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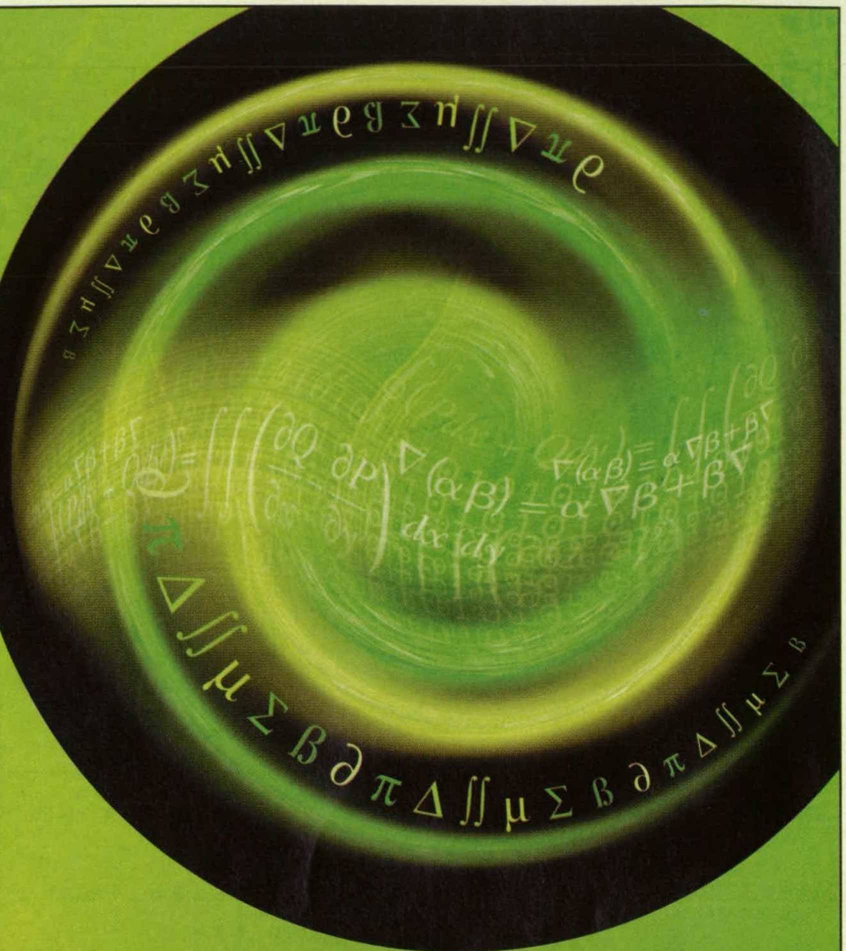

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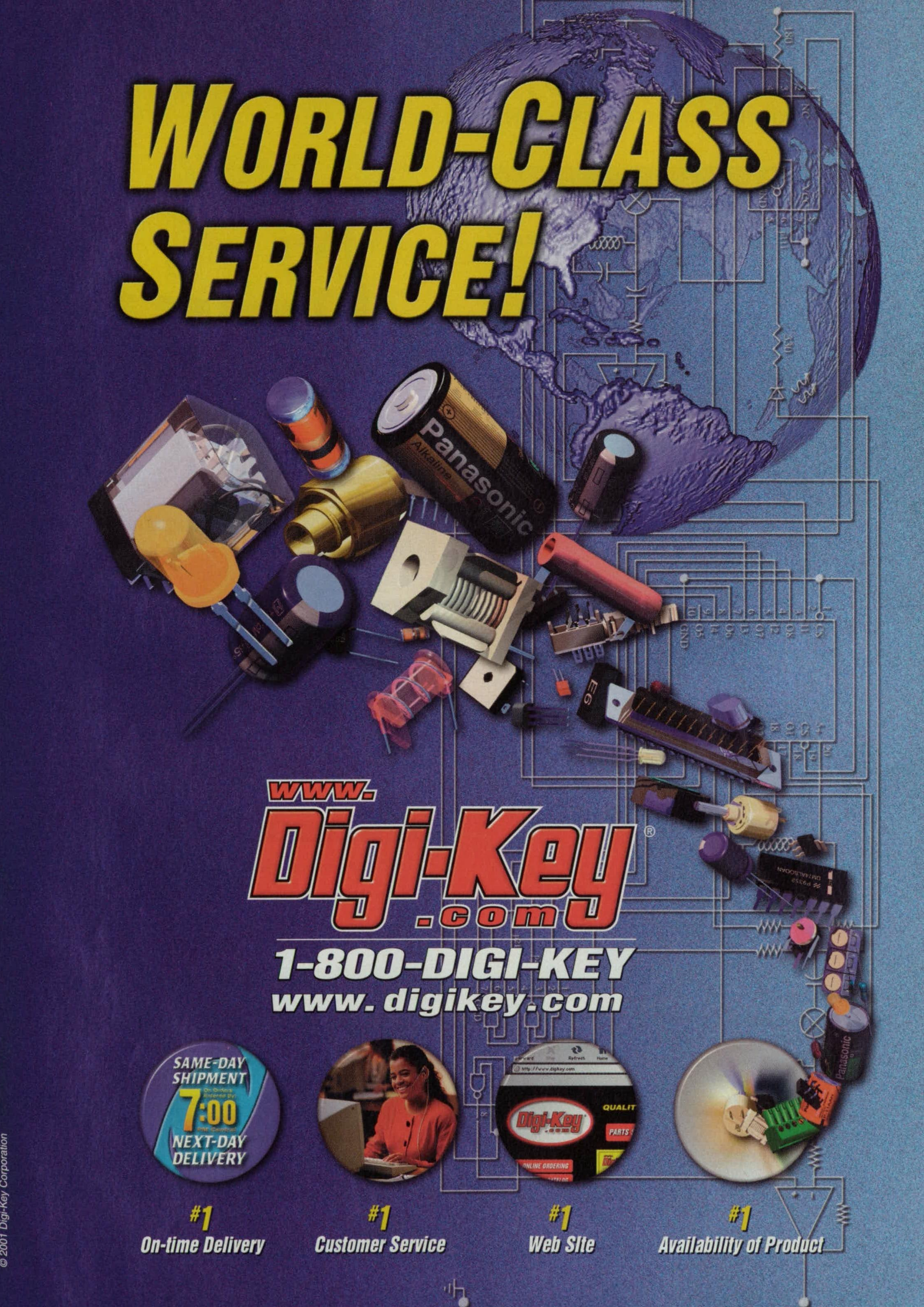
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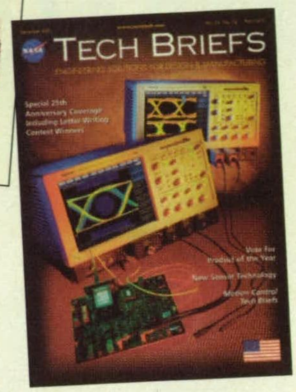

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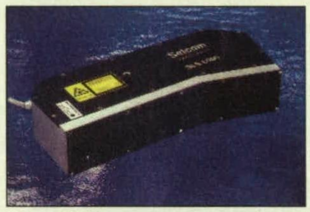

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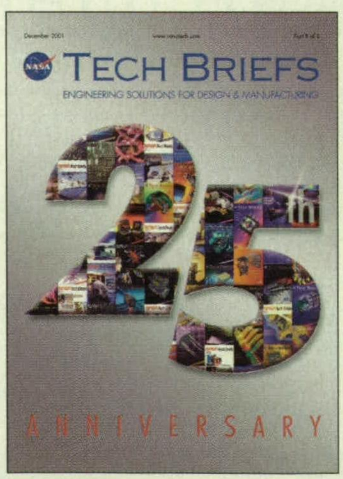
DEPARTMENTS

NEW FOR DESIGN ENGINEERS



Part II

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The celebration continues in Part II of this month's issue with our special 25th Anniversary coverage.

Contents *continued*

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PRODUCT OF THE MONTH

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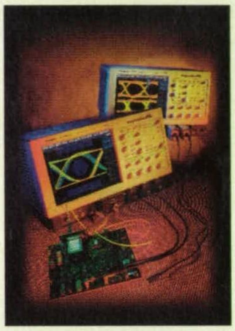
ON THE COVER



The CSA7404 is the first product in a new series of real-time digital oscilloscopes from Tektronix, Beaverton, OR. The new scopes integrate an optical reference receiver, clock recovery, and serial triggering, and are for use in the design and debug of high-speed optical and electrical communications equipment. For more information on the CSA7404 — and to read about more new products — see New on the Market on page 60.

(Image courtesy of Tektronix)

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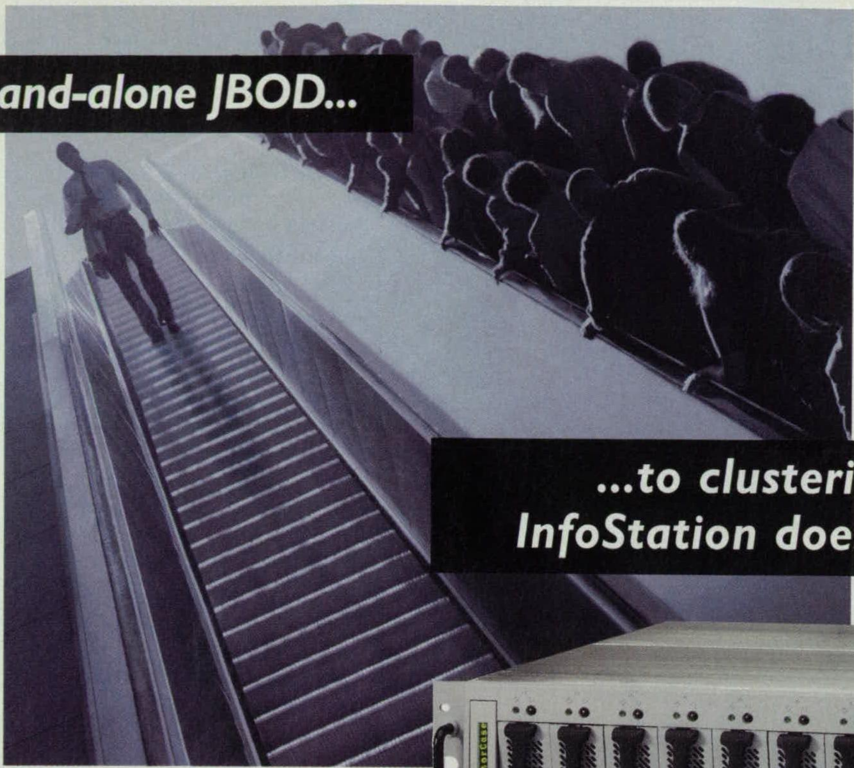

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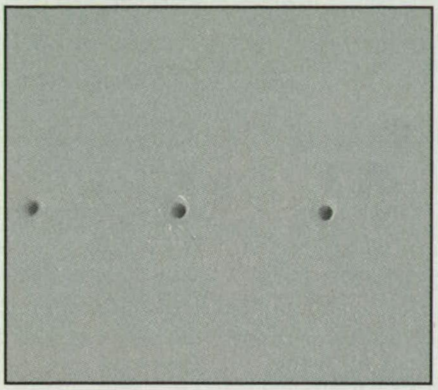


75-micron holes drilled in 0.015" ceramic (alumina) using a Synrad 240-watt CO_2 laser.

