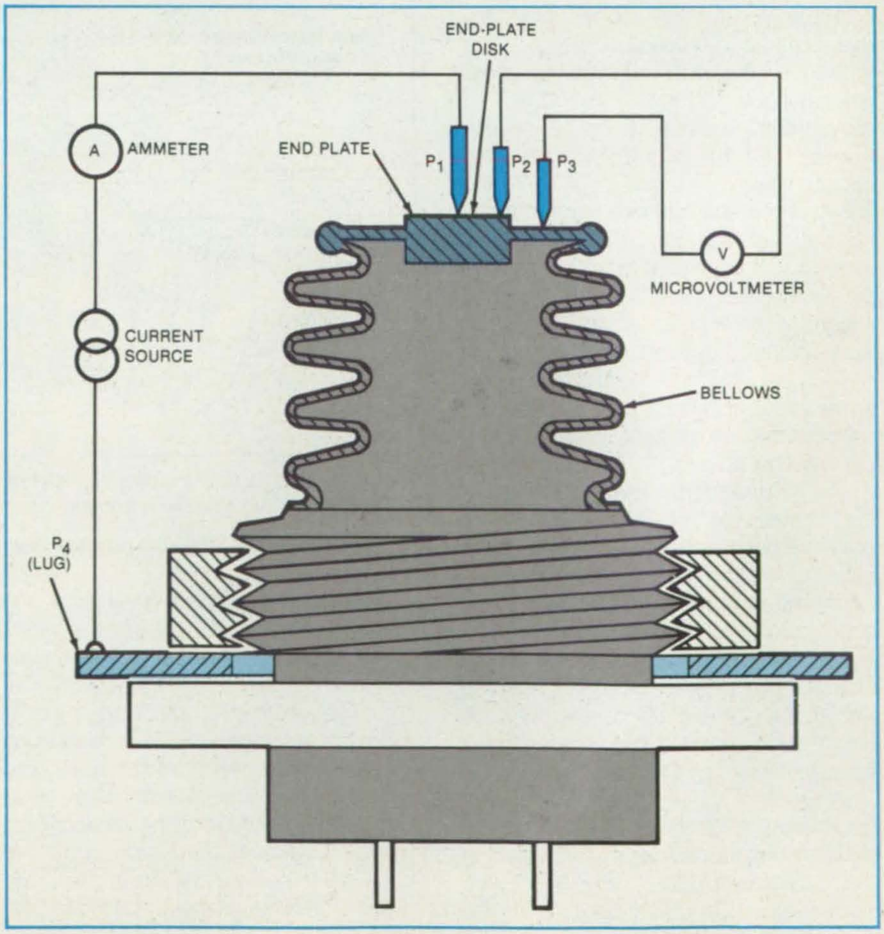
NASA's Jet Propulsion Laboratory, Pasadena, California

The thickness of metal parts can be measured from one side with the aid of a Kelvin probe. The method was developed for measuring the thickness of an end plate on a sealed metal bellows from the outside. It is suitable for thicknesses of a few thousandths of an inch (a few hundred micrometers). The method might also be used to determine the thickness of metal coatings applied by sputtering, electroplating, and flame spraying.

Kelvin probes are widely used to measure resistance. The instrument is a four-point device: It injects current into a specimen from two outer points and senses the specimen resistance by measuring the voltage between two inner points. For the thickness-measurement application, the thickness of the specimen in the region between the inner points should be inversely proportional to the resistance between them.

For the bellows-thickness measurement, a lug is bolted on the base of the bellows, connecting one of the current-supply terminals to the unit (see figure). The other supply terminal is connected to the end plate of the unit by a fixed tungsten needle. The lug and needle constitute the outer points of the Kelvin probe and provide a current of 200 milliamperes to the unit.

Two additional tungsten needles are placed on the end plate and connected to a microvoltmeter. One of the needles is fixed



Outer Probes Supply Current for resistance measurement via voltage measurement by inner probes. P_1 and P_4 are the outer probes. P_2 and P_3 are the inner, or sensing, probes.

near the edge of the central disk on the end plate. The other needle is movable over the surface of the end plate. These needles are the inner points of the Kelvin probe.

First, a calibration chart is prepared. The probe is moved over the surface by a micrometer positioner while the resistance readings are recorded. A map of position vs. resistance is drawn from these data. The end plate is then cross-sectioned, and the thicknesses of the sections are correlated with the resistance map. A calibration chart of resistance vs. thickness is plotted. The thickness of other bellows end plates is then determined by referring their resistance measurements to the calibration chart.

The relationship between thickness and resistance proved to be nearly linear for the bellows end plate. A few maverick data points were found, but they could be attributed to such features as welded regions or bellows convolutions under the probe. If the movable point is kept within 0.010 inch (0.25 millimeter) of the fixed probe, these features are expected to have little effect.

This work was done by Alex Shumka of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 26 on the TSP Request Card.*
NPO-16340

Low-Noise Supersonic Nozzle

The two-dimensional nozzle uses both a rapid expansion contour and a large width-to-height ratio.

Langley Research Center, Hampton, Virginia

To advance transition research at supersonic speeds and simulate the low-noise environment of high-altitude flight, a new type of wind tunnel is required that will eliminate or reduce high-intensity noise radiated into the test section from turbulent boundary layers on nozzle walls. In well-designed conventional wind tunnels, the wall boundary layers can be maintained laminar, but only at such low Reynolds numbers that transition is not obtained on simple models.

A small-scale mach-3.5 low-disturbance tunnel for boundary-layer transition research has been designed, built, and tested over a unit Reynolds number range from 10 to 60 million per meter. A two-dimensional nozzle used in the facility incorporates unusual design features of a rapid expansion contour, boundary-layer bleed slots upstream of the throat, and an exit width-to-height ratio of 1.7 to provide noise levels in the upstream regions of the test rhombus that are substantially lower than in conventional nozzles.

The normalized rms levels of fluctuating static pressures obtained from hot-wire measurements vary from extremely low values of less than 0.03 percent (essentially within the instrument noise range) up to about 0.8 percent, depending on the unit Reynolds number, the axial location in the test rhombus, and the bleed-slot flow. The higher noise levels are caused by eddy mach wave radiation from the turbulent boundary layers on the nozzle walls.

When the valve that controls the boundary-layer bleed flow is open, the wall boundary layers over upstream regions of the nozzle are laminar at the lower unit Reynolds numbers. The low noise levels and the absence of high-frequency radiated noise then result in transition Reynolds numbers on test models that are in the range of free-flight data.

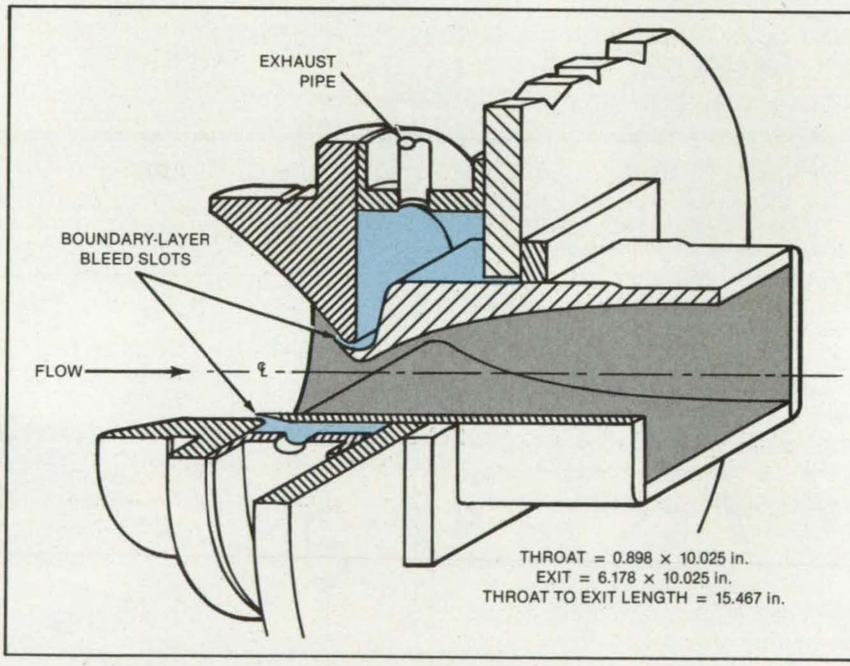


Figure 1. This **Cutaway Isometric Sketch** of a nozzle shows the boundary-layer removal slots in subsonic approach and slot suction plenum.

The dimensions of the nozzle throat and exit and the length of the nozzle are shown in Figure 1. The inflection point on the rapid expansion nozzle contour wall is only 0.5 in. (1.3 cm) downstream of the throat where the maximum wall angle is 28.75°, which is much larger than in conventional mach 3.5 wind tunnel nozzles. The boundary-layer bleed slots located upstream of the throat on both the contour wall and side wall, the boundary-layer bleed plenum, and a portion of one of 16 exhaust pipes are also shown in the figure.

The boundary-layer bleed flow could be cut off by closing a valve downstream of the bleed manifold. When this bleed valve is closed, the boundary layer in the subsonic approach spills around the slot leading edges. When this bleed valve is open, the entire boundary layers on both the contour walls and side walls of the subsonic approach are removed. The bleed mass flow was maintained constant at a given value of stagnation pressure by the use of sonic flow in the minimum area section of the channels. This sonic flow prevents any disturbance in the plenum flow from entering the nozzle.

The reasons for the generally lower noise levels that have also been measured in this nozzle when the wall boundary layers are turbulent become evident from Figure 2, which shows the contour and side wall to scale with mach lines from typical wall noise sources shown in the vertical and horizontal center planes. The vertical and horizontal half sections of the nozzle are depicted folded about the centerline into the same plane.

If the inviscid wall mach numbers, M_w, at the noise-radiating sources are less than about 2.75 in a rapid expansion nozzle, the noise levels in a portion of the test rhombus are reduced to about 0.2 percent, even if the nozzle wall boundary layers are fully turbulent. Since noise is propagated along mach lines in supersonic flow, this finding indicates that the quiet test core region shown in Figure 2 should experience low levels of radiated noise from the contour wall and very little, if any, radiated noise from the side walls since the values of M_w are less than or equal to 2.75 at the pertinent source locations. In fact, noise radiation from the side walls into the center region of the test rhombus should not be significant to x = 17 or 18 in. (43 or 46 cm) because of the large width-to-height ratio of the nozzle. These low-noise expectations were fully realized.

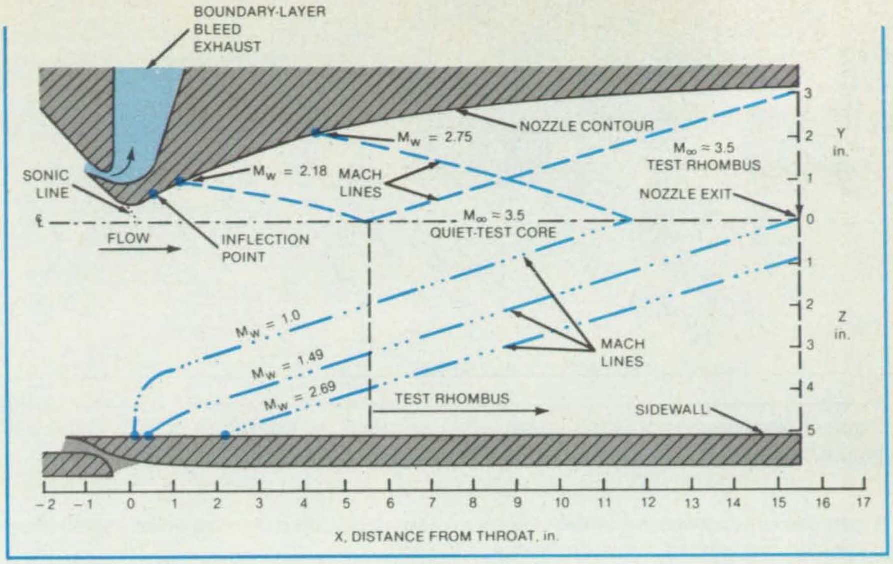


Figure 2. **Nozzle Wall Cross Sections** in vertical and horizontal center planes of a nozzle show mach lines, which outline the quiet test core with inviscid wall mach numbers at the corresponding acoustic origin locations.

This work was done by Ivan E. Beckwith of **Langley Research Center.** *For further information, Circle 21 on the TSP Request Card.*
LAR-13192

Toggle Hinge for Deployable Struts

Hinge eliminates end play to make structures more rigid.

Marshall Space Flight Center, Alabama

A toggle hinge allows deployable structures to be erected without the end play encountered in conventional hinged structural members. The new hinge thus ensures rigidity in portable bridges, masts, towers, platforms, and other deployable (and retractable) structures. Positioned halfway along the length of a folding strut, the hinge allows the halves of the strut to pivot 180° about the center.

When a conventionally hinged strut is deployed, its length reaches a maximum shortly before it is fully extended, then decreases slightly as the strut continues to its final position (Figure 1). The excess travel — that is, the difference between the maximum and final lengths — is typically of the order of 1 mm, the exact value depending on the hinge location and strut length. As a consequence, the holes in the end pivots of the strut must be slotted to accommodate the excess travel. The resulting structure is therefore not rigid.

A toggle-hinged strut, in contrast, does not reach its maximum length until it is in the toggle, or locked, position — that is, until it is fully extended. There is no excess travel, and no allowance need be made in the end holes.

The new strut includes a pair of clevis fittings attached to two tubular members (Figure 2). The clevis fittings are joined by a pair of toggle links attached to each other by a hinge pin. As the strut is unfolded, two pairs of sector gears rotate on each other until the toggle springs snap into the fixed toggle position and lock the strut into its fully extended configuration.

The sector gears resist shear forces across the hinge. Each sector gear is centered on one of the link pivot pins. If the strut

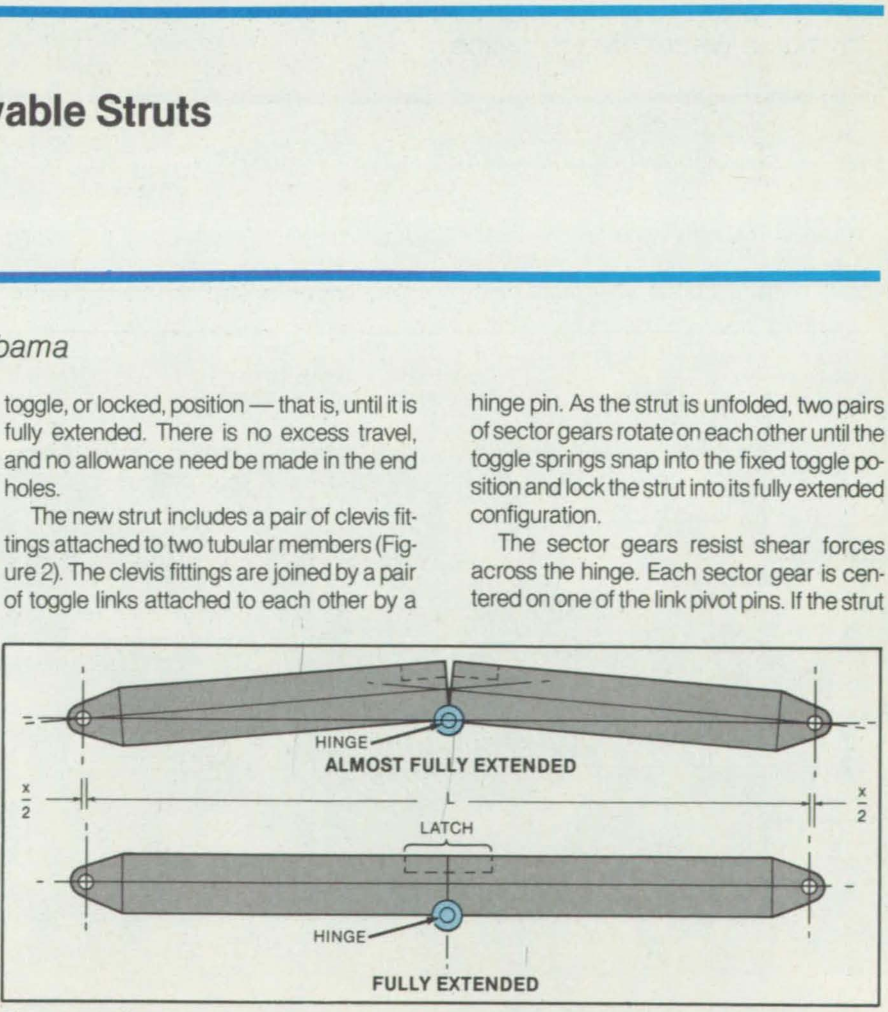


Figure 1. A **Kinematic Analysis** of the motion of a strut with a conventional offset hinge at its center shows that the strut elongates slightly and then contracts before reaching its fully deployed position. The excess length is here designated X.

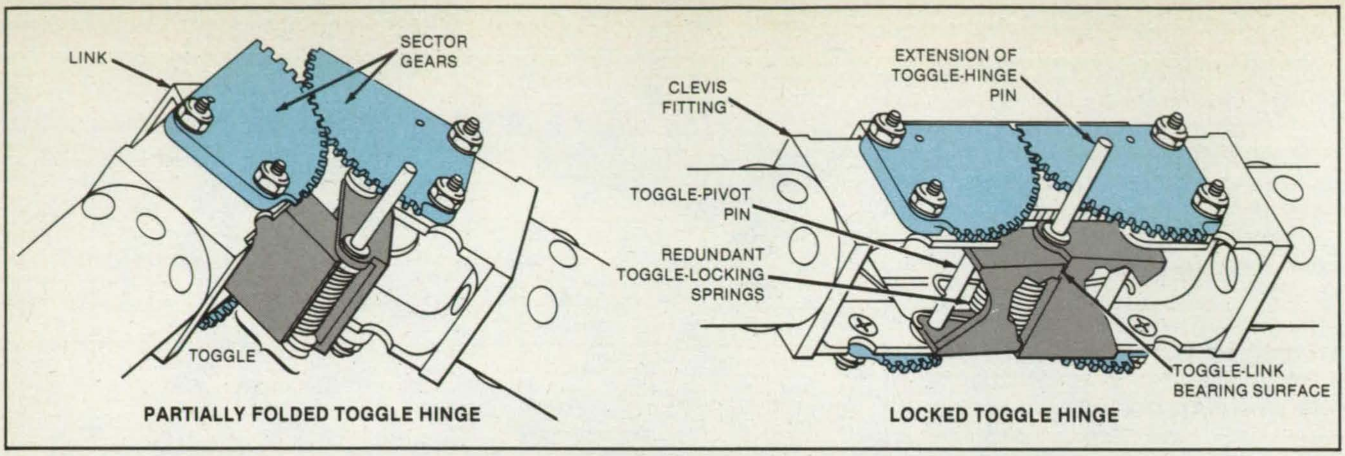


Figure 2. **Meshing Sector Gears** brace a strut as it deploys. The toggle unfolds and finally snaps and locks in place. An extension on the toggle-hinge pin allows it to be grasped by a toggle-opening tool for retraction.

is to be compression loaded, tension cables are routed through the struts and hinges. The toggle links have webs that stabilize the toggle during compression loading.

To retract a deployed strut, a hooked tool is applied to an extension of the toggle-hinge pin to pull the toggle out of the locked position.

This work was done by Richard T. Barbour of Rockwell International Corp. for **Marshall Space Flight Center.** *For further information, Circle 11 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 25]. Refer to MFS-28037.

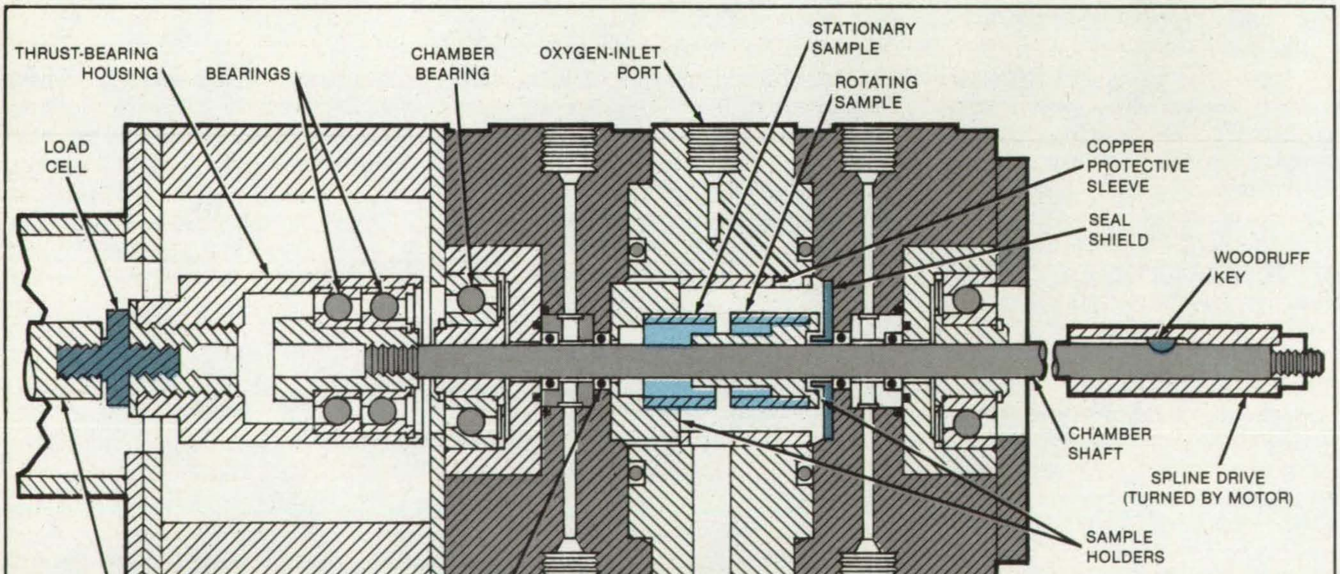
Friction-Testing Machine

Specimens are rubbed together at high speeds to evaluate wear characteristics.

Lyndon B. Johnson Space Center, Houston, Texas

A testing machine evaluates the wear and ignition characteristics of materials in rubbing contact. It offers advantages over other laboratory methods of measuring wear because it simulates the operating conditions under which the material will actually be used.

At the heart of the machine is a chamber in which a rotating specimen is forced



Materials Are Tested by rubbing ends of cylindrical specimens together. A motor drives the chamber shaft, which turns the rotating specimen against the stationary one. A key in the spline and shaft severs when the torque exceeds 300 lb-in. (34 N-m), thereby protecting the shaft from excessive stress.

against a stationary specimen (see figure). The behavior of the specimens is monitored by transducers and observed through a television camera. Pressures, forces, speeds, and temperatures are measured.

The chamber can withstand internal pressures up to 10,000 lb/in.^{2} (69 MPa). It is constructed of a nickel/copper alloy so that it can endure the harsh environment of high temperatures and burning metals. It consists of three sections that can be slid apart on rails for access to the chamber interior.

A shaft extending through the chamber rotates specimens at speeds up to 10,000 revolutions per minute while transmitting an axial force of up to 1,000 pounds (4,400 N). For maximum shaft stability, forces are applied to the stationary specimen in such a way that the shaft is always in tension. The axial force is applied by an air cylinder.

The spring-loaded rotary seals on the shaft are made of molybdenum disulfide and glass-filled polytetrafluoroethylene. They function at peak speed, temperature, and pressure simultaneously even in pure oxygen. The seals are cooled by flowing water.

The chamber is designed to accommodate extensive instrumentation. Up to six different temperature measurements can be made: two of them with such noncontact devices as a thermopile or a two-color pyrometer. A pressure sensor can be included in the chamber.

Frictional forces and torques are measured by a load cell, which senses forces from a moment arm attached to the chamber. Another load cell measures the force transmitted axially through the chamber shaft. The axial position of the chamber shaft is measured dynamically by a displacement transducer. The shaft speed is measured by a magnetic-pickup tachometer. The machine can be used for the following:

- To determine wear characteristics;
- To rank and select materials for service with such active oxidizers as oxygen, halogens, and oxides of nitrogen;
- To measure wear characteristics; and
- To determine coefficients of friction.

This work was done by Frank J. Benz and David S. Dixon of **Johnson Space Center** *and Randall C. Shaw of Lockheed Corp. For further information, Circle 28 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center [see page 25]. Refer to MSC-20622.

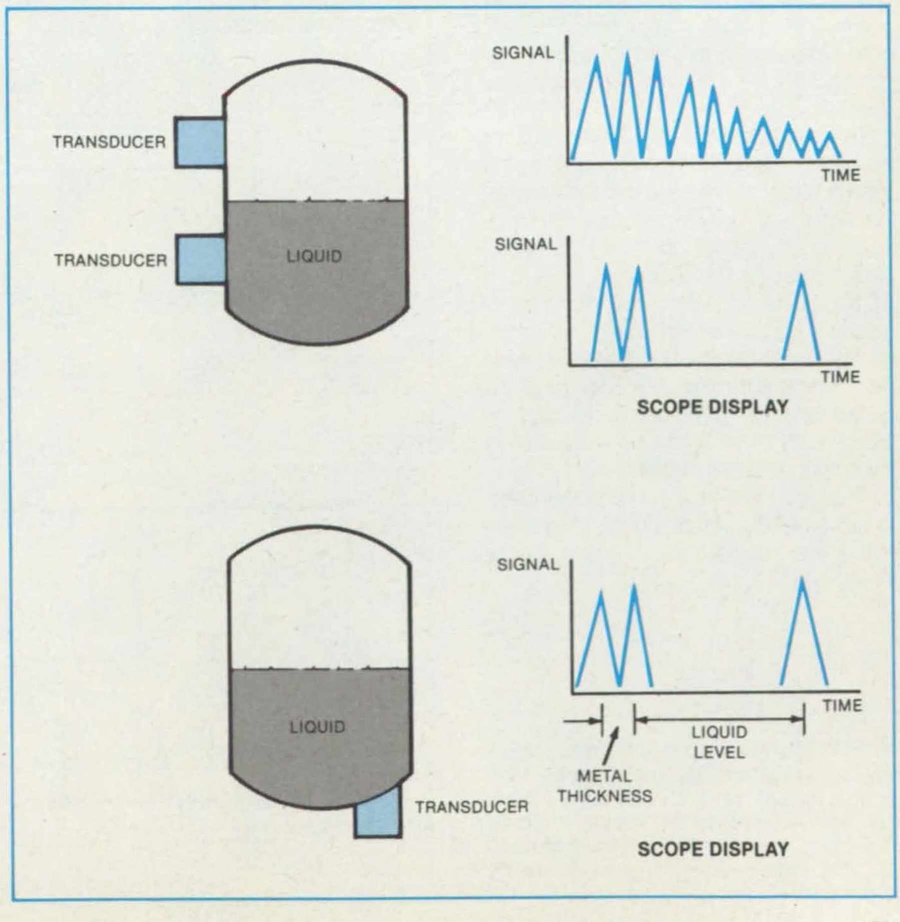
Noninvasive Fluid Level Sensor for Organometallic Sources

Two ultrasonic methods offer fast, accurate, level measurement in closed containers.

Langley Research Center, Hampton, Virginia

Two ultrasonic methods are available for measuring the level of organometallic liquid in a stainless-steel (or other homogeneous solid) container. The methods require no disassembly or weighing of the container. Commercially available ultrasonic flaw detectors, some of which have digital readouts and computer interfaces, can be used in the techniques.

Both methods are illustrated in the figure. One involves moving a piezoelectric transducer up and down the outside of the container. A difference in response is easily detected when the transducer is moved from the filled to the empty part of the container. The accuracy of this method is limited to approximately 1/8 inch (3 mm) by the transducer diameter, but the method is fast, requires no calibration, and works on different container shapes.



Two Methods Are Used to Measure Organometallic Liquid Level. Method 1 (top) relies on the detection of a change in resonance levels when the transducer is placed adjacent to the liquid-filled portion of the container and then placed adjacent to the empty portion. Method 2 (bottom) involves measuring the sound propagation time for reflection off the liquid surface.

The second, more accurate, method is suited to process control. The transducer is placed on the outside bottom of the container to send the ultrasonic beam upward. This method is identical in concept to a marine depth sounder, but the higher frequencies of the transducer (1 to 20 MHz versus approximately 50 kHz) allow an accuracy on the order of ±0.001 in. (±0.03 mm) versus the accuracy of the sounder at ±1 in. (±25 mm). This second method measures the time required for an ultrasound pulse to travel from the transducer through the container wall to the liquid surface and back to the transducer.

Both methods can be used in crystal growth to determine the level of liquids contained in sealed, opaque containers. For example, organometallic chemical vapor deposition for growing epitaxial layers of semiconductor materials requires the use of stainless-steel bubblers containing the organometallic sources. These sources must be maintained in an ultrahigh purity condition. Any intrusive measurement would introduce oxygen that would destroy this purity.

This work was done by Wayne Gerdes of **Langley Research Center.** *No further documentation is available.*
LAR-13265

Flowmeter for Clear Fluids

Optoelectronic instrument generates electrical signal proportional to fluid-flow rate.

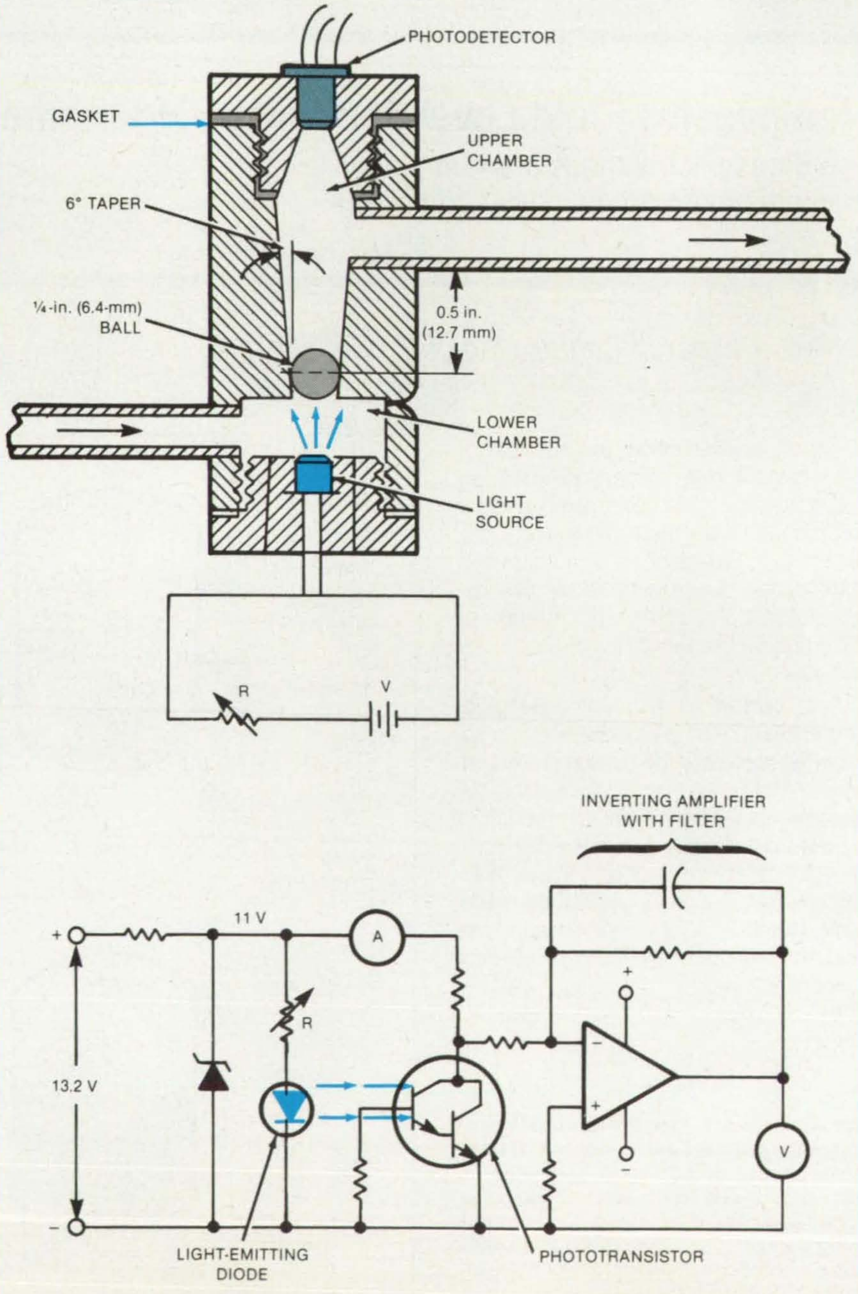
Mashall Space Flight Center, Alabama

An electronic flowmeter measures the flow rate of clear or translucent fluids. The instrument produces an electrical signal proportional to the volume of fluid flowing through it per unit time.

The meter contains at its center a cylindrical lower chamber and a tapered upper chamber (see figure). A ball rests in the tapered section just above the lower chamber. Fluid flows from a pipe into the lower chamber, around the ball, into the upper chamber, and out through a pipe. The ball, case, pipes, and other parts are selected for compatibility with the fluid chemistry, flow rate, and specific gravity.

The ball rises in the tapered section until its weight balances the force exerted by the flowing fluid. The ball is illuminated from below and, as it rises in the taper, allows increasing amounts of light to fall on a photodetector above. The electrical output from the photodetector is thus proportional to the height of the ball. An external circuit amplifies the sensor signal and makes it linearly proportional to the flow rate. The unit is calibrated for a given type of fluid by adjusting the intensity of the light source, the gain of the output amplifier, or both.