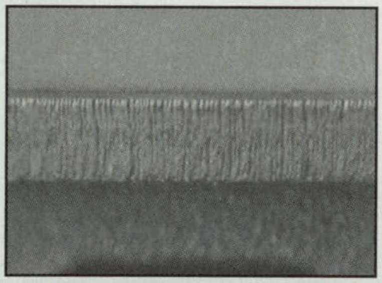
The use of lasers to machine ceramics for the electronics industry is on the rise - a result of the increased availability of laser technology and an improved knowledge of ceramics processing in the laser and electronics communities. Cutting, drilling, and scribing of ceramic require a better understanding of both the laser and the process than many other applications. With proper understanding and suitable adjustment of processing parameters, however, high quality, repeatable results can be attained. In fact, ceramic processing has become increasingly routine - speed and feature size limitations continue to be pushed.

The thermal brittleness of ceramics that results from localized heating means that the heat input must be carefully controlled during processing. Therefore, the laser should be used in a pulsed mode. In the example at left, a 75-micron, 0.003" diameter hole has been drilled with a 240-watt CO_2 laser in 0.015"-thick alumina ($Al_2 0_3$) using 2 pulses of 500 ms. The key to successful ceramic processing is to maximize peak power density and optimize pulsing parameters.

Another significant factor in the outcome of this application is the role of the assist gas. The assist gas pressure affects the spread of the expelled ceramic above the hole, and prevents adhesion of dross to the exit of the hole. The gas also shields the focusing optic from debris that is forcefully ejected from the hole or scribe. Additionally, the gas type can enhance the process on a chemical level.

Laser Cutting 75Cr-1 Steel

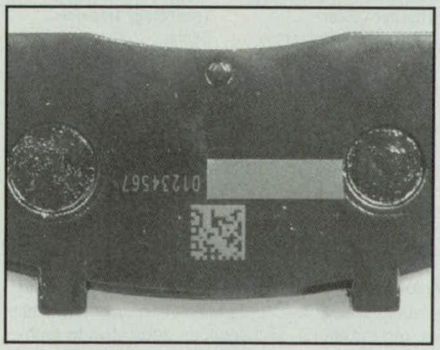
This material, used primarily for high strength and wear applications such as circular saw blades, cuts well with a 240-watt sealed CO_2 laser. Minor dross results at the bottom edge of the cut.



0.1"-thick steel, cut with a Synrad 240-watt laser at 25" per minute.

Laser Marking Brake Pads

This brake pad can be marked on either side. An engraved mark can be produced on the actual contact side of the pad, while a great contrasting mark can be made on the painted side (shown in the photograph at right) at very high speed. Both the text and code were marked in less than 2 seconds.



Laser marked with 15-watts of power at speed of 65"/second.

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NASA Commercial Technology Team

NASA's R&D efforts produce a robust supply of promising technologies with applications in many industries. A key mechanism in identifying commercial applications for this technology is NASA's national network of commercial technology organizations. The network includes ten NASA field centers, six Regional Technology Transfer Centers (RTTCs), the National Technology Transfer Center (NTTC), business support organizations, and a full tie-in with the Federal Laboratory Consortium (FLC) for Technology Transfer. Call (609) 667-7737 for the FLC coordinator in your area.

NASA's Technology Sources

If you need further information about new technologies presented in *NASA Tech Briefs*, request the Technical Support Package (TSP) indicated at the end of the brief. If a TSP is not available, the Commercial Technology Office at the NASA field center that sponsored the research can provide you with additional information and, if applicable, refer you to the innovator(s). These centers are the source of all NASA-developed technology.

Ames Research Center
Selected technological strengths: Information Technology; Biotechnology; Nanotechnology; Aerospace Operations Systems; Rotorcraft; Thermal Protection Systems.
Carolina Blake
(650) 604-1754
cblake@mail.arc.nasa.gov

Dryden Flight Research Center
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Jenny Baer-Riedhart
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Goddard Space Flight Center
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galcorn@gsfc.nasa.gov

Jet Propulsion Laboratory
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merle.mckenzie@jpl.nasa.gov

Johnson Space Center
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commercialization@jsc.nasa.gov

Kennedy Space Center
Selected technological strengths: Fluids and Fluid Systems; Materials Evaluation; Process Engineering; Command, Control and Monitor Systems; Range Systems; Environmental Engineering and Management.
Jim Aliberti
(321) 867-6224
Jim.Aliberti-1@ksc.nasa.gov

Langley Research Center
Selected technological strengths: Aerodynamics; Flight Systems; Materials; Structures; Sensors; Measurements; Information Sciences.
Sam Morello
(757) 864-6005
s.a.morello@larc.nasa.gov

John H. Glenn Research Center at Lewis Field
Selected technological strengths: Aeropropulsion; Communications; Energy Technology; High Temperature Materials Research.
Larry Viterna
(216) 433-3484
cto@grc.nasa.gov

Marshall Space Flight Center
Selected technological strengths: Materials; Manufacturing; Nondestructive Evaluation; Biotechnology; Space Propulsion; Controls and Dynamics; Structures; Microgravity Processing.
Vernotto McMillan
(256) 544-2615
vernotto.mcmillan@msfc.nasa.gov

Stennis Space Center
Selected technological strengths: Propulsion Systems; Test/Monitoring; Remote Sensing; Nonintrusive Instrumentation.
Kirk Sharp
(228) 688-1929
kirk.sharp@ssc.nasa.gov

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NASA Program Offices

At NASA Headquarters there are seven major program offices that develop and oversee technology projects of potential interest to industry. The street address for these strategic business units is: NASA Headquarters, 300 E St. SW, Washington, DC 20546.

Carl Ray
Small Business Innovation Research Program (SBIR) & Small Business Technology Transfer Program (STTR)
(202) 358-4652
cray@mail.hq.nasa.gov

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NASA's Business Facilitators

NASA has established several organizations whose objectives are to establish joint sponsored research agreements and incubate small start-up companies with significant business promise.

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Lewis Incubator for Technology
Cleveland, OH
(216) 586-3888

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Mississippi Enterprise for Technology
Stennis Space Center, MS
(800) 746-4699

Julie Holland
NASA Commercialization Center
Pomona, CA
(909) 869-4477

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(713) 743-9155

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Joanne W. Randolph
BizTech
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(256) 704-6000

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Ames Technology Commercialization Center
San Jose, CA
(408) 557-6700

Marty Kaszubowski
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If you are interested in information, applications, and services relating to satellite and aerial data for Earth resources, contact: Dr. Stan Morain, **Earth Analysis Center,** (505) 277-3622.

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V-83

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UpFront

This month we celebrate a publishing milestone with the 25th anniversary issue of *NASA Tech Briefs*. The origin of the magazine actually dates back to the beginning of the "space race" — the October 1957 launch of Sputnik, which spurred the U.S. Congress to form a new federal agency charged with meeting the Soviet challenge.

In drafting the National Aeronautics & Space Administration's charter, lawmakers mandated that the agency share with the American public any new, commercially-promising technologies resulting from its taxpayer-supported R&D. This started with one bulletin and quickly became a steady stream of reports. In 1976, NASA decided to compile these "tech briefs" in a quarterly magazine for the engineering community.

Then and now: magazine covers from volumes 1 and 25

By the early 1980s, *NASA Tech Briefs* had hit a budget ceiling at 75,000 circulation, with as many as 12,000 engineers and scientists on a waiting list to receive the magazine. NASA was under pressure to cut costs and considered eliminating a number of its publications, NTB included. But rather than sever one of its main links to U.S. industry, NASA made the precedent-shattering decision to privatize NTB and chose ABP International (ABPI) of New York City as its commercial partner.

The idea: to recoup all publishing costs heretofore covered by NASA through the sale of advertising. The result: more than $30,000,000 in taxpayer savings on printing and postage alone since the commercial launch in 1985.

Through the NASA-ABPI partnership, we have increased the magazine's frequency (monthly since 1989) and circulation (now 195,000+, with total monthly readership approaching half a million). We've also introduced an array of value-added products — from the *Photonics Tech Briefs* and *Motion Control Tech Briefs* special editions to the INSIDER series of e-mail newsletters.

And just last month, NTB became the first design engineering publication to offer subscribers a digital (pdf) version via the Web (which you can sample at www.qmags.com/ntb).

Thank you for your continued support.

Joe Pramberger, Publisher
joe@abpi.net

Vote for
NASA Tech Briefs'
Seventh Annual Readers' Choice Awards

Each month, the editors of NASA Tech Briefs *choose a Product of the Month — a new product with exceptional technical merit and practical value to our more than 195,000 engineering and management readers. This month, we ask you to vote for the one new product introduced for the engineering community this year that deserves the honor of Product of the Year.*

TECH BRIEFS 2001 Product of the Year

The nominees are:

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thinkdesign 6.0 CAD software

OMEGA Engineering
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Wavetek Meterman Test Tools
Meterman test and measurement instruments

ifm efector
OJ series photoelectric sensors

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VX Corp.
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Dolch Computer Systems
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MathSoft Engineering & Education
Mathcad® Client collaborative math software

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Measurement Studio™ 6.0 test & measurement software

Mountz
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Find out more about the nominated products and cast your vote by visiting
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Indicate your choice on the Product of the Year ballot.

Only one vote per person will be counted. Your completed ballot must be submitted by January 25, 2002. All eligible voters will be entered in a random drawing to win valuable prizes.

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Space Administration
Office of the Administrator
Washington, DC 20546-0001

A Message from the Administrator

25 Years of *NASA Tech Briefs*

NASA research programs have always been at the forefront of technology. Every day, American lives are touched by NASA technology in many different ways. More than 1,300 space program technologies have benefited U.S. industry, improved the nation's quality of life, and created jobs for Americans. The products developed by NASA research range from artificial hearts to cordless power tools. It is *NASA Tech Briefs* that transfers information about NASA research to the American people.

Since 1976, when *NASA Tech Briefs* published its first issue, NASA has landed spacecraft on Mars, put astronauts on the Moon, and built the second phase of the International Space Station, the single largest international cooperative space project ever undertaken by humankind. As NASA has evolved over the years, so too has *NASA Tech Briefs.* The government-funded, black-and-white circular featuring abstracts and diagrams has grown into a full-color magazine with a circulation of more than 195,000.

Looking ahead, NASA's vision for the next 25 years is to explore space beyond low-Earth orbit. To do this, NASA will need to aggressively invest in technology in order to develop an ever-expanding suite of capabilities that will take our explorers ever farther into deep space. *NASA Tech Briefs* will continue to play a vital role in disseminating knowledge from the latest NASA discoveries and technological developments for the benefit of the American people.

I offer my congratulations to *NASA Tech Briefs* as it celebrates its 25th anniversary. Although its success over the past 25 years is impressive, I am confident that the best is yet to come.

Daniel S. Goldin
Administrator
11/1/01

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The Readers Speak Out — Anniversary Messages for NTB

To help NASA Tech Briefs *celebrate its 25th anniversary, we wanted to offer a contest that would let you — our readers — tell us about the impact the magazine has had on you during the past quarter-century. Our anniversary letter-writing contest allowed you to do just that. And what an overwhelming response we received! Whether you've been reading* NASA Tech Briefs *for one year or 25 years, you told us of the important role the magazine plays in your work and your daily lives. Many of you also cited specific cases in which a tech brief or other information obtained from the magazine helped you solve a problem or even start a business.*

We've reproduced here the five winning letters and five Honorable Mentions, as well as some impressive comments from other entries. Thanks to all of our readers for continuing to support the magazine. And a special thanks to those who participated in the contest. We enjoyed sharing your experiences of how NASA Tech Briefs *keeps you thinking and creating.*

Winners

To: NASA Tech Briefs
From: Volker D. Heydemann, Senior Scientist, Sterling Semiconductor, Sterling, VA
Years as a Reader: 6
Area of Expertise: Semiconductor Materials

NASA Tech Briefs is an essential resource of up-to-date information on a wide spectrum of topics that impact my daily work as senior scientist in a challenging industrial field. The semiconductor industry has benefited greatly in all areas from the scientific methods and instrumentation that NASA Tech Briefs has featured since I started reading it. Not only does it help me keep up with the forefront of scientific work at NASA and in NASA's contract companies, but it also gives an overview of the advances of scientific methods, instrumentation, materials, and people and companies. Many of the methods and approaches that are featured in NASA Tech Briefs have their application in my daily scientific work, and many of the technologies can be used to characterize and advance my daily semiconductor materials research. My compliments to NASA Tech Briefs – I know that many of my colleagues feel the same way about this great resource of knowledge and reports on cutting-edge technology. I have not seen any other publication with this much beneficial scope and focus.

To: NASA Tech Briefs
From: Dr. Joe Resnick, Chief Scientist, Petrol Rem Southern R&D Labs, Crystal River, FL
Years as a Reader: 15
Area of Expertise: Environmental Studies/Bioremediation

The real story of what NASA Tech Briefs means to me began at just about the time the Voyager space probe was leaving our solar system. In reading about Voyager, I learned that several components either utilized microscopic-sized particles, or several of its critical optical/guidance systems were calibrated using the particles. When I first read about these magnificent little "microspheres," hundreds of ideas and potential uses for them popped into my head. From that first exposure in NASA Tech Briefs, I was able to develop a novel delivery system for environmental cleanup efforts – or bioremediation – with direct assistance from NASA scientists at Marshall Space Flight Center in Huntsville, AL. As a result of exposure to the respective technologies, R&D centers and staff, and information taken directly from NASA Tech Briefs, humanity is now armed with a new generation of environmental tools and biotechnologies that are being utilized to effectively and economically clean oil spills of every size on literally every waterway in the world. To me, NASA Tech Briefs means that humans will continue to have the resources and means to continue to care for each other and the planet in the years to come.

To: NASA Tech Briefs
From: Stephen E. Hyre, Clinical Engineer, Tri-County Baptist Hospital, LaGrange, KY
Years as a Reader: 5
Area of Expertise: Hospital Clinical Equipment

Some 20 years ago when I first started working in a hospital, patient monitoring was not very sophisticated by today's standards. I recall repairing monitors by sorting through a box of spare tubes until I found one with just the right characteristics so the circuit would work. There have been amazing changes in technology. Those changes have helped the medical community save many lives. Clinical research today would be impossible without them. I use many resources to try to stay current and NASA Tech Briefs is one of the best. It's not just a synopsis of new ideas or designs. Most of the articles have a practical application that puts theory into use – something I can understand. Patient monitoring today is complex, not only in the technology, but in what it can reveal about the human body. I look to NASA Tech Briefs to keep apprised of what is on the horizon for healthcare technology.

To: NASA Tech Briefs
From: Glenn G. Whiteside, Manufacturing Engineer, Koch-Glitsch, Wichita, KS
Years as a Reader: 10
Area of Expertise: Aviation, Oil & Chemical Processing

NASA Tech Briefs has impacted my work and my life in many positive ways. It has inspired me to always strive for better solutions and to continually learn and keep an open mind so that whatever I can dream, I can do. The technologies and products featured in NASA Tech Briefs over the years have helped me to look at problems in many new and different ways. Although I cannot pinpoint any exact solutions, I have used many of the ideas in conversations and meetings to help stimulate thinking and develop alternative solutions to some very tough problems. Technologies and products I have read about in NASA Tech Briefs that I think will drive important innovations in the next 25 years include new analysis software, improved hardware, environmental research and remediation procedures, advanced robotics, medical research, improved sensors, nanotechnology, and microgravity research. A great feature of NASA Tech Briefs is the Reader Forum, where readers can send and receive responses to technical questions. I believe that this two-way interaction is vital to the success of NASA's technology transfer efforts, and I would encourage developing this section further. Thanks to NASA Tech Briefs for a great 25 years, and here's hoping for many more to come.

To: NASA Tech Briefs
From: Ronald Sobchik, Senior Staff Engineer, TRW S&E, Redondo Beach, CA
Years as a Reader: 6
Area of Expertise: Actuators and Sensors

My job is to stay on top of the latest spacecraft actuator and sensor technology. I have found that NASA Tech Briefs makes it incredibly easy to stay on top of the latest breaking developments at NASA. While I have used the information in NASA Tech Briefs many times, I'll relate the latest instance of how this publication allowed me to find a new, NASA-developed technology to benefit my work at TRW. In a recent article, a newly developed Reaction Wheel Assembly (RWA) was discussed. While the thrust of the article was how finite element analysis techniques were used to optimize the design of this satellite attitude control actuator, the RWA described was something I had been looking for. The article did not give a point of contact at NASA for more information, but an e-mail request to NTB sent me to the center where the wheel was developed, as well as the point of contact, Chuck Clagett. A couple of calls later, I was speaking with Chuck and getting the information I needed on this hardware. Chuck was able to answer all my questions and informed me that NASA had licensed the RWA to Orbital Sciences. He also shared some information on the newer spacecraft avionics packaging techniques being used at Goddard Space Flight Center. I am sure that we will be using these ideas to optimize our own spacecraft designs, and deliver better and cheaper hardware to NASA and other customers.

Honorable Mentions

To: NASA Tech Briefs
From: James T. Frane, Engineering Supervisor, Bechtel National, Orinda, CA

NASA Tech Briefs provides a wealth of information about new technical innovations in virtually all fields. This information is of interest to me personally and professionally because it opens new vistas of possible applications. I am often involved in mechanical and systems engineering for first-of-its-kind situations. During this process, I consult hard copy and Internet resources for related information. NASA Tech Briefs is a resource that I review cover to cover. I always find items of interest that stimulate thought. Sometimes, I request additional details for possible use in designs and applications, as well as for future reference. The broad areas covered practically guarantee nearly everyone in a technical endeavor will find items of interest and possible use.

To: NASA Tech Briefs
From: Christine L. Robblee, Electrical Engineer, WASTECH International, Portsmouth, NH

I am a relatively new reader of NASA Tech Briefs — I have been receiving the magazine for three or four years. My job is very demanding. While I work diligently, I am normally always behind. Over the last year or two, I've been working on reprioritizing my workload. To get out of the grind that was becoming my work, one of the things I did was to quit putting NASA Tech Briefs into the "will get to" pile and just began checking it out as soon as I get it. I found that in many cases, it would add insight or a different view to some of the things I was working on, as well as open up the world around me. Your magazine covers a wide range of interesting material that just makes the mind sizzle. I have really enjoyed the Insider newsletter — you can cover so many different happenings in just a few minutes.

To: NASA Tech Briefs
From: Michael S. Beaton, Senior Manufacturing Engineer, Fisher Controls International, Marshalltown, IA

NASA Tech Briefs is a mind-stretcher. It says, "The future begins now." Once the basic science is worked out, general industry will find ways of using the ideas in many ways. The forum provided in NTB is great for the cultivation of thought. New developments are reported in one field, but may have application or relevance in other fields, whether it is materials, mechanical devices, or software. Many of the businesses that are current advertisers began from ideas reported in NASA Tech Briefs. I have purchased software, adhesives, and electronic components from these companies. NTB continues to contribute to the economy of today and the future. Over the years, NASA Tech Briefs has adapted with the changing environment, such as adding online information retrieval and the e-mail newsletter, which got me to this Web site to provide my input.

To: NASA Tech Briefs
From: Bill J. Pope, Chairman, US Synthetic Corp., Orem, UT

NASA Tech Briefs helps engineers and scientists "take the blinders off" and keep the creative juices flowing. NTB is the first mail I read if one is in the pile. I can remember a clue from an article in NASA Tech Briefs a number of years ago when I was working for an aerospace company. It helped me solve a serious propulsion problem. I still get new knowledge, solutions to current problems, new ideas, and enjoyment from reading NASA Tech Briefs. My thanks to the contributors, editors, and publishers of NTB for the impact the magazine has had on important, but often overlooked research.

To: NASA Tech Briefs
From: Dan Cartier, Electronics Technician, Heidelberg, Durham, NH

Thanks to NASA Tech Briefs, I am able to stay current with new products, developments, and scientific breakthroughs. Based on NTB's reader service program, I have been able to acquire timely information relating to articles or advertisements for products. I have annual projects to complete, and many of them include upgrading existing capabilities or providing new capabilities. NASA Tech Briefs has provided me with a solid foundation of invaluable current information to help me perform my job more effectively, and with some interesting conversation topics to share with my colleagues, family, and friends.

"NASA Tech Briefs has provided the latest developments in products, research, and information that is not available elsewhere. It allows the expansion of the thought process and even out-of-the-box concepts. The technical information and support packages offer top-notch references and contacts to carry on the research and development process."

Lionel Whitmer
Cessna, Wichita, KS

"NASA Tech Briefs open up the world outside our R&D facility. The ideas and product developments found in this publication are a valuable tool to spawn new ideas and introduce new product initiatives."

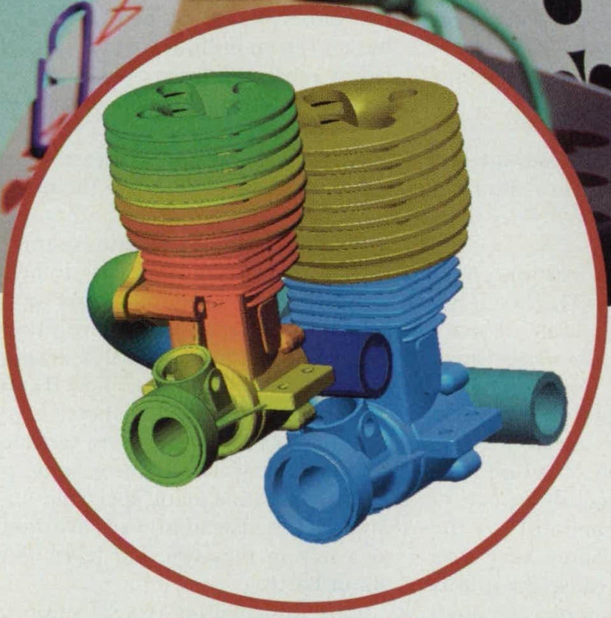
Joe Langan
Moore North America, Grand Island, NY

"I have always looked to NASA Tech Briefs for the latest innovations in science and technology, and how to initially apply them. I have derived ideas on how to better do my job by reading NTB. Even if the article was not directly applicable to my situation, some part of it got the wheels turning."

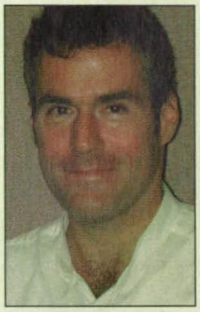
Samuel Marderness
Aberdeen Test Center, Aberdeen Proving Grounds, MD

"The access to leading-edge ideas and technology, and the discussion of their applications by NASA Tech Briefs, gives an engineer a one-stop shopping approach to the technology currently being developed."

Ian Gibson
Honeywell Engines & Systems, Phoenix, AZ



Dr. Michael Watkins, Project Scientist, Gravity Recovery and Climate Experiment, Jet Propulsion Laboratory



Dr. Watkins is the project scientist for the Gravity Recovery and Climate Experiment (Grace mission), based at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, CA. The Grace mission will make very precise measurements of the variations in Earth's gravity field in order to understand Earth's structure, oceans, and climate, and how they are changing.