The lower chamber reduces the turbulence in the fluid so that measurements are stable and reproducible. The light source



LIGHT SOURCE/DETECTOR/AMPLIFIER CIRCUIT

With Fluid At Rest, a small stainless-steel ball rests in a tapered hole. Flowing fluid pushes the ball upward. A variety of materials may be used for the casing and ball, depending on the chemical composition, flow rate, density, and other characteristics of the fluid.

may be an incandescent lamp or a light-emitting diode; the photodetector is selected to match the wavelength of the light source. Small glass lenses separate the source and sensor from the fluid chambers, protecting them from abrasion by particles in the fluid and, in the case of the sensor, from damage by the ball during a surge in flow. A reverse taper at the top of the upper chamber focuses light into the sensor.

This work was done by Paul R. White and Walter R. McIntosh of **Marshall Space Flight Center.** *No further documentation is available.*
MFS-28031

Tiltable-Wing, Tiltable-Rotor Aircraft

Independent wing movement reduces the download of the rotor.

Ames Research Center, Moffett Field, California

In a proposed version of the tiltable-rotor airplane, the wings would be tiltable also. Airplanes with rotors and engines that tilt between horizontal and vertical axes cruise efficiently and can also hover. In hovering flight, however, the rotor downwash impinges on the wings, creating a downward load on the airplane. Although flaps have been used to reduce the download — and vanes and air-blowing techniques have been proposed — the net download reduction is only about 40 percent.

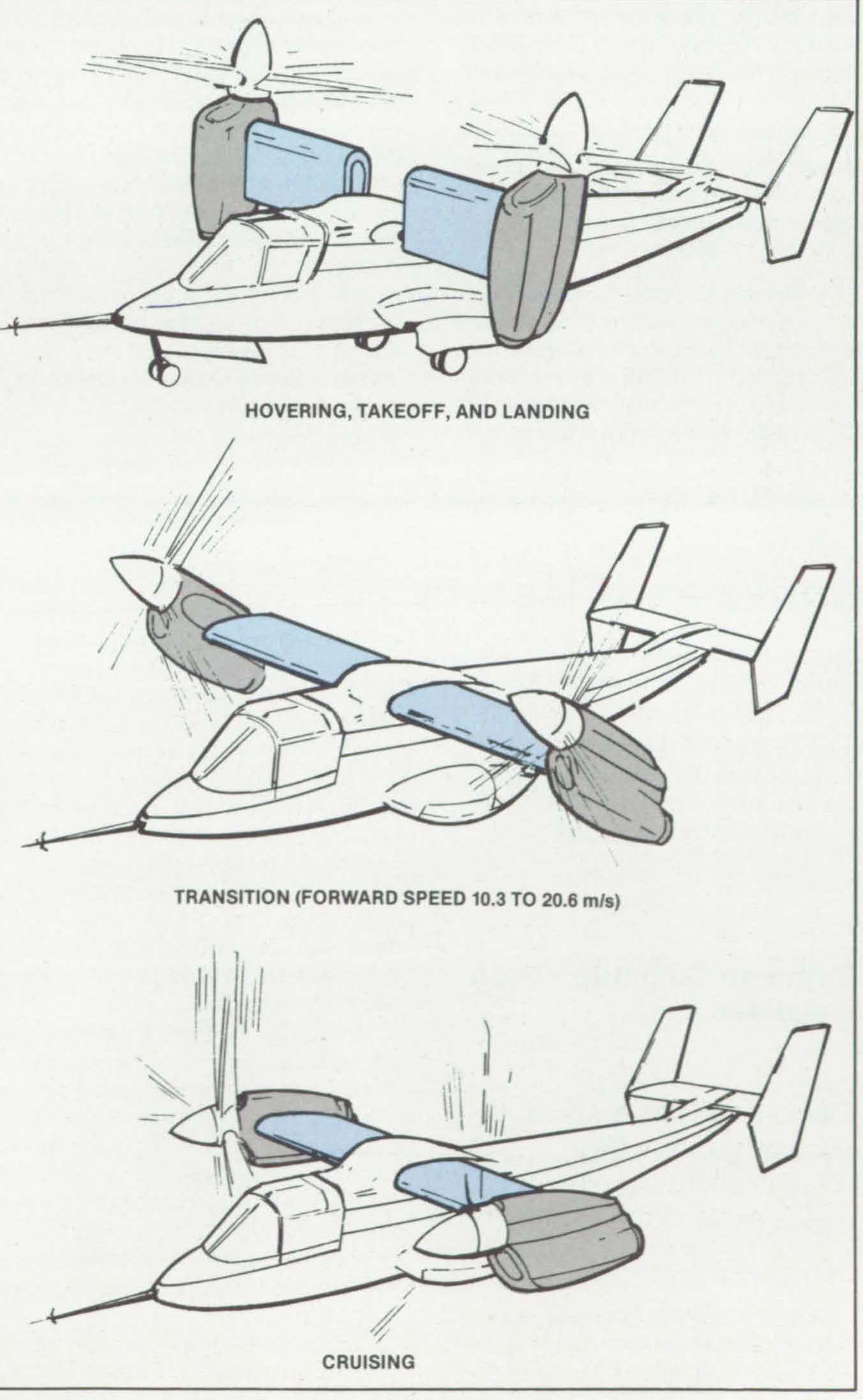
In the new airplane the wing would tilt 90°, leading edge up, to feather into the rotor downwash during hovering, takeoff, or landing (see figure). After hovering or takeoff, the rotors are tilted forward slightly to accelerate the airplane into forward flight. As the airplane accelerates, the wings start to tilt forward. At speeds of 20 to 40 knots (10.3 to 20.6 m/s), the wings are in their horizontal orientation. In this speed range, the rotor power requirements have decreased sufficiently to allow the wings to assume their normal orientation.

Finally, the rotors are tilted full forward, and the plane is in the cruise mode. For landing, the tilting sequence is reversed.

Modifications to the wing structure and the addition of a tilting mechanism would be necessary to pivot the wing about a spanwise axis coincident with the rotor cross-shaft. Additional hydraulic hoses and lines, electric wiring, and fuel lines would be needed to carry services to the tiltable wing.

The tiltable wings would be movable independently of the tiltable rotors. Thus, they could be tilted at whatever pitch schedule yields the greatest efficiency.

This work was done by Robert H. Stroub of **Ames Research Center.** *No further documentation is available.*
ARC-11420



In Takeoff Sequence, wings are oriented so that they offer minimum resistance to rotor downwash at liftoff and during hovering. As the plane picks up forward speed, the wings assume their normal (horizontal) cruise orientation.

Noncontacting Measurement With a Thermocouple

A tentlike covering brings the thermocouple to within a few degrees of the surface temperature.

Lyndon B. Johnson Space Center, Houston, Texas

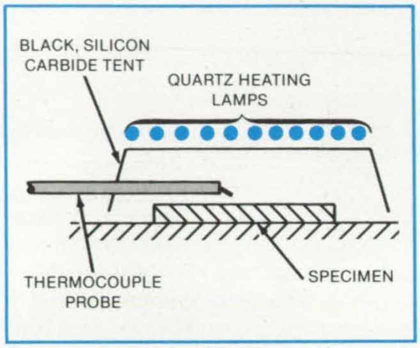
A technique originally developed for measuring the surface temperature of quartz fabric under radiant heating requires no direct contact with the heated surface. The technique is particularly useful when measuring the surface temperatures of materials that might be damaged if a thermocouple or other temperature sensor were to be attached.

As shown in the figure, a thermocouple is positioned above a specimen, and a "tent" of black SiC cloth is placed over the thermocouple. A heat source, such as an array of quartz lamps, heats the tent.

The tent acts as a black body, transforming the shorter wavelength radiation from the quartz lamps into longer wavelength infrared radiation. Everything in the tent is heated to nearly the same temperature. By bathing the experimental apparatus in black-body radiation, the tent prevents the differences in radiant heating that would result from the differences in emissivity and absorptance among the objects directly exposed to the heating lamps.

In an experiment to verify the technique, a thermocouple was installed on the surface of an insulating material, while another thermocouple was suspended just above the surface. Without the tent, there was a difference of 100° to 200° F (50° to 111° C) between the temperatures measured by the two thermocouples. With the tent, the two thermocouples agreed within a few degrees.

This work was done by William T. Weatherill, Cecil J. Schoreder, and Heinz J. Freitag of Rockwell International Corp. for **Johnson Space Center.** *No further documentation is available.*
MSC-20834



Ceramic-Fiber Cloth covers a test specimen. Despite the separation between them, the thermocouple and the specimen reach nearly the same equilibrium temperature.

Books and Reports

These reports, studies, and 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.

Tethered Communication Satellites

Proposed scheme would ease orbital crowding more economically than space platforms

A report describes a concept for placing several communication satellites in a geostationary orbit without taking up more space than is assigned to a single satellite. The problem of crowding in geostationary orbits would thus be greatly alleviated.

According to the concept, a Space Shuttle crew would assemble a stack of communication satellites in low Earth orbit with the aid of the Shuttle remote manipulator. The satellites would be joined to each other by sets of four mechanical plugs and sockets. Coiled within each plug/socket junction would be a tether line. When a stack of satellites had been assembled, the crew would attach a rocket engine to the stack. The engine would move the stack to its geostationary orbit and then would separate from the stack.

At this point, the axis of the stacked satellites would be tangential to the orbit path. Attitude control systems in the two outer satellites would rotate the stack so that its axis pointed toward Earth. The plug/socket junctions would disengage, and the tether lines would uncoil. In their final positions, the satellites would be strung out in a direction radial to the center of Earth. They would be stabilized by the weak gradient of the gravitational force from Earth.

The satellites would then begin telecommunication operations. They would have individual attitude control systems that would cooperate to maintain a specified orientation for the tethered stack. Each satellite would have an independent power system. It would provide such features as individual location pointing, frequency discrimination, time-division multiplexing, spread-spectrum transmission, and narrow-beam antennas.

The tethered satellites offer an economical alternative to complex communication satellite platforms. The concept would require minimal redesign of existing satellites and would accommodate many satellites in just one orbital slot. Moreover, such a system would be much lighter in weight than a geostationary platform and therefore easier and more economical to transport.

This work was done by Georg von Tiesenhausen of **Marshall Space Flight Center.** *To obtain a copy of the report, "Tethered Geostationary Communication Satellite Constellation," Circle 16 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of the technology described in this report should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 25]. Refer to MFS-28042.

Computer Programs

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

Predicting Two-Dimensional, Unsteady Turbulent Combustion

Model links turbulence, combustion, and the velocity field.

MIMOC calculates the flow field and flame propagation in a turbulent combustion tunnel. The program employs an algorithm for turbulent combustion modeling described by Ghoniem, Chorin, and Oppenheim. It utilizes the random vortex method of Chorin, which has the advantage of allowing the turbulent field to evolve as a fundamental solution of the Navier-Stokes equations without averaging or closure modeling. The flame front, which is treated as an interface between the reactants and products, is computed using an algorithm developed by Chorin that exploits a technique by Noh and Woodward for "simple line interface" calculation. The flow is treated as "slightly compressible," allowing for the increase in specific volume in the course of combustion to modify the flow field without any acoustic effects, thus modeling the effect of significant changes in density that occur at relatively low mach numbers.

The computer code is based on a model that establishes the link between turbulence and combustion in terms of the primary dynamic variable: the velocity field. Turbulence is solved from first principles in terms of the dynamics of the vorticity field using the random vortex method. The random vortex method computes the vorticity field as an equivalent number of discrete elements called vortex blobs. The interaction of each vortex blob is determined, and the vortex blobs are moved with each time step. Diffusion is represented by the random walk of the blobs. This method does not impose an averaging procedure, which in turn requires closure modeling, nor does it introduce extra numerical diffusion into the solution that may dampen the inherent natural instabilities of the flow field. Thus, it is capable of reproducing detailed turbulent eddy interactions in rapidly changing fields.

The mechanical effects of combustion are modeled by the motion of the flame front. The flame front is composed of advection and normal propagation as a laminar flame as well as a distribution of volumetric sources inside the combustion zone that introduces the effect of combustion exothermicity into the velocity field. The linkage between turbulence and combustion in this model provides the mechanism through which the interaction between the two fields evolves with time and spreads throughout the field. This makes the algorithm particularly useful for the study of such phenomena as inflammation, flame instabilities, and transient flow fields occurring in internal-combustion engines.

The program is capable of providing numerical and graphical information about the vorticity field, flame front location, and composition profiles expressed in terms of the ratio of reactants to products, all as time-evolving fields. These data can be used to obtain average and stationary statistics of the turbulent field. In addition, overall performance parameters like the turbulent flame speed and the reattachment length behind a rearward-facing step in a channel can be deduced from these data.

The program offers some flexibility by making most of its operation essentially independent of the geometry of the enclosure containing the flow field. While most calculations are carried out in a universal transformed plane, the description of the geometry of the channel is restricted to a group of subroutines, thus allowing for a variety of configurations to be treated with a minimum of modification.

The program was used to study the flow field in a model combustor, formed by a rearward-facing step in a channel, in terms of the vorticity field, the velocity field, the turbulent shear stresses, the flame contours, and the concentration field. The program is written in FORTRAN IV for use on an IBM 370 computer.

This program was written by Cecil J. Marek of **Lewis Research Center** *and Ahmed F. Ghoniem and Antoni K. Oppenheim of the University of California. For further information, Circle 45 on the TSP Request Card.*
LEW-14027

Airfoil Smoothing and Scaling Programs

Two programs smooth and scale arbitrary airfoil coordinates.

Since its early beginnings, NASA has been actively involved in the design and testing of airfoil sections for a wide variety of applications. Recently, a set of programs has been developed to smooth and scale arbitrary airfoil coordinates.

The airfoil smoothing program (AFSMO) utilizes both least-squares polynomial and least-squares cubic-spline techniques to smooth iteratively the second derivatives of the y-axis airfoil coordinates with respect to a transformed x-axis system that unwraps the airfoil and stretches the nose and trailing-edge regions. The corresponding smooth airfoil coordinates are then determined by solving a tridiagonal matrix of simultaneous cubic-spline equations relating the y-axis coordinates and their corresponding second derivatives. The camber and thickness distributions of the smooth airfoil are also computed.

The airfoil scaling program (AFSCL) may then be used to scale the thickness distribution generated by the smoothing program to a specified maximum thickness. Once the thickness distribution has been scaled, it is combined with the camber distribution to obtain the final scaled airfoil contour.

The airfoil smoothing and scaling programs are written in FORTRAN IV for batch execution and have been implemented on a CDC CYBER 170 series computer with a central memory requirement of approximately 100k (octal) of 60-bit words. Both programs generate plotted output via CALCOMP-type plotting calls. These programs were developed in 1983.

This program was written by Harry L. Morgan, Jr., of **Langley Research Center.** *For further information, Circle 81 on the TSP Request Card.*
LAR-13132

Thermal, One-Dimensional Analyzer Program

It can be used to evaluate insulative properties of composites.

This thermal, one-dimensional analyzer program enables the user to predict the surface temperature of fibrous, feltlike insulation that has been exposed to some external radiant heat source or to convective heating produced by aerodynamic forces. The prediction is derived from readings of a thermocouple embedded in the material at some depth below the surface.

Using an implicit, one-dimensional approach, the solution takes the form of a tridiagonal matrix inversion, which solves for the surface temperature at each time step for each iteration of boundary conditions. The program has been used to analyze flight data obtained from thermocouples embedded in the surface insulation of the Space Shuttle to determine the surface temperature during flight. The program should be useful in the analysis and evaluation of the insulative qualities of similar or new compositions.

This program is written in FORTRAN IV

for batch execution and has been implemented on an IBM 370 series computer with a central memory requirement of approximately 650k of 8-bit bytes. This program was developed in 1983.

This program was written by Dashrath K. Patel and Daniel P. Jones of Rockwell International Corp. for **Johnson Space Center.** *For further information, Circle 19 on the TSP Request Card.*
MSC-20703

NASTRAN®/DISCOS/ SAMSAN DMAP Bridging Program

Three programs for the design and analysis of flexible structure controllers are integrated.

The design of a controller for a flexible structure must incorporate flexible body data in a format compatible with design and performance evaluation methods. The control designer may have to work with several different programs to obtain all the data and capabilities needed.

The NASTRAN®/DISCOS/SAMSAN bridging program and its associated data-file processor provide the flexible structure control designer with a means of tying together the following programs: (a) the NASA Structural Analysis (NASTRAN®) system, which provides general finite-element and matrix manipulation capabilities for the analysis of structures; (b) the Dynamic Interaction Simulation of Controls and Structure (DISCOS) program, which provides for the time and frequency domain analysis of any dynamic system that can be modeled as a system of interconnected rigid and flexible bodies; and (c) the SAMSAN library, which provides a self-consistent set of algorithms for the support of large-order controls system design and evaluation studies with an emphasis on sampled-system analysis. The NASTRAN®/DISCOS/SAMSAN bridging program allows the engineer to integrate these three programs into a complete package for the design and analysis of flexible structure controllers.

The NASTRAN®/DISCOS/SAMSAN bridging program and its associated data-file processor may be used to obtain all of the data necessary for defining a flexible body to DISCOS or to any program developed using the SAMSAN library. The bridging program consists of a NASTRAN® DMAP sequence that may be used to obtain a variety of different types of modal data including standard, Craig-Bampton, augmented body, and boundary compliance. The user may also request the generation of the following: Mass, stiffness, damping, and constraint matrices; data for fine- to coarse-mesh mass-distribution interpolation programs; modal damping, modal observability/controllability matrices; coarse- or fine-mesh modal data; and an assortment of matrices useful for non-DISCOS applications and diagnostic analysis.

All data are output from NASTRAN® via the functional module OUTPUT2. The associated data-file processor can reformat an OUTPUT2 data file into a format compatible with the sparse matrix read routines in the SAMSAN library.

The NASTRAN®/DISCOS/SAMSAN bridging program is written in the NASTRAN® DMAP language and the associated OUTPUT2 data file processor is written in FORTRAN IV. Both programs are intended for batch execution and have been implemented on a DEC VAX series computer operating under VMS. The bridging program and associated data-file processor were developed in 1983. The NASTRAN®, DISCOS, and SAMSAN software packages are available separately from COSMIC.

This program was written by Harold P. Frisch of **Goddard Space Flight Center.** *For further information, Circle 38 on the TSP Request Card.*
GSC-12902

Inelastic Analysis of Thermomechanically Cycled Structures

An elastic solution is the input; the stress/strain history is the output.

A simplified inelastic analysis computer program (ANSYMP) was developed for predicting the stress/strain history of a thermomechanically cycled structure from an elastic solution. The program uses an iterative and incremental procedure to estimate the plastic strains from the material stress/strain properties and a simulated plasticity hardening model.

The drive toward increased performance and fuel economy for aircraft gas-turbine engines has resulted in higher turbine inlet temperatures, pressure ratios, and rotor speeds. These more severe operating conditions have subjected the hot section components to thermomechanical load cycles that induce significant inelastic strains and eventual fatigue cracking. It has become increasingly difficult to design reliable components to meet both the engine life and performance requirements. Improvements in the durability of these components depend on accurate structural analysis and life prediction. Life prediction methods have been under development by the Lewis Research Center and other organizations. Application of these methods requires knowledge of the temperature/stress/strain history at the critical crack initiation location of the structure.

Nonlinear, finite-element computer programs are too costly to use in the early design stages for hot section components of aircraft gas-turbine engines. In order to improve the durability of these components, it was necessary to develop simpler and more economical methods for representing structural response of materials under cyclic loading.

The computer program ANSYMP was developed to simplify nonlinear structural analysis using only an elastic solution as input data. The simplified method was based on the assumption that the inelastic regions in the structure are constrained against strain redistribution by the surrounding elastic material; therefore, the total strain history can be defined by an elastic analysis. Appropriate material stress/strain properties and a plasticity hardening model are incorporated into the program. Effective stresses and plastic strains are approximated by an iterative and incremental solution procedure.

The basic problem in developing the simplified analytical procedure was to characterize the yield surface in terms of the total strain obtained from an elastic analysis or strain measurements. Classical plasticity theory specifies the yield surface by a yield criterion to describe yielding under multiaxial stress states and a hardening model to establish the location of the yield surface during cycling. The simplified procedure was set up to accommodate itself to any yield criterion or hardening model. The only requirements are that the elastic input data be consistent with the yield criterion and the appropriate material properties be used in conjunction with the hardening model. Currently, the simplified analysis is limited to consideration of time-independent plasticity.

The elastic input data is subdivided into a sufficient number of increments to define the stress/strain cycle. These increments are analyzed sequentially to obtain the cumulative plastic strains and to track the yield surface. An iterative procedure is used to calculate the yield stresses for increments undergoing plastic straining. First, an estimated plastic strain is assumed for calculation of an initial yield stress from the stress/strain properties and the simulated hardening model. Second, a new plastic strain is calculated as the difference between the total strain and the elastic strain components. Then the yield stress is recalculated using the new plastic strain value. The iterative procedure is repeated until the new and previous plastic strains agree within a tolerance of 1 percent.

Analytical predictions from ANSYMP showed excellent agreement when compared to a computer program using a nonlinear finite-element technique (computer program MARC). Nonlinear stress/strain histories were computed from the ANSYMP program with less than 1 percent of the CPU time required by the MARC program. The program is written in FORTRAN IV for use on an IBM 370 or a Cray computer.

This program was written by Albert Kaufman of **Lewis Research Center.** *For further information, Circle 44 on the TSP Request Card.*
LEW-14011

Geometric and Material Nonlinear Structural Analysis

The program supports fracture-mechanics studies of debonding and delamination.

GAMNAS (Geometric and Material Nonlinear Analysis of Structures) is a two-dimensional finite-element stress-analysis program that supports fracture-mechanics studies of debonding and delamination. GAMNAS options include linear, geometric-nonlinear, material-nonlinear, and combined geometric- and material-nonlinear analysis.

GAMNAS can analyze plastic deformations of isotropic materials. It calculates strain-energy release rates using a virtual crack-extension technique. The element available to the GAMNAS user is a four-node isoparametric quadrilateral with full or reduced integration. GAMNAS has been used to investigate debonding and delamination of adhesively bonded composites.

GAMNAS is written in FORTRAN 77 for batch execution and has been implemented on a PRIME 700-series computer. As currently dimensioned for a maximum global stiffness matrix of 1,300 degrees of freedom and a bandwidth of 70, GAMNAS has a central-memory requirement of approximately 604K of 16-bit words. GAMNAS was developed in 1983.

This program was written by John D. Whitcomb and B. Dattaguru of **Langley Research Center.** *For further information, Circle 30 on the TSP Request Card.*
LAR-13279

Analysis of Scramjet Inlets

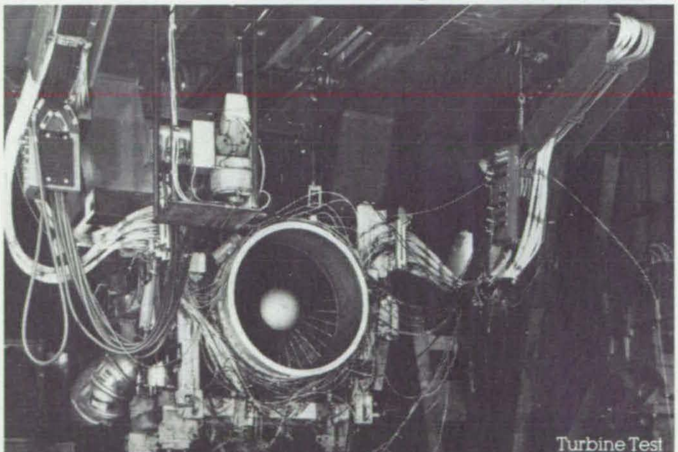
Viscous flow can be accounted for in the computations.

NASCRIN analyzes two-dimensional flow fields in supersonic combustion ramjet (scramjet) inlets. It solves the two-dimensional Euler or Navier-Stokes equations in conservative form by an unsplit, explicit, two-step finite-difference method. A more recent explicit/implicit, two-step scheme has also been incorporated for viscous flow analysis. An algebraic, two-layer eddy-viscosity model is used for the turbulent flow calculations.

NASCRIN can analyze both inviscid and viscous flows with no struts, one strut, or several struts embedded in the flow field. It can be used in a quasi-three-dimensional sense for some scramjet inlets under certain simplifying assumptions. Although developed for supersonic internal flow, NASCRIN may be adaptable for other flow problems. In particular, it should be readily adaptable to subsonic inflow with supersonic outflow, supersonic inflow with subsonic outflow, or fully subsonic flow.

NASCRIN is written in highly vectorized FORTRAN for batch execution on the CDC CYBER 203 (or similar) computer and has a central-memory requirement of approximately 300K of 64-bit words for a grid size of about 3,000 points. NASCRIN was developed in 1983.

This program was written by Ajay Kumar of **Langley Research Center.** *For further information, Circle 73 on the TSP Request Card.*
LAR-13297



Machinery

Hardware, Techniques, and Processes

Computer Programs

Constant-Pressure Sawing

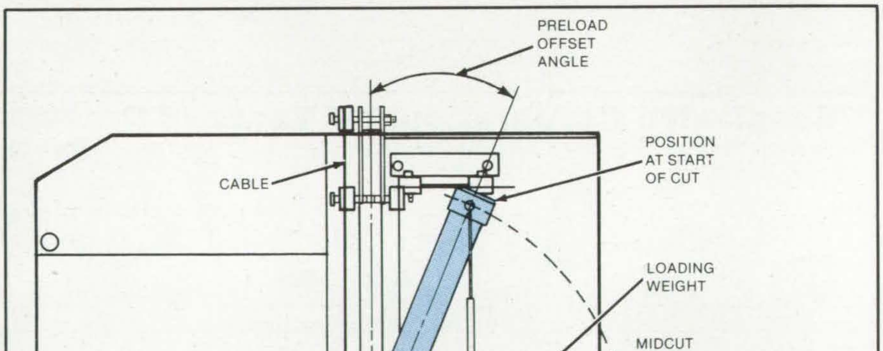
A regulating device controls the cutting force on cylindrical workpieces.

NASA's Jet Propulsion Laboratory, Pasadena, California

An attachment for a reciprocating power-saw maintains a nearly constant cutting pressure even though the kerf length varies. The attachment was developed for wire saws used to slice cylindrical silicon ingots into wafers for semiconductor devices. By maintaining constant pressure, the attachment helps to ensure smooth, flat, uniform wafers. The principle is adaptable to straight, toothed saws as well as to wire saws.

The attachment varies the perpendicular force it applies to the cutting edge: As the kerf length increases or decreases, the attachment automatically increases or decreases the cutting force by an approximately proportional amount. An arm on the attachment holds a weight at one end. As the work is elevated by a platform, the arm is rotated by a cable and pulley (see figure). The arm thus lowers its weighted end, thereby altering its leverage and the force applied to the blade. The leverage and force are greatest at the midpoint of the arm rotation where the kerf is longest. The force gradually increases as the arm approaches the midpoint and decreases as it recedes from the midpoint.

This work was done by Gregory M. Orris and John F. Gerrety of Solarex Corp. for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 108 on the TSP Request Card.*
NPO-15233



The **Lever Arm Adjusts the Cutting Force** to suit the kerf length. The diameter of the pulley that turns the arm depends on the ingot diameter.

Rotating Connection for Electrical Cables

The coil band mechanism supports and contains the cables, preventing entanglement of multiple cables.

Goddard Space Flight Center, Greenbelt, Maryland

A cable reel provides electrical connections between a fixed structure and a rotating one. The reel carries power and signal lines while allowing the rotating structure to turn up to 360° with respect to the fixed structure. The reel replaces sliprings, which are unreliable and electrically noisy. It can be used, for example, to electrically connect the arm of a robot with the body.

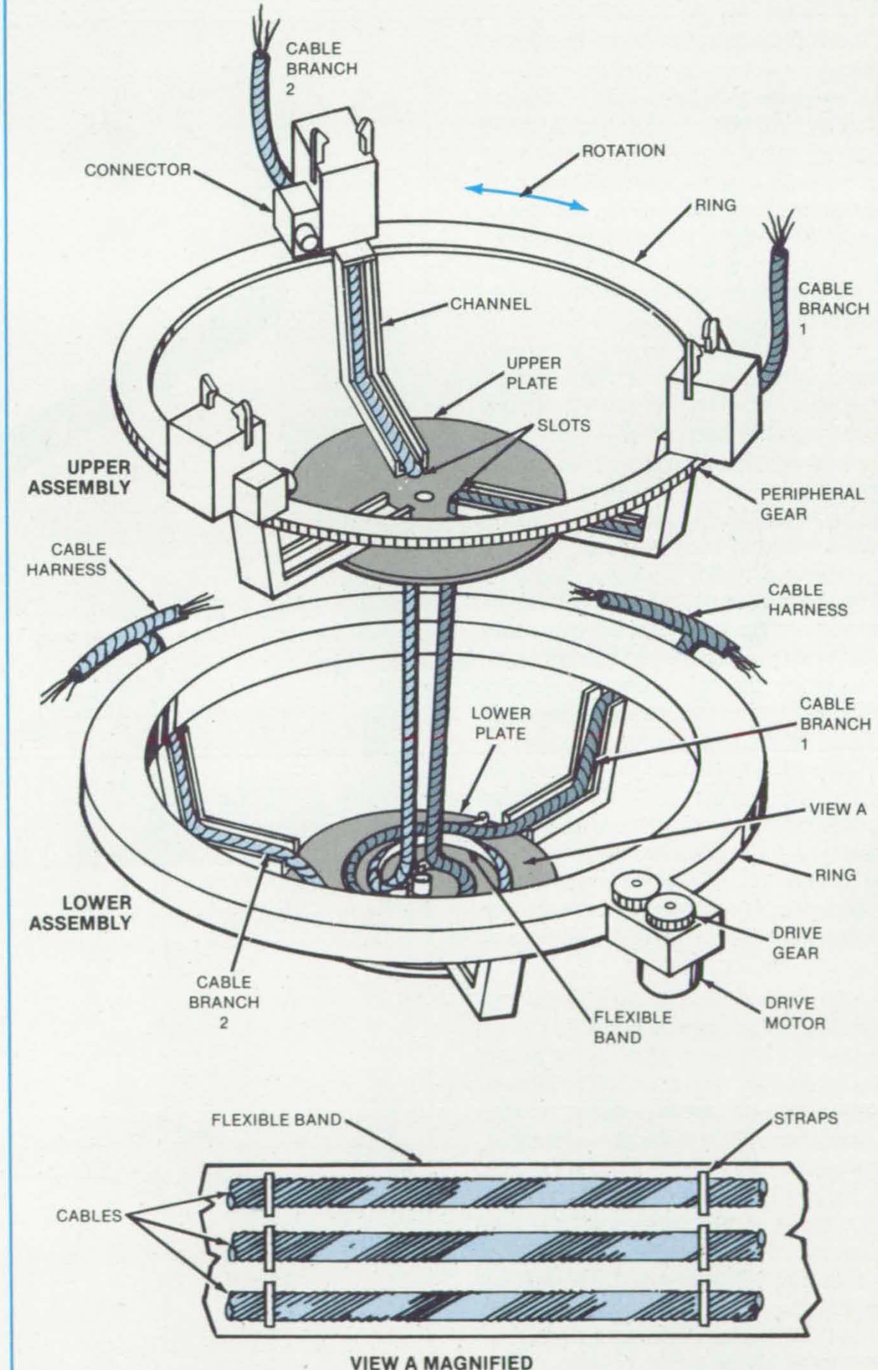
The reel releases cable to the rotating part as it turns and takes up the cable as the rotating part comes back to its starting position, all without tangling, twisting, or kinking. It includes two ring assemblies (see figure). The upper assembly is composed of a ring connected to a lower round plate by three equidistant channels. The upper assembly nests in the lower assembly, which also consists of a ring, lower plate, and connecting channels. A motor and gear train on the lower assembly engage a peripheral gear on the ring of the upper assembly; the lower unit can thus rotate the upper one. The upper and lower units are alined by a shaft that passes through their centers.

A cable harness outside the reel splits into sections that enter the lower ring, pass along separate channels into a region below the upper assembly plate, and enter passages delineated by flexible bands on the lower assembly plate. Each of the two bands is anchored at its ends to posts — on the upper plate at one end and on the lower plate at the other. Each of the cable sections is attached to a band by plastic straps at regular intervals. When the upper assembly turns counterclockwise, it tends to uncoil the bands. When the upper assembly turns clockwise, it tends to wrap the bands more tightly, thereby taking up the slack in the cable.

The cable branches extend from the bands through slots in the upper assembly plate and through channels to the upper ring. There, each of the branches joins an umbilical connector from whence it passes to the rotating structure.

This work was done by David R. Manges of **Goddard Space Flight Center.** *For further information, Circle 52 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, Goddard Space Flight Center [see page 25]. Refer to GSC-12899.



Exploded View of Cable Reel shows paths of cable branches. With the three channels on the upper and lower assemblies, the reel can accommodate up to three output and input branches of the cable.

More Secure Fastening for Tracked-Vehicle Pads

Rod-through-tab fastening prevents accidental loss of pads.