***NASA Tech Briefs:* Explain your interest in – and NASA's reasons for – studying gravity.**

Dr. Michael Watkins: Two aspects of gravity interest scientists. The first is the static gravity field, which doesn't change over time, but does have small variations. Earth is a fairly uniform sphere, and gravity's pull is about the same anywhere on the surface. But if you look more carefully, you find a bit of variation. The second aspect of gravity that interests scientists is the part that isn't static. Some very slow processes inside Earth cause the gravity field to change. For example, the polar caps used to be much bigger. The weight of that ice flattened Earth a bit at the poles. Since that ice melted off, the land is now rebounding – Northern Canada and Scandinavia are rising. Earth is becoming more spherical again, and this change is reflected in the gravity field. These changes in gravity over time are one of the things that Grace is going to look at.

NTB: How does the Grace mission work?

Watkins: To measure gravity, what you really want to do is track a particle in space – namely, a satellite – and track it very accurately. That's what Grace is going to do. We're going to track one satellite with another satellite with extremely high precision. The two Grace satellites are going to be about 220 kilometers (137 miles) apart. We're going to be able to measure the distance between them to within 1 micron. That's like measuring the distance between Pasadena and San Diego to within the thickness of a red blood cell.

Even though the satellites are way up there, you can get a little lump of atmosphere that might cause the separation between the satellites to change a bit. To get rid of that, we'll carry one of the most precise accelerometers that has ever been built. It is so sensitive that it can sense the drag caused by something as small as a particle of smoke.

NTB: Once the gravity measurements are made, how will you use them?

Watkins: Grace measurements of Earth's gravity field are going to be 100 times more accurate than those we now have. They are going to revolutionize our understanding of Earth's structure, oceans, and climate, and how they are changing. These measurements are the only kind of remote sensing technique that doesn't scatter light or some part of the electromagnetic spectrum off an object, but instead uses gravity directly as a way to measure and learn things about Earth.

This information is very important for oceanographers, for example. They want to be able to know how much of the ocean topography they see – the hills and valleys – on the ocean's surface is the result of gravity rather than ocean currents. As water moves around the world, Grace is going to be able to track it by mass. We'll be able to measure the depth of an aquifer and actually see sea-level changing. We'll be able to weigh the ice sheets. This is a whole new branch of science, and we're just beginning to understand its applications.

*A full transcript of this interview appears on-line at **www.nasatech.com/whoswho.** Dr. Watkins' comments were excerpted from a longer interview that appeared originally on the JPL Web site (www.jpl.nasa.gov). Dr. Watkins can be reached at michael.m.watkins@jpl.nasa.gov.*


IF YOU CAN THINK IT, WE CAN DO IT.

Technologies of the Month

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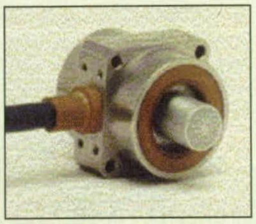
For more information on these and other new, licensable inventions, visit www.nasatech.com/techsearch

Integrated Linear Thrust Motor and Absolute Position Sensor (ILTMAPS)

JRA Aerospace

This actuator uses a novel, dual-function configuration of windings in a moving magnet design to achieve both a high-efficiency linear thrust motor and a fully integrated and absolute position sensor. This integrated sensor/actuator arrangement results in an extremely compact and rugged assembly with a minimal number of electrical connections and a mechanically simple moving part. It provides precisely controlled linear motion over the range of movement from a few microns to 15 mm.



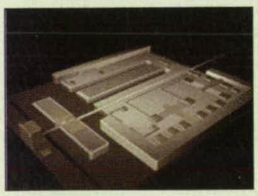
Intended for use in a variety of automation and control applications, the ILTMAPS features patented actuator and control circuit developments. The actuator can be used as a valve/regulator controller, a dispensing/metering pump actuator, a pick-and-place head actuator, a servo force sensor, or a gauging probe positioner.

Get the complete report on this technology at:
www.nasatech.com/techsearch/tow/jra.html

In-Package MEMS Aligner

The Boeing Co.

Use of an In-Package MEMS (microelectromechanical systems) alignment device and soldering technique provides precise and rapid alignment of single-mode optical fibers to laser sources, photodetectors, and other single-mode optical fibers. This will enable high-volume, low-cost manufacturing processes for opto-electronic devices and optical fiber connectors. The MEMS aligner can be used for the precise alignment of a single-mode fiber with an active device contained within a hermetically sealed housing.



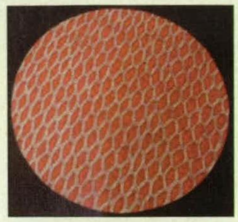
It is also useful for the precise alignment of optical fibers (in particular, single-mode fibers) in an optical connector, which is critical for their proper operation in all optical fiber-based telecommunication networks. It can be used for the precise alignment of a single mode or multimode fiber in the screening, testing, and characterizing of electro-optic devices.

Get the complete report on this technology at:
www.nasatech.com/techsearch/tow/boeing.html

Soft, Strong, Apertured Nonwovens

P&G

This technology modifies an ordinary, nonwoven web by adding a series of uniform, small apertures, which change the web's characteristics to fit a variety of needs. It creates webs that are strong, soft, breathable, decorative, and low-cost. Products made with this nonwoven have controlled porosity, allowing their use in a variety of filtering situations. Stiff, thicker webs may be processed creating flexible, yet tough, structural or functional membranes. The modified nonwoven can act and feel like a soft cloth. The apertured web maintains good strength and remains lint-free.



Potential applications include disposable products, filters, decorative coverings, and low-cost garment and upholstery components. It also is used as a replacement for components in medical, architectural, and other industries; as a substitute for abrasive substrates; and as temporary structural devices, barriers, and netting. The nonwoven also can be used in applications where a porous, fishnet type of web is needed, such as in luggage components and backpacks.

Get the complete report on this technology at:
www.nasatech.com/techsearch/tow/P&G.html

Artificial Neural Network Verification Tool

Goodrich

This software tool verifies a certain class of neural networks, which are a computationally efficient method for solving many complex engineering problems. Without the benefit of neural nets, many difficult-to-solve numerical problems can only be solved approximately. The Artificial Neural Networks (ANN) tool allows deterministic verification of pre-trained, non-adaptive, feedforward (non-dynamic) neural nets. ANNs are a class of biologically motivated algorithms that allow solution of complicated data processing problems. Verification will enable the use of ANNs in many complicated computational tasks that currently rely on less efficient methods.

This tool was developed to facilitate certification of flight software, but other applications include process control and simulation, signal processing, electric power networks, image processing, medical equipment, automotive, aerospace, pattern recognition, robotics, autonomous vehicles, and other industrial automation, navigation, and defense applications.

Get the complete report on this technology at:
www.nasatech.com/techsearch/tow/goodrich.html

Application Briefs

Refrigerated Container Helps NASA Transport Arctic Crystals

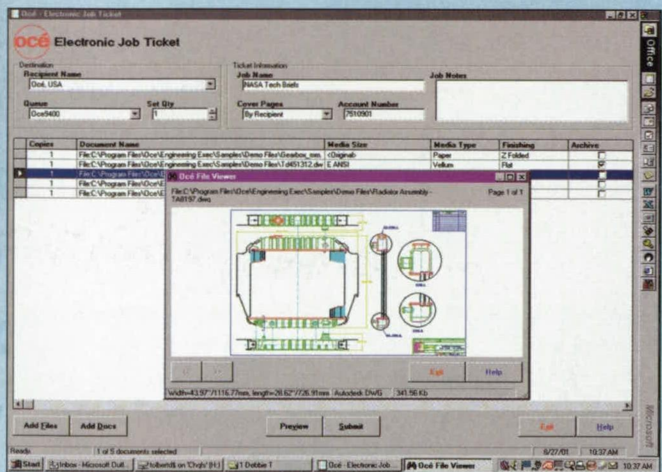
Kodiak™ Cold Chain shipping container
Kodiak Technologies
Houston, TX
800-856-3425
www.gokodiak.com

The chemistry of calcium carbonate crystals that form in certain low-temperature environments on Earth — such as the Arctic — are very similar to the crystals found in meteorites originating on Mars. However, some of these chemicals are stable only at cold temperatures. Geologist Rick Socki, senior scientist for Lockheed Martin — which handles some NASA Mars projects — traveled above the Arctic Circle to retrieve carbonate crystals from caves. The crystals then were transported back to NASA in Houston to help researchers study the geology of Mars. The return trip took three days, during which the temperature of the crystals had to be maintained.

The Cold Chain container used to transport the crystals resembles a recreational cooler and is made of polyethylene. While most refrigerants rely on dry ice or frozen gel, the Cold Chain container utilizes a thermally isolated gel that extracts heat from the transported substance in order to maintain a desired temperature. On the outside of the box is an LED panel that gives exact temperature readouts for both inside and outside the box. Vacuum-insulated panels within the walls and the lid of the container maintain the temperature between 2 and 8°C. To use, the lid of the container is removed and frozen. A thermal control regulator in the lid operates without electrical power or computers, and regulates the flow of energy as it senses the temperature, maintaining it within the prescribed range during shipping.

For Free Info Circle No. 720 or Enter No. 720 at www.nasatech.com/rs

Document Management Software Aids Space Shuttle Tank Design



Océ Engineering Exec® document management software
Océ-USA
Chicago, IL
773-714-8500
www.oceusa.com

Space Shuttle External Tanks (ETs) are the shuttle's external backbone, absorbing almost six million pounds of stresses and loads during ascent. The ETs carry over 530,000 gallons of liquid oxygen and liquid hydrogen for use in the orbiter's three main engines. Built by Lockheed Martin Space Systems, Michoud Operations, in New Orleans, LA, ETs are the only major non-reusable components of the Space Shuttle, built for every shuttle launch.

In order to build new, lighter ETs that provide improved performance for deployment of more payloads into space, Super Lightweight ETs are being manufactured. Drawing changes to the new tank design occur weekly as improvements and material changes are implemented. Lockheed Martin had to be able to access and store thousands of small- and large-format drawings and specs, so they chose Engineering Exec® software to manage, print, and archive the documents. The documents can be accessed from a workstation, and the documents that previously occupied hundreds of filing cabinets and a large amount of floor space now are stored securely and electronically. The software retrieves and prints the latest version of a specific drawing without the need to print an entire set of drawings.