NASA's Jet Propulsion Laboratory, Pasadena, California

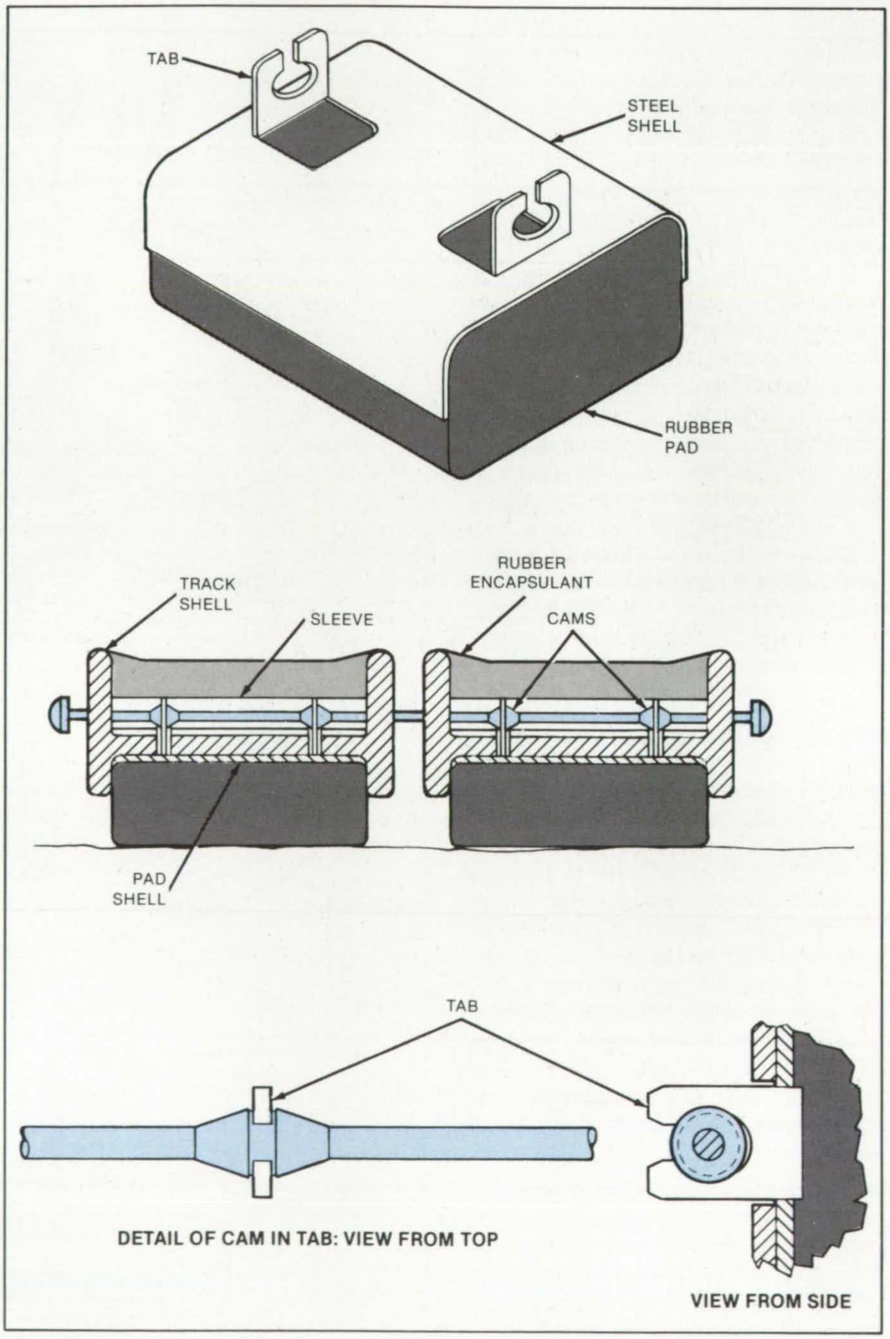
A way of fastening road pads on tracked vehicles would ensure that the retaining tabs are properly installed and that they are less likely to fail from shock or pad squirming when a tracked vehicle turns. There is no risk that squirming of a pad might overcome the retaining force of the rubber encapsulation or that the teeth of a split-collet fastener might shred the soft-iron projections on the pad shell, thereby causing inadvertent release of the pad.

As in the split-collet scheme, a rod with cam surfaces enters the tab holes through small slots. As before, the retaining tabs are die-cut from the steel-pad shell.

In one variation, the rod bears four sets of tapered cams with a central groove on each cam (see figure). For assembly, a rod is translated slightly along its axis so that cams are displaced slightly from their final positions. The rubber pad and its shell are inserted in the track; the tab slot slips easily over the narrow rod. The rod is thereby centered in the tab hole. Next, the installer strikes the end of the rod with a hammer. This forces the large-diameter sections of the tapered cams through the tab holes. As this happens, the tabs snap into the central grooves on the cams. With the tabs in this position, the rod holds the pads securely. For disassembly, the procedure is reversed: A hammer blow on the rod forces the cams through the tabs. The pads are then drawn away from the rod.

Slight misalinements are accommodated by the compliance of the rod, which can bend a moderate amount. For protection against dirt and rocks, the rod can be passed through sleeve sections within a rubber encapsulant in the tank-tread shell.

In another variation, the rod is threaded at one end. Both ends of the rod contain recesses for a hexagonal wrench. Thus, from either end, the rod can be screwed into or out of a mating thread in the track-shell wall so that the cams are engaged or disengaged from the tabs. The installation procedure takes longer in this variation, but the rods are less vulnerable to accidental release by a blow. In addition, the rods are not free to rattle when the road pads are not in place.



A **Rod Extending** through the track shells and tabs on pad shells includes grooved cams to secure the pads. The detail view shows the position of the groove in a tab hole.

This work was done by Earl R. Collins, Jr., of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 3 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 25]. Refer to NPO-16321.

Compact Hybrid Automotive Propulsion System

Front-wheel-drive system includes an internal-combustion engine and an electric motor.

NASA's Jet Propulsion Laboratory, Pasadena, California

The power train illustrated in the figure is proposed for an experimental vehicle that would be powered by both an internal combustion engine and an electric motor. Intended for a front-wheel drive automobile, the power train could be mass produced using existing technology.

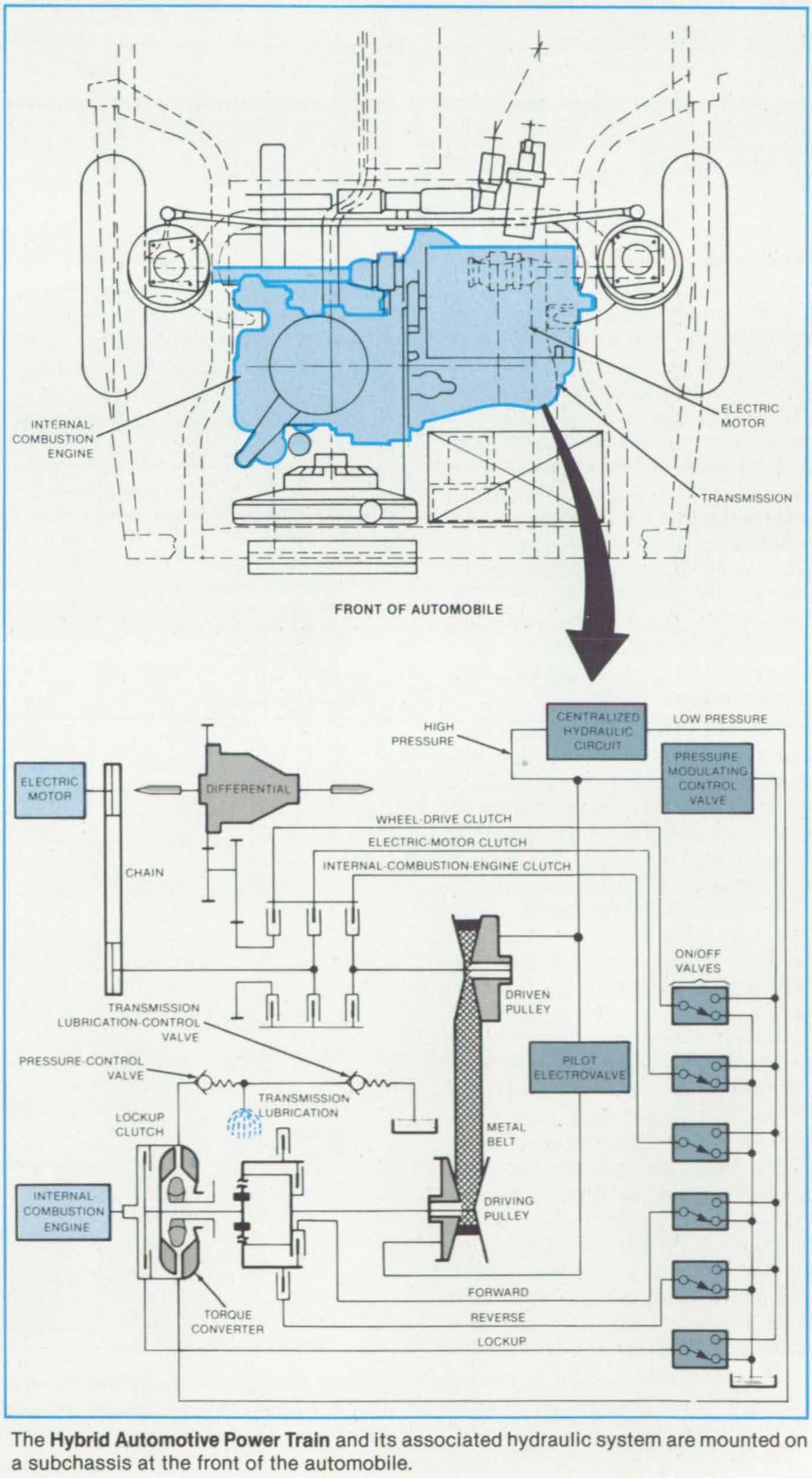
The system includes an internal-combustion engine, an electric motor, a continuously variable transmission, a torque converter, a differential, and control and adjustment systems for the electric motor and transmission. The continuously variable transmission is integrated into a hydraulic system that also handles power steering and power brakes. Batteries for the electric motor would be mounted elsewhere in the vehicle.

A microprocessor-based computer located in the dashboard selects and controls such operating modes as the use of the internal-combustion and electric motors individually or in parallel, recharging the batteries with the internal-combustion engine while the vehicle moves or stands still, and regenerative braking. The computer system can be characterized by four logical subdivisions: The first of these, energy management, supervises the remaining three, which are internal-combustion-engine control, electric-motor control, and transmission control.

To allow better damping of vibration and to ease assembly and disassembly, the propulsion components are mounted on an auxiliary chassis fitted with shock-absorbing mounts, one on the engine side and two on the transmission/differential side. The auxiliary chassis also supports the front suspensions, the steering system, and the hydraulic system.

The internal-combustion engine is mounted transversely and tilted 20° forward to reduce height and to allow room to mount the electric motor on the transmission. The transmission and differential are in line with the internal-combustion engine. Combustion power is transmitted to the wheels via a torque converter with a lockup clutch and a metallic-belt continuously variable transmission. The electric motor is connected directly to the transmission output shaft.

Transmission power losses are minimized by a dry-sump lubrication system. A low-pressure pump in the hydraulic system supplies oil. Solenoid-operated proportional



The **Hybrid Automotive Power Train** and its associated hydraulic system are mounted on a subchassis at the front of the automobile.

valves modulate the oil pressure to control the transmission ratio and belt tension. On/off valves fed by a single modulating valve control various transmission and converter clutches.

A thorough analysis of vibration and noise characteristics of the entire propulsion system would be required before production. In addition, the effects of the hood and fenders on air circulation and temperature distribution should be analyzed.

This work was done by Giorgio Lupo of Centro Richerche Fiat S.p.A. for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 33 on the TSP Request Card.*
NPO-16117

$LaNi_5$ Hydrogen-Absorption Cryogenic System

Three thermally cycled absorbers/desorbers act as compressors.

NASA's Jet Propulsion Laboratory, Pasadena, California

A hydrogen-absorption refrigerating system provides about 650 mW of cooling at 20 to 29 K in continuous, closed-cycle operation. The system is shown schematically in Figure 1. Hydrogen exhausting from the cryogenic stage is driven by its pressure of ~6 atm (600 kPa) through a train of heat exchangers. At room temperature, the hydrogen is absorbed by one of three $LaNi_5$ absorption units (Figure 2, top). The temperature of the $LaNi_5$ is then raised by an electric heater (or by waste heat through a heat switch) to ~100° C, causing it to desorb the hydrogen at a pressure of ~40 atm (4 MPa). This very large pressure/temperature relationship is characteristic of the reaction of hydrogen with a family of rare-earth compounds known as hydrides.

While one of the $LaNi_5$ units is being heated, one or both of the others are being cooled by water back to room temperature. An electronic timer controls the thermal cycles of the units: The heating and cooling intervals are each 3 minutes long, and each unit is operated 120° out of phase with the others so that absorption and desorption occur continuously. Check valves prevent backflow that would cause interference between absorbing and desorbing units. Thus, the timed combination of three units acts as a continuous compressor. The 40-atm pressure drives the H_2 gas back into the chain of heat exchangers toward the cryogenic end.

In the first heat-exchanger stage, the H_2 is cooled by water to room temperature. The H_2 then passes through a 2-m-long coiled counterflow heat exchanger, where H_2 coming from the cryogenic stage reduces the temperature to about 80 K. The counterflow heat exchanger coils are mounted in the cryogenic Dewar along with the colder stages and are surrounded by closed-cell insulation to minimize parasitic heat leaks.

The H_2 is cooled to 77 K by passing through a 1-m heat-exchanger loop immersed in liquid N_2. At this point, the heat-exchanger coils enter a high-vacuum container that is also immersed in liquid N_2 (Figure 2, bottom, left side). A 2-m-long counterflow heat exchanger in the vacuum uses H_2 exhausting from the cryogenic stage to cool the entering H_2 to slightly above the boiling point.

The H_2 then expands through a special valve to a pressure of ~6 atm (600 kPa) and is thereby cooled by the Joule-Thomson effect (Figure 2, bottom, right side). As a result, the H_2 is partially liquefied. The liquid H_2 is collected in a small chamber and boiled to provide constant-temperature cooling at 29 K. (A lower temperature can be reached if lower

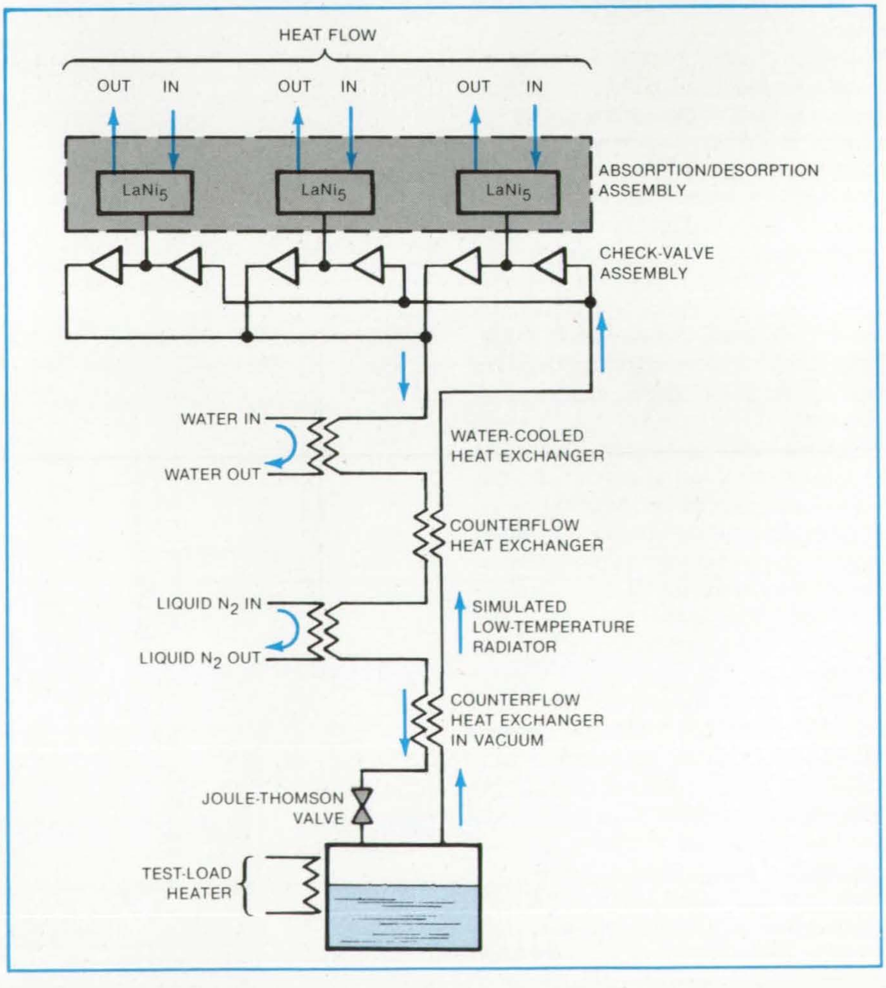


Figure 1. The **Hydrogen-Absorption Refrigerating System** includes three $LaNi_5$ absorption units at the room-temperature end and a Joule-Thomson expansion valve at the cryogenic end. Except for the control and check valves and electrical relays, there are no moving parts.

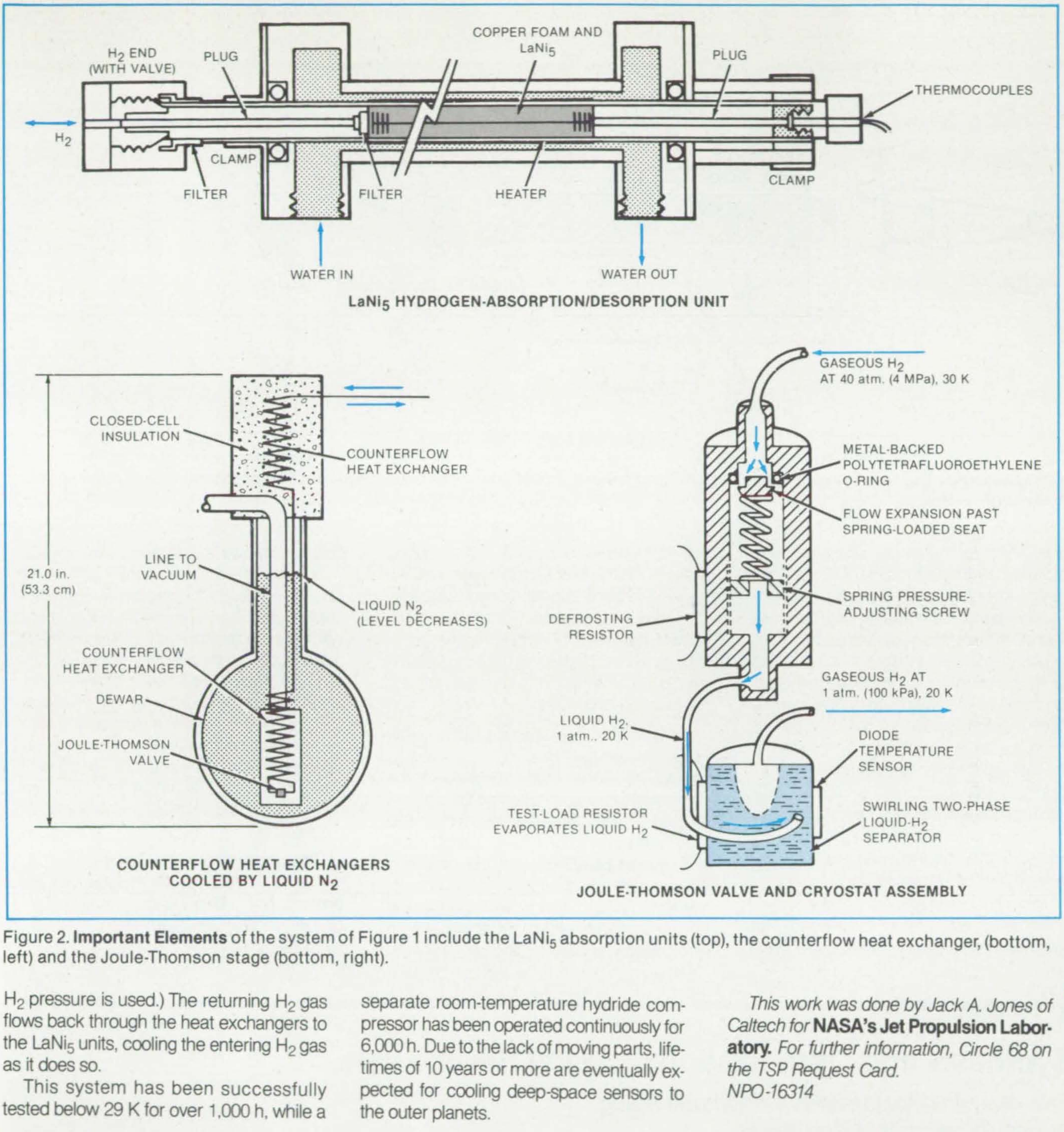


Figure 2. **Important Elements** of the system of Figure 1 include the $LaNi_5$ absorption units (top), the counterflow heat exchanger, (bottom, left) and the Joule-Thomson stage (bottom, right).

H_2 pressure is used.) The returning H_2 gas flows back through the heat exchangers to the $LaNi_5$ units, cooling the entering H_2 gas as it does so.

This system has been successfully tested below 29 K for over 1,000 h, while a separate room-temperature hydride compressor has been operated continuously for 6,000 h. Due to the lack of moving parts, lifetimes of 10 years or more are eventually expected for cooling deep-space sensors to the outer planets.

This work was done by Jack A. Jones of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 68 on the TSP Request Card.*
NPO-16314

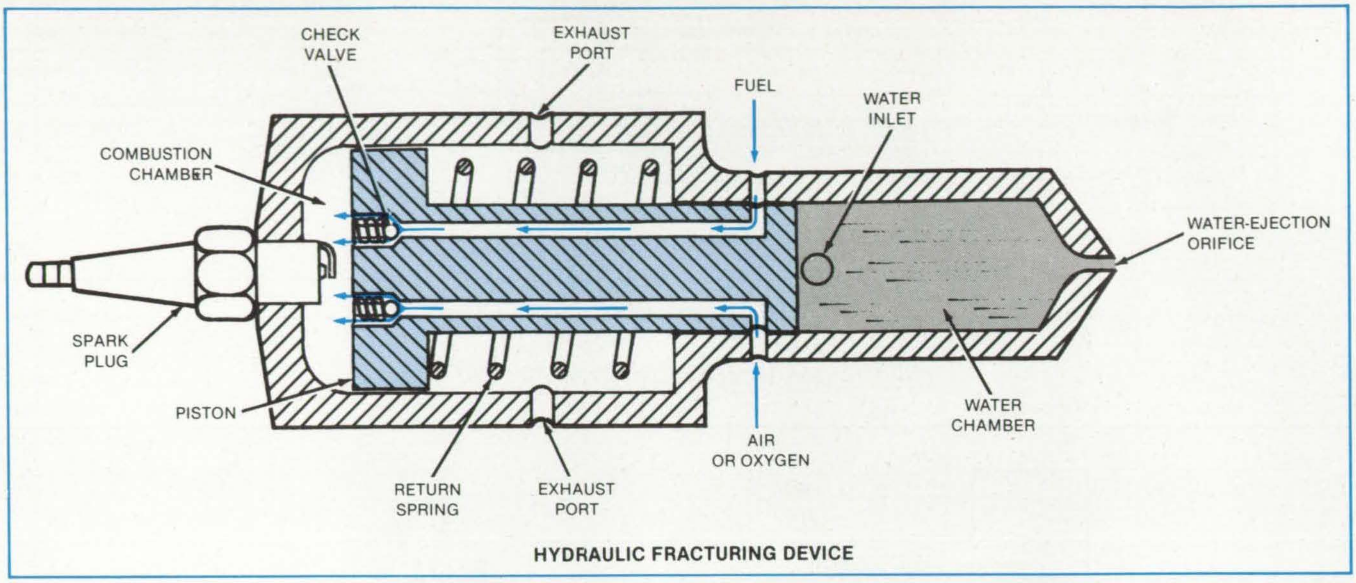
Pulsed, Hydraulic Coal-Mining Machine

Internal combustion would directly drive a hydraulic cutter.

NASA's Jet Propulsion Laboratory, Pasadena, California

In a proposed coal-cutting machine, a piston forces water through a nozzle, expelling a pulsed jet that would cut into the coal face. The spring-loaded piston reciprocates at the end of its travel to refill the water chamber. The machine would be a one-cylinder, two-cycle, internal-combustion engine, fueled by gasoline, diesel fuel, or hydrogen.

Current hydraulic coal-mining machines expel steady jets of water at high pressure. These machines are costly and wear rapidly. The pumps are located far from coal



The **Combination Engine and Pump** would push bursts of water through an orifice to dislodge coal from the working face of an underground mine.

faces and must deliver high-pressure water to the faces through hoses. Despite their heavy armor, the hoses can burst under repeated flexure and abrasion and thus pose a constant hazard to miners and equipment.

The proposed internal-combustion pump, in contrast, can be placed in the cutting head at the coal face. Water can be supplied at lower pressure, since the full cutting pressure is not needed for delivery to the coal face. Moreover, a pulsed water jet might be made to cut more efficiently than a conventional steady jet: If the pulse rate matches the mechanical-resonance frequency of the coal face, pieces of coal will flake off the face more readily.

When the piston is in the position shown in the figure, fuel and air (or oxygen) inlet ports are alined with internal passages in the piston. Pressure in the fuel and air supply lines opens the inlet check valves, and the fuel and air enter the combustion chamber. The mixture is ignited, driving the piston toward the water chamber. As the piston moves, it compresses the return spring and expels the water from the chamber through the ejection orifice with great force.

At the end of its power stroke, the piston clears the exhaust ports to expel exhaust gases. The spring returns the piston to the combustion chamber, opening the water in let port to refill the chamber. The cycle then repeats.

The water-pulse frequency can be altered by several means to match the coal characteristics. Ignition timing and gas-supply pressure can be varied, either singly or in combination. In addition, the spring can be changed to alter the reciprocation speed.

The internal-combustion mining machine also promises to be more efficient than conventional hydrojet machines. In conventional machines, more energy conversions occur, each reducing efficiency: For example, there are efficiency losses in generating electrical energy by the electrical utility or generators at the mine and in conversion of this electrical energy to mechanical energy again at the pump. In the proposed machine, fuel would be converted more directly into the mechanical energy of the water jet.

This work was done by Earl R. Collins, Jr., of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 41 on the TSP Request Card.*
NPO-15859

Synthesis and Optimization of Spiral Bevel Gears

Two mathematical models help in optimizing the design of spiral bevel gears.

Lewis Research Center, Cleveland, Ohio

Spiral bevel gears have widespread applications in the transmission systems of helicopters, airplanes, trucks, automobiles, tanks, and many other machines. Major requirements in the field of helicopter transmissions are improved life and reliability, reduction in overall weight (i.e., a large power-to-weight ratio) without compromising the strength and efficiency during the service life, and reduction in the transmission noise.

To calculate gear-tooth strength, life, and noise generated by the gear mesh, one must first have a dimensional description of the gear tooth and the pinion tooth. Normally, such a description is unavailable at the design stage for spiral bevel gears, whereas there is a simple equation (involute equation) that describes the shape of spur gears. The reason there is no equation for the spiral bevel gears is that the gears are generated by complicated motions of the gear manufacturing machines (cutting and grinding). The gear-tooth shapes are not described directly by equations — only by the setup conditions of the manufacturing equipment (machine settings).

New math models are used to resolve this problem. In this approach, direct relationships between the principal curvatures and directions of the tool surfaces and those of the generated gear surface are obtained. Therefore, the principal curvatures and directions of gear-tooth surface are obtained without trying to define the complicated equations of these surfaces, which is (in most cases) impossible to do.

In essence, what is done is to replace the actual generated tooth surface with a mathematical conjugate approximation. The tooth surfaces of spiral bevel gears are, in theory, replaced (or approximated) by conjugate tooth surfaces. These surfaces can be generated: (1) by two conical surfaces that are rigidly connected with each other and are in linear tangency along a common generatrix of tool cones and (2) by a conical surface and a surface of revolution that are in linear tangency along a circle.

The math models make it possible to explore the existence of optimized designs. Therefore, designers and researchers can now solve the Hertzian contact stress problem and define the dynamic capacity and contact fatigue life without using a complex analysis based on machine settings.

In summary, the following two approaches were developed out of the simplified mathematical analysis: The first approach utilizes effective methods of kinematic and analytic geometry (e.g., matrices for coordinate transformation and kinematic relations between motions of contact point and unit normal vector of two surfaces). With the aid of these analytical tools, the Hertzian contact problem for conjugate tooth surfaces can be solved. These results are useful in determining compressive load capacity and surface fatigue life of spiral bevel gears. The second approach is a general theory of kinematical errors caused by manufacturing and assembly errors. This theory may be used to determine the analytical relationship between gear misalinements and kinematical errors that produce noise. In the past, the influence of manufacturing errors and assembly errors on two surfaces in contact could be determined only by using numerical methods and a digital computer.

This program was written by F. L. Litvin, Pernez Rahman, and Roberg N. Goldrich of the University of Illinois for **Lewis Research Center.** *Further information may be found in NASA CR-3553 [N82-25516/NSP], "Mathematical Models for the Synthesis and Optimization of Spiral Bevel Gear Tooth Surfaces" [$13]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*

LEW-13920

Puncture-Tolerant Heat Radiator

Coolant in a rotating shell would not escape through small punctures.

NASA's Jet Propulsion Laboratory, Pasadena, California

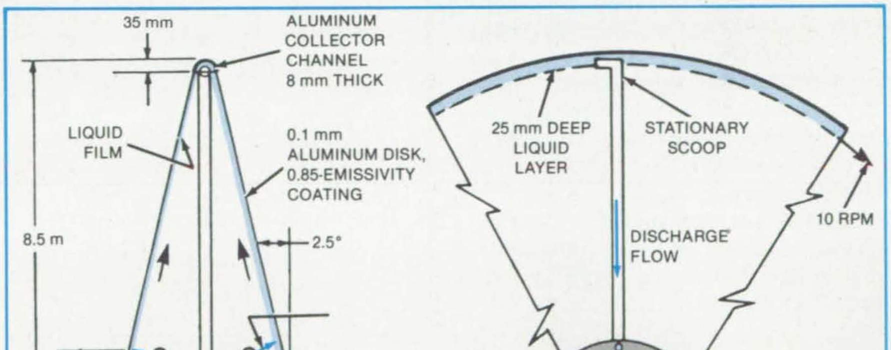
A heat radiator originally proposed for electric powerplants in space would not lose coolant through small punctures and does not require heavy, cumbersome shielding as protection against the punctures. Small holes in the radiator would cause no outpouring of coolant; only the small amount that might evaporate through the hole would leave the system.

The radiator for a 100-kW powerplant, for example, consists of an 8-mm-thick aluminum shell, 17 m in diameter, formed by two shallow cones (see figure). The shell has a highly emissive coating on the outside. It is mounted on a bearing and drive-motor assembly at its center. Inside are stationary coolant-injection nozzles about 2 m from its center and a stationary scoop for collecting the coolant just inside its periphery.

The shell rotates at a speed of 1 rad/s (about 10 rpm). The silicone-oil coolant at a temperature of 390 K is sprayed from the nozzles onto the inside surface of the disks at a rate of 1.9 kg/s.

The sprayed coolant forms a film on the inside of the shell and flows toward the circumference by centrifugal force. The cone angle of the shell members gives rise to a component of centrifugal force that pushes the flowing liquid against the shell walls, thereby ensuring close contact for efficient heat transfer.

The liquid takes 30 s to reach the circumference, thinning from 0.14 mm near the injection point to 0.08 mm near the periphery.



A **Film of Silicone Oil** flows along the interior surface of an aluminum shell, transferring much of its heat to the shell and the outside. The unit can provide cooling for a 100-kW nuclear powerplant.

It cools to 310 K as it transfers heat to the shell, which in turn radiates the heat at a rate of 250 kW.

The coolant collects in a layer 25 mm thick in a groove at the periphery and thus can be scooped up readily. It enters the scoop with a velocity of 8.5 m/s — enough to maintain flow through the discharge line and heat exchanger.

If the outside surface of the shell is coated with an antiwetting agent, then when the shell is punctured, it tends to hold the liquid through capillary action. In that case, only the liquid evaporating through the hole is lost from the system, even with holes as large as 10 mm in diameter.

The shell could accumulate 150 mm^2 of punctures and still lose no more than 30 kg of coolant by evaporation in 10 years — 10 percent of its initial amount. This would leave ample liquid for proper cooling. The total radiator mass is 430 kg.

This work was done by David G. Elliott of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 23 on the TSP Request Card.*
NPO-16401

Dolly Swivel for Forklift

Large dollies are maneuvered like trailers.

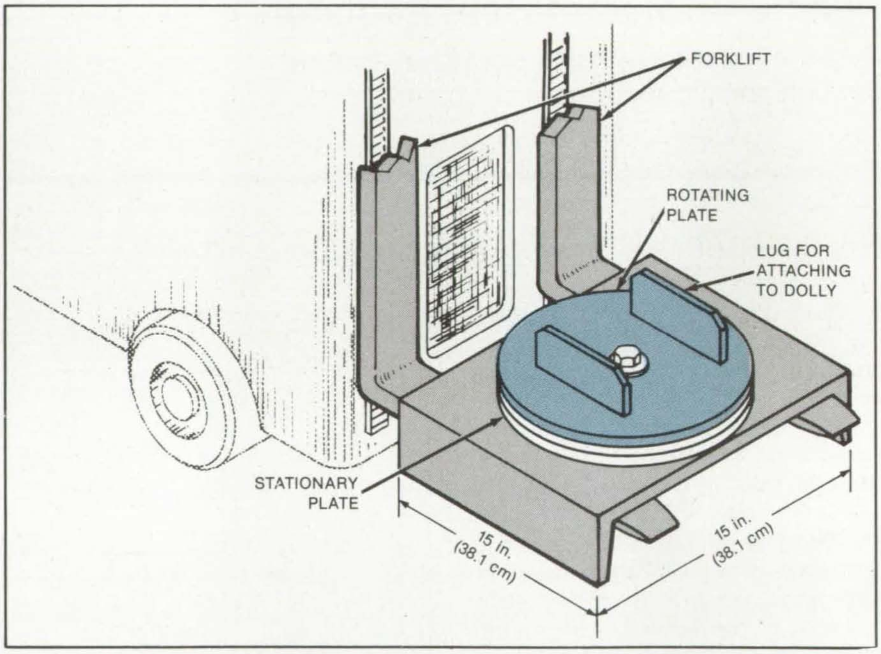
Marshall Space Flight Center, Alabama

An adapter enables a large dolly to be towed or pushed by a forklift truck and to swivel on the forklift on turns. The adapter prevents the dolly from slipping off the forks and damaging the loads.

The adapter includes a round steel plate with lugs that connect to the dolly (see figure). The plate is centered by a bolt and rotates on a large washer of almost the same diameter as that of the plate. The large washer is bolted to a round plate that rests on an inverted channel.

The forklift is slipped under the channel; it lifts the channel off the floor, thereby lifting one end of the dolly. The dolly is then maneuvered by the forklift in the way that trailers are maneuvered by tractors.

This work was done by James T. Jones and P. B. Arbino of Rockwell International Corp. for **Marshall Space Flight Center.** *For further information, Circle 9 on the TSP Request Card.*
MFS-19866



The **Swivel Adapter** rests on a forklift and provides a pivot for towing a dolly.

Lightweight, Switchable Peristaltic Pump

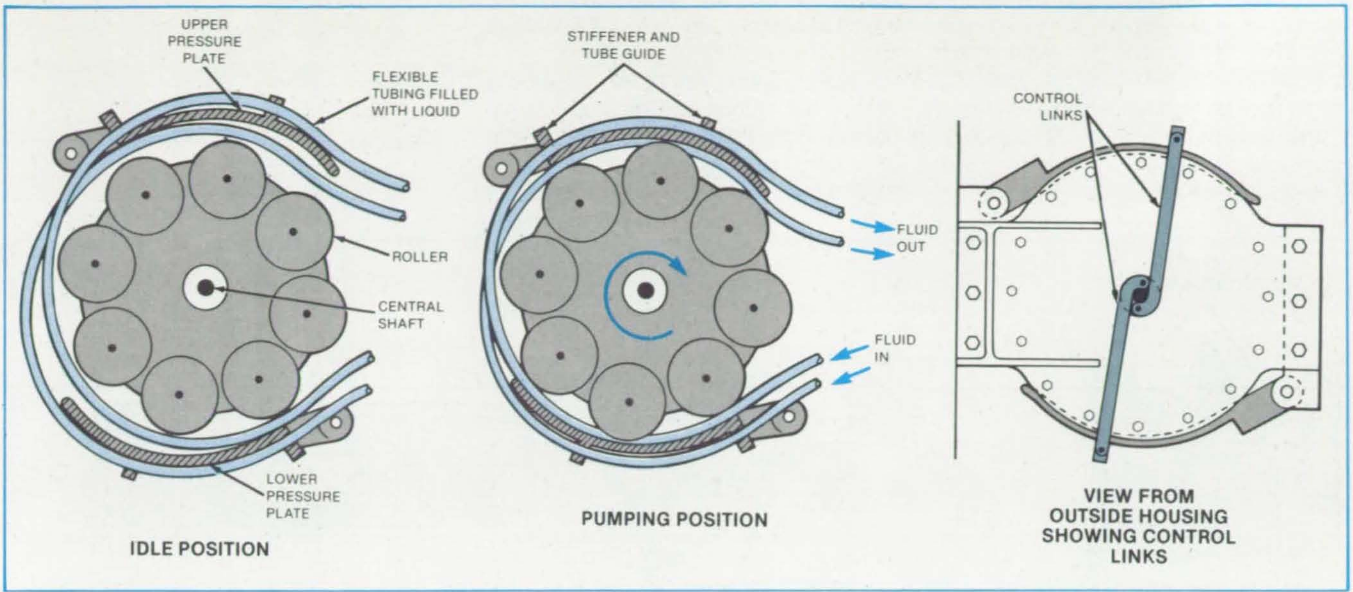
Dual-mode pump ensures crimp-free channels for liquid delivery.

Marshall Space Flight Center, Alabama

A proposed peristaltic pump moves liquids through 50 or more channels simultaneously. A special feature of the pump is that its pressure plates could be remotely set between idle and operating positions.

In conventional peristaltic pumps, it is necessary to pre-position the plates for the operating mode. As a consequence, the elastic channels are pinched for an indeterminate period before operation and thereby can acquire a set that reduces pumping efficiency. In the new design, it is unnecessary to pre-position the pressure plates and, therefore, also unnecessary to enter the pump housing to move the plates into the operating mode.

Two rows of flexible tubing constitute the channels for liquid flow (see figure). A pres-



When the Peristaltic Pump Is Not Used, the pressure plates are separated from the tubing and roller (idle position). To move liquid through the tubes, the plates are pressed against them while the rollers are rotated (pumping position). For lightness, the rollers are hollow.

sure plate is juxtaposed over each row of tubes. The tubes are laced through holes in ridges in the plates: The ridges hold the tubes securely and stiffen the plates. In the idle position, the plates are separated outwardly from the roller assembly that lies on the inner side of the tubes.

In the pumping position, the plates are pressed against the roller assembly. The rollers squeeze the tubes as they rotate, pushing discrete volumes of liquid along the tubes in rhythmic progression.

A pulley and lanyard that can be moved manually from a distance could be attached to the central shaft that drives the control links of the pressure plates to switch the plates to and from the pumping position. Alternatively, a rotary actuator motor can be used to move the plates into and out of the operating position.

This work was done by Robert R. Below of **Marshall Space Flight Center.** *For further information, Circle 107 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, Marshall Space Flight Center [see page 25]. Refer to MFS-28059.

Bistable Articulated Joint

The joint springs to fully extended or fully folded positions.

NASA's Jet Propulsion Laboratory, Pasadena, California

A joint with a four-bar-linkage geometry has the following attributes:

- The two shafts, panels, or other similar items connected by the joint can swing through a full 180° arc, making it useful in equipment that must fold compactly for storage;
- A torsion spring in the joint applies a torque that holds the joint in either its extended or folded position and biases out any play in the joint; and
- The joint automatically locks in its extended position.

The joint combines zero backlash, positive locking, and centerline pivoting. It could be used in folding tool handles, portable antenna booms, and many other deployable structures.

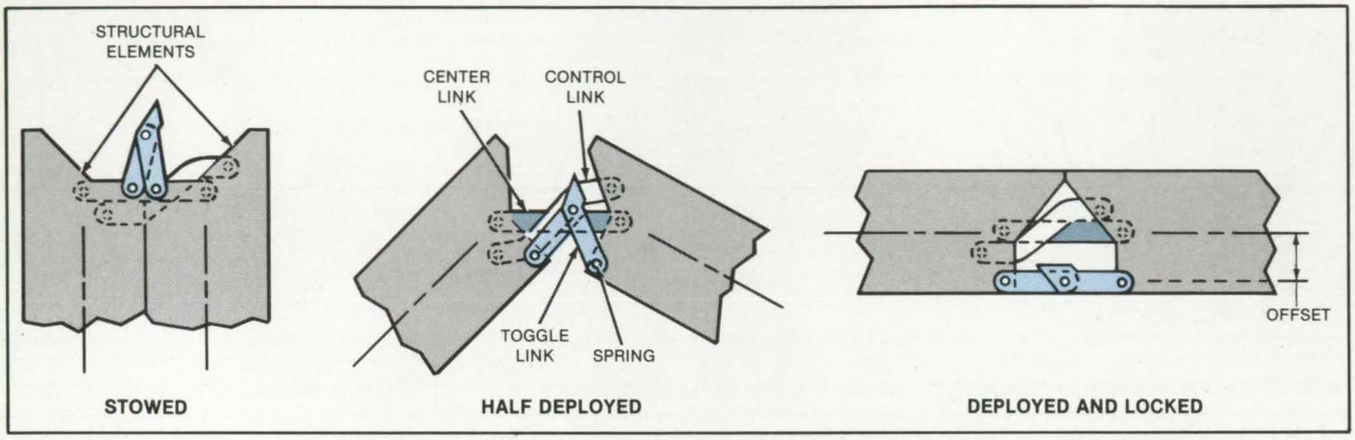
The two structural elements to be joined are connected by three links: Two of fixed length and one hinged in the middle (see figure). The center link is the shortest. It lies on the centerline of the assembly when the joint is in its extended position. The S-shaped control link crosses from one side of the centerline to the other. Together, the center and control links constrain the motion of the joint so that it has only one degree of freedom.

The two-piece toggle link is hinged in the middle. Its attachment points are offset to one side of the centerline. As the joint is fully extended, the two halves of the link line up, and the motion of the toggle link is stopped by a pad. At the same time, the ends of the joint assembly on the side opposite the toggle link just come into contact. The combined action of a torque applied to the toggle link (see below) and this contact places the center link under tension and the two halves of the toggle link under compression. This locks the joint in the open position and permits the joint to withstand both compression and tension loads.

A torsion spring acts at the end of the toggle link that is attached on the side of the centerline opposite the control-link attachment. The geometry of links and attachment points interacts with the spring torque in such a way that the spring tends to bias the joint toward either extended or folded positions. For the same reason, the spring also biases out any backlash in the joint linkage. By changing the link sizes, or attachment points, or the offset distance between the hinged link and the centerline, both the angle at which the biasing torque on the joint changes sign and the ratio of the open- and closed-position torques can be changed.

This work was done by Norwood D. Craighead II, Richard J. Preliasco, and Timothy D. Hult of Lockheed Missiles & Space Co., Inc., for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 25 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 25]. Refer to NPO-16038.



The **Bistable Articulated Joint** is shown in various stages of deployment. The links are placed such that the spring torque biases the joint toward either extended or folded position. When the joint is fully extended, the toggle link snaps against a stop, thereby locking the joint.

Compensating for Shrinkage in Machined Ceramics

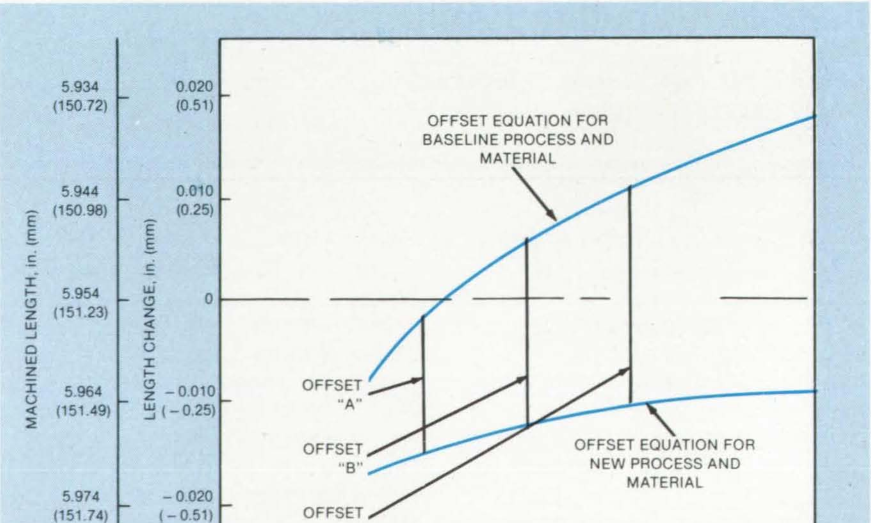
The machine tool automatically compensates for the shrinkage that occurs when the ceramic is baked.

Lyndon B. Johnson Space Center, Houston, Texas

A technique originally developed for Space Shuttle surface-insulation tiles insures that machined ceramics shrink to the correct dimensions after they are baked in a kiln. The new method automatically compensates during machining for the shrinkage that will occur later, when the part is baked. It is applicable to numerically controlled machines that include a provision to adjust for variations in cutting-tool size, but do not provide for automatic verification of the dimensions of machined parts. Because of the lack of verification, the machine can be "deceived" into compensating for a fictitious tool size.

A typical numerical-control program includes a provision for entering a letter-code control signal to denote the tool size and an equation (see figure) that calculates the offsets that compensate for part shrinkage. This offset equation applies to only one baseline material and treatment schedule and is derived from prior measurements on parts of the same composition and process.

For parts of other compositions and processes, shrinkages must be measured anew. But rather than rewriting the program by revising the offset equation for each new



Letter Codes denote the machine-tool offset to be used for a given blank thickness. The offset depends on the composition of the part and on the fabrication process. The dimensions shown here are for the example only.

material or process, the difference between the baseline and the new case is calculated for each part and assigned a letter code corresponding to an equivalent tool size.

Each part to be machined is usually accompanied by a computer card punched with such relevant information as the source, date of fabrication, method of fabrication, and material. The card also includes the applicable letter code. When the part is brought to the machine, the card is fed into the machine, which reads the letter code and makes the offset adjustment.

This work was done by L. Aguilar and B. T. Fitchett of Lockheed Missiles & Space Co., Inc., for **Johnson Space Center.** *No further documentation is available.*
MSC-20684

Replaceable Transfer Tube for High-Pressure Cavities

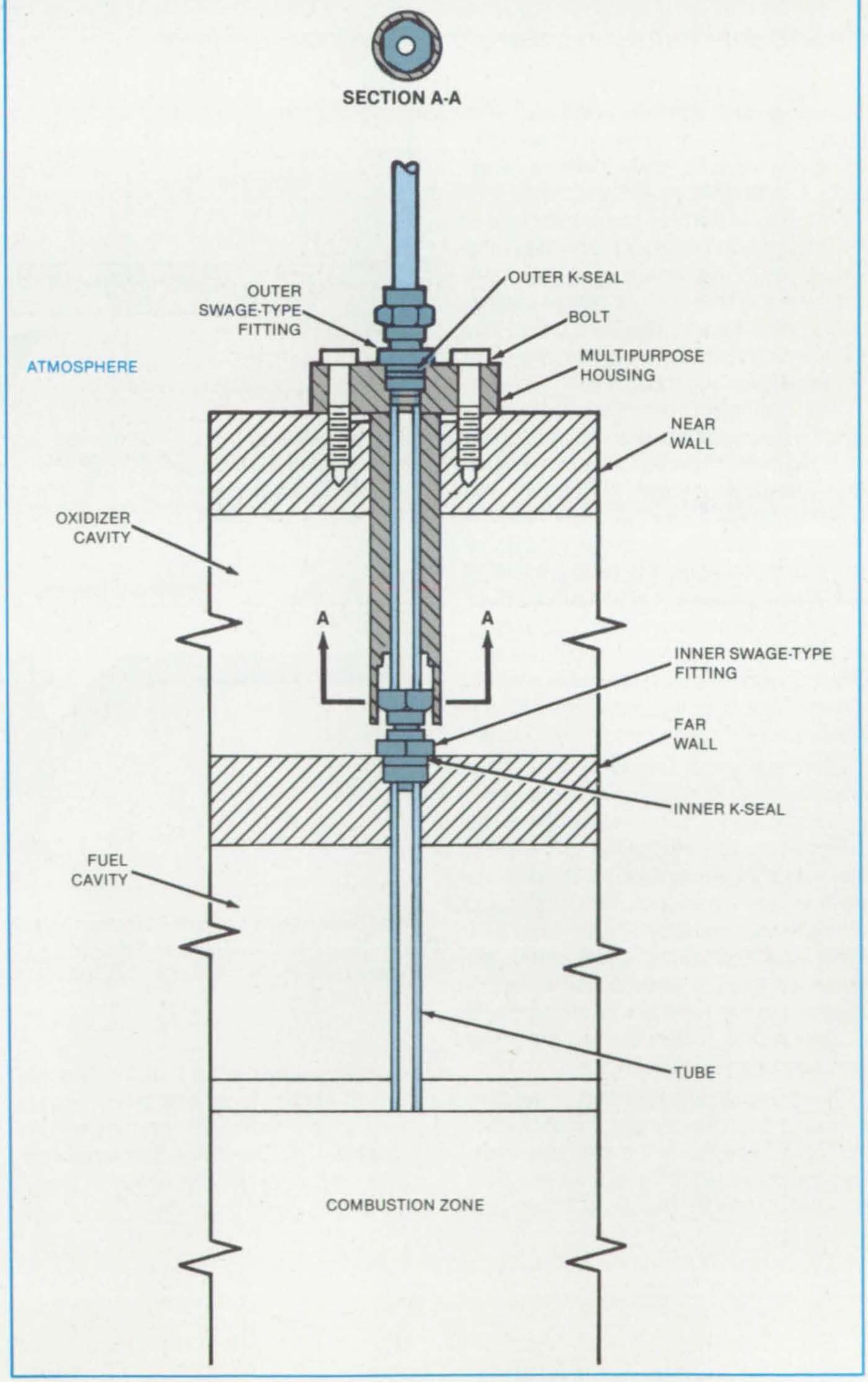
Materials can be carried through two high-pressure zones without leakage.

Marshall Space Flight Center, Alabama

A set of fittings allows a fluid to be injected into an inner chamber, passing through two cavities containing fluids at different high pressures. The injection tube can readily be replaced, and the fittings provide a tight seal between the cavities after replacement. The tube and fittings are made from off-the-shelf parts, and thus are both familiar to workers and relatively inexpensive. Previously, injection tubes were welded in place and could not be removed easily and replaced to accommodate design changes.

The tube-and-fitting arrangement (see figure) was developed for introducing a hypergolic igniter fluid into the combustion zone of a rocket engine from outside the engine. The tube passes through one cavity containing oxidizer and one containing fuel before reaching the combustion zone. The seals at the cavity walls must prevent leakage of the pressurized oxidizer into the atmosphere or into the lower pressure fuel cavity. It must also prevent leakage of the igniter fluid into the fuel cavity, since the igniter and fuel are highly reactive and could destroy the engine if mixed prematurely.

The tube-assembly-and-sealing concept can be adapted to a variety of other applications. For example, it can be used to introduce liquids or gases into test chambers or reactors or to introduce film cooling into pressurized machinery. It can be used to transfer one fluid through another, incompatible fluid. It can also be used to route optical fibers or instrumentation wires into equipment for internal inspection or monitoring.



Swage-Type Fittings surround a central tube, securing it and preventing leakage to or from the pressurized cavities through which it passes. The swage-type fittings and other hardware are conventional and readily available.

The assembly procedure is as follows:

- The inner swage-type tube fitting and seal are installed in the far wall of the oxidizer cavity. The fitting is tightened with a torque wrench on an extended socket.
- The inner fitting nut and ferrule, the multipurpose housing and seal, and the outer fitting and seal are installed loosely on the transfer-tube core.
- The tube is inserted through the holes in the chamber walls and the outer fitting is slipped over the tube into its proper position.
- The inner nut is torqued in place by using the multipurpose housing as a socket wrench.
- The housing is adjusted to aline its bolt holes with those in the near wall of the oxidizer cavity and bolted in place. The housing then prevents the inner nut from backing out of position.
- The outer swage-type fitting is torqued into place, and its nut and ferrule are tightened.

This work was done by Don Sorensen and Jacob Rietdyk of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-19775

Heat-Powered Pump for Liquid Metals

Thermoelectric device extracts heat energy from the liquid it pumps.

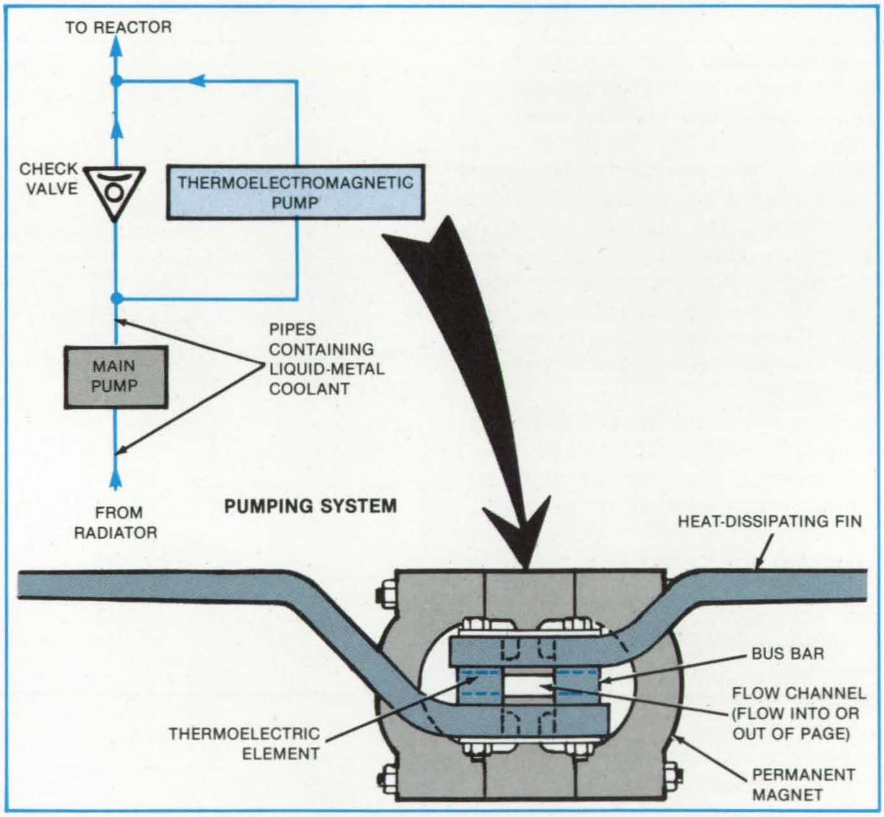
NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed thermoelectromagnetic pump for liquid metal would be powered by waste heat; it would need no battery, generator, or other external energy source. In a thermoelectric element, some of the heat in the metal liquid flowing through the pump would create electrical current that interacts with the field of a permanent magnet surrounding the unit. The force created by the interaction of the current and the magnet would push the liquid metal.

The thermoelectromagnetic pump (see figure) was developed as an auxiliary pump for liquid-metal coolant in a nuclear reactor. It is just large enough to circulate the amount of coolant necessary to remove the decay heat from the reactor immediately after shutdown, when the heat generation rate is about 5 percent of that at full power. Unlike the main pump, which may be electrically powered, the thermoelectric pump is unaffected by electrical failures in external circuitry. As long as there is decay heat to be removed, the unit can perform its function.

The thermoelectromagnetic pump is hydraulically in series with the main pump, but in parallel with a check valve. Thus, the pump offers little resistance to the main flow, which passes through the check valve. As long as the main pump is operating, the check valve is held open by the main flow. When the main pump shuts down, the check valve closes, and the thermoelectromagnetic pump continues or augments its pumping action. Neither a valve-control system nor other valves are needed.

The pump is self-regulating. If the flow through it becomes too fast, the back electromotive force due to the motion of the liquid metal will equal or exceed the thermoelectric voltage. The unit will then stop pumping. Further forcing of the flow will cause the pump to act as a thermoelectric heat pump or cooler, with resistance to the increased flow. Conversely, the pump will increase its flow as the flow forced through it by the main pump decreases.



The **Thermoelectromagnetic Pump** turns part of the heat in the liquid metal into pumping energy. In combination with the primary pump or on its own, the thermoelectric pump circulates the coolant between the reactor and a radiator.

This work was done by Robert J. Campana of GA Technologies for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 24 on the TSP Request Card.*
NPO-16457

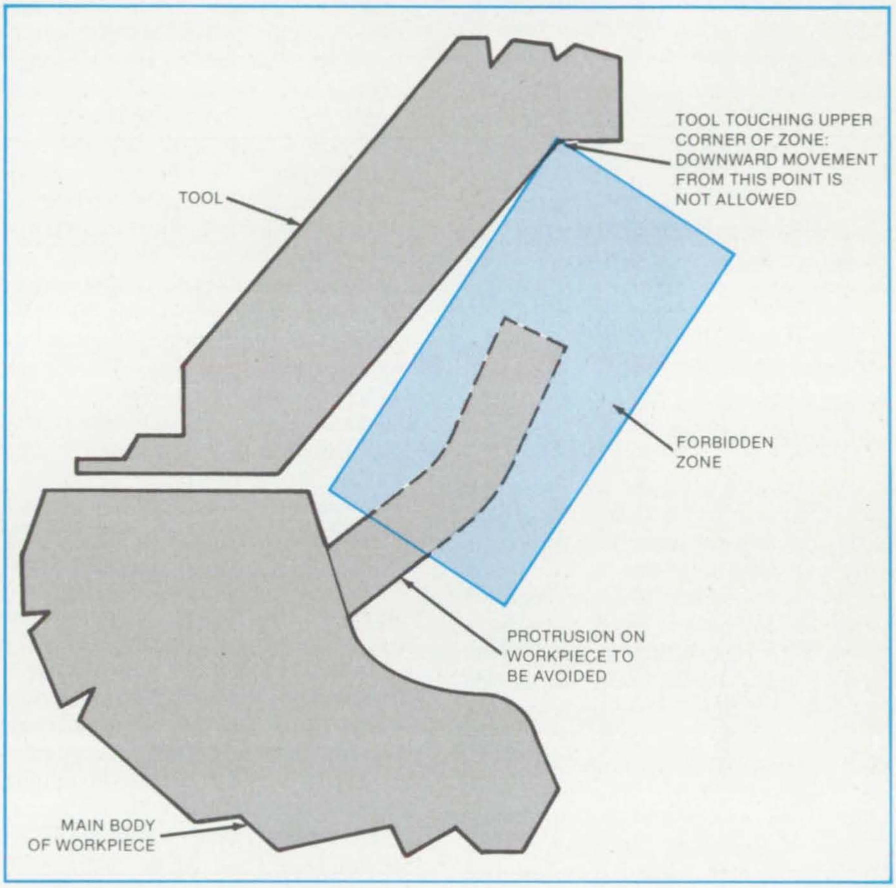
Forbidden Zones for Numerically-Controlled Machine Tools

The safety of operators and of delicate protuberances is enhanced.

Marshall Space Flight Center, Alabama

A computer-controlled machine tool is prevented from striking and damaging protruding members on a workpiece by creating a forbidden zone in the control program. With the aid of computer graphics, the tool profile and the coordinates of the forbidden zone (see figure) are digitized and stored in the computer memory as part of the tool path. Then, whenever parts of the same type are machined, the program will not allow the cutting tool to be moved into the zone. Developed for a computer-numerically-controlled lathe, the method is equally suitable for such other tools as milling machines.

This work was done by Dennis Philpot of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-19950



The **Corners of a Forbidden Zone** are established so that lines drawn between them enclose a projection on the workpiece. The cutting tool is prevented from entering the zone.

Drilling Holes in Graphite/Epoxy Composites

Drilling with conventional bits and an abrasive slurry is inexpensive and efficient.

Marshall Space Flight Center, Alabama

With a new method, holes are drilled in graphite/epoxy composites quickly with conventional drill bits. The technique was developed for preparing specimens of graphite/epoxy for shear testing: Nine holes, 0.5 inch (1.27 centimeters) in diameter, had to be drilled in graphite/epoxy boards 0.040 to 0.060 inch (1.0 to 1.5 millimeters) thick.

Notoriously difficult to machine, graphite/epoxy composites quickly blunt the cutting edges on carbon steel drill bits and counterbores. If an operator succeeds in drilling a good hole in the material, the hole is likely to have cracked edges and still be unusable. Although tools with silicon carbide cutting edges can be used for such jobs, they are costly and still require sharpening.

In the new method, a slurry of silicon carbide powder in water is fed onto the bit while it is drilling. The slurry contains about 60 percent silicon carbide by weight. The slurry can be recirculated by a low-power pump.

The powder particles become trapped between the cutting edges and the graphite/epoxy composite and apparently remove the composite material by abrasion. The particles do no damage to the cutting edges except to dull them, but cutting is unaffected. With the slurry, dull tools cut as fast as, or faster than, sharp ones. With the slurry, the holes could be drilled rapidly and efficiently regardless of the ply orientation; whether unidirectional, quasi-isotropic symmetrical, or cross-ply.

This work was done by Julia G. Daniels, Frank E. Ledbetter III, Benjamin G. Penn, and William L. White of **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 25]. Refer to MFS-28044.

Computer Programs

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

Multistage Planetary Power Transmissions

Program simulates the thermomechanical characteristics of a planetary bearing.

PLANETSYS simulates the thermomechanical performance of a multistage planetary power transmission. Two versions of this code were developed, an SKF version and a NASA version. The difference between the two versions resides in the calculation of the elastohydrodynamic (EHD) film thickness and traction forces that develop between rolling element/raceway and rolling element/cage concentrated contacts. The film-thickness model of Dowson-Higginson and a Tallian traction model are used in the SKF version, while the NASA version uses a Loewenthal model to calculate film thickness and an Allen model to determine traction forces.

The major function of the program is to compute performance characteristics of the planet bearing for any of the six kinematic inversions. This bearing may be a cylindrical or spherical roller bearing with an outer ring that is either rigid or flexible. The bearing may contain one or two rows of rollers, and its inner ring is taken as an elastic solid.

The main program consists of the following major subprograms:

1. Bearing Analysis, which is largely based on the methods of Liu and Chiu; the bearing outer ring is either rigid or flexible; effects of the latter are reflected in fatigue-life calculations and load distributions;
2. Bearing Dimensional Change Analysis, which is based on the methods of Timoshenko and adapted to the bearing system by Crecelius; and
3. Generalized Steady-State and Transient-Temperature Mapping and Heat Dissipation Analyses, which are based on the methods of Harris, Fernlund, and Andreason.

The user can select which of the two models (SKF or NASA) is employed in the calculation of EHD film thickness and concentrated contact traction. Both versions of PLANETSYS also make use of the following bearing-related models:

1. Three components of bearing-cage-related friction are treated for both lubricated and dry operation; for dry operation, coulomb friction is assumed; with lubrication, hydrodynamic lubricant shear models are used as follows: (a) Cage web-roller friction according to the methods of Dowson, (b) cage rail-roller end using the methods for a plain bearing from Marks, and (c) cage rail-ring land using the methods for a short journal bearing according to Dubois and Ocvirk;
2. A model for the effect on bearing fatigue life of the ratio of EHD plateau film thickness to composite surface roughness is incorporated.

Additionally, models for lubricant temperature viscosity and pressure viscosity variation as functions of temperature were adopted.

PLANETSYS can solve the heat-balance equations for either the steady-state or the transient thermal conditions, and it produces temperature maps for the mechanical system. The program is structured to handle up to three planetary stages. The power flow through each stage is assumed to be identical. All planets for each stage are assumed to behave identically. Each stage may be different. PLANETSYS is written in FORTRAN IV for use on a UNIVAC computer.

This program was written by G. B. Hadden, G. J. Dyba, M. A. Ragen, R. J. Kleckner, and L. Sheynin of SKF Industries, Inc., for **Lewis Research Center.** *For further information, Circle 47 on the TSP Request Card.*
LEW-14100

Three-Dimensional Turbomachine-Blade-Row Analysis Code

Input code is generated from a minimum of geometry and flow-variable information.

A computer program (MERNEW3D) has been developed that prepares the bulk of the input data set required for the Denton three-dimensional inviscid turbomachine-blade-row analysis code. The Denton input is generated from a minimum of geometry and flow-variable information by using cubic spline curve fits for interpolation and extrapolation. The curve-fitting procedures are taken from a previously developed and widely used NASA computer program (MERIDL), which performs a meridional streamsurface analysis. [MERIDL is described in "Flow Velocities and Streamlines"(LEW-12966) on page 100 of *NASA Tech Briefs,* Vol. 3, No. 1.]

For any flow-analysis code, the most burdensome part of preparing the input is describing the geometry of the flow passage. The Denton code requires the axial coordinate, the radial coordinate, the circumferential coordinate of one blade surface, and the blade tangential thickness for every streamwise grid location on each of the input blade-to-blade surfaces. Although the program can interpolate spanwise when generating the grid, it cannot interpolate in the streamwise direction. Since a minimum of three input planes (and often more) is usually required to describe the flow passage, the amount of input data is considerable.

To ease the burden of preparing geometry input, MERNEW3D was developed so that it prepares the bulk of the input data set required for the Denton code. This program is based on the extensive geometric features of the MERIDL code in order to generate the Denton input from a minimum of geometric information. MERIDL is used for meridional streamsurface analysis of turbomachine blade rows, and the MERNEW3D code, for convenience, can read a MERIDL input data set. The data set produced by the MERNEW3D code contains all of the necessary geometry input, the required flow variable input, and some of the control variables.