For Free Info Circle No. 721 or Enter No. 721 at www.nasatech.com/rs

Collaboration
we know
they know
Innovation
CATIA: driving innovation, this advanced 3D design and engineering software from Dassault Systemes links design and manufacturing, improves collaboration, reduces costs and gets products to market faster. Along with IBM's industry expertise, it's part of a complete PLM solution. See it at ibm.com/solutions/catia
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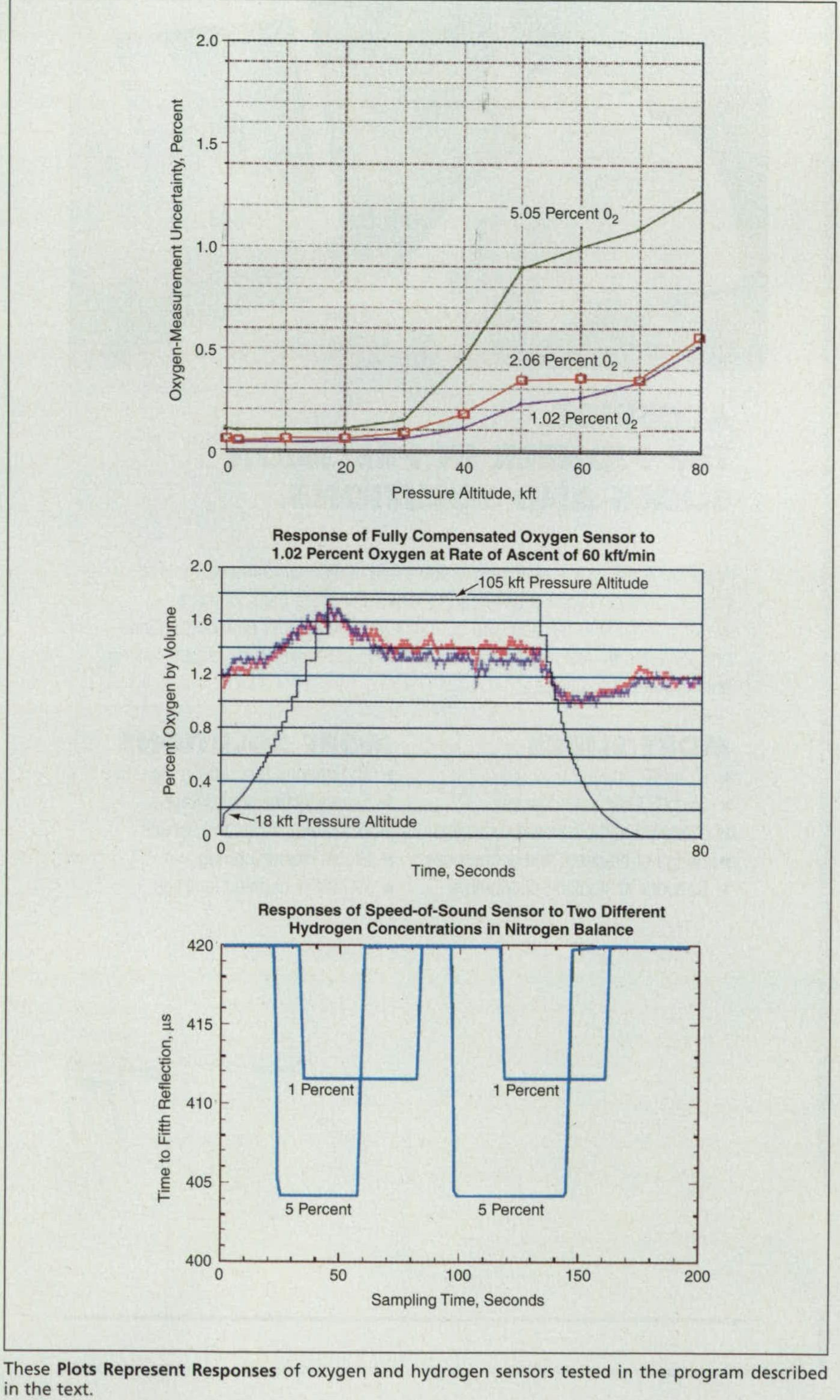
Development of Sensors for Detecting Leaks of O_2 and H_2

Both commercial and noncommercial sensors show promise.

Dryden Flight Research Center, Edwards, California

The Propulsion group at Dryden Flight Research Center is performing analyses of the effectiveness of chemical-species sensors for detecting and assessing leakage. The group is also studying relationships between (1) rates at which high-energy species leak from the propellant-feed systems of advanced aircraft and spacecraft and (2) the rates of leakage of inert species substituted for the high-energy species in the same systems. Several commercial sensors and a prototype noncommercial sensor have been and continue to be subjected to tests of their ability to detect their respective chemical species accurately and quickly. Analysis of the data from these tests is expected to determine whether it is possible to develop instruments capable of detecting propellant leaks over a wide range of temperature and pressure. If suitable, the instruments can be employed in various flight experiments in which there are requirements for such leak-detection capability. Analysis of data from inert- and high-energy-propellant leak testing will help in scaling leakage from gaseous propellant feed systems without the need to use high-energy propellants during subsequent leak tests.

Commercial-off-the-shelf (COTS) oxygen sensors that were intended for automotive and medical uses have proven quite effective for monitoring oxygenated environments. Calibrations with a 1 percent oxygen gas have demonstrated uncertainty of 0.1 percent at pressure altitudes up to 50 kft (≈15 km). The top part of the figure presents results of an uncertainty analysis of one these sensors. The middle part of the figure presents results of a dynamic test in which a calibrated fully compensated (that is, pressure-and-temperature-compensated) oxygen sensor was operated at a rate of ascent of 60 kft/min (≈0.3 km/s) from 18 kft (≈5.5 km) to 105 kft(≈32 km) and found to be accurate to within 0.7 percent. The lower part of figure presents results of a test in which a prototype sensor that measures changes in the speed of sound was found to afford a capability for



These **Plots Represent Responses** of oxygen and hydrogen sensors tested in the program described in the text.

measuring concentrations of hydrogen mixed into nitrogen.

Calibration of the COTS and the fully compensated oxygen sensors have been finished and these sensors have been integrated into the Hyper-X vehicle (an experimental hydrogen-fueled hypersonic airplane) for flight testing. Validation testing of these sensors was scheduled to begin at or about the time of reporting the information for this article. Calibration and dynamic tests of a fully compensated hydrogen sensor were also scheduled to begin about a month earlier. It was expected that if the results of the tests of the hydrogen sensor show that requirements are satisfied, then this sensor would also be integrated into the Hyper-X vehicle. Also at the time of reporting:

- Negotiations to procure another prototype speed-of-sound sensor for characterization and calibration were under way; and
- At the University of California at Los Angeles, there was research in progress to determine a correlation between the rates of leakage of gaseous hydrogen and gaseous helium.

This work was done by Neal Hass of **Dryden Flight Research Center.** *For more information, contact the Dryden Commercial Technology Office at (661) 276-3689. DRC-01-36*

Micromachined Emitter/Bolometer Structures for Infrared Gas Sensors

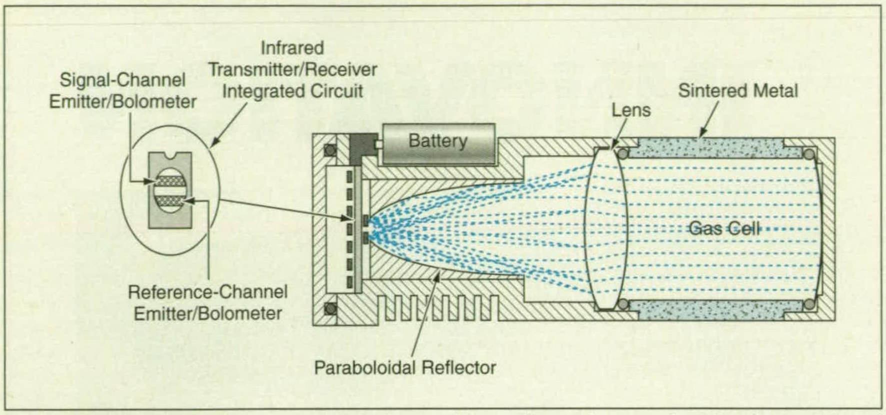
Small, inexpensive, mass-producible gas sensors would be enabled by these novel micromachined wavelength-selective emitter/bolometers.

NASA's Jet Propulsion Laboratory, Pasadena, California

Infrared gas sensors that could be mass-produced at relatively low cost have been proposed for a variety of applications — for example, detecting carbon monoxide in air inside houses. A sensor of this type would include a housing into which ambient air could diffuse. The gas of interest would be detected via an infrared absorption measurement. The novel micromachined emitter/bolometer structure being developed is a heated strip of lithographically patterned, single-crystal silicon that will function as both an emitter of infrared radiation at a precise wavelength and as a bolometer. The emitted radiation would traverse a path within the sensor housing and would be reflected back along that path to the emitter/bolometer. In the presence of an infrared-absorbing gas, the amount of radiation returning to the emitter/bolometer would decrease, causing the emitter/bolometer to come to thermal equilibrium at a lower temperature than it would in the absence of such a gas. The temperature-dependent electrical resistance of the emitter/bolometer would be measured and used to infer the concentration of the infrared-absorbing gas.

In addition to the emitter/bolometer, the sensor housing would contain a paraboloidal reflector, a lens, and a mirror that would direct the infrared radiation along the desired optical path beginning and ending at the emitter/bolometer (see figure). To maximize the sensitivity and signal-to-noise ratio of the sensor, the emitter/bolometer surface would be made (as described in more detail below) to emit and absorb maximally over a narrow band of wavelengths rather than over the whole black-body spectrum. Also to maximize sensitivity, the emitter/bolometer would be in the form of a suspended single-crystal silicon resistor with a high temperature coefficient of resistance.

The development of the proposed gas sensors and, in particular, the wavelength-selective emitter/bolometer components of the sensors, would exploit advances in (1) the understanding of the interactions between electromagnetic radiation and textured solid surfaces and (2) the wafer-scale fabrication of semiconductor devices. It has been observed in prior experiments that a surface textured microscopically by ion-beam etching exhibits increased optical absorption over a defined wavelength band, and, when heated, emits preferentially over the same wavelength band. In fabricating the proposed sensors, electron-beam lithography was used to texture the surfaces of the emitter/bolometers for a much more precise and narrow wavelength selectivity. The textures were designed according to the principles of photonic-band-gap (PBG) structures, which are characterized by spatially periodic variations of refractive index that give rise to narrow "forbidden" wavelength transmission bands. This effect was exploited to make two-dimensional PBG structures in high reflectivity (low emissivity) material that preferentially emit infrared light predominantly in the desired, narrow bands when heated.



This **Gas Sensor**, shown here at approximately actual size, will contain a wavelength-selective infrared emitter/bolometer and associated optical components. Infrared absorption in the gas of interest would affect the temperature, and thus the electrical resistance, of the emitter/bolometer.

An additional innovation was to take advantage of the exponential dependence of resistivity of single-crystal silicon on the temperature in the "intrinsic" conduction regime. This effect enhances the signal-to-noise ratio of the bolometer considerably and enables the manufacture of a small, low-power, high-sensitivity gas sensor.

This work was done by Thomas George, Daniel Choi, and Eric Jones of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

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

Intellectual Property group
JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-2240

Refer to NPO-20931, volume and number of this NASA Tech Briefs *issue, and the page number.*

Electroceramic Actuators for Operation at Low Temperatures

Relatively large strokes are produced at temperatures between 30 and 60 K.

Marshall Space Flight Center, Alabama

Electrostrictive ceramic actuators that can function at low temperatures have been developed for controlling the shapes of mirrors in the Next Generation Space Telescope (NGST). On Earth, electrostrictive ceramic actuators may be useful for fine control of the positions of objects in cryogenic laboratory apparatuses and in industrial cryogenic (including superconducting) systems.

On the basis of a number of candidate electroceramic materials, one material was found to be capable of a relatively large stroke in the temperature range of 60 K, such as to satisfy the specific stroke requirement for the NGST. Deformable mirrors that included actuators made from this material were assembled, using cutting and bonding techniques to form the material into actuators of the required sizes and shapes.

This work was done by Maureen L. Mulvihill and Mark A. Ealey of Xinetics, Inc., for **Marshall Space Flight Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*

MFS-31634

Radiation-Tolerant CMOS Image Sensors

Several design changes to reduce radiation-induced dark current are under investigation.