Since the MERNEW3D code works with the same input options as does the MERIDL code, blade shape can be input in one of three ways: (1) Mean camber-line coordinates and tangential thickness; (2) mean camber-line coordinates and normal thickness; and (3) coordinates for both surfaces. Leading and trailing-edge mean-camber-line tangency angles may or may not be specified. This controls the method of grid extrapolation into the upstream and downstream regions. Inlet flow characteristics can be input either as functions of radius or stream function. Since MERNEW3D does no flow computations, conversion from stream function to radius is made with the assumption of constant flow per unit area.

Since MERIDL does not perform a blade-to-blade surface-flow analysis, blunt leading and trailing edges are typically specified. MERNEW3D, as an option, will round off the leading edge. The trailing edge is not rounded off because the Denton code is usually run with a cusp at the trailing edge to assure a smooth flow path. The leading edge may or may not require a cusp, and the rounded leading edge may have to be further modified to provide a smooth transition if a cusp is used.

The Denton code can accept any consistent set of units as input. MERNEW3D can either leave the units as they were in the MERIDL input or convert U.S. customary units to SI units. The program is written in FORTRAN IV for use on an IBM 370 computer.

This program was written by Arthur J. Glassman and Jerry R. Wood of **Lewis Research Center.** *For further information, Circle 60 on the TSP Request Card. LEW-14061*

Predicting the Dynamic Behavior of High-Speed Roller Bearings

Program performs two-dimensional or three-dimensional simulations.

A computer program has been developed for solving the nonlinear differential equations of motion of a high-speed, lightly loaded, cylindrical roller bearing. The program is organized into three major parts: The main program, which controls the input and output; the differential equation solver; and the subroutines, which are used to evaluate the vector function.

The prediction of transient dynamic behavior of high-speed cylindrical roller bearings is necessary to evaluate new design concepts and design changes in existing bearings. Many phenomena, such as cage/roller impacts and roller/flange impacts, which limit life or affect bearing performance, are of a transient nature and may not be predicted using steady-state simulations. The prediction of roller or cage stability must be done using methods of transient dynamic analysis with the proper nonlinear models.

The computer program has the capability of performing either a two-dimensional or a three-dimensional simulation. Numerical solutions of the governing differential equations are obtained to simulate the motion of a roller bearing. Computer-generated plots present such data as roller/cage interaction forces, roller/race traction forces, roller/race relative slip velocities, and cage angular speed over a nondimensional time equivalent to 1.2 revolutions of the inner race. Roller axial displacement, roller skew angle, and skew moment are also plotted for the three-dimensional solution. The trajectory of the cage center is plotted for both the two and three-dimensional solutions. The program is written in FORTRAN IV for use on a Control Data CYBER 76 computer.

This program was written by Thomas F. Conry of the University of Illinois for **Lewis Research Center.** *For further information, Circle 59 on the TSP Request Card. LEW-13467*

Off-Design Performance of Radial-Inflow Turbines

A computer code determines the rotor exit flow from hub to tip.

A computer program has been developed called RTOD (Radial Turbine Off-Design), which computes off-design performance of a radial turbine by modeling the flow with (1) stator viscous and trailing-edge losses; (2) with a vaneless space loss between the stator and the rotor; and (3) with rotor incidence, viscous, clearance, trailing-edge, and disk friction losses. The analysis procedures of the existing computer programs [described in "Predicting Off-Design Performance of Radial-Inflow Turbines" (LEW-12500), on page 249 of *NASA Tech Briefs*, Vol. 1, No. 2] for predicting the off-design performance of radial-inflow turbines were extensively modified to improve their accuracy and to extend their applicability.

The rotor inlet slip factor correlation was replaced by one that includes rotor-blade sweep. At the rotor exit, a sector analysis was used in place of the original meanline analysis to model the large radial variations occurring there. Disk friction, clearance, and vaneless space losses were added to the loss model, and the method of computing trailing-edge loss was changed. Finally, the entire analysis procedure was recoded.

RTOD can analyze a variable stator, including the leakage flow in the clearance gap. RTOD determines the rotor exit flow variation from hub to tip and can account for the effect of swept rotor blading. The user must specify the stator and rotor viscous losses (which represent the combined effects of profile, endwall, and secondary flow loss) to match a reference performance point. RTOD then calculates the turbine performance over a specified operating range.

Comparing calculated results with experimental data shows that the revised program predicts mass-flow rate better than the original programs. Calculated results are also used to illustrate the potential improvement in off-design performance offered by rotor back-sweep for high-work-factor radial turbines. This computer program is written in FORTRAN IV for use on an IBM 370 computer.

This program was written by P. L. Meitner and A. J. Glassman of **Lewis Research Center.** *For further information, Circle 58 on the TSP Request Card. LEW-14060*

Fabrication Technology

Hardware, Techniques, and Processes

High-Efficiency, Low-Weight Power Transformer

A unique structure cools the magnetic core and windings.

Lewis Research Center, Cleveland, Ohio

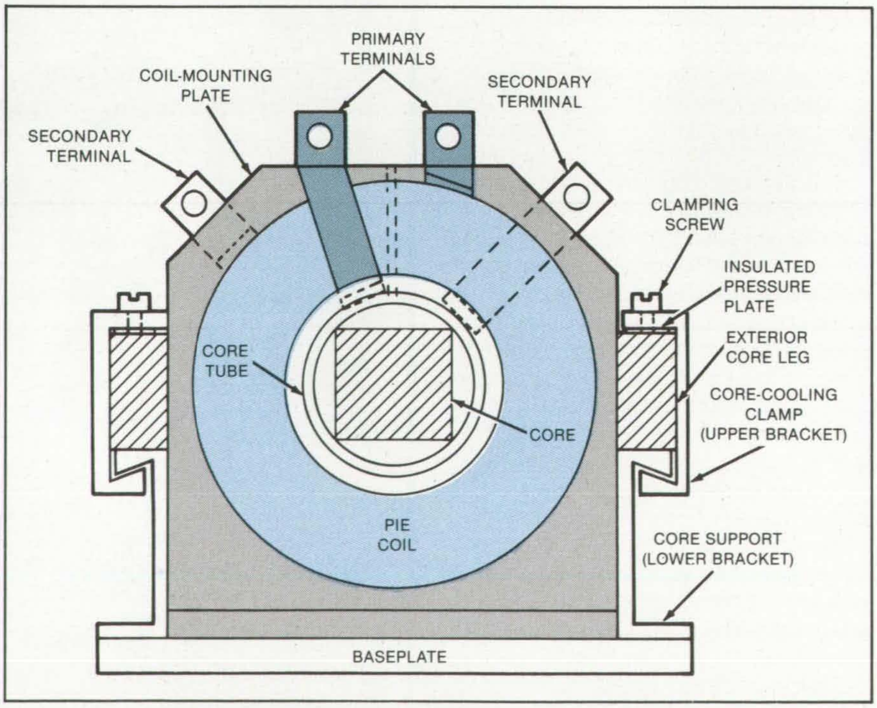
The technology for the design and fabrication of a radically new type of conduction-cooled high-power (25 kVA) lightweight transformer having outstanding thermal and electrical characteristics has been developed. This new technology fulfills a long-standing need for conduction-cooled transformers and magnetics with low internal thermal resistances. The development techniques were limited to conductive heat transfer, since other techniques such as liquid cooling, forced liquid cooling, and evaporative cooling of transformers were impractical in a zero-gravity space environment.

The transformer is uniquely designed such that its mechanical structure also serves as the thermal paths for conduction cooling of the magnetic core and windings (see figure). A description of the nonconventional construction of the transformer is as follows:

The primary and secondary windings are assembled from individual pie or pancake-wound, single-layer coils. The coils are individually bonded to aluminum mounting plates that have been machined to the required thickness. The bottom portion of each plate has a foot that is used to mechanically secure the plates to an aluminum baseplate. A thin slot is cut from the center hole of a plate to its top edge so that the plate does not act as a shorted turn.

A primary coil is bonded to one side of the mounting plate and a secondary to the opposite side, with insulation placed between plate and coil to control voltage breakdown. This type of coil arrangement helps to ensure low leakage inductance between the windings. This transfer has a leakage inductance of less than 10 H relative to the primary. In addition, the metal mounting plates provide a natural electrostatic shield between the windings. The heat loss generated in each coil is transferred by conduction to its mounting plate and then to the baseplate. The baseplate is maintained at a specified temperature by external cooling.

The individual coil/plate assemblies fit over the center leg of the magnetic core structure. Two cut "C"-type cores placed adjacent to each other form the magnetic core structure.



A **Primary Coil is Bonded** to one side of the mounting plate and the secondary coil is bonded to the opposite side. Eight such coil/plate assemblies are incorporated into a 25-kVA transformer. The magnetic core is held in place by pressure-clamping each exterior core leg between two brackets.

High-Performance Seals

for demanding aerospace sealing requirements

DOUBLE-ACTING SEALS

SINGLE-ACTING SEALS

AGT® RING

Aerospace standard of quality since 1965. For static and dynamic applications (linear and oscillatory), rod or piston. Easy installation. No leakage. Long Life. Bi-directional.

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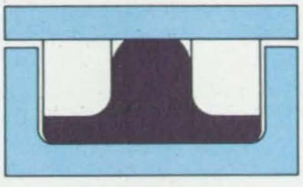
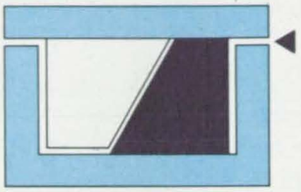




TRAPEZOIDAL* SEAL

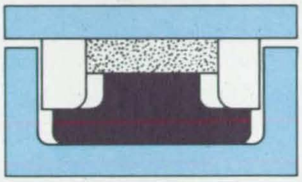
High-pressure seal for rod and special piston applications where pressure is from one side. Endless backup ring's shear section is approximately twice that of conventional backups; assures exceptional resistance to seal nibbling. *Patented by Vought Aero Products

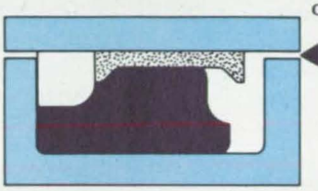
Circle Reader Action No. 329

CAPPED G-T RING

Double-acting, high-pressure piston seal combines the space-saving, positive sealing and non-extrusion features of an AGT ring piston seal with the low-friction, long-life characteristics of O-ring energized TFE cap-type seals.

Circle Reader Action No. 330





CAPPED GTL-RING

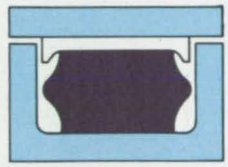
High-pressure rod seal combines the space-saving, positive-sealing and non-extrusion features of an AGT-Ring rod seal with the low-friction, long-life characteristics of O-ring energized TFE cap-type seals. Uni-directional.

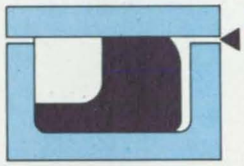
Circle Reader Action No. 331

ENER-CAP™ SEAL

Pressure-activated hydraulic seal combines low break-out and running friction with minimal leakage and a high degree of stability over an extended service life. ENER-CAP is available in no back-up, one back-up and two back-up sizes to fit O-ring glands to MIL-G-5514F.

Circle Reader Action No. 332





GTL-RING

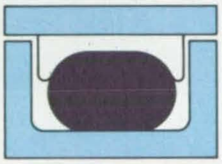
Space-saver design. Static or dynamic applications. Uni-directional. Rods (dynamic) or sleeves (piston type-static). Allows thick back-up in no back-up groove.

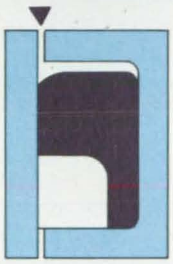
Circle Reader Action No. 333

COR-SEAL™

Low cost. Low friction. long life. Dynamic applications. Bi-directional for rods and pistons.

Circle Reader Action No. 334





STATIC FACE SEAL

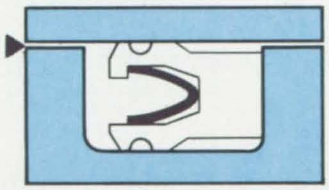
For difficult static face sealing jobs where conventional seals leak or fail. Highly cost-effective replacement for transfer tubes.

Circle Reader Action No. 335

All of these sealing devices available to fit MIL-G-5514F glands. For other gland sizes, contact your Greene, Tweed representative.

Greene, Tweed seals are available for 3000, 4000 and 8000 PSI hydraulic systems.

Note: ◀ indicates direction of pressure.



MSE™ SEAL

PTFE/metal spring energized seal; provides excellent static and dynamic sealing at temperatures from cryogenic to 500F+. For applications outside temperature, fluid compatability and seal-friction parameters of elastomic seals.

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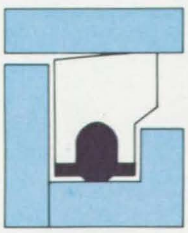
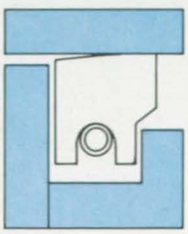
PLUS . . . TFE SCRAPERS TO MS33675

SERIES 4186

Endless TFE Scraper Rubber Energized. MS28776M2, BAC534A and S11065 replacement.

Circle Reader Action No. 337





SERIES 4178

Scarf-Cut TFE Scraper Garter Spring Energized. Equivalent to BAC534A.

Circle Reader Action No. 338

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The individual primary and secondary coils can, within certain limitations, be connected in various series/parallel combinations. The ends of each coil terminate on copper tabs, which become an integral part of the primary and secondary busbar assembly. The series/parallel combination used is dependent on the input and output voltage requirements and also the permissible heat-flux rejection rate in each coil. The heat-flux rates are controlled by the allowable-current density in each coil.

This 25-kVA transformer has eight coil/plate assemblies. The primary coils are connected in parallel for a 200-V input, and the secondary coils are connected in series for a 1,500-V output. Under full-load conditions, the minimum load current flowing is 125 A in the primary and 16.67 A in the secondary.

The magnetic core structure is physically held in place by pressure-clamping each exterior core leg between two brackets. The upper bracket, with a thin insulating plate between the inner bracket surface and core, is fitted snugly over the top and side surfaces of the core and held in place with machine screws along the top surface of the bracket. The lower bracket mates to the upper bracket along the bottom side of the core by a "Z"-type clamping arrangement. The bottom portion of the lower clamp has a foot that is secured to the baseplate with machine screws. The core brackets also serve as the thermal paths for the conduction cooling of the magnetic structure.

Thus, the coil-mounting plates and core brackets, which are attached individually to the baseplate, form the mechanical structure to support the coils and cores, respectively. This mechanical structure then serves the dual purpose of providing the thermal paths for the conduction cooling of the entire transformer. For a baseplate temperature of 50° C, the windings of this 25 kVA transformer have a maximum temperature rise of 43° C, while the core has a maximum temperature rise of 52° C.

The servicability of this transformer is also unique. If a particular winding becomes inoperative, only the defective pie coil in that winding needs to be replaced. The weight of the transformer is 6.95 lb, and the efficiency is 99.2 percent.

This work was done by James P. Welsh of Thermal Technology, Inc., for **Lewis Research Center.** *Further information may be found in NASA CR-168082 [N83-29596/NSP], "Design and Development of Multi-kW Power Electronic Transformers for Long Duration Space Applications" [$7]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Lewis Research Center [see page 25]. Refer to LEW-14074.

Coating a Sphere With Evaporated Metal

Rotation and rocking increase coating uniformity.

NASA's Jet Propulsion Laboratory, Pasadena, California

In a vacuum coating apparatus, metal is evaporated onto a sphere from a small source located some distance away. The sphere is held in the path of the metal vapor while being rotated about an axis that rocks back and forth.

The principle of operation is illustrated in Figure 1. The sphere is rotated on supporting rods that hold it at antipodes. The rods, and consequently the axis of rotation, are tilted at angle α. This angle is varied with time according to a schedule that produces as even a coat as possible over most of the surface (except at and near the supporting-rod contacts, where shadowing by the supporting rods precludes uniformity).

One tilting motion that is particularly easy to produce is sinusoidal rocking with a frequency much lower than the rotational frequency. Another such motion involves equal alternating exposures at fixed angles of α and $180° - \alpha$, with sudden moves between the two angles, which can be changed manually, thereby simplifying the apparatus. It is also possible to dispense with the tilting motion and use two evaporative sources located at angles α above and below the equator of the sphere.

The apparatus was developed for coating single-crystal sapphire spheres with niobium. The spheres about 3 cm diameter would be used for cryogenic operation in a ruby maser oscillator. During the coating process, the sphere was oriented with its optical axis along the axis of rotation. Thus, the holes left in the coating by the supporting rods were where holes would have to be made in any event for the microwave apertures. The supporting rods were made of titanium with platinum tips to enhance thermal contact with the sphere.

The sphere-holding-and-rotating apparatus (Figure 2) was placed with the rest of

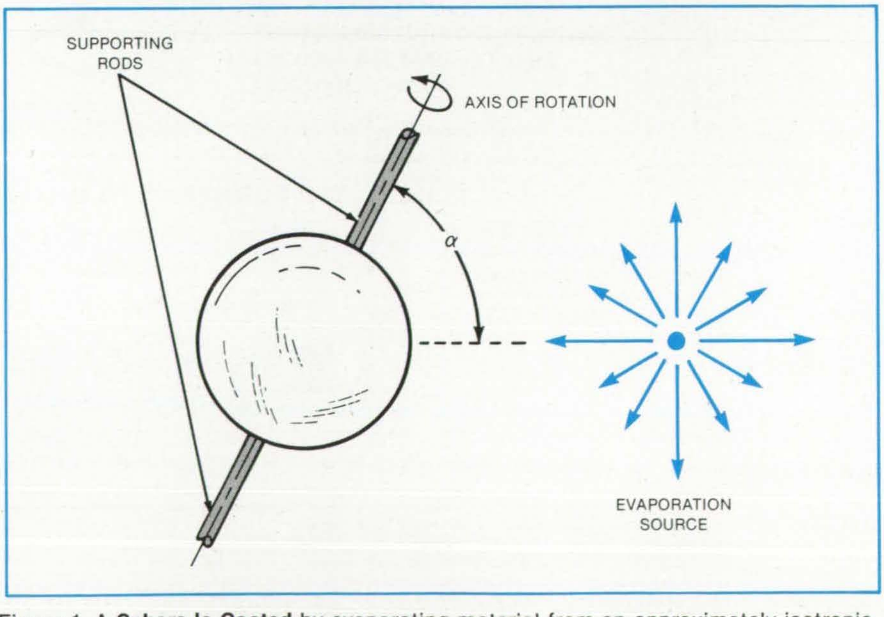


Figure 1. A **Sphere Is Coated** by evaporating material from an approximately isotropic source. The sphere is rotated, and the tilt of the axis of rotation is varied periodically.

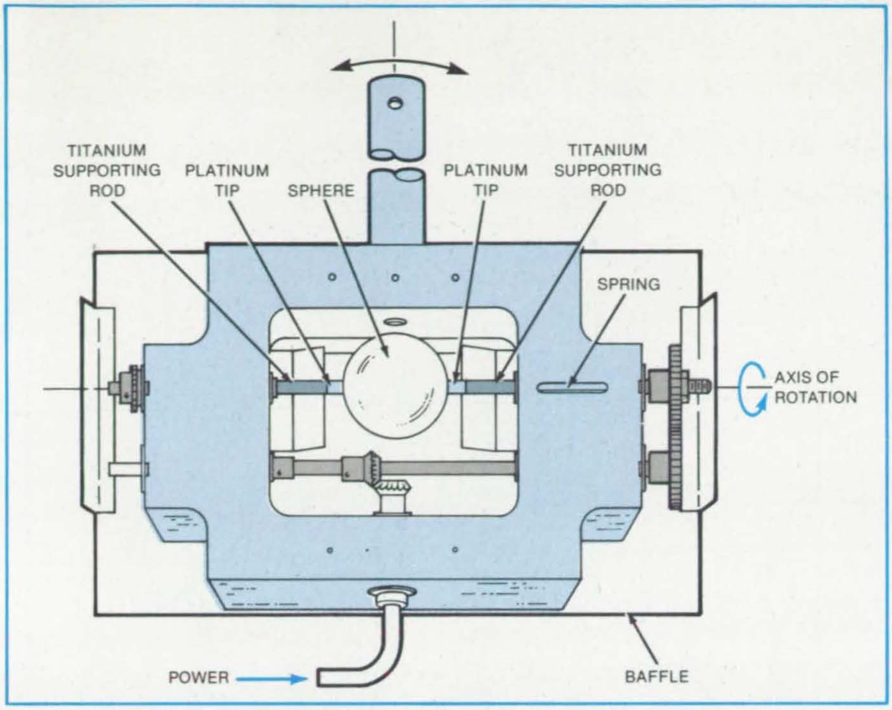


Figure 2. A **Sphere Is Held** by clamping it with the ends of the supporting rods. The right supporting rod is spring loaded toward the left to supply the clamping force. Power for the rotation is supplied by a magnetic feedthrough.

the coating equipment in a vacuum chamber pumped down to about 1 μPa. The platinum tips were heated by an electron beam to raise the temperature of the sphere to 400° C for good adhesion of the niobium. The niobium target was placed at about 18 cm from the sphere and heated by an electron-beam gun fed by a 2-kW power supply. The niobium flux density was equivalent to a deposition rate of 400 to 500 Å per minute at the sphere.

In one experiment, the deposition was carried on for 26 minutes. The manual tilting method was used, alternating between 2-minute exposures at $\alpha = 45°$ and $\alpha = 135°$. (The transition between the two orientations typically required 20 seconds.) The coating thickness reached an average of about 2,500 Å. As measured by He^+-ion backscattering, the variation of coating thickness with latitude on the sphere agreed well with the predicted variation.

This work was done by Donald M. Strayer, Henry W. Jackson, and John R. Gatewood of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 101 on the TSP Request Card. NPO-16436*

Economical Fabrication of Large Parabolic Mirrors

Rigid, lightweight mirrors are fabricated by rotational casting.

Langley Research Center, Hampton, Virginia

Long-focal-length parabolic mirrors are fabricated economically by rotational casting. This technique is an improvement over earlier methods in that it not only applies to very large mirrors but also incorporates new foam/fiberglass techniques that are ideal for producing rigid, lightweight mirrors.

The new process was developed to produce mirrors that concentrate Sunlight for a solar-pumped laser. To achieve lasing in glass or liquid lasers using solar radiation, it is necessary to concentrate the incoming radiation by a factor of more than a thousand and, at the same time, to deliver one kilowatt or more at the laser. Although such concentrations are readily achieved with a high-quality optical system using parabolic mirrors or lenses, the expense and weight for the large-area intercept systems needed are prohibitive.

The first stage of the fabrication (see Figure 1) is the carving of the front face of a polyurethane block measuring 8 feet by 8 feet by 3 inches (2.44 meters by 2.44 meters by 7.6 centimeters) into the shape of a parabolic surface having a predetermined focal length — in this case, 44 feet (13.4 meters). A square cross section is used, rather than the usual circular, because it simplifies construction.

The parabolic contour is formed with the aid of an aluminum template attached to a rigid beam. The template can be pushed into the foam, thereby guiding the carving process and allowing a surface accuracy of better than 0.12 inches (3 millimeters).

Once the parabolic shape has been carved, the entire foam surface including the sides and back is encased in fiberglass impregnated with epoxy resin. When the epoxy hardens, a very rigid, lightweight structure is formed. Next, a rectangular wood box with back ribbing is constructed. Its dimensions are chosen so that the foam sheet can just be inserted. Extra fiberglass and epoxy resin are used to bond these two units to form a single, rigid structure.

This combination is next placed onto a rotating system consisting of a heavy stationary table (Figure 2) and a rotating vertical shaft. The shaft is held by bearings and is driven by a variable-speed electric motor. The frame/foam combination is dynamically balanced on top of the drive shaft and is set into rotation at a constant angular velocity, which is monitored electro-optically. The rotation rate can be kept constant to within 1 percent over periods as long as 8 hours. The rotation period for the constructed mirrors was 10.4 seconds, which is consistent with the formation of a 44-foot (13.4-meter) focal-length parabolic surface made by pouring a liquid into the rotating parabolic dish.

The final parabolic mirror surface is fabricated by pouring liquid epoxy into the spinning dish and letting the epoxy harden. Typical solidification times are 5 hours. The rotation is maintained for well over 8 hours to ensure sufficient hardening. The final hardened surface is estimated to be within 0.04 inch (1 millimeter) of a perfect parabola over the entire mirror surface, with the exception of a few localized indentations believed to be due to air bubbles trapped between the fiberglass and foam surface during fabrication. For

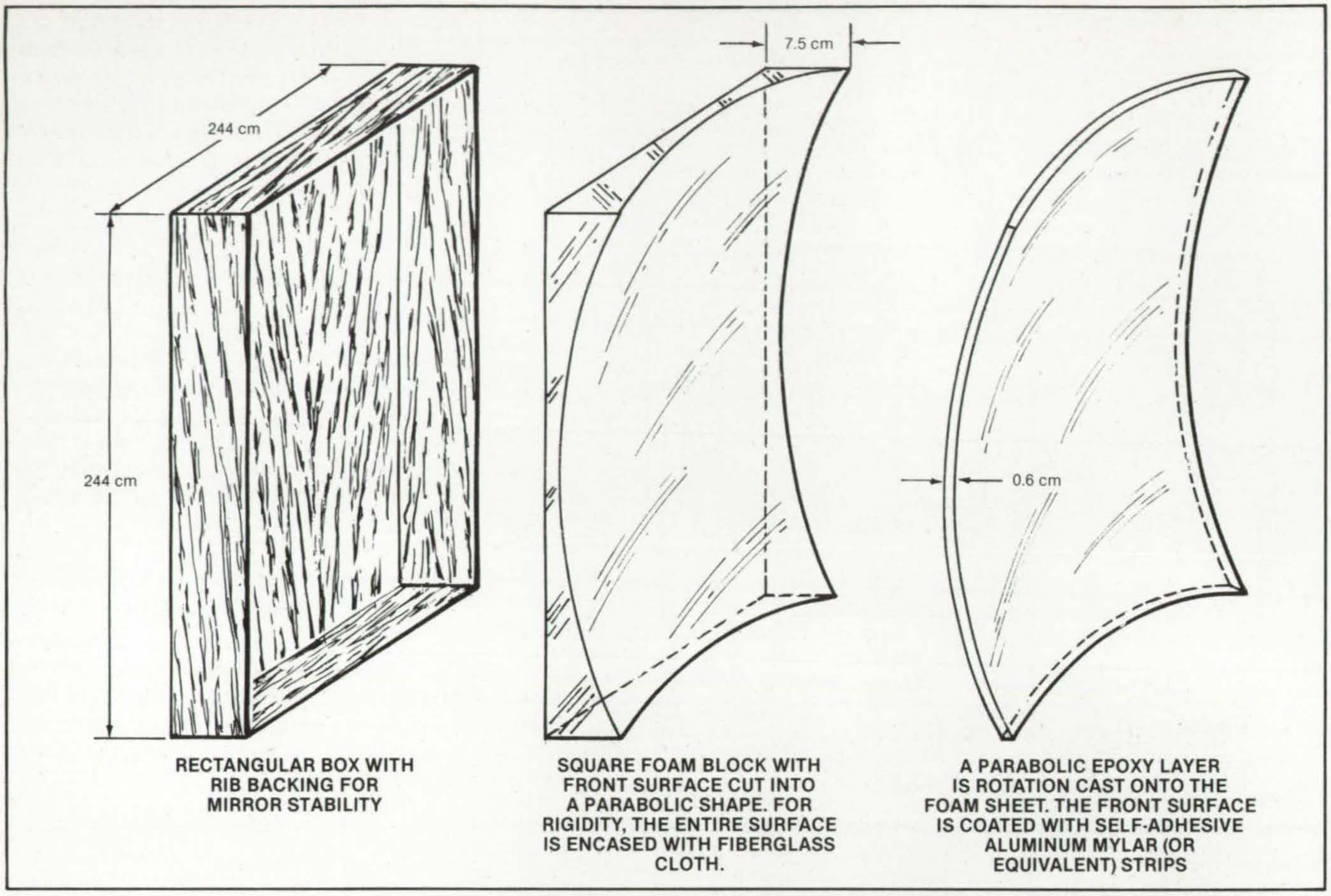


Figure 1. A **Parabolic Contour** is cut from a polyurethane-foam block. The wooden frame adds rigidity to the structure.

proper solidification, the relative humidity has to be maintained at less than 70 percent.

The last stage of the fabrication process involves placing strips of self-adhesive aluminized acrylic film onto the hardened epoxy surface. Since this surface has small curvature, there is no difficulty in applying 2-foot (0.58-meter) wide strips of the film directly onto the surface without wrinkling problems.

Two mirrors were fabricated and oriented in a vertical plane, with no signs of deterioration after more than 6 months. When not in use, they are covered with a nontransparent plastic sheet. Their final weight was about 300 pounds (140 kilograms) each.

This work was done by Richard T. Schneider, Ulrich H. Kurzweg, and John D. Cox of the University of Florida for **Langley Research Center.** *Further information may be found in NASA CR-172121 [N83-23588/NSP], "Research on Solar Pumped Liquid Lasers" [$8.50]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
LAR-13139

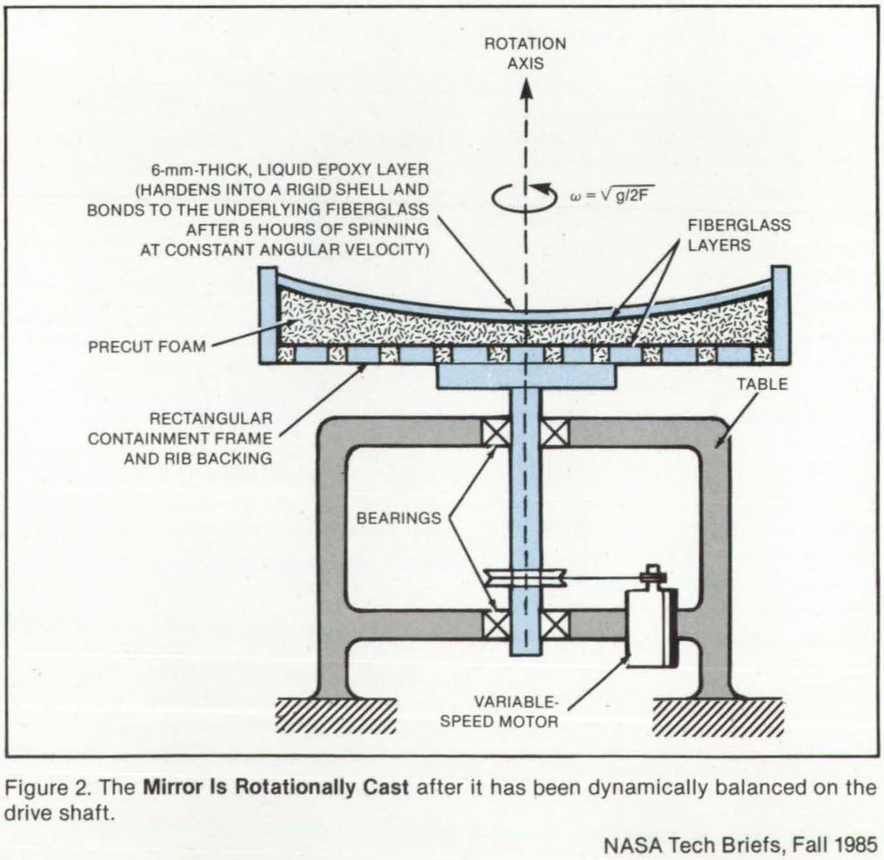


Figure 2. The **Mirror Is Rotationally Cast** after it has been dynamically balanced on the drive shaft.

1700 pounds of optical perfection.

Perfection is not a term we use lightly. Or frequently. We've been taught for generations that perfection, in lens-optics terms, means ¼ wavelength. We've bettered this tolerance in the manufacture of an "egg crate" mirror, one-fifth the weight of a solid mirror. Manufactured for the Space Telescope Program, every point on its nearly 8-foot-diameter aspheric surface is within 1/10 wavelength of perfection. So while we're not 100% perfect, we're within several millionths of an inch of that goal.

We put all our experience into play in the manufacture of this massive optical element 97½ inches in diameter and 1700 pounds in weight. And our challenges were many. Since this lens is intended to perform in orbit, where the pull of gravity has been neutralized, we had to solve a gravity-distortion problem during the manufacturing cycle. We solved the problem with an air cushion, a membrane that inflates for testing to provide a uniform support and thus eliminate gravity-induced strain. The support deflates for polishing operations.

An aspheric mirror to gather information from the universe is an example of our large-optics capability. (Optics of this kind are ground, polished, and tested in our own lab with its vibration-isolated, six-story-high interferometric test towers.) But we're big in small things, too. Like lenses for cameras and copiers. We meet customers' needs with pride, precision, and stringent quality control.

In addition to massive, sophisticated equipment, a century of optical progress, and systems utilizing our ability to the fullest, we offer customers a tradition of realism when predicting costs and delivery.

That's important. Whether you seek to get a clearer picture of your neighbor or of celestial objects.

For more information about Kodak's contribution to the Space Telescope Program, write for the booklet *Mirror for the World's Most Powerful Telescope.* Send your request to: Richard M. Price, Government Systems Division, Eastman Kodak Company, Rochester, NY 14650.

Kodak

Circle Reader Action No. 339

High-Quality, Thin-Film Germanium Single Crystals

Plasma-enhanced chemical-vapor deposition successfully produces the single-crystal films.

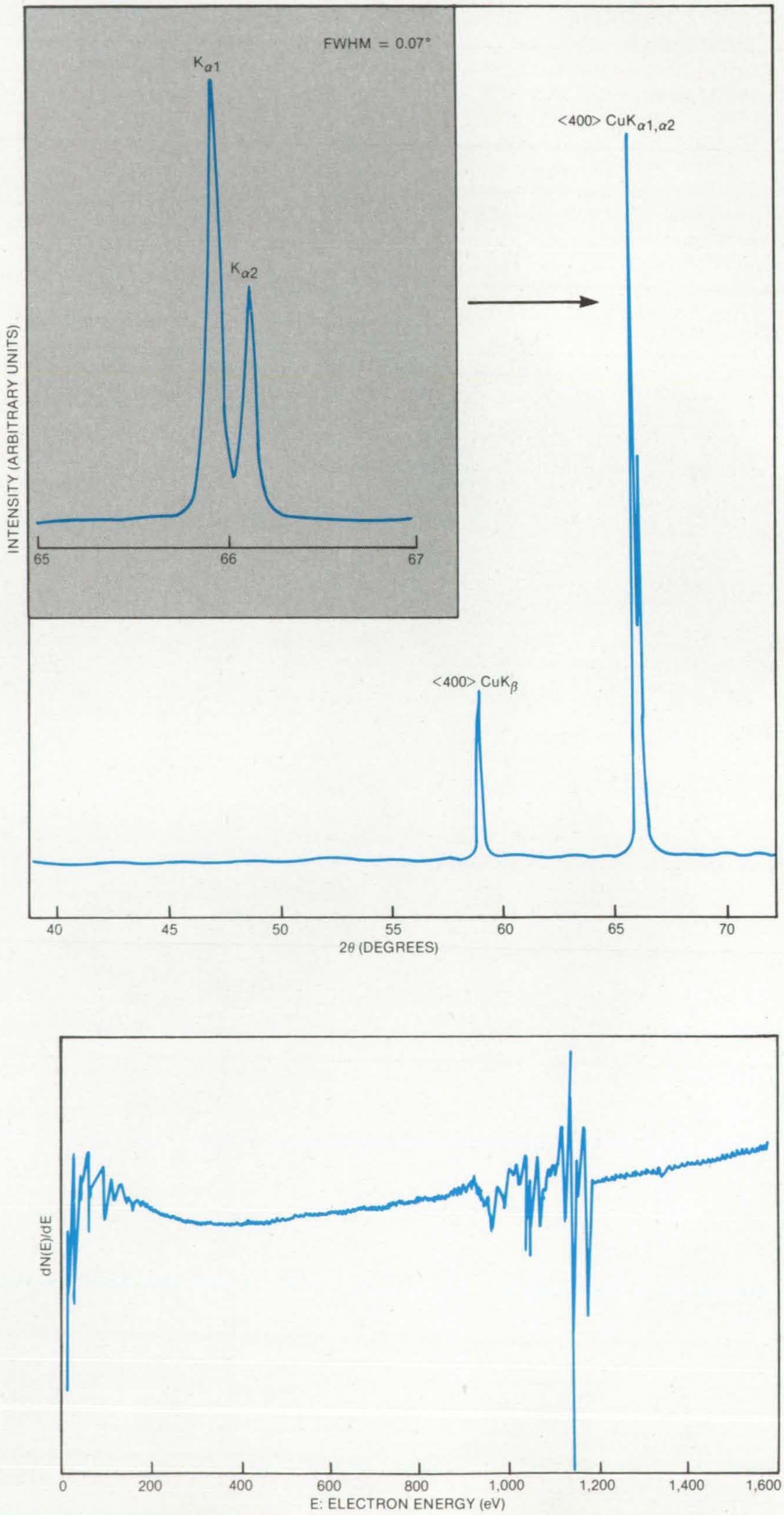
Langley Research Center, Hampton, Virginia

The demand for large solar-cell arrays for space applications has stimulated considerable interest in thin-film photovoltaics, primarily because of their projected high power-to-weight ratio (>1 kW/kg). A promising approach to the development of this type of solar cell is to grow epitaxially high-efficiency photovoltaic thin films onto thin-film, low-weight substrates by vapor deposition. Since thick (250 μm or greater) $Al_xGa_{1-x}As/GaAs$ heteroface solar cells have exhibited high efficiencies and superior radiation resistance, especially under continuous annealing, development of such cells as thin films (<25 μm) is highly desirable.

Germanium (Ge) has crystallographic characteristics similar to those of GaAs (e.g., approximately the same lattice constant and a diamond cubic crystal structure) and is compatible with heteroepitaxial growth of GaAs. Further, since efficient heteroface cells have already been grown on thick Ge single crystals, Ge appears to be an excellent substrate candidate for the thin-film cells. What is required is a single-crystal Ge thin film.

Accordingly, a method has been developed for epitaxially growing high-quality 10-μm Ge thin films on <100> NaCl substrates by plasma-enhanced chemical-vapor deposition (PECVD) and then separating these Ge films by either melt-away or differential-thermal shear stress techniques. The free-standing films are then used for the growth of the $Al_xGa_{1-x}As/GaAs$ heteroface cells by similar techniques.

The resulting cells are highly sensitive to the surface topography and crystalline perfection of the Ge films. Electron microscopy of a typical growth surface topography for a 10-μm Ge film shows a very uniform surface, and, visually, the films are quite specular. As indicated on the top of the figure, the only X-ray ($CuK_{\alpha 1,\alpha 2}$) diffraction peaks



The **Intense <400> $CuK_{\alpha 1, \alpha 2}$ Double Peak,** shown at the top of the figure, indicates a high degree of crystalline order. The bottom of the figure shows a germanium spectrum with no detectable bulk contamination. The spectrum is produced by an Auger electron microscopy survey, which measures elemental composition.

from the Ge film were for the <400> orientation. A small <400> peak from residual CuK_β X-rays was also observed. The intensity of the <400> doublet peak was quite large, and the full width at half maximum (FWHM) of the $K_{\alpha 1}$ peak compared well with the $K_{\alpha 1}$ peak of a high-quality Ge<100> crystal obtained commercially. This indicates a very high degree of crystalline order.

The bottom of the figure shows an Auger electron spectroscopy (AES) survey after sputtering through a very thin layer (< 10 Å) of oxygen and carbon surface contamination. The AES survey, which measures elemental composition, is a classical Ge spectrum with no detectable bulk contamination. Energy-dispersive analysis with X-rays also shows no detectable contamination. In summary, the data indicate that the high-quality Ge thin-film crystals necessary for the growth of efficient thin-film GaAs solar cells are producible by the PECVD technique.

This work was done by R. A. Outlaw and P. Hopson, Jr., of **Langley Research Center.** *For further information, Circle 112 on the TSP Request Card.*
LAR-13211

Supporting Structures for Flat Solar-Cell Arrays

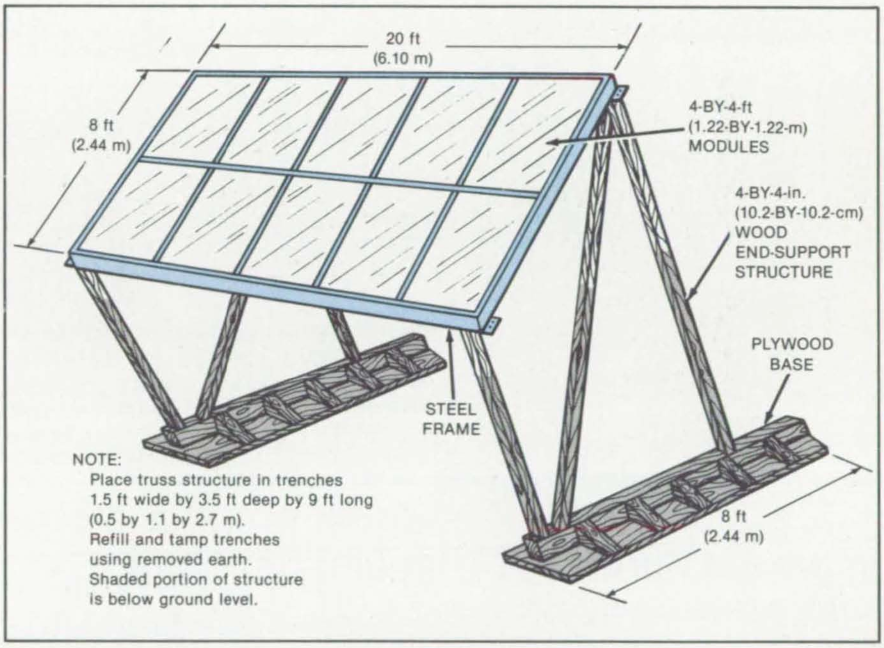
Costs are kept low by using inexpensive materials and minimizing field installation work.

NASA's Jet Propulsion Laboratory, Pasadena, California

Strong supporting structures for flat solar photovoltaic arrays (see figure) have been built with such commonly available materials as wood and galvanized steel sheet. The structures will resist expected static loads from snow and ice as well as dynamic loads from winds and even Earthquake vibrations.

Construction-grade lumber, treated to resist termites and rot, is used for the end supports. The members are assembled with galvanized steel nailing plates and 16d galvanized steel nails. The bases of the end supports are buried in trenches. The weight of backfilled soil resists the uplifting force of wind as effectively as concrete footings, but at much less expense.

A panel frame was designed to support the solar-cell modules and transfer their loads to the ground through the end supports. To eliminate redundant structure and minimize installation labor, the panel frame was designed to support modules only at the periphery and to allow module installation in the factory. Fully assembled panel frames with modules and electrical connections would then be shipped on flatbed trucks to the site. To keep costs low, the panels are fabricated from rolled steel-sheet beams instead of more costly hot-rolled members.



The **Solar-Array-Supporting Structure** uses inexpensive materials. The parts are prefabricated to minimize assembly work in the field.

This works was done by Abraham H. Wilson of Caltech for **NASA's Jet Propulsion Laboratory.** *Further information may be found in NASA CR-164716 [N81-30558/NSP], "Low-Cost Solar Array Structure Development" [$8.50]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
NPO-15600

Metalization Patterns by Thermal Decomposition

Contacts on semiconductor substrates can be formed by radiant heating of metallo-organic compounds.

NASA's Jet Propulsion Laboratory, Pasadena, California

A metal interconnection pattern can be deposited on an integrated circuit or solar cell economically by thermal decomposition of a metallo-organic compound. In the proposed process, a beam from a laser or quartz lamp would be swept over the substrate in the required metalization pattern; wherever the beam would impinge on the substrate, radiant heat would decompose the compound, depositing the metal. The metal lines can be narrower than 4 micrometers, comparable to the line widths produced by photolithographic masking methods. The proposed process, however, would require less costly equipment and less time than conventional metalization.

The process, readily adaptable to very-large-scale integrated (VLSI) circuits, is illustrated in the figure. A coating of the metallo-organic compound is applied as a drop at the center of a silicon wafer containing the VLSI chips; the wafer is then spun so that the compound spreads over the wafer completely and evenly. The wafer is placed on a small table that can be moved in the horizontal plane by computer control.

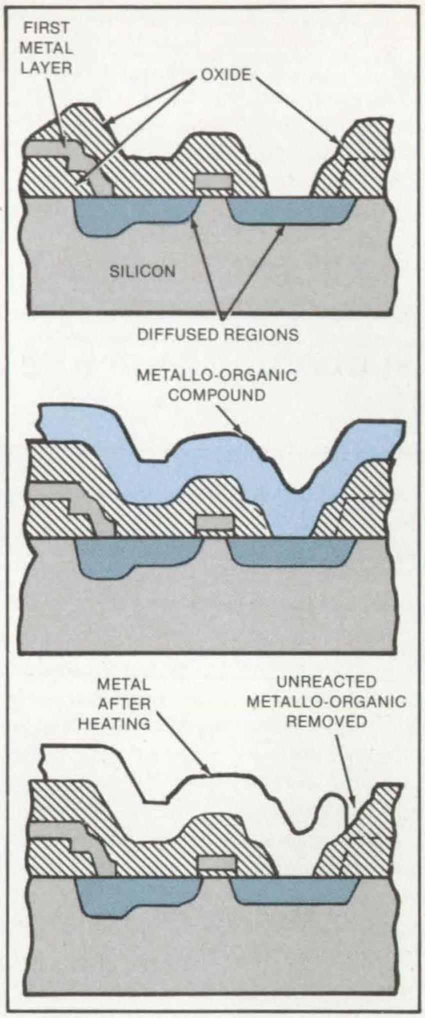
A laser beam is directed at the wafer, and the computer guides the table in the metalization pattern that has been established by computer-aided design. The metal interconnections are thus formed, and the unreacted compound is washed away by organic solvents. (The unreacted material is reclaimable.)

An excimer laser is a good choice as the heat source because its beam size and power distribution are easily controlled. The beam intensity is adjusted to produce a temperature of about 300° C — low enough that the substrate device is not damaged. The metallo-organic compound silver neodecanoate, for example, decomposes into silver at 250° C.

For a representative n-type metal-oxide-semiconductor chip, the minimum resolution and metal-line width allowed by design rules are 2.5 and 7.5 micrometers, respectively. Lenses can narrow a laser beam (and even a quartz-lamp beam) down to this size.

This work was done by Brian D. Gallagher of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 91 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 25]. Refer to NPO-16413.



This **Cross Section of a Small Part** of an integrated circuit at several fabrication stages illustrates the steps in metalization by thermal decomposition.

Improved Surface of Titanium Structure

Tooling pickup is eliminated during superplastic forming and diffusion bonding.

Langley Research Center, Hampton, Virginia

A potential problem when titanium is superplastically formed and diffusion bonded is a reaction between the titanium and the tooling material, commonly called tooling pickup. The depth of tooling pickup may approach 0.009 in. (0.23 mm). This is not acceptable on sandwich panels that have face sheets 0.016 in. (0.41 mm) thick. In this application, the tooling pickup problem was eliminated by changing the tooling slipsheet from type 321 CRES to type 430 stainless steel and coating both the slipsheet and face sheet with boron nitride powder and binder thinned in acetone.

A smooth slipsheet is critical. Type 321 CRES with a surface roughness of 5 μin. (130 nm) rms produced surfaces having varying degrees of tooling pickup. Type 430 stainless steel with a surface roughness of 1.5 μin. (40 nm) rms produced the best surface. When one half the slipsheet of 430 stainless steel was roughened by sanding, this half produced scattered tooling pickup on the titanium face sheet. The unsanded half produced a defect-free surface.

The coating of boron nitride and binder thinned in acetone did not seem to reduce surface irregularities significantly, but did reduce the general surface roughness. Coating the slipsheet and titanium face sheet with a 1-to-1 mixture of boron nitride and binder resulted in a panel that had a surface roughness of 50 to 60 μin. (1.3 to 1.5 μm) rms. When the binder was thinned with an acetone mixture (1 part binder, 3 parts acetone), the general roughness decreased to 20 μin. (0.5 μm) rms. Sandwich panels fabricated by this method were free of tooling pickup and required minimum chemical milling, 0.003 in. (0.08 mm), to restore face sheet ductility.

This work was done by Richard C. Ecklund, Masashi Hayase, and Ken K. Yasui of McDonnell Douglas Corp. for **Langley Research Center.** *No further documentation is available.*
LAR-13148

Controlled-Shape, Ultrasonic-Angle-Beam Standard Reflector

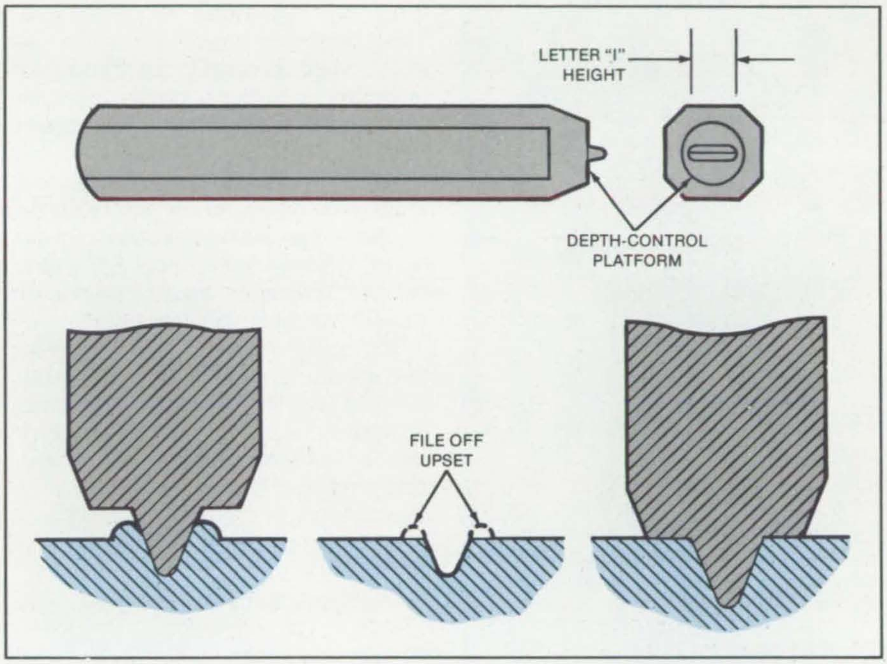
Ordinary handtools replace machining operation.

Langley Research Center, Hampton, Virginia

The nondestructive evaluation (NDE) of material for critically stressed applications utilizing ultrasonic inspection techniques necessitates a definitive set of reference reflector standards. These standards are used to select appropriate equipment, establish sensitivity levels, and verify technique adequacy. Traditionally, these standards have been machined "V" notches or half-circle profiles that require electric-discharge machine operations and considerable expense and time to place them in the inspected item.

A new ultrasonic angle-beam standard reflector uses the impression (see figure) of a letter "I" steel-die stamp. The NDE techniques and standard reflector apply to the use of pulse-echo-type ultrasonic equipment for the inspection of wrought metals including forgings and forging stock; rolled billet, bar or plate; and extruded bar, tube, and shapes.

The "I" reference standard reflector affords the advantages of easy insertion in the inspected item using common handtools and greatly reduced implementation time through the elimination of machining operations. Furthermore, by using a commercially available die stamp, variations in reflector size are eliminated.

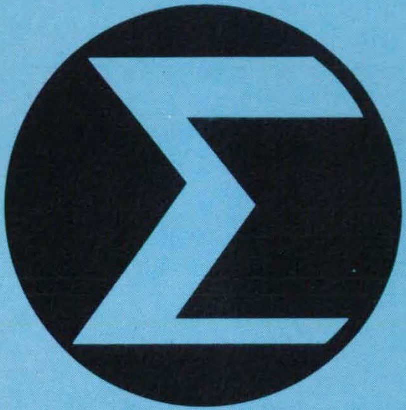


The **Angle-Beam, Reference-Standard-Impressing Technique** involves impressing the die stamp into the material surface, filing off the upset material to the original contour, and repeating these steps until the depth-control platform contacts the material surface.

This work was done by Robert F. Berry, Jr., of **Langley Research Center.** *For further information, Circle 104 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 25]. Refer to LAR-13153.

Mathematics and Information Sciences



Hardware, Techniques, and Processes

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Computer Programs

Coding for Electronic Mail

A proposed adaptive coding technique would reduce the number of bits per message.

NASA's Jet Propulsion Laboratory, Pasadena, California

A scheme for coding facsimile messages promises to reduce data transmission requirements to one-tenth the current level. The coding scheme paves the way for true electronic mail in which handwritten, typed, or printed messages or diagrams can be sent virtually instantaneously — between buildings or between continents.

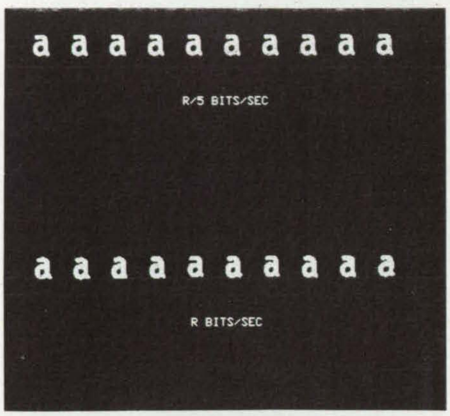
With the coding scheme, an estimated 3 to 25 billion messages per year would be handled in the United States alone. For the higher message figure, about $35 million per year (1978 prices) would be saved over conventional facsimile transmission.

The coding scheme, called Universal System for Efficient Electronic Mail (USEEM), uses unsupervised character recognition and adaptive noiseless coding of text. The image quality of the resulting delivered messages is improved over that of messages transmitted by conventional coding. The coding scheme is compatible with direct-entry electronic mail as well as facsimile reproduction. Text transmitted in this scheme can be automatically translated to word-processor form.

In unsupervised character recognition, input segmented bit patterns are compared to prototype bit patterns already stored in a pattern library by computing a mathematical "distance" between them. If the distance measure is sufficiently small, the input pattern is regarded as matching the library pattern. If such a match is found, only an identifier for the library pattern need be communicated. If there is no match, then the input pattern becomes a new library prototype and must be communicated separately as a bit pattern and added to an equivalent library at the receiving site.

In noiseless coding, text composed of sequences of library identifiers (including one to indicate that a new library prototype must be inserted) enters the coding system. This data stream is split into several new data streams that are separately coded and concatenated to form the complete output.

Data are treated as making up either words or nonword groups of characters. (Nonword groups include blank characters, certain infrequently occurring symbols, and end-of-line markers. The system examines sequences of words and nonwords to learn the statistical character of the language in the message. It can then account for such factors as the relative frequency of occurrence of words and characters and the correlation of adjacent characters (for example, a "u" following a "q") in customizing an efficient code for the message.



USEEM Can Provide Better Image Quality at a lower bit rate. The bottom row of a's is a facsimile of a document scanned at 200 points per inch (79 points per centimeter) and reproduced bit by bit. The top row is from the same document scanned at 300 points per inch (118 points per centimeter) at USEEM stage 5. Although the images of the characters are sharper in the top row, the transmission rate was only one-fifth that for the bottom row.

USEEM can be implemented in six stages, each of which provides further capability to communicate electronic mail. The first stage, called predictive coding, consists of techniques for coding scanned and digitized binary images noiselessly (that is, bit-by-bit, exact reconstruction).

Stage 2, segmentation coding, partitions a document into all-white regions and regions containing black-and-white transitions. It performs a crucial function for higher stages. Stages 3 and 4 introduce prototype-character libraries and replace the restrictive criterion of bit-by-bit, exact reconstruction by the looser but nonetheless demanding criterion that the user be satisfied with the transmission. Contrary to intuitive expectations, this criterion can result in better fidelity in the transmitted image (see figure).

Stage 5 capitalizes on the redundancy in language by applying noiseless coding to characters and words resulting from stage-4 operations. It directly reduces the number of bits required for library identifiers by a factor of 2 or 3. Stage 6 applies the effi-

cient coding algorithms developed for facsimile in stage 5 to messages entered directly from terminals.

This work was done by Robert F. Rice and Jun-Ji Lee of Caltech for **NASA's Jet Propulsion Laboratory.** *Further information may be found in NASA CR-173201 [N84-16429/NSP], "The Development of Efficient Coding for an Electronic Mail System" [$10]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.* *NPO-16350*

Improved Numerical Evaluation Method for Elliptic Integrals

Two modifications increase both the rate of convergence and the accuracy.

Ames Research Center, Moffett Field, California

Two modifications to Bartky's method for the numerical evaluation of complete elliptic integrals increase the rate of convergence and eliminate the loss of accuracy due to roundoff errors. Other integrals (nonelliptic) can be evaluated by manipulating the integrand into the form F(R)/R required for evaluation by this method.

Integrals of the elliptic type occur in conformal mapping problems of electric or fluid potential theory, in the solution for the motion of a real pendulum, and in many other fairly-common engineering calculations, such as the design of magnets and the flow of fluids in and around corners. Bartky's method applies to integrals of the type

$$I(m_0, n_0) = \int_0^{\pi/2} \frac{F(R_0)}{R_0}\, d\phi_0$$

The integrand function $F_0(R_0)$ is assumed to be a continuous function of a parameter R_0 defined as

$$R_0{}^2 = m_0{}^2 \cos^2 \phi_0 + n_0{}^2 \sin^2 \phi_0$$

where m_0 and n_0 are positive real numbers.

Bartky's method first changes the integral so that the limits of integration are from n_0 to m_0. These limits are then used to compute the successive arithmetic and geometric means, m_i and n_i. Bartky's method then repeatedly applies a transformation that replaces the initial integral by one in which the difference between the two limits of integration is reduced. This transformation process is repeated until the limits of integration are so close to each other that the integrand remains essentially constant over the interval of integration. The integral is then approximated by treating the integrand as a constant.

In the modification to Bartky's method, one increase in accuracy is achieved by replacing a sum by an approximation that is computationally better behaved. The sum consists of two terms that could be shown to approach equality asymptotically. However, one of the two terms could be calculated much more accurately than the other. Accuracy was improved by replacing the original sum by 2 times the more-accurately computable term. This change also improved the convergence rate of the iterative process.

A second improvement in computational accuracy was obtained by reformulating an expression to avoid an amplification of roundoff error. Bartky's method involves an expression

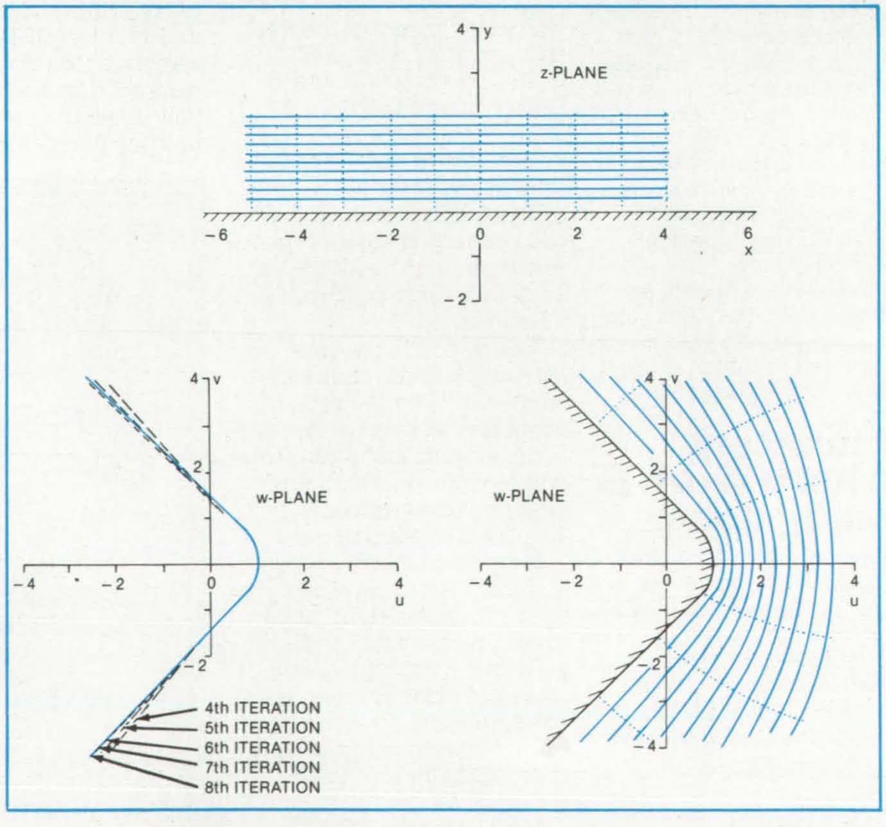
$$R_{L-1}k_{L-1} = n_L \pm (n_L{}^2 - n_{L-1}{}^2)^{1/2}$$

which must be evaluated in each iteration of the transformation process. This expression is a source of inaccuracy. Since $n_L \sim n_{L-1}$, the quantity in the square root in the expression for R involves the subtraction of two nearly equal numbers, causing the number of significant figures in the result to deteriorate with each iteration.

The new formulation avoids this problem by reexpressing the square root in other variables that were chosen to obtain a computationally stable expression involving division rather than subtraction:

$$(n_L{}^2 - n_{L-1}{}^2)^{1/2} = c_{L-1}\left(\frac{n_{L-1}}{2m_L}\right)^{1/2}$$

This change leads to a pair of well-behaved



The **Conformal Mapping** of the upper half of the complex plane (top) onto the exterior of a round-nosed wedge can be accomplished accurately using the improved Bartky's method described in the text. In the case shown, the calculations converged to the proper shape in eight iterations (lower left). The full mapping after eight iterations is shown at the lower right.

recursion relations that permit Bartky's method to be applied to any level of approximation (number of iterations) with no more than the usual arithmetic loss of significant figures.

The improved method has been used to map the upper half of the complex plane conformally onto the interior or exterior of round-nosed wedges of various angles (see figure). Such shapes approximate the boundaries of various devices wherein the region on either side of the boundary can be represented by differential equations, such as Laplace's equation.

This work was done by Vernon J. Rossow of **Ames Research Center.** *For further information, Circle 54 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 25]. Refer to ARC-11467.

Three-Dimensional Grids for Flow-Field Calculations

A mapping technique simplifies flow-field calculations for complex bodies.

Ames Research Center, Moffett Field, California

A new procedure generates boundary-conforming three-dimensional grids suitable for calculating flow fields around bodies with complex shapes. It is an extension of earlier methods that were limited to mapping two-dimensional flow regions onto rectangular grids in transformed planes. The technique will also be useful in solving thermodynamic and electrostatic fields near complex surfaces.

A quasi-two-dimensional grid is constructed on each of the surfaces bounding the physical region to be analyzed. The technique used to construct each surface grid is itself an extension of the earlier methods for mapping two-dimensional plane regions onto rectangles.

It is usually necessary to divide a complex-shaped flow region into a collection of simply-connected contiguous subregions. The surfaces that separate adjacent regions are selected for convenience and need not be planar. Each such imaginary surface is considered as if it were a physical boundary of the adjacent subregions.

Preferably, each subregion is bounded by six surfaces, so that it can be mapped onto a cube (see Figure 1). Each face of the cube is the image of one of the six surfaces, and the grid on each face is the image of the grid on the corresponding surface.

The mapping transformation, and hence the three-dimensional grid throughout the physical subregion, is obtained as a numerical solution to an elliptic Dirichlet problem for the cube. For each face of the cube, the Dirichlet boundary values represent the coordinates of nodes in the grid of the corresponding physical surface. The governing elliptic equations incorporate the Dirichlet boundary values into a set of source terms. The source terms in the interior of the cube are found by interpolation from the boundaries. The interior grid generated by this technique reflects both the geometric shape of the boundary and the spatial distribution of grid points along the boundary.

Since the same boundary values are used for the interpolation of source terms in-

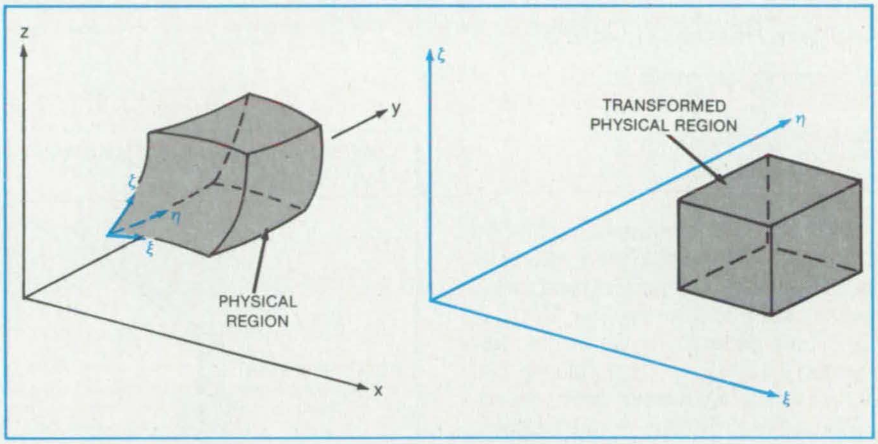


Figure 1. A **Six-Sided Three-Dimensional Physical Region** is mapped onto a cube in a nonphysical calculation space. The coordinates and the boundary conditions are simpler to express, and the calculations are simpler in the calculation space.

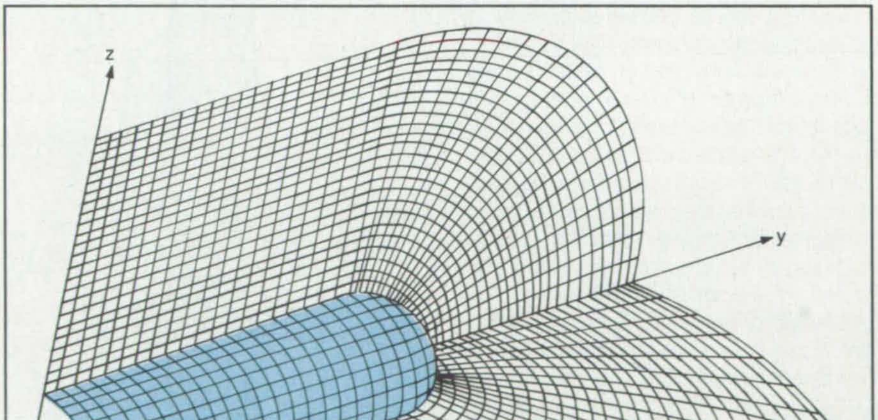


Figure 2. A **Grid System** is laid out in the space around an idealized aerodynamic object. The gridlines at the surface of the object conform to that surface.

to both regions on either side of a bounding surface, continuity and smoothness of the gridlines across the surface are assured. One can thus employ grids of different topological structure in each subregion while maintaining an overall continuity and smoothness of the composite grid formed by the union of the subregion grids.