NASA's Jet Propulsion Laboratory, Pasadena, California

Complementary metal oxide semiconductor (CMOS) integrated-circuit image sensors that are highly tolerant of high-energy radiation ("radiation hard") are undergoing development. These devices are sensitive to visible light, yet are insensitive to diverse types of highly energetic radiation, including protons at kinetic energies >1 MeV, neutrons, heavy ions, high-energy γ rays, x rays, and electrons. They can continue to function substantially as designed, even after exposure to radiation doses in excess of 10 megarad (Si).

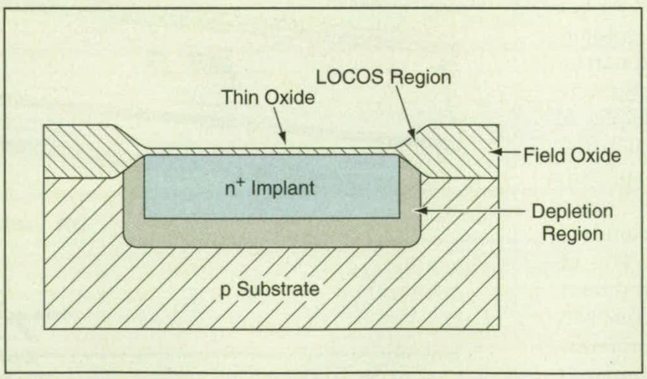


Figure 1. In a **Conventional CMOS Pixel Photodiode**, interaction between the LOCOS region and the depletion region is the primary source of susceptibility to radiation-induced generation of dark current.

The integrated circuits now used predominantly for visible-light image sensing are charge-coupled devices (CCDs), which are notoriously radiation-soft due to the need for repeated and accurate charge transfer. CMOS image sensors do not require charge transfer and hence are more suited for operation in radiation-rich environment. The main mechanism of degradation

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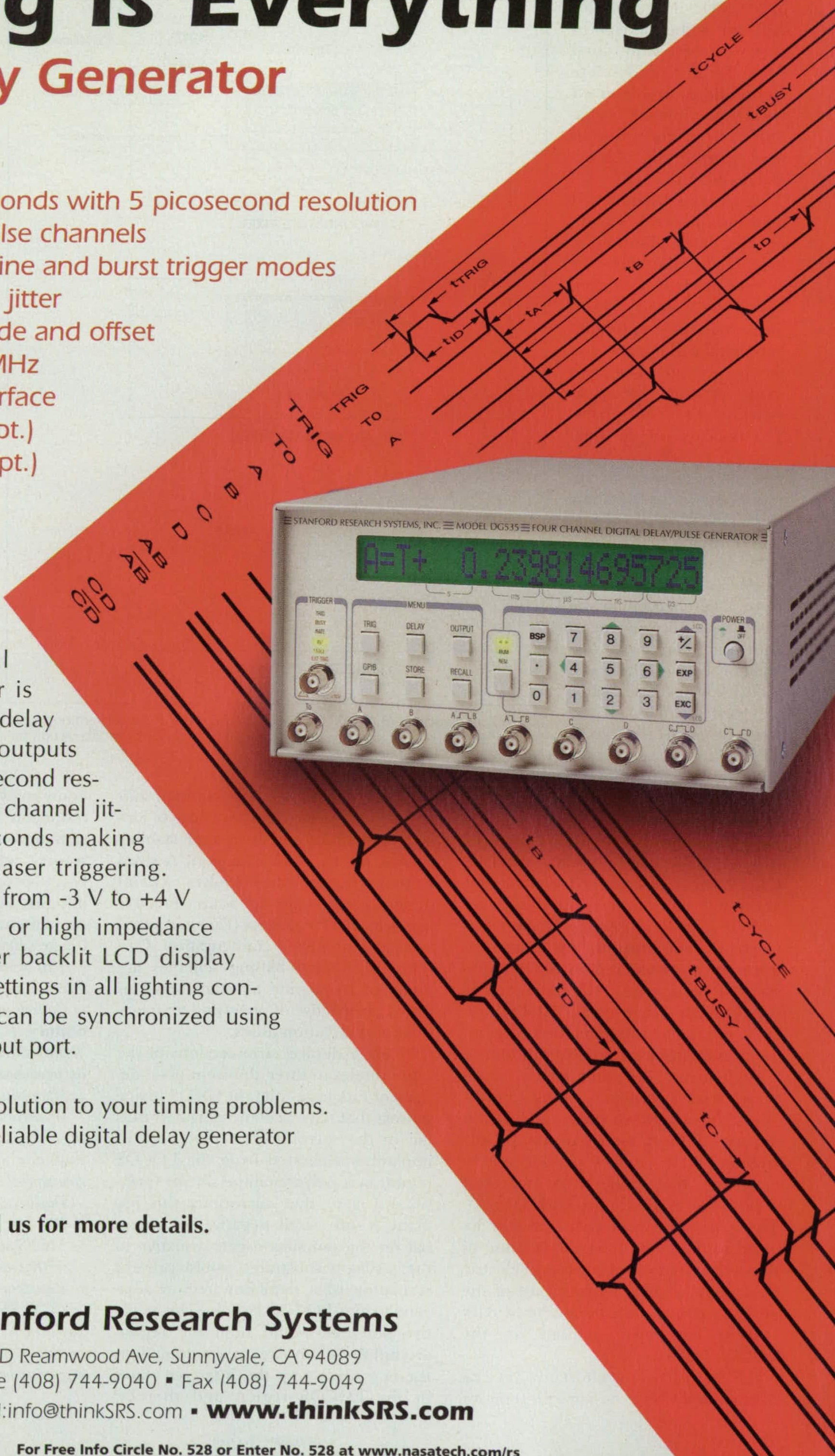

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of a CMOS imager under radiation is the increase in dark current with total dose. The present development efforts are directed toward minimizing radiation-induced increases in dark current in CMOS image sensors.

Figure 1 is a simplified depiction of a cross section of a typical photodiode used as the photodetector in one pixel of a conventional CMOS image sensor. The photodiode is formed between the n^+ implant and the p substrate. The field oxide provides electrical isolation between pixels. The thickness of the field oxide is chosen to ensure that the underlying silicon cannot be inverted at any bias applied on the oxide. The transition between the field oxide and the thin oxide that covers the n^+ implant is denoted either the bird's beak (because of its appearance in cross section) or the LOCOS region [because it is fabricated by the local oxidation of silicon (LOCOS) process (a process of masked oxidation near the surface of the silicon substrate)].

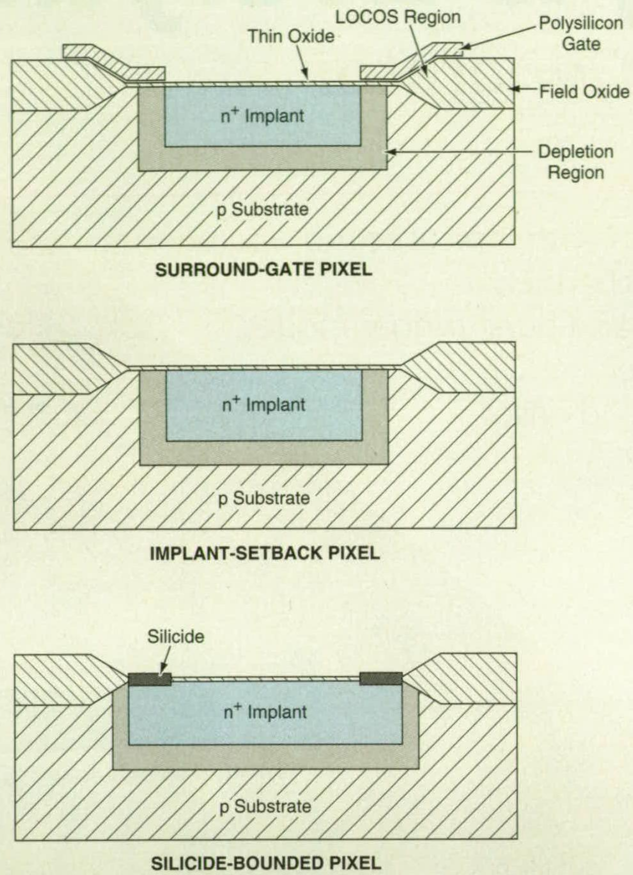

Figure 2. **Radiation-Hard CMOS Pixel Photodiodes** differ from conventional ones by incorporating features that suppress the deleterious effects of interaction between the LOCOS and depletion regions.

The LOCOS region is under elevated mechanical stress, and the densities of dangling molecular bonds and interface traps in this region are greater than that at the interface between the thin oxide and the n^+ Si. Because the n^+ region is in electrical equilibrium, the interface traps above the n^+ region do not substantially participate in the generation of dark current. However, the LOCOS region intersects the depletion region, which is in electrical non-equilibrium.

High-energy radiation creates additional dark-current-generating centers at interfaces between silicon and silicon dioxide. In the presence of thermal excitation, these centers provide excess electrons that collectively manifest themselves as increased dark current. The generation centers are usually located in the LOCOS region because of the concentrations of stress and electric field there. Hence, a major part of the effort to reduce radiation-induced dark current has been focused on the LOCOS region.

Another part of the effort involves a radiation-hard CMOS design with superior immunity against latch-up, minimal shift of threshold voltage per unit dose of ionizing radiation, and increased stability against electric-field inversion. A third major part of the effort involves a circuit design that provides for source-follower bias field-effect transistors (FETs) arranged in a current-mirror configuration. Current-mirror-based biasing schemes are intended to provide constant bias currents, irrespective of operating temperatures and radiation doses.

Figure 2 depicts cross sections of the photodiodes in three different pixel designs of radiation-tolerant CMOS image sensors that have been investigated thus far. In the surround-gate pixel, the n^+ implant is separated from the LOCOS region by a polycrystalline silicon (polysilicon) gate that surrounds the implant. A sufficiently negative DC potential on the polysilicon gate (relative to the p-silicon substrate) would prevent formation of a depletion region adjacent to the LOCOS region. The negative potential would hold the region around the n^+ implant in accumulation, thereby passivating the interface states in the LOCOS region and thereby, further, suppressing radiation-induced dark current.

In the implant-setback pixel, the edge of the n^+ implant is deliberately set back from the LOCOS region to prevent interaction between the LOCOS region and the depletion region around the implant. Holding the LOCOS region in electrical equilibrium is expected to reduce the generation of dark current. A threshold-adjust implant is expected to prevent the formation of a depletion region at the surface and to provide additional radiation hardness.

In the silicide-bounded pixel, a thin silicide film is formed over an annular region around the edge of the n^+ silicon implant. The formation of the silicide film is expected to reduce the stress in the LOCOS region, thereby reducing the probability of formation and/or activation of dark-current-generating centers in the LOCOS region.

Tests of the three designs have led to two preliminary conclusions. The first conclusion is that silicide-bound-pixel design effects a significant reduction of both pre-irradiation and radiation-induced dark current. The second conclusion is that the silicide-bound-pixel and implant-setback-pixel designs are the most promising for implementing radiation-hard CMOS image sensors.

This work was done by Bedabrata Pain, Bruce Hancock, and Thomas Cunningham of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*

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

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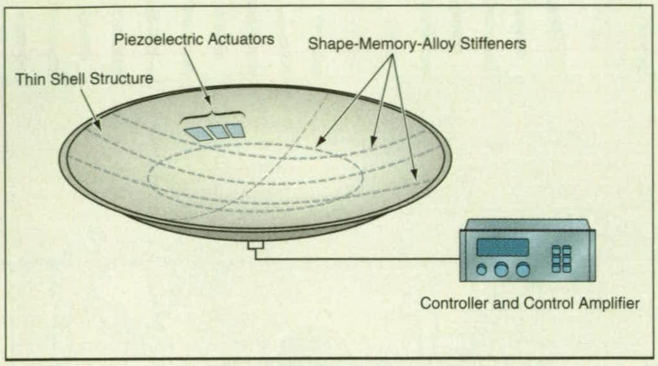
Refer to NPO-30185, volume and number of this NASA Tech Briefs *issue, and the page number.*

Deployable Shell Structures With Shape-Control Actuators

Hierarchical distributed control systems would effect both deployment and fine shape control.