As an example, a three-dimensional grid was constructed in the space around an idealized aerodynamic body comprising a cylindrical fuselage with hemispherical end caps and a straight wing. Figure 2 shows one octant of the composite grid on the wing, fuselage, and symmetry surfaces.

This work was done by P. D. Thomas of Lockheed Aircraft Co. for **Ames Research Center.** *For further information, Circle 86 on the TSP Request Card.*
ARC-11394

Computing Relative Joint Positions of Robot Arms

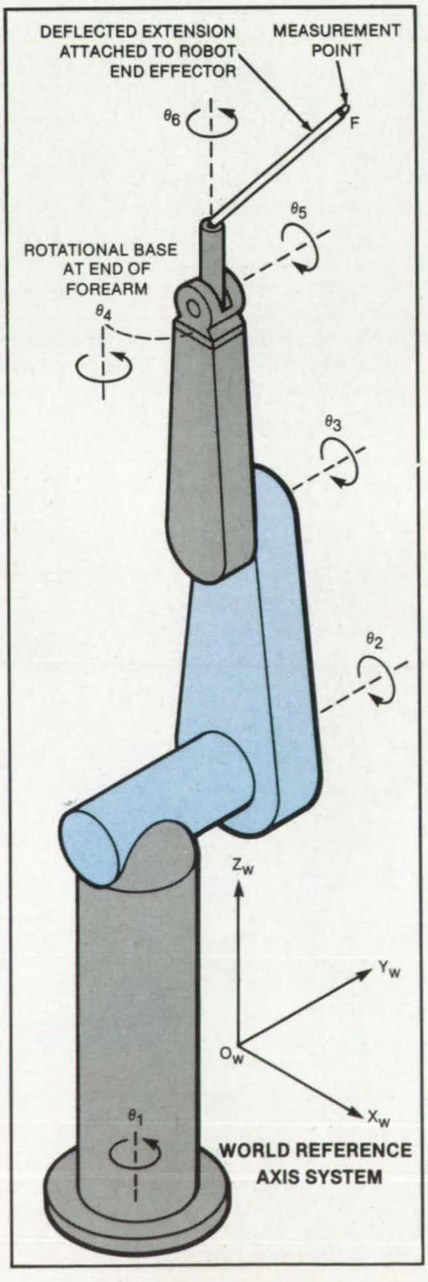
An algebraic method extracts parameters that describe the relative positions of joint axes in robot arms.

Langley Research Center, Hampton, Virginia

Transformation matrices from one joint axis to another are used in the control of robot arms and in the passage of sensor information along the arms. The Denavit-Hartenberg parameters, which precisely describe the relative location of one joint axis with respect to another, define the elements in these matrices. A vector-algebra method has been developed for extracting the Denavit-Hartenberg parameters for any assembled robot arm.

Measurement data needed to extract the parameters can be generated by varying the joint angles in a robot arm and measuring the location of a point on the robot hand or other extension. The Denavit-Hartenberg parameters relating consecutive joint axes are then calculated with these data. The only measurements required are the locations of a point on the robot hand (see figure) for different joint angles. A minimum of three locations (i.e., world coordinates for three locations of the point) is required for each rotational joint or two positions for each sliding joint. However, more points should be used to reduce the effects of measurement errors.

The robot arm is positioned by changing a set of joint angles, which are referenced to an arbitrarily specified zero position; and then the location of a point on the robot hand is measured with respect to a fixed world axis system, which is also arbitrarily specified. These positions and joint angles are used in equations to extract the relative joint parameters. More specifically, trajectories generated by a point on the robot arm (circular trajectory for rotational joints and line trajectory for sliding joints) and obtained by individual joint movements provide sufficient information to determine unit vectors along the lines of rotation or translation and to extract the Denavit-Hartenberg parameters.



A **Robot Arm Extension** and a world reference axis system are used in making joint geometry measurements.

The method for extracting relative joint geometry of robot arms will be useful to researchers who need these data for existing robot arms for either validation of mathematical models or for studies involving the actual control of these devices. This method, which does not require the robot arm to be disassembled, may also be useful in the recalibration of a misalined or bent robot arm and, if sufficiently accurate, could become a useful industrial procedure. A merit of the method is that errors are not propagated.

This work was done by L. Keith Barker of **Langley Research Center.** *Further information may be found in NASA TP-2191 [N83-34661/NSP], "Vector-Algebra Approach to Extract Denavit-Hartenberg Parameters of Assembled Robot Arms" [$8.50]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
LAR-13264

Books and Reports

These reports, studies, and 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.

Requirements Analysis for Information-Intensive Systems

Viewpoints are defined and integrated to help attain objectives.

A report discusses the role of requirements analysis in the development of information-intensive systems. A system can be examined from a variety of human viewpoints during design, development, and implementation. Such an examination, called requirements analysis, ensures that the system will simultaneously meet a number of distinct but interacting needs.

An information-intensive system is one in which the use and production of information is either a major function or a major component of the control of the function. The components of such a system are usually hardware and humans using software and procedures, respectively.

A major source of problems during the design and implementation of an information-intensive system is the conflict between system complexity and human limitations in handling large amounts of complex information. Over a period of time, a person can deal with a great number of intricately related concepts, but can deal with only a few at one particular time.

An important way that humans deal with this complexity is to work with views. Formalization of viewpoints forces the articulation of fundamental, hidden assumptions. Making the hidden assumptions public facilitates the exchange of information (results of work) between individuals.

A viewpoint is simply the position of an individual taking a view. A view is the result of filtering the available information about a situation and selecting a subset that is useful in doing a particular task.

The six key viewpoints are:

- User Needs, consisting of unanalyzed requirements: Also called "buyer's viewpoint," it is a set of specifications, a scenario, or a temporal exposition of the interdependent activities of the environment, the system, and the system operators in accomplishing a particular purpose;
- User Design, principally concerned with extracting a common, logically consistent set of requirements from the requirements expressed by individual users: These requirements provide an envelope of services that encompass reasonable demands by individual users;
- Implementation Design, concerned with laying out an overall structure, or architecture, of components to meet user design requirements;
- Detailed Design, Implementation, and Training, concerned with the specifics of constructing the system according to the architecture developed from the Implementation Design viewpoint: Training is included because it provides the human components of the system with the guidelines and procedures they will use during system operation;
- Integration and Test, concerned with fitting the parts of the system together to produce a properly operating whole that is ready for use in achieving the users' objectives; and
- User Operations, concerned with applying the system, as constructed, to achieve the users' objectives: The experience gained from this viewpoint is a rich source of user needs for the next (or modified) system.

There is another important viewpoint associated with the development process — that of project management. Project management plans and controls the development process by viewing and monitoring the efforts of the major development activities performed from the six other viewpoints.

From the user viewpoints, requirements analysis is a design activity. The design is synthesized from various incomplete and inconsistent user scenarios and other expressions of needs. The emphasis is on what functions the system is to perform and how the system interacts with the users. It is helpful in distinguishing between user design and implementation design to say that, from a user design viewpoint, the functions of the system are performed "as if by magic." One major pitfall is the temptation to specify implementation details in the statement of the user design.

Requirements analysis is an important activity at both the information-system and software-engineering levels. As an increasing number of system levels are added to the description of a product system, requirements analysis will first be done at the information-system level. Later, requirements analysis will again be performed at software-subsystem levels. It thus allows engineers, designers, and implementers to better handle the ever-increasing levels of complexity of information-intensive systems.

This work was done by E. David Callender, Christopher Hartsough, Richard V. Morris, and Yuzo Yamamoto of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "The Role of Requirements Analysis in the System Life Cycle," Circle 98 on the TSP Request Card. NPO-15944*

Coding for Efficient Image Transmission

Data are transmitted with minimal numbers of bits.

A NASA publication is the second in a series on data-coding techniques for noiseless channels. The techniques can be used even in noisy channels, provided that the data are further processed with a Reed-Solomon or other error-correcting code. The techniques are discussed in the context of the transmission of monochrome imagery from the *Voyager II* spacecraft but are just as well applicable to other streams of data.

The objective of this type of coding is to "compress" the data; that is, to transmit them using as few bits as possible by omitting as much as possible of the portion of information that is repeated in subsequent samples (or picture elements). Because most images contain a large amount of redundant information, data compression considerably increases the amount of information transmitted in a given time interval.

The efficacy of a compression technique can be judged by comparing the number of bits per sample in the coded data stream with a theoretical minimum number of necessary bits per sample that depends on the statistical properties of the data stream. This theoretical minimum is the entropy of the data stream.

A grainy image with no gross features in which each picture element can take on any of 256 gray levels with equal probability would have an entropy of 8 bits per sample, according to an equation defined for a memoryless data source. There is no redundancy in the random graininess, and the full 8 bits must be used to transmit each picture element or grain.

Suppose that this picture were changed so that half of all picture elements were at one gray level but still randomly distributed among all the other elements at other gray levels. In that case, the entropy would be about 5.5 bits per grain. Because a fraction of a bit cannot be transmitted, an optimal coding scheme should be able to transmit this image using no more than 6 bits per sample.

A primitive way to compress is to transmit an initial sample value followed by a sequence of differences from one sample to the next. Redundancy is reduced further by incorporating a convolutional prediction formula into the coding algorithm and thereafter transmitting the differences between the actual and formula-predicted sample values. In essence, compression-coding algorithms specify the prediction formulas, the numbers of bits to be transmitted, and the mappings between code and sample values.

In real imagery, data entropy varies from line to line and from image to image. Advanced coding algorithms therefore employ variable-length codes to achieve performances close to the time-varying entropy limit. The optimum code for a particular set of image or data statistical properties is simply the one that gives the shortest output sequence.

The report describes a number of adaptive algorithms, including one called Basic Compressor. This algorithm includes four code options and gives optimal compression at entropies up to about 4 bits per sample. It has been used on image data from the *Voyager* encounter with Saturn. The *Voyager* imagery includes 256 gray levels and would therefore require 8 bits per picture element in the absence of compression. With the Basic Compressor algorithm, images are transmitted at bit rates close to the *Voyager* entropy limit, ranging from about 2 to 5 bits per sample.

Algorithms have to be more complicated to compress adequately at higher entropies. For example, in a split-sample algorithm, the least- and most-significant bits of a data stream are taken apart into separate sequences. The advantage of such a scheme is that a sequence of most-significant bits often has lower entropy than the accompanying sequence of least-significant bits: The most-significant bits are therefore susceptible to compression even though the least-significant bits may remain random and therefore incompressible.

This work was done by Robert F. Rice and Jun-Ji Lee of Caltech for **NASA's Jet Propulsion Laboratory.** *Further information may be found in NASA CR-172769 [N83-28069/NSP], "Some Practical Universal Noiseless Coding Techniques, Part II" [$10]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
NPO-16444

Computational Simplification of Robot-Arm Dynamics

Matrix- and vector-reduction techniques simplify the state equations.

A report presents two general methods for reducing the mathematical complexities of the state equations of robot-arm dynamics. The robot arms may contain both rotary and linear joints.

Both methods start with homogenous coordinates and the Lagrangian formulation of mechanics, which are briefly summarized in the report. The first method uses matrix-analysis techniques; the second, vector-analysis techniques. The vector-analysis method includes a new differential-vector representation of centripetal and Coriolis forces.

Any of the customary Lagrangian, Newton-Euler, or Hamiltonian methods can be used to derive the equations of motion of rigid-body robot arms. Generally, however, closed form, analytical solutions of the resulting set of complex, nonlinear, coupled, ordinary differential equations do not exist. Formulating efficient computer algorithms for generating torque and force values for a given set of motion variables and constant geometric and inertia parameters of robot arms is one way to attack the mathematical complexities. Such algorithms do not show dynamical details explicitly. A second approach — namely, formulating explicit state equations for robot-arm dynamics — may exhibit too many insignificant details. Both methods require lengthy computation.

The report presents both general and case-specific methods of reducing the computational complexity in the state-equation approach. Five general and three specific model reductions or simplifications are derived by matrix methods. They are based in part on exploiting symmetry properties of "dynamic-projection functions," which represent inertial properties and dynamic-coupling coefficients and which are the sums of the traces of certain matrix products appearing in the formulations. One of the general reductions corresponds to the physical observation that the centripetal force of a rotary joint is not felt by the motor of the same rotary joint. The case-specific reductions apply to arms with specified combinations of types of joints.

The report section on model reduction by vector analysis introduces differential vectors representing all of the dynamic-projection functions, including those for centripetal and Coriolis forces. Four of the general reductions from the matrix-analysis section are rederived through vector analysis. These general reductions decrease the number of projection functions to about one third of the original number. Seven specific reductions are also derived.

The final section of the report considers three further approximate reductions. These simplifications in the dynamic-projection functions are obtained by neglecting terms that are expected to be negligibly small when certain arm-geometry conditions exist. An example of the simplification of one projection function for an actual robot arm is quoted: A 16-line expression was reduced to a single line. In this case, the worst-case error introduced was less than 8 percent; the average error was about 4 percent. The reduction in computational length was greater than 90 percent.

This work was done by Antal K. Bejczy and Sukhan Lee of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 100 on the TSP Request Card.*
NPO-16377

Computer Programs

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

Modal Analysis and Gain Estimation

This interactive program yields eigenvectors, eigenvalues, and gains for feedback-control systems.

The Interactive Modal Analysis and Gain Estimation System (IMAGES) provides an eigensystem synthesis capability to the control-system engineer. IMAGES is modular and flexible. It is capable of both modal and spectral synthesis of multi-input control systems. IMAGES is a user-oriented, interactive program that frees the engineer to concentrate on the eigensystem synthesis. The engineer is provided with a scratch-pad capability that should speed the control-system design.

IMAGES is based on algorithms developed by Srinathkumar for control-system synthesis using the concept of pole placement. These algorithms estimate either eigenvectors, eigenvalues, or gains for either state-feedback or output-feedback control systems. A spectral-synthesis algorithm is included to extend the flexibility of the system.

IMAGES is designed for interactive use and provides menus, questions, messages, and diagnostics. The various control system matrices and other critical variables are printed at the terminal as they are generated. In many instances, the user is permitted to modify these values. The user may also permute the A, B, C, and D matrices. As a design aid, the user can graphically display the control-system response to inputs. A design can be modified repeatedly until the desired response is obtained.

IMAGES is written in FORTRAN IV for interactive execution and has been implemented on a CDC CYBER 170-series computer with a central-memory requirement of approximately 74K (octal) of 60-bit words. Developed in 1984, IMAGES can be executed from any standard text terminal.

This program was written by Ruben L. Jones of **Langley Research Center.** *For further information, Circle 111 on the TSP Request Card.*
LAR-13334

Text Exchange System

A transportable system for management and exchange of programs and other text

The Text Exchange System (TES) exchanges and maintains organized textual information including source code, documentation, data, and listings. The system consists of two computer programs and the definition of a format for information storage. A comprehensive program is used to create, read, and maintain TES files. To allow the system to be distributed on magnetic tape in TES format, a simpler program capable only of copying TES format tapes to user files is provided. Although operation of the comprehensive program is controlled by 35 simple commands, information may be read from a TES file by using as few as 3 commands. In addition to its use for information exchange, TES is helpful in maintaining libraries of text.

TES was developed to meet three goals. The first goal is the easy and efficient exchange of programs and other textual data between similar and dissimilar computer systems via magnetic tape. Although several ANSI standards for information exchange exist, they each have shortcomings in real applications. TES files are readable on any system on which one of the transportable TES programs has been installed. The TES data structure contains such features as space reduction by means of redundant character elimination and data integrity insurance by means of recovery information.

The second goal is to provide a transportable management system for textual information. To organize information, each program, subprogram, listing, or data group may be recorded as a separate module of text. Categorized descriptive information, called control information, may be associated with each module.

The third goal is to provide a common user interface, over a wide variety of computing systems, for all activities associated with text exchange. In addition to the functions of storage, retrieval, and organization of text, TES provides a common method of distributing corrections, revisions, and enhancements by means of a simple but flexible updating mechanism. As an aid to maintenance and development of programs consisting of several modules, constant data such as global variable declarations may be automatically inserted at specified positions in the text when user files are created.

TES is written primarily in ANSI standard FORTRAN 66 with some small machine- or system-sensitive-modules. Machine-sensitive modules may be written in FORTRAN 66 or extensions, FORTRAN 77, Assembler language, "C," or other languages depending on the system. The current TES distribution tape includes versions for the IBM 370 series, CDC 6000 (SCOPE and NOS) series, Sperry UNIVAC 1100 and V70 series, DEC VAX (UNIX and VMS), PDP 10, PDP 11 (RSX-11), DEC-system 20 series, and Data General MV/8000 series.

Development of TES was completed in 1981. TES has been published as an algorithm in *ACM Transactions on Mathematical Software,* Vol. 9, No. 4, December 1983, page 427.

This program was written by William V. Snyder of Caltech and Richard J. Hanson of Sandia National Laboratories for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 75 on the TSP Request Card.*
NPO-16357

Subset Regression

Backward elimination procedure minimizes prediction errors of equations fitted to factorial experiments.

Subset regression programs for fitting equations to data usually select a conditional number of terms, partly dependent on a user-specified level of significance testing. The level that minimizes prediction error is usually unknown.

The problem of minimizing prediction error is now solved for the two-level full- or fractional-factorial experiment with 16 factorial points and 0 to 6 center points. Such an experiment provides 16 orthogonal coefficient estimates for an empirical polynomial model. Each coefficient is estimated with low variance error because it is estimated from 16 observations. For a low cost in data, the 16 coefficients can provide a large amount of information on direct and synergistic effects of many independent variables. Response surface studies suggest that 0 to 6 center points be added to the 16 factorial points.

For such an experiment, significance testing with a large number (greater than three) of center points might best be done against the F-distribution, but if the number is small, or if many terms are rejected, continued significance testing might best be done against a distribution of order statistics. A large-scale Monte Carlo investigation optimized significance testing procedures against an unfavorable distribution of model coefficients. The procedures were also optimized for significance levels and for conditional switching from the F-distribution to an order statistics distribution. Procedures were optimized for the cases of small observation error, observation error unknown, and large observation error.

Because the program takes data from a two-level factorial experiment, it uses Yate's method of coefficient estimation and is therefore free of the usual regression numerical problems of matrix inversion. The program, POOL10, was written in FORTRAN IV.

This program was written by Arthur G. Holms of **Lewis Research Center.** *Further information may be found in NASA TM-82995 [N83-28172/NSP], "Computer Program To Minimize Prediction Error in Models From Experiments With 16 Hypercube Points and 0 to 6 Centerpoints" [$8.50]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
LEW-14002

Solving Large Systems of Normal Equations

Solutions are obtained for equations with square normal coefficient matrices that are nonnegative definite.

The SOLVE II program combines any number of sets of normal equations and obtains the solution vector and related statistics. The normal equations are of a square, nonnegative definite matrix form, and the program utilizes only the upper symmetric portion of the matrix. The program uses a partitioned Cholesky decomposition method for matrix inversion to accommodate large parameter systems.

SOLVE II was developed as a companion program for GEODYN, which is described in the article "GEODYN" (GSC-12014) in *NASA Tech Briefs*, Vol. 1, No. 3 (Fall 1976), p. 429. The program design provides great flexibility in obtaining least squares solutions for geodynamic quantities such as spherical harmonic gravity coefficients, gravity anomalies, tracking-station coordinates, solid Earth and ocean tide parameters, polar motion parameters, and satellite orbital parameters.

This program is written in FORTRAN IV and Assembler for batch execution and has been implemented on an IBM 370-series computer with a central memory requirement of approximately 350k of 8-bit bytes. The SOLVE II concept and design have undergone a continuous evolution since 1974 based on user requirements. The program has been vectorized to run on the CDC CYBER 205 computer, where a benchmark test solution involving 1,921 parameters required 107 CPU seconds.

The SOLVE II program was developed under the direction of Barbara Putney for the Geodynamics Branch of **Goddard Space Flight Center.** *The current version of the program was written by Ronald Estes of Business and Technological Systems, Inc. For further information, Circle 67 on the TSP Request Card.*
GSC-12858

Transportable Applications Executive

A collection of executive programs standardizes the user interface to application programs.

The Transportable Applications Executive (TAE) is a collection of "executive" programs that interact with the user to manage the execution of application programs. All applications running under TAE have the same interface. Since TAE manages the entire interactive session, the user does not need to know the command language of the host computer.

TAE is utilized effectively and efficiently by both the first-time user and the experienced user. It can provide extensive assistance to the user at any stage of an interactive session.

TAE permits the user to operate in three different modes. In the menu mode, the user proceeds through a session by selection from a list of options. Each entry in a menu refers to an application function or to another menu. In the command mode, the user communicates with TAE through a simple command language. In the tutor mode, the user establishes and reviews sets of parameters to be supplied to an application program. An extensive "HELP" facility is available in each mode. Also, the user is free to switch among modes as desired. Because the implementation of an application function is independent of the TAE mode, every application is available from each of the modes.

Special features are provided to assist the application programer in interfacing with TAE. A major aspect of the TAE/application program interface is the "proc" entity, which can be executed to perform a function. A proc is either a process or a procedure. A process is a program for which executable code exists. A procedure is a "command procedure" written in the TAE command language. Extensive proc management capabilities are available to the application programer. A library of TAE utility subroutines is available to standardize access to primitive host functions and to enhance the portability of the calling program. The programer is also assisted in the development of "HELP" text files and menus.

TAE is written in the C programing language. It runs on a DEC VAX 11/780, under VMS and UNIX, and on SUN Microsystems and Gould SEL computers, both under UNIX. TAE is being used as the executive for multidisciplinary studies in meteorology, climate land resources, oceanography, and CAD/CAM applications.

This project is managed by Martha R. Szczur of **Goddard Space Flight Center.** *For further information, Circle 36 on the TSP Request Card.*
GSC-12881

Text File Display Program

The user can rapidly examine any section of an ASCII text file.

The LOOK program permits a user to examine a text file in a pseudorandom access manner. Many engineering and scientific programs generate large amounts of printed output. Often, only a few sections of this output need to be examined. On minicomputers (like the DEC VAX), high-speed printers are usually at a premium. One alternative is to save the output in a text file and examine it with a text editor. The slowness of a text editor and the possibility of inadvertently changing the output make this an unsatisfactory solution. The LOOK program provides the user with a way of rapidly examining the contents of an ASCII text file.

LOOK opens the text file for input only and then accesses it in a blockwise fashion. It handles the text formatting and displays the text lines on the screen. The user can move forward or backward in the file by any number of lines or blocks. LOOK also provides the ability to "scroll" the text at various speeds in the forward or backward directions. The user can perform a search for a string (or a combination of up to 10 strings) in the forward or backward directions. Also, user-selected portions of text may be extracted and submitted to be printed or placed in a file. Additional features available to the LOOK user include: Cancellation of an operation with a keystroke, user-definable keys, switching mode of operation (e.g., 80/132 column), online help facility, trapping broadcast messages, and the ability to spawn a subprocess to carry out document-control language functions without leaving LOOK.

LOOK is written in FORTRAN 77 and MACRO Assembler for interactive execution and has been implemented on a DEC VAX computer using VAX/VMS with a central memory requirement of approximately 430k of 8-bit bytes. LOOK operation is terminal independent but will take advantage of the features of the DEC VT100 terminal if available. LOOK was developed in 1983.

This program was written by Jon L. Vavrus of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 50 on the TSP Request Card.*
NPO-16358

Data Manipulation and Display

Database management programs provide a user-friendly environment for scientific data processing.

Engineers and scientists often face the task of performing a large number of complex operations (i.e., calculations) on an array of numbers. BDMADS, a BASIC Data Manipulation and Display System, is a software package that runs on an Apple II Plus or IIe personal computer to provide a user-friendly environment in which to perform those operations.

BDMADS permits a user to:

1. Type in sets of numbers (measurements) at the keyboard using BDMADS' data base management program,
2. Store the measurements in a user-named disk file,
3. Interactively manipulate (e.g., edit, search, and sort) the data using the facilities of the data-base management program,
4. Incorporate a user-defined calculation subroutine (programed in BASIC) into the BDMADS calculation program,
5. Perform all of the calculations on any or all of the sets of measurements,
6. Obtain hard-copy printouts of the measurements and the calculated variables, and
7. Interactively change the calculation equations and immediately obtain new results.

Multiple Pages Missing from Available Version

An additional feature of BDMADS is its ability to store results in disk files that are compatible with VisiCalc, the popular electronic spreadsheet program.

BDMADS is written, for the most part, in Applesoft BASIC. Two associated subroutines are written in 6502 Assembler. BDMADS runs on an Apple II Plus or IIe personal computer having at least 48k 8-bit bytes of random-access memory. The program was developed in 1982.

This program was written by John R. Szuch of **Lewis Research Center.** *For further information, Circle 27 on the TSP Request Card.*
LEW-14101

Flexible Airframe Response Program

Program output can be used in aircraft flight control design.

A generalized set of flexible vehicle equations-of-motion (EOM's) has been developed and incorporated into the Flexible Airframe Response (FAR) program. The general approach for obtaining airframe dynamics in transfer function form is to solve the perturbed vehicle force and moment equations. The linearized, six-degree-of-freedom EOM's are decoupled into longitudinal and lateral planes by an assumption that the vehicle is symmetrical and that a small disturbance creates motion in its own plane. The airframe dynamics are solved separately in the pitch and the yaw/roll planes. The ouptut from the FAR program could be used in aircraft flight control system design.

In FAR, the flexible vehicle EOM's are an expansion of the rigid vehicle EOM. Included in the flexible vehicle EOM are force equations, moment equations, hinge moment equations, body-bending equations, the rate equation, and the accelerometer equation. Input to the FAR program includes: Vehicle mass properties, geometrical data, flight conditions, and structure-related data. FAR obtains the airframe dynamics transfer function in Laplace form for any system-independent parameter over any control-dependent parameter. The outputs from the program are in root and polynomial form.

The FAR program is written in FORTRAN IV for batch execution and has been implemented on a CDC CYBER 70 series computer with a memory requirement of approximately 120k (octal) of 60-bit words. The FAR program was developed in 1983.

This program was written by Chiang Lin of McDonnell Douglas Corp. for **Johnson Space Center.** *For further information, Circle 48 on the TSP Request Card.*
MSC-20762

Universal Noiseless Coding Subroutines

They noiselessly code integer and binary data strings and decode the results.

This software package consists of FORTRAN subroutines that perform universal noiseless coding and decoding of integer and binary data strings. The purpose of this type of coding is to achieve data compression in the sense that the coded data represents the original data perfectly (noiselessly) while taking fewer bits to do so. The routines are said to be universal because they can be applied to virtually any "real-world" data source.

Two classes of coders and decoders are included: One class for integer samples and one class for binary data. The routines were developed with the research and engineering user in mind. They provide an easy way to test and demonstrate the effectiveness of universal noiseless coding techniques as applied to a wide variety of real-world problems. The user needs only to be concerned with meeting certain probability ordering requirements to obtain very efficient encoding. The routines have been employed at the Jet Propulsion Laboratory in the development of imaging data compression systems.

The collection of subroutines is written in ANSI standard FORTRAN IV for batch execution and has been implemented on an IBM 370 series computer with a central memory requirement of approximately 140k of 8-bit bytes. The package was developed in 1979.

This program was written by Alan P. Schlutsmeyer and Robert F. Rice of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 18 on the TSP Request Card.*
NPO-15451

TRASYS for Beginners

This user's manual teaches the elements of a thermodynamic-analysis program.

A self-teaching manual is designed for first-time users of TRASYS (Thermal Radiation Analysis System), a computer program widely used by engineers involved in thermodynamic analyses. It is simpler than the full TRASYS manual: Readers need no previous knowledge of the program or of the FORTRAN language in which it is written.

The self-teaching manual gives specific instructions in the operation of the program and three step-by-step examples. In addition to the examples, it contains sections on the input deck, surface data, surface-data format, and data-block formats.

The difficulty of the examples increases progressively. Example 1 illustrates the job-control languages (JCL's) needed to run the simplest program. Example 2 shows the user how to build the geometrical mathematical model and how to use the proper TRASYS subroutines to compute form factors and radiation conductors. Example 2 also defines the JCL's needed to store results on tape. Example 3 illustrates the geometric mathematical models of all geometries allowed by TRASYS. It also teaches the user how to use the "restart input" and "restart output" operations.

Because of its complexity, the complete TRASYS manual is used primarily as a reference. It is intended to be all-encompassing and to provide general instructions for all segments of the program. Some knowledge of FORTRAN is needed to make full use of it.

This work was done by Kenneth T. So of Rockwell International Corp. for **Johnson Space Center.** *Further information may be found in NASA CR-161077 [N82-10754/NSP], "TRASYS II: Simplified TRASYS User's Manual" [$34]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
MSC-20855

Subject Index

A FRAMEWORK FOR ACTION:
Improving Quality and Productivity in Government and Industry

The following themes represent both a synopsis and synthesis of the issues discussed and the ideas, examples and recommendations offered at the 1984 NASA-sponsored "Symposium on Quality and Productivity: Strategies to Improve Operations in Government and Industry." They are the collective wisdom of the more than 650 top executives from major American corporations, government agencies and universities who attended the symposium.

The major findings are organized into nine themes, three of which are presented here. (The remaining six will be presented in future issues of NASA TECH BRIEFS.) Each theme begins with a brief overview of the need for action, followed by a series of recommended actions and management practices that have been shown to contribute to high quality and productivity.

THEME 1: Challenge for the Competitive Edge: Responding to Competitive Pressures.

The worldwide market competition we face as a nation and its impact on our organizations presents a serious threat. Eighty percent of our products are now challenged in the marketplace, compared to 20 percent ten years ago. A continuous quest for improvement, greater cooperation and trust, and a world-class standard needs to be built into organizational philosophies. All employees should understand the nature of the challenge. Management needs to convey the message and generate pressure for improvement.

> "Being competitive today is a matter of what the whole society does: it is government, managers, employees, unions, educational institutions, consumers and taxpayers...all together, all part of the action." (Ruben Mettler, TRW, as quoted by Malcolm Stamper, The Boeing Company)

Whether they realize it or not, virtually all U.S. organizations are operating in a world economy. There is hardly a U.S. market that does not have at least 20 percent foreign penetration, and in some markets it runs as high as 80 percent. At the same time, our dependence on international markets is increasing. The message is clear: U.S. firms cannot continue to do business as they have in the past. Even high technology is not immune and must adapt, adjust and change in order to survive.

> "Surprisingly to many, in the last decade even our share of world exports of high technology products has declined from 25 to 20 percent. And the U.S. share of world trade in such services as insurance, finance, aviation, shipping and engineering also has declined from 25 to 20 percent." (Richard Foxen, Rockwell International Corporation)

Recommendation 1.1 Recognize Foreign Quality/Productivity Gains

During the late '60s and early '70s, the U.S. industrial base began to lose ground as Japan, West Germany and other industrialized nations cut into our industrial competitive edge. Robert Cole of the University of Michigan summarized the problem this way:

> "Suffice it to say that increasingly, our products have become less competitive worldwide and domestically when it comes to price, quality, and even product innovation."

Egils Milbergs, Executive Director of the President's Commission on Industrial Competitiveness, suggests that the U.S. public and private sectors "are beginning to define a uniquely American response to the competitive challenges we face."

> "Perhaps the most difficult, yet in some ways the most important, action is to take immediate steps to educate both our management and our work force regarding the significance of this globally interdependent environment." (Foxen)

Foxen points out that we need to understand:
- The U.S. share of world auto markets has declined from 32 to 21 percent, and from 19 to 10 percent for steel.
- In 1960, only 5 percent of our Gross National Product depended on foreign trade; today it is over 14 percent.
- Exports create a large demand for employment. Between 1977 and 1980, 30 percent of the increase in private sector employment was attributable to export growth.
- The more a company invests abroad, the greater its exports and employment at home.

These kinds of facts challenge many of the prevailing myths in our society regarding international trade and overseas investment. Before we can build a consensus for action among managers, labor unions and employees, we must examine these facts and develop a common understanding of the global challenge. Awareness precedes action. All employees must be made aware of the need to become a world-class competitor in order to survive. In addition, we must develop more effective management approaches to organizational activity even in those organizations which are not directly challenged.

Recommendation 1.2 Use Consensus-Building in U.S. Societal Groups

When decisions are primarily reserved for "top" management, we tend to find large staffs, bottlenecks and stifled initiative. Based on organizational research, William Ouchi of UCLA has concluded that in the long run, the high performing type of company is the M-Form or multi-divisional organization. This organizational form addresses a major impediment to productivity—the ability to confront different points of view and reach a consensus on future directions at the lowest practical level. Consensus building encompasses cooperation, informal discussions, and better coordination.