NASA's Jet Propulsion Laboratory, Pasadena, California

Advanced control systems that include built-in smart-material elastic-deformation structural actuators have been proposed for deployable thin-shell structures that are required to be maintained in precise shapes once deployed. This approach to structural shape control was conceived to enable the development of lightweight telescope mirrors, radar reflectors, and the like that could be stowed compactly for launching and transport, then deployed in outer space to required precise shapes at much larger dimensions (of the order of 10 m). The concept may also be applicable to similar, but probably smaller structures for terrestrial use.



A **Deformable Curved Mirror** of paraboloidal or similar shape would contain stiffeners, made of shape-memory alloys, that would also serve as global shape-control devices. In addition, piezoelectric actuators would serve as local shape-control devices.

A typical shell structure according to the proposal (see figure) would include (1) a flexible single- or multiple-layer face sheet that would include a reflective mirror surface; (2) structural supports in the form of stiffeners made of shape-memory alloys; and (3) bimorph-type piezoelectric actuators, possibly of a variety of sizes and shapes. The actuators, together with an electronic control subsystem, would implement a concept of hierarchical distributed control: The shape-memory actuators would be used for global shape control and would generate the large deformations needed for the deployment process. The piezoelectric actuators would generate smaller deformations and would be used primarily to effect fine local adjustments of the shape of the mirror.

Because of the geometric and material nonlinearities of shell structures, this work considers the essential nonlinearity of the large deformations needed for stowage and deployment, and the further complexity and nonlinearity that obtains in structures that include flexible membranes. This research and development effort will serve as a foundation for designing and building such structures integrated with hierarchical distributed control systems. The proposed work will take advantage of recent advances in mathematical modeling, dynamics, and distributed sensing and control of structures that exhibit nonlinear responses and undergo large deformations.

This work was done by Gregory Hickey and Shyh-Shiuh Lih of Caltech and Horn-Sen Tzou of the University of Kentucky for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*
NPO-21138

"Smart" Actuators for Alleviating Buffet of Aircraft

Peak stresses could be reduced without sacrificing control authority.

Dryden Flight Research Center, Edwards, California

An active-control surface modal (ACSM) device has been developed as an improved means of alleviating buffet of an aircraft. The ACSM device is a "smart" actuator system that includes an array of antagonistic piezoelectric actuators installed within a rudder or other aircraft control surface (see Figure 1). These actuators are used to deform the control surface in what amounts to controlled vibration modes (see Figure 2), the frequencies and mode shapes being chosen to affect unsteady aerodynamic damping to suppress the dynamic effects of buffet.

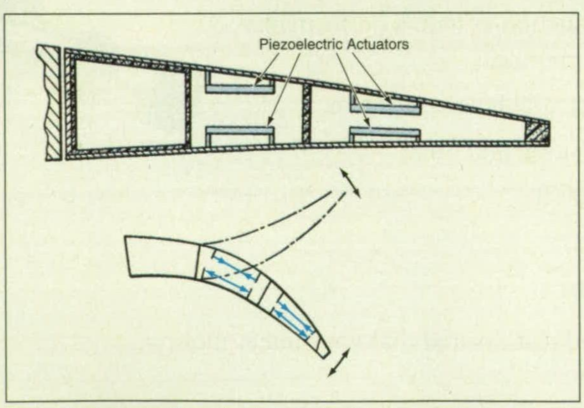


Figure 1. **Piezoelectric Actuators** are built into a control surface in a configuration to enable controlled deformation of the surface.

Buffet is a turbulent airflow phenomenon that originates from the separated flow shed behind aerodynamic lifting surfaces of an aircraft. An instability in this flow gives rise to random fluctuations of pressure that excite vibrations of the tail surfaces of the aircraft. These vibrations contribute to fatigue damage and thus to life-cycle cost and maintenance time.

Prior to the development of the present ACSM, both passive and active methods of alleviating buffet were considered. The passive methods included the use of fences and other modifications to minimize the strengths of shed vortices. Active methods included, variously, the use of hydraulic or piezoelectric actuators to superimpose, upon control motions, oscillations of the affected control surfaces about their hinges to affect aerodynamic damping. The two major shortcomings of this prior active method are the following: (1) For a given aircraft, the flight-control system and the buffet-load-alleviation control system must use the same degree(s) of freedom of the same control surface(s), so that the availability of the control surface(s) for each role (flight control or alleviation of buffet) is reduced. (2) Because it is difficult to make a massive control surface oscillate about its hinge at a high frequency, operation is limited to relatively low frequencies.

The use of piezoelectric actuators in an ACSM device to deform a control surface (in contradistinction to trying to make the control surface oscillate about its hinge) makes it possible to use modal frequencies that are high enough to encompass the frequency spectrum of buffet, gusts, and flutter. Although the ACSM is an integral part of the rudder or other control surface, it can be actuated according to control laws independent of those of flight-control system; hence, the control surface can respond to flight-control commands as well as the dynamic buffet-load-alleviation signals.

The vertical tail of the F-18 airplane was selected for benchmark case study for a demonstration of the ACSM approach to alleviation of buffet loads. Buffet-load data generated by NASA Langley Research Center in experiments on a 16-percent-scale model of the F/A-18 airplane were used in the study. Frequency-response analyses were performed for open- and closed-loop control test cases. In the closed-loop case, two acceleration signals measured at leading and trailing edges of the tail tip section were used as the feedback signals to command the actuators. These analyses showed that the use of the ACSM device would reduce peak tail-root stresses by 60 to 80 percent; this would translate to an eight-fold enhancement of the fatigue life of the vertical tail. The maximum total actuator power needed to effect this reduction was found to be 182 W. It was also concluded, from the results of these analyses, that gust loads could be alleviated and flutter suppressed by use of the ACSM device.

This work was done by K. Appa and J. Ausman of Appa Technology Initiatives, K. S. Khot of the Air Force Research Laboratory, and Martin Brenner of **Dryden Flight Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category.*

DRC-01-25

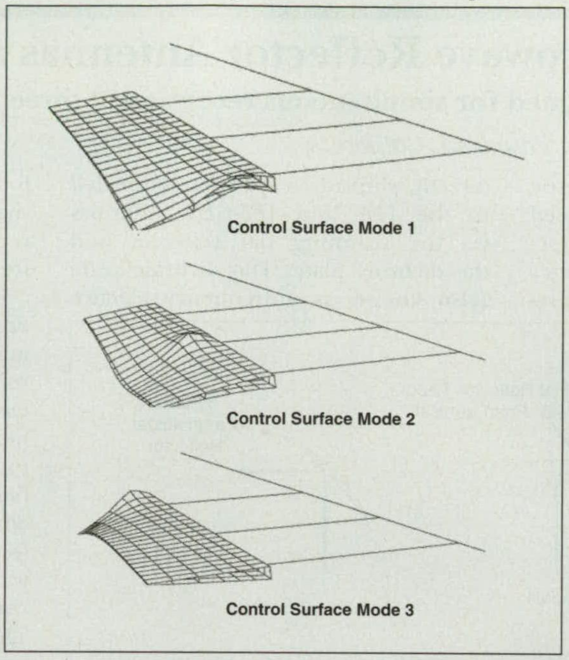


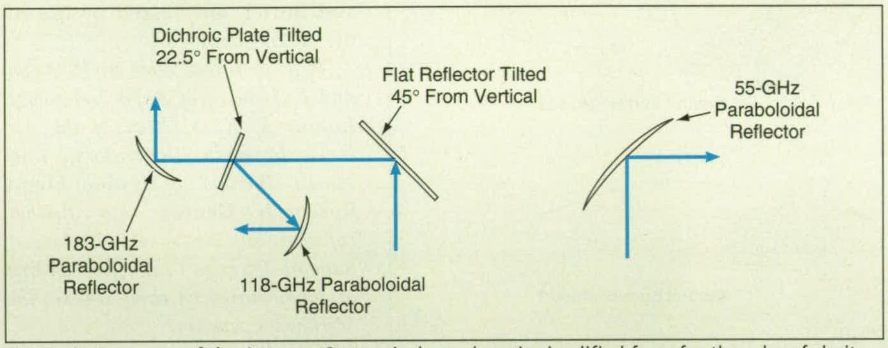
Figure 2. These **Examples of Mode Shapes** are typical of rudder deformations generated by an ACSM to reduce buffet loads.

Low-Sidelobe Microwave Reflector Antennas and Dichroic Plate

This antenna system is designed for simultaneous reception at three frequencies.

NASA's Jet Propulsion Laboratory, Pasadena, California

The figure depicts the basic geometric features of an antenna system designed to be part of a miniature atmosphere-sounding passive microwave radiometer to be flown at high altitude aboard a remotely piloted aircraft. The system includes (1) a scanning flat reflector; (2) a dichroic plate; and (3) three low-sidelobe, offset-paraboloidal reflector antennas for reception in three frequency bands that include, and are denoted by, nominal frequencies of 55, 118, and 183 GHz, respectively.



The **Basic Geometry of the Antenna System** is shown here in simplified form for the sake of clarity.

In operation, the antennas are aimed downward toward the Earth. The 55-GHz reflector receives input radiation directly, while input radiation is directed to the 118- and 183-GHz antennas via the scanning flat reflector and the dichroic plate. The dichroic plate [also known as a frequency-selective surface (FSS)] is a plate that contains a hexagonal array of subwavelength-diameter holes with dimensions chosen precisely so that at an angle of incidence of 22.5° the plate transmits most of 183-GHz radiation while reflecting most of the 118-GHz radiation. The paraboloidal main reflector in each antenna concentrates the incident radiation into a corrugated feed horn, followed by a circular-to-rectangular transition, followed by a rectangular waveguide that couples the radiation into a receiver operating in the designated frequency band.

The feed horns were analyzed and designed by use of a full-wave mode-matching technique. The paraboloidal reflectors were analyzed and designed by use of physical-optics theory. The directional radiation patterns of the reflectors were computed by use of the near-field patterns of the feed horns. The analysis and design of the dichroic plate for the instant case of oblique incidence was based on the method of moments in conjunction with Floquet harmonics. The calculations for analysis and design were performed by use of computer programs developed at NASA's Jet Propulsion Laboratory and elsewhere for the analysis of reflector systems, corrugated horns, waveguide junctions, and frequency-selective surfaces.

This work was done by Vahraz Jamnejad and Abraham Riley of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*
NPO-21157

Simple Phase Shifter for a Scanning-Beam Antenna

Phase is shifted by mechanically perturbing dielectric/air/conductor boundaries.

John H. Glenn Research Center, Cleveland, Ohio

A simple, inexpensive device has been conceived for shifting the phase of a signal in a feed line of a scanning-beam microstrip antenna in order to change the direction of the beam. Heretofore, phase shifters used for this purpose have been relatively bulky and expensive.

The phase shifter and the overall scanning antenna are made more compact than they otherwise would be by integrating the feed line and the phase shifter. The feed line in this case is a dielectric waveguide made of a ceramic that is characterized by low loss at a wavelength of the order of a millimeter. The waveguide feeds the microstrip antenna through a slot.

The design of the device exploits the fact that the phase velocity, and thus the phase, of a signal propagating along the ceramic waveguide, can be varied by perturbing dielectric/air/conductor boundaries. In particular, the variation in phase and thus the scanning ability of the beam is effected by rotating a cam on top of the ceramic waveguide. The phase varies with the gap between the ceramic waveguide and the cam.

The development of this device is at the prototype stage. The one major source of difficulty in fabrication and use is that the waveguide/cam gap is less than a tenth of a millimeter and must be controlled accurately.

This work was done by XiaoDong Wu, Robert Knox, Kenneth Gilliam, and Dawei Li of Epsilon Lambda Electronics Corp. for ***Glenn Research Center.***

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135.
Refer to LEW-16912.

High-Capacity Nickel-Hydrogen Cells

These cells retain capacity and integrity under severe conditions.

John H. Glenn Research Center, Cleveland, Ohio

Nickel-hydrogen electrochemical cells with capacities of 350 ampere-hours have been developed. These cells are intended primarily for use in government and commercial satellites; they have been fully qualified to satisfy performance requirements for operation in geosynchronous satellites for as long as 15 years. They may also prove useful in terrestrial applications in which there are requirements for long-life, lightweight, high-capacity cells that retain capacity over a wide temperature range and retain integrity when subjected to severe acceleration.

Each cell has a diameter of 5.5 in. (≈14 cm). Notable features of the cell design and construction include the following:

- Electrochemically impregnated, sintered nickel positive electrodes;
- Single-layer zirconium oxide cloth separators;
- Platinum-catalyzed hydrogen electrodes;
- High-current cell terminals; and
- A lightweight nickel-alloy pressure vessel.

In a test, a pressure vessel of the type used in these cells withstood a pressure of 2,100 psig (gauge pressure ≈14.5 MPa) without bursting. In another test, a cell exhibited both electrical and mechanical integrity after exposure to a sine burst of acceleration with an amplitude of 50 times normal Earth gravitation. In still another test, a cell exhibited charge/discharge capacities above those of acceptance requirements at temperatures from –22 to +42 °C.

This work was done by Robert K. Taenaka, Allen R. Powers, W. Rex Oswald, and Joel A. Schwartz of Hughes Space & Communications Co. for **Glenn Research Center.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135.

Refer to LEW-16867.

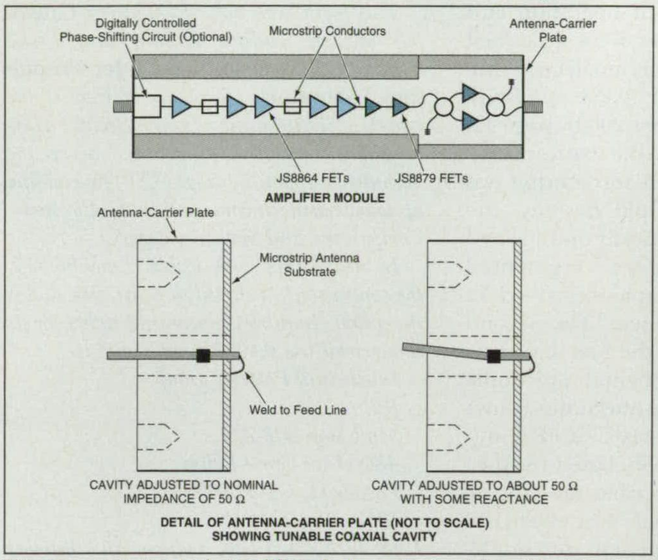
K_a-Band Solid-State Power Amplifier Module

Applications could include mobile communications and phased-array antennas.

Lyndon B. Johnson Space Center, Houston, Texas

A compact K_a-band power amplifier has been built with GaAs field-effect transistors (FETs) and microstrip conductors on a quartz substrate. Prior to the development of this amplifier, K_a-band solid-state amplifiers with useful output power levels (of the order of 1 W or more) were not readily available, and it was common practice to use traveling-wave-tube amplifiers (TWTAs), which are capable of higher power levels but are also relatively bulky and expensive. TWTAs are not well suited for applications in which compactness is paramount. The present amplifier is better suited for such applications, which include phased-array antennas and mobile communication systems.

The figure illustrates the basic functional blocks of the radio-frequency part of the amplifier circuit. There are (1) five driving stages, each containing a JS8864 GaAs FET, (2) two driving stages, each containing a JS8879 GaAs FET, and (3) a power stage containing two JS8879 FETs. Impedance-matching microstrip circuits between the stages are etched in gold film on the quartz substrate. At the output end, the amplifier can be matched to a load via an antenna-carrier plate that contains a tunable coaxial cavity. The load can be a microstrip antenna mounted flush on the antenna carrier plate, or else an external load that is reached via a coaxial connector mounted on the plate.



This **Compact K_a-Band Amplifier** features GaAs FETs with interstage impedance-matching microstrip conductors and a tunable coaxial cavity for matching output impedance.

The amplifier provides 30.5 dB of small-signal gain over a frequency band about 760 MHz wide at a middle frequency of 29.6 GHz. The output power saturates at 28.5 dBm (≈ 0.7 W), and the onset of saturation is characterized by a 1-dB-compression output power of 25.5 dBm (≈ 0.35 W).

The development of this amplifier involved refinement of prior designs and design techniques within constraints and specifications more stringent than those governing the design of solid-state amplifiers that operate at lower frequencies. In addition to providing for a useful output power level at K_a band, the design of this amplifier accommodates the planned addition of a digitally controlled radio-frequency circuit that would produce phase shifts in increments of 22.5°. Development of the amplifier was stopped before the phase-shifting circuit could be incorporated; completion of this aspect of development would be prerequisite to phased-array applications.

Some of the technological advances embodied in this amplifier may have been surpassed by other, more recent advances in solid-state K_a-band technology. Noteworthy examples include advances in monolithic microwave integrated circuits and high-electron-mobility transistors. Nevertheless, the present amplifier can serve as a prototype for design alternatives with commercial potential.

This work was done by Patrick Fink of **Johnson Space Center** *and Roland Shaw, David Kilpatrick, and Sheryl Andrews of Shason Microwave Corp. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*
MSC-22450

Skutterudite Thermoelectric Unicouples for Generating Power

NASA's Jet Propulsion Laboratory, Pasadena, California

A report presents some results of continuing efforts to develop advanced thermoelectric devices and, more particularly, thermoelectric unicouples for generating electric power from diverse thermal sources, including automotive exhausts and other waste-heat sources. The basic principles of operation and design of these devices were described in "Highly Efficient Thermoelectric Unicouples" (NPO-20872), *NASA Tech Briefs*, Vol. 24, No. 10 (October 2000), page 42. The report reiterates the basic principles and then goes on to describe two thermoelectric-unicouple designs, the first of which is theoretically optimal and similar to that of a segmented thermoelectric unicouple described in the cited previous article. The second design — a variant of the first design — is that of an experimental unicouple that was made from skutterudite (only) thermoelectric materials: $CeFe_4Sb_{12}$-based (p-type) and $CoSb_3$-based (n-type) alloys. The report describes the fabrication and the thermal and electrical tests of the experimental unicouple. Among the reported test results are a thermal-to-electrical energy-conversion efficiency of as much as 9.8 percent during operation at hot- and cold-side temperatures of 863 and 363 K, respectively. The report projects that, in the future, more nearly optimal designs could yield efficiencies as large as 15 percent.

This work was done by Thierry Caillat, Jeff Snyder, Andrew Zoltan, and Leslie Zoltan of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "Skutterudite Thermoelectric Unicouples for Power Applications," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*

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

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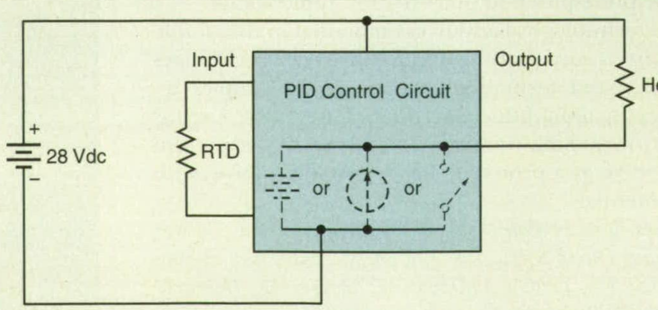
Refer to NPO-30128, volume and number of this NASA Tech Briefs *issue, and the page number.*

Miniature Proportional Temperature Controllers

These would be smaller and lighter than are their commercial predecessors.

Goddard Space Flight Center, Greenbelt, Maryland

Miniature proportional + integral + derivative (PID) temperature controllers that would be implemented as hybrid microcircuits have been proposed to satisfy special requirements to minimize size and mass and to maintain γ-ray-detector modules at temperatures of 10±0.5 °C. These temperature controllers



A **Miniature PID Temperature Controller** would generate an output in the form of (1) a proportional current or proportional voltage supplied to a heater, or (2) switching of a solid-state relay for on/off control of the heater.

would be significantly smaller and less massive than are commercial PID temperature controllers, and would control temperatures more accurately than do commercial hybrid solid-state on/off-switching thermostats.

The basic idea is to sense the temperature of a module and to regulate the electric power supplied to a film heater that is bonded to the module. The major drawback of on/off switching of heater power is that it causes the temperature to oscillate about the set-point temperature and can give rise to significant overshoot during warmup or load changes. In the intended application, the oscillations and overshoots, as well as the temperature gradients that occur when heater power is on, make it impossible to satisfy the requirement to keep the temperature within ±0.5 C° of the set point.

A controller as proposed would supply full power to a heater until the temperature entered a specified proportional-control band that would contain the set point. The controller would then reduce the heater power gradually until the temperature became stabilized at the set point. The advantage of the PID control characteristic is that it would prevent overshoot and compensate for droop, thereby increasing the accuracy of temperature control.

The controller would have dimensions of about 0.25 by 1 by 1.5 in. (about 0.6 by 2.5 by 3.8 cm). Its mass would be about 0.5 oz (about 14 g). The figure is a simplified schematic diagram of the controller in relation to the temperature sensor and the heater. The temperature sensor would be a platinum resistance temperature detector (RTD) or epoxy-encapsulated thermistor, which could be either separate from the controller or laminated inside the body of the controller. Hybrid microcircuits inside the body would generate the PID response.

Due to the use of hybrid microcircuits, each controller could consist of multiple temperature control units. This reduces the number of temperature controllers required significantly. Also, the temperature set point of the controller could be changed in flight by using a temperature-versus-voltage calibration curve.

This work was done by Michael K. Choi of **Goddard Space Flight Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*
GSC-14315

Software

External Data and Attribute Hyperlink Programs for Promis•e®

External Data and Attribute Hyperlink are computer programs that can be added to Promis•e®, which is a commercial software system that automates routine tasks in the design (including drawing schematic diagrams) of electrical control systems. The programs were developed under the Stennis Space Center's (SSC's) Dual Use program to provide capabilities for SSC's 3 MCS configuration management system, which uses Promis•e®. The External Data program enables the storage and management of information in an external database linked to a drawing. Changes can be made either in the database or on the drawing. Information that originates outside Promis•e® can be stored in custom fields that can be added to the database. Although this information is not available in Promis•e® printed drawings, it can be associated with symbols in the drawings, and can be retrieved through the drawings when the software is running. The Attribute Hyperlink program enables the addition of hyperlink information as attributes of symbols. This program enables the formation of a direct hyperlink between a schematic diagram and an Internet site or a file on a compact disk, on the user's hard drive, or on another computer