When the M-Form organization succeeds, it has achieved a balance between competition and teamwork. The organization is decentralized in the sense that each division operates as if it were a small entrepreneurial business, to encourage flexibility and creativity.

Ouchi argues that this principle can also be extrapolated to the national level and even to societies:

> "The basic building blocks are in place...the American Business Conference, the Conference Board, National Association of Manufacturers, Chamber of Commerce ...They ought to be linked to one another..."

He points out that we need similar mechanisms in labor, municipalities and states, and civic and consumer groups. Mechanisms for consensus building will aid our ability to adapt to new economic realities.

Recommendation 1.3 Build Organizational Structures That Allow Change

Organizations must have the capacity to react to changing circumstances as they occur.

> "... in order to seize the competitive edge, we must maximize the flexibility and adaptability of American workers and managers." (Foxen)

Management must pay attention to practices and institutional conditions which impair responsiveness. These include antagonistic labor/management relations, short-term profit orientation, bureaucratic structures, and the lack of incentives and mechanisms for worker retraining.

> "We must create a stimulating, supportive environment in which our employees can become the sensors and masters of change rather than its victims." (R.J. Boyle, Honeywell, Inc.)

To make maximum use of our work force requires leadership and organizational attention to "basics." For instance, we need to:

- develop long-term rather than short-term scenarios for deploying capital and human resources;
- accommodate individual employee differences with respect to hours of work, career paths, and job design, etc.;
- create new ways to continuously upgrade employee skills;
- insist on management practices which foster customer interaction at all levels; and
- reinforce individual accountability for results.

To meet the competitive challenge we must have responsive organizations that can evoke the best efforts of all employees. As John R. Stepp, U.S. Department of Labor, observed:

> "In our present internationally competitive environment the increased productivity and the increased flexibility to respond to economic and business conditions which can result from labor-management cooperation may well make the difference between jobs or unemployment for many American workers."

THEME 2: Make a Management Commitment to Quality and Productivity: Leading from the Top

Quality and productivity are the responsibility of top management. Too often, however, they are assigned to staff with a "Fix it if it goes wrong" mentality. As a result, they become buzz words rather than measurable objectives for which line managers are held accountable. Management involvement is meaningless unless demonstrated commitment is perceived by employees as genuine and long-range.

> "We at Sony believe that quality and productivity are the responsibility mainly of management." (Sadami Wada, Sony Corporation of America)

By virtue of position, top management develops the motivation and attitudes and thus the basic direction for an organization. Management leadership is also necessary to insure that the chosen strategies are translated into effective action. Long-term planning provides a consistent set of goals against which continuous improvements can be made. Leadership, however, should not be confused with authority:

> "Authority is position; leadership is style. One demands respect; the other earns it." (Malcolm Stamper, The Boeing Company)

Recommendation 2.1 Toward a Top Management Philosophy Committed to Quality/Productivity

> "... lack of commitment from the top is the major impediment to getting a productivity program off the ground. If there is not action and demonstrated commitment from the president and/or CEO on down, forget it." (David Hamilton, Intel Corporation)

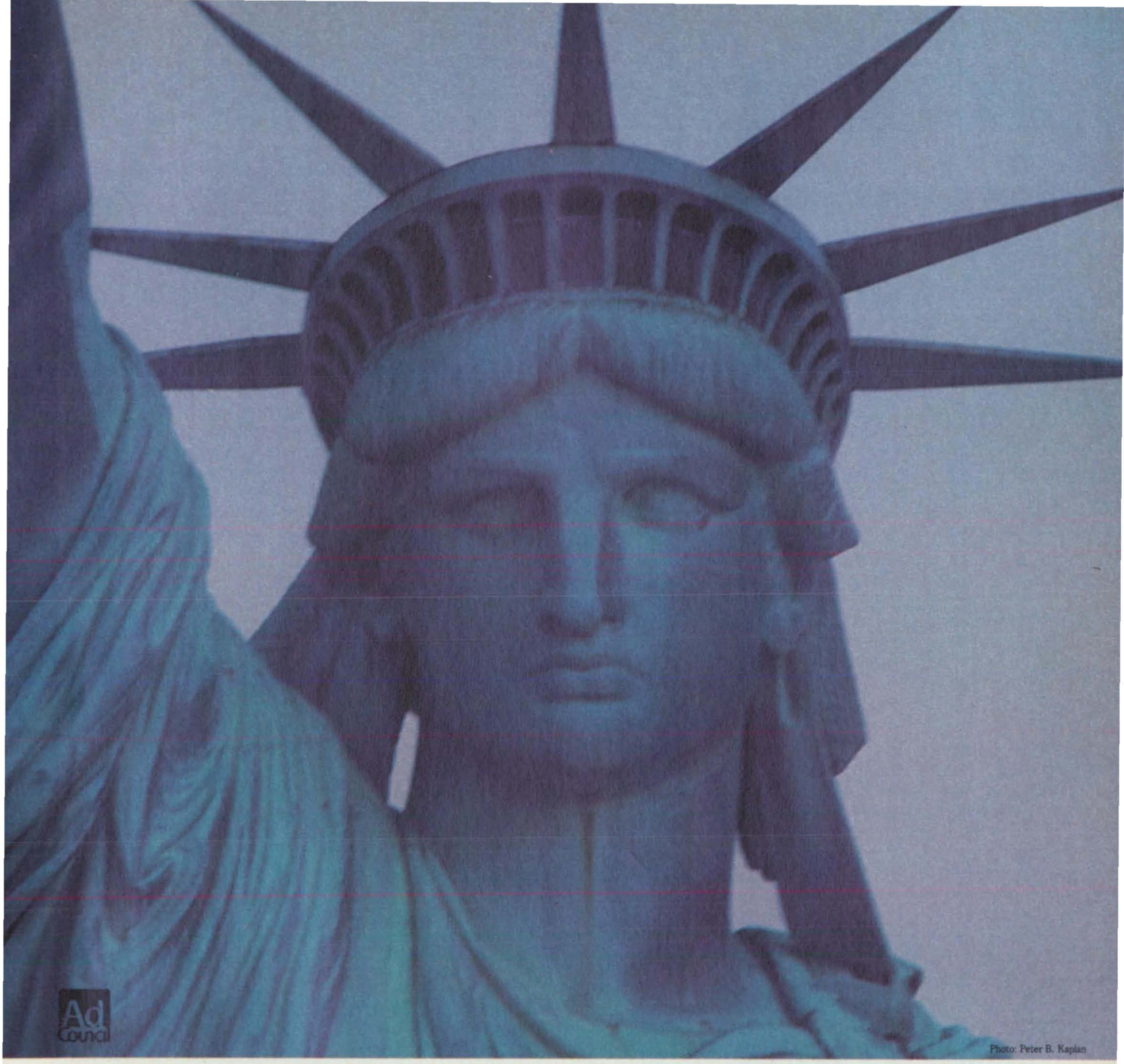


Photo: Peter B. Kaplan

If you still believe in me, save me.

For nearly a hundred years, the Statue of Liberty has been America's most powerful symbol of freedom and hope. Today the corrosive action of almost a century of weather and salt air has eaten away at the iron framework; etched holes in the copper exterior.

On Ellis Island, where the ancestors of nearly half of all Americans first stepped onto American soil, the Immigration Center is now a hollow ruin.

Inspiring plans have been developed to restore the Statue and to create on Ellis Island a permanent museum celebrating the ethnic diversity of this country of immigrants. But unless restoration is begun now, these two landmarks in our nation's heritage could be closed at the very time America is celebrating their hundredth anniversaries. The 230 million dollars needed to carry out the work is needed now.

All of the money must come from private donations; the federal government is not raising the funds. This is consistent with the Statue's origins. The French people paid for its creation themselves. And America's businesses spearheaded the public contributions that were needed for its construction and for the pedestal.

The torch of liberty is everyone's to cherish. Could we hold up our heads as Americans if we allowed the time to come when she can no longer hold up hers?

Opportunities for Your Company.

OFFICIAL SPONSOR LIBERTY

You are invited to learn more about the advantages of corporate sponsorship during the nationwide promotions surrounding the restoration project. Write on your letterhead to: The Statue of Liberty-Ellis Island Foundation, Inc., 101 Park Ave, N.Y., N.Y. 10178.

Save these monuments. Send your personal tax deductible donation to: P.O. Box 1986, New York, N.Y. 10018. **The Statue of Liberty-Ellis Island Foundation, Inc.**

An organization is guided by its beliefs. These beliefs are the foundation upon which all policies and actions are based. One organization with such a credo is IBM. John Jackson of IBM discussed how Thomas Watson, Jr., stated that, to survive, an organization must have a sound set of beliefs, must adhere to these beliefs and:

> "...to meet the challenges of a changing world, it must be prepared to change everything about itself except those beliefs..."

Use every opportunity to show visible management support. The message should be delivered through all available media. Charles Joiner, Jr. of the Mead Corporation suggests using formal employee meetings, videotapes, company brochures, newsletters and individual meetings as well as normal contacts in the course of day-to-day business. The commitment must be sincere, long-term and not be compromised by short-term considerations or crises.

> "It is vital that top management make a true commitment to quality/productivity leadership...this commitment must be communicated to all employees, and reinforced through management actions and involvement. Make no mistake, employees can discern whether management is just paying lip service or is genuinely committed. If the Chief Executive Officer isn't committed, the employees won't be either." (John Manoogian, Ford Motor Co.)

Quality and productivity goals often become slogans that are not reinforced through management policies. This must be corrected, since a manager's example speaks louder than words. While the President or CEO may be the most visible champion, the key considerations of any management team are working together effectively and "modelling" to the rest of the organization the values and skills that are desired. As Charles Joiner stated:

> "The leader is the architect of that vision and above all else he or she must be for employees—the shining example of permanent human aspiration—inspiring employees to devote their powers to jobs worth doing."

He further stated:

> "...our team was built through sheer hard work ...Our first meeting was tough and full of game playing...We simply needed to develop the trusting relationships found in mutual friendships ...In the process we learned some new skills...Once the team was functioning it was then possible to begin moving...[it]... down through the organization."

Recommendation 2.2 Make Management's Goals and Long-Term Plans Known Throughout the Organization

As Lemmuel L. Hill of the Naval Surface Weapons Center stated: "Organizational effectiveness...is heavily dependent on...two attributes...dedicated, capable people, and a sense of purpose and direction." Transmitting the quality/productivity goals resulting from long-term planning to all employees is one of the most necessary kinds of communication, but at the same time one of the most difficult. In the words of Charles Joiner:

> "Once the future has been determined, it must be shared with all employees through an intensive communication process."

A clear and consistent view of the strategic direction of the organization must be communicated to all organization members. Organizations gain direction from a strategic vision and from the basic philosophies and values it embodies.

The need to lengthen time horizons was a persistent theme at the symposium. F. Blake Wallace points out how the long-term view affects capital investment decisions at General Motors:

> "The solution which we at GM are using, and I believe that others in the industry are applying, is not to abandon the ROI analysis, but to supplement it with a clearer picture of our aspirations for five, ten or even fifteen years in the future and make appropriate factory modernization decisions to reflect those aspirations."

Long-term goals are important not only for capital investment, but for human resource development and product planning as well. This theme was echoed by Rockwell International's Richard Foxen, who said business leaders need to return to the basics of providing leadership in the development of both capital and human resources.

Recommendation 2.3 Develop Organizational Structures and Policies to Support Management Philosophy

Make sure that promotion policies, compensation policies, planning and budgeting systems, information systems, and other systemic mechanisms are in alignment with strategic direction and organizational philosophy. The behavior of managers and employees is shaped in part by management's example and in part by organizational structure and systems.

> "To create a trusting work environment, the manager's behavior must remain consistent with the stated beliefs in people." (Joiner)

Joiner uses management systems as a way of assuring that managers' actions are consistent with stated beliefs. These include the compensation program, selection process, performance reviews, educational opportunities, "speak-up" programs, and systematic approaches to planning and budgeting. Regular surveys are designed and carried out periodically to assess organizational health and insure that systems are aligned with the strategic vision.

Often the most powerful media are not those usually associated with communications. Harvey Weiss of Digital Equipment points out that communication in Japanese firms is enhanced by job rotation. Japanese managers and engineers rotate through many parts of the organization during their careers. They know the people and the operations, thereby facilitating communication and coordination. Weiss also warns that:

> "...we may mistakenly encourage people to stray from the 'desired mission' of the enterprise through the structure, the measurement system or the reward system we put in place."

THEME 3: Mesh Goals and Responsibilities: Opening Two-Way Communications

A clearly articulated management philosophy can guide managers to speak and act honestly and confidently with customers and suppliers. To earn the support of all employees, management must communicate the goals and objectives of the organization. A clear, long-term management philosophy provides a sense of direction. On a broader level, government, industry and labor unions need to be less adversarial.

> "In all organizations there are a number of prominent feelings or attitudes which the company stands for that influence how one should act in performing job assignments." (Fred A. Manske, Federal Express Corp.)

Communication in an organization is analogous to the nervous system of a human being: it provides the linkage between plans, behavior and actions. Thus, communication coordinates the joint actions of individuals, teams and departments. It is used to gain cooperation among different elements, to reward and recognize employees, and to convey information. In short, open two-way communications processes are essential to effective functioning.

Richard Kraft of Matsushita expresses well the relationship between organizational philosophy and communications:

> "My experience has convinced me that a clear management philosophy can allow managers to be confident in their business activities, and guide managers to speak and act honestly with both customers and employees."

Recommendation 3.1 Talk with Customers, Vendors and Contractors

Every level of organization has "customers" and each should be attuned to these customer needs and desires. Lewis Lehr of the 3M Company describes how his company creates opportunities for both employee/customer interaction and vendor dialogue. These range from requiring officers of the company to spend one day a month selling the product, to user conferences involving face-to-face contact between designers and customers.

> "Imagine what would happen if the designers of, say, an office machine had to spend one day a month in the field, making service calls or listening to customer complaints. What would happen if the people responsible for drafting regulations in an agency had to spend one day a month helping people fill out the forms and meet the requirements?" (Lehr)

John Manoogian reinforces this point and adds a new dimension:

> "The customer is the final judge, so it is better to *determine needs from the customer's viewpoint*... The term 'customer' refers not only to the *external* purchasers of our products but also to our *internal* customers—the next person or organization in every stage of our business and manufacturing process."

If we are to improve quality and productivity, everyone, at every stage of the production process, must identify and listen to the customer. Encourage your vendors to communicate with you. Work closely with your vendors to identify and solve mutual problems. Establish mechanisms for regular interaction with your vendors. At Matsushita this takes the form of a mutually agreed upon quality improvement plan.

> "This plan usually includes a system for rapid and accurate feedback between the company and vendor so that problems on either side can be identified and acted upon, suggestions for improvement can be exchanged and progress can be tracked." (Kraft)

Recommendation 3.2 Foster Government/Industry Cooperation for Mutual Benefit

More and more government agencies are reaching out to their contractors to enhance quality and productivity to the benefit of both. One notable example was related by Gerald Griffin of NASA's Johnson Space Center:

> "...in a series of workshops held last winter, we asked industry to give their views on the major impediments to a more successful industry-NASA working relationship. And lo and behold, as a Walt Kelly comic strip character once put it so well: 'We have met the enemy, and they are us!' Our partners came back in short order and quickly pointed to a number of areas where we, NASA, presented stumbling blocks."

Such dialogue can lead to improved quality, shortened delivery schedules and reduced costs on government procurements. When coupled with incentive contracts, this can be a true win-win situation.

As an example of government's role in promoting this form of communication, John Mittino of the U.S. Department of Defense described steps being taken to encourage productivity-oriented capital investment by industry. This effort includes sharing productivity savings with subcontractors as well as prime contractors through the Industrial Modernization Incentives Program. □

Look for more on Quality and Productivity in NASA Tech Briefs, *Winter 1985.*

Mission Accomplished

(continued from page 195)

to make an incision that will be as precise as that which the surgeon makes with his scalpel. I believe that it will have major applications in eye surgery, possibly in surgery on the stomach and intestines, and in blood vessels."

For their part, laser scientists at Jet Propulsion Laboratory are also excited about the potential of the excimer laser. The incorporation of the magnetic switch on the excimer laser's power supply has expanded the laser's potential for space-borne applications. According to Jet Propulsion Laboratory's Dr. James Laudenslager, "This same technology—the magnetic switch technology—also allows us to build larger devices for other applications. One such application we're currently building is a five-jewel propulsed laser which will measure stratospheric ozone. This laser will be scaled up to fifty times the energy of these little devices that are being used for the bio-medical application."

Working with NASA scientists on the excimer laser project seems to have made quite an impression on Cedar-Sinai's Dr. James Forrester. He expresses his sentiments about the delays required for final development of the bio-medical device in terms NASA personnel can well appreciate: "I feel like the man who invented the airplane. He had all the parts and they all seemed to work, but the plane had not yet flown." □

Letters

The "Letters" column is designed to encourage a wide exchange of ideas among *NASA Tech Briefs* readers. To contribute a request for information or to respond to such a request, use the feedback cards in this issue, or write or call: Manager/Technology Transfer Division, P.O. Box 8757, Baltimore/Washington International Airport, MD 21240; (301) 859-5300. While we can print only a small number of letters, we will endeavor to select those that are varied and of wide interest.

OPENING DOORS

NASA Tech Briefs *has helped me on several technical problems.* Tech Briefs *has also had an influence off my daily job, and has opened doors to those who are handicapped. As a volunteer, I feel that* NASA Tech Briefs *is meeting that goal and I hope you will continue to do so.*

Claude Perez, Jr.
Baker Packers
Houston, TX

STIMULATION FOR INNOVATION

Tech Briefs *was and still is a reference that I use to stimulate manufacturing engineering and engineering involved in upgrading our methods of fabrication.*

While on 2nd shift, without the aid of engineering, Tech Briefs *many times helped us meet our objectives by overcoming oversights of engineering. Example: pinpointing vacuum links with a hypodermic needle.*

Robert P. Atkins
Abar-Ipsen Industries
Rockford, IL

The ingenious ideas portrayed on Tech Briefs *pages not only offer remedies for exact situations but also for situations that are only similar, by triggering thoughts that often lead to solutions of manufacturing problems. I believe this is attributable to the powerful content and concise information transfer, which promotes innovation without laborious detail.*

Richard Olzak
Sundstrand
Redmond, WA

I have a continuing need to find better methods and tools to verify the accuracy of manufacturing operations. Consequently, Tech Briefs *is a source of the best and newest methods in manufacturing technology and materials development and metrology.*

James C. Dunmire
Westinghouse Elect. Corp.
Lester, PA

This publication is very helpful in exposing our company to new technology opportunities in energy sectors, and identifying license on development opportunities for future marketing programs.

Jack M. Androvich
CP National Corp.
Concord, CA

FUTURE APPLICATIONS

You certainly are meeting your goal! In your Spring 1985 issue the article titled "Fastening Parts Having Mismatched Thermal Coefficients" (p. 37) was of particular interest to myself and to our management team for future application in the advanced composites field.

Robert L. Webster
The Boeing Co.
Seattle, WA

MORE CONGRATULATIONS

Fantastic information system! The new commercial aspects of your publication are a good idea. It's too bad the rest of government can't catch on to the same idea.

Mart Resman
Hewlett Packard
Boise, ID

PATENT ABSTRACTS

A recent article in the Wall Street Journal *mentioned your mandate to disseminate your technology for commercial applications. This news is very encouraging and I hope you can help me. The article also mentioned some 3500 items on your patent abstracts list that may need licensing and development. Please send the list along with any other information you feel may be helpful in starting a new venture with NASA.*

Greg Goodman
Tucson, AZ

The *NASA Patent Abstracts Bibliography* is a semi-annual publication containing comprehensive abstracts and indexes for NASA-owned inventions covered by U.S. patents and patent applications. Each issue of the bibliography has separately bound abstract and index sections. Each abstract section covers the six-month period since the preceding issue; each index section is fully cumulative, covering all NASA-owned inventions announced since May 1969. The bibliography is available from the National Technical Information Service (see address below). The document inquiry code is NASA SP-7039.

You may also wish to write to the following NASA Office which answers questions of potential vendors and assists business firms with sales procedures, such as preparing contract proposals and quotations: Procurement Office, Code H, NASA Headquarters, Washington, DC 20546.

METALLIC GLASSES

Please send to my attention more information on metallic glasses produced by sound energy.

Loren Godfrey, Jr.
Rain Hill Group, Inc.
New York, NY

You may wish to purchase the following publications from the American Institute of Aeronautics and Astronautics (see address below):

A80-53062, *Metallic Glasses - Fabrication, Structure and Crystallization*

A84-44708, *Metallic Glasses: Production, Properties and Applications*

A78-39398, *Soft Magnetic Metallic Glasses - An Introduction and Status Report*

A78-30736, *Metallic Glasses*

A78-25281, *Stability of Some Metalloid-Free Metallic Glasses*

Please write to AIAA directly to inquire about costs and mailing arrangements.

For extensive literature search services in your area of interest, you may wish to contact the NASA Industrial Applications Center nearest you. These Centers offer computerized access to a comprehensive collection of scientific and technical documents produced by NASA, by other government agencies, and by corporate and academic research organizations around the world. Each Center also has a professional staff that can help you evaluate your needs. More about the Industrial Applications Centers is contained on page 25, this issue.

LIQUID PLASTIC

Several months ago I came aross an article in the Memphis Commercial Appeal *describing "a liquid plastic that soundproofs materials on which it is painted." If the article is correct, your agency developed this product. I would appreciate your help in finding out what this product is, what trade name or names it is sold under and where it is available.*

Charles G. Fisher
Covington, VA

Additional information on SMART Products (a liquid plastic mixture with exceptional energy/sound absorbing qualities), may be obtained by writing directly to the manufacturer at the following address: Mr. Arthur C. Metzger, Environmental Health Systems, 46 Irving Street, Framingham, MA 01701.

MOON ROCKS

Please send information about tests done by scientists on the rocks brought back from the moon.

Debra L. Hofland
Adams Elementary School
Janesville, WI

We regret that the information you requested is not available from this office. The following publications can be purchased from the American Institute of Aeronautics and Astronautics (see address below).

A82-39999, *The Natural Radioactivity of Rocks Of The Moon And Planets*

A79-44766, *The Distribution Of Zirconium And Hafnium In Terrestrial Rocks, Meteorites And The Moon*

A77-26402, *You Can't Eat Moon Rocks*

A75-39729, *Internal Friction In Rocks And Its Relationship To Volatiles On The Moon*

OLD TECH BRIEFS

I have an old copy of your NASA Tech Briefs *Index 1977 which contains a lot of interesing subjects. I was wondering if copies of the Briefs would still be available. If they are available, I would appreciate any help you may give. I am also interested in any articles that you may have on radio astronomy.*

James W. Searcy
Gulfport, MS

Enclosed are copies of the *NASA Tech Briefs* you requested. You may also wish to purchase the following document from the National Technical Information Service (see address below):
N78-18771, *The Search For Extraterrestrial Intelligence (SETI).*

The following publications in your area of interest can be purchased from the American Institute of Aeronautics and Astronautics (see address below):
A85-18864, *Pulsar Radio-Emission Propagation In The Interstellar Medium And Certain Properties Of Observed Pulses*

A85-14514, *Detection Of A Radio Emission At 3 kHz In The Outer Heliosphere*

A84-43621, *Natural Radio Noise - A Mini-Review*

A84-21337, *Cosmic Ray Astrophysics*

A84-19041 *Low-Frequency Jovian Emission And Solar Wind Magnetic Sector Structure*

A84-11100, *The Radio Universe (3rd Edition)*

Please write to AIAA and NTIS directly to inquire about costs and mailing arrangements.

STATUE OF LIBERTY RENOVATION

I learned recently that NASA is involved in the repairs of and research on The Statue of Liberty. In pursuit of our studies on the centennial of the Statue, we are eager to acquire "realia" materials (charts, articles, photographs, sketches, layouts, etc.) relating to the Statue's renovation.

Would you be so kind as to explain to us NASA's role and to forward to us any "realia" as detailed above.

Donald Marks
Principal
The Peter G. Van Alst School
Long Island City, NY

"Mission Accomplished" in the Summer 1985 issue of *NASA Tech Briefs* details one aspect of the Statue of Liberty's renovation in which NASA plays a role.

To inquire about the availability and cost of documents published by the American Institute of Aeronautics and Astronautics, write: AIAA, Technical Information Services, 555 West 57th Street, New York, NY 10019. To purchase publications from the National Technical Information Service, write: NTIS, 5285 Port Royal Road, Springfield, VA 22161.

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Mission Accomplished

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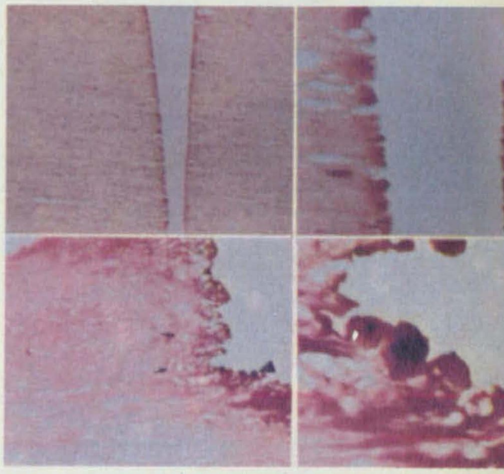

The top photos show human aortic tissue that has been cut with the excimer laser. Bottom photos depict tissue that has been cut with an infrared laser, and shows evidence of thermal and blast damage.

An estimated 150,000 Americans undergo by-pass surgery annually. The procedure involves removing a portion of blood vessel, usually from the patient's leg, and transplanting it into the aorta, the artery which carries blood from the heart to the extremities. When the transplant is complete, the patient's blood will flow around, or by-pass, the obstructed portion of the aorta.

The procedure itself takes several hours, and requires a hospitalized recovery period of at least a week, followed by an additional home recovery period, the length of which varies according to the patient's age and previous health. Another variable is the success of the surgery. There is no guarantee that fatty plaque will not build up in the by-pass blood vessel, creating further blockages which may require additional surgery. One outcome, however, is certain. The coronary by-pass is one of the more costly medical procedures, and the patient can expect a whopping hospital bill.

An innovative research program involving laser scientists at NASA's Jet Propulsion Laboratory in Pasadena, California, and surgeons at Los Angeles' Cedar-Sinai Medical Center shows promise of changing all this. The cooperative research effort has developed a new procedure which, when perfected, will permit the nonsurgical cleaning of clogged blood vessels, and may one day render coronary by-pass surgery obsolete.

At the heart of the new system is the excimer laser. Developed at NASA's Jet Propulsion Laboratory in 1975-76, the excimer laser was originally designed to measure atmospheric gases and parameters. The medical application of the excimer laser came about when physicians at Cedar-Sinai reached an impasse in their development of laser techniques for cleaning clogged blood vessels. They had hoped to combine the technology of angioscopy, which employs a catheter-borne fiber optic instrument to obtain video images of the inside of blood vessels, with a laser technique for vaporizing the visible blockages. Available Argonne lasers, which operate in the infrared region, proved unsatisfactory to this application because they caused so much thermal damage to the side wall of the tissue that the vessel would reclose.

The physicians concluded that they needed a shorter wavelength, ultraviolet laser, which would interact with tissue in a chemical, rather than thermal, fashion. Such a laser method would result in molecular cleavage, or chemical bond-breaking which causes tissue to break apart, rather than creating thermal motion or heat, which melts the tissue.

According to Dr. James Forrester, director of cardio-vascular research at Cedar-Sinai, "In researching the literature on lasers, we discovered that one type of laser seemed to cut with precision, and this was the excimer laser. We called around the country to find out who had it, and we were very fortunate to discover that this laser existed right here in our home town at the Jet Propulsion Laboratory." Preliminary experiments confirmed that the precision effect of the excimer laser would be satisfactory for use on human tissues, and identified the refinements necessary to the successful adaptation of the excimer laser for bio-medical applications.

In modifying the excimer laser, scientists at Jet Propulsion Laboratory developed and incorporated a magnetic switching concept. This allows for precise control of the laser discharge, pulse duration, beam divergence and beam quality, and renders the laser sufficiently reliable for surgical use. The laser was then joined with modified fiber optic technology in a catheter-borne device, and preliminary procedural evaluations were undertaken.

Basically, the procedure involves making a small incision and threading a 1.55mm-catheter into the obstructed blood vessel. The laser is carried by one of the three bundles of fibers enclosed in the bendable catheter. Another group of fibers shines a light into the blood vessel. A third bundle of fibers carries a lens at its tip which provides video images of the vessel's interior. When an obstruction is sighted, the physician will, under visual control, activate the laser's magnetic switch, delivering laser energy which vaporizes the obstruction and restores blood flow in the vessel.

To date, the procedure has been tested on animals and human cadavers, but only the angioscope has been used in the operating room so far. The Cedar-Sinai physicians expect that they'll begin testing the procedure in the operating room very shortly. If they're successful, then ultimately the excimer laser will be used in a nonsurgical catheterization laboratory, where the entire procedure could be completed in 1-2 hours. The physicians expect that it will take about two years to develop the procedure to that point, but from all indications it will be worth the wait. In addition to minimizing the length of time needed to perform the procedure, the laser system will reduce costs as well. One day of hospitalization following the procedure is expected to be a sufficient recovery period for most patients.

Dr. Forrester of Cedar-Sinai feels that, ultimately, the excimer laser has boundless medical applications. "The way I see it, the excimer laser has the potential to become the hands and eyes of the surgeon in remote parts of the body. We can use the laser energy

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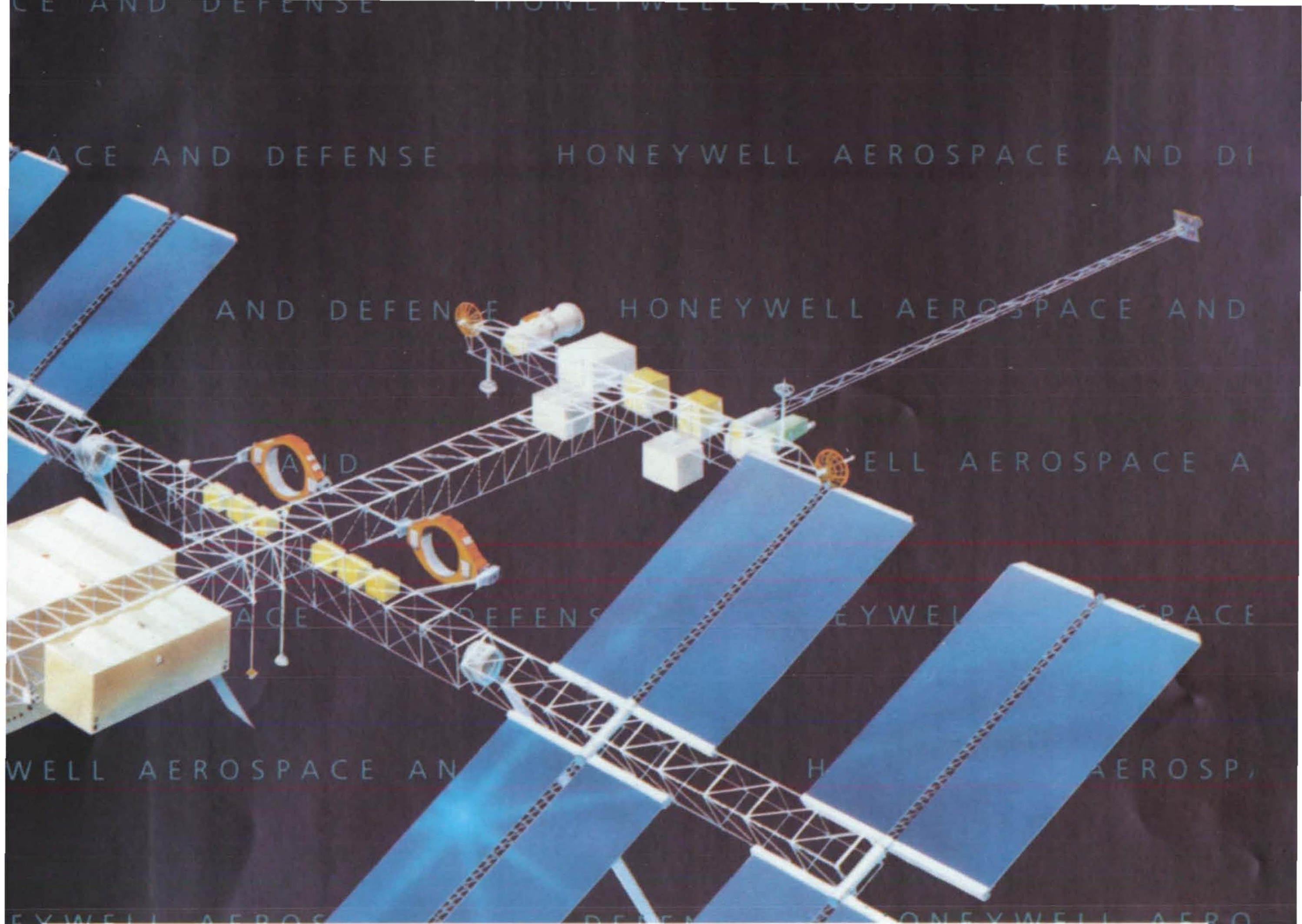

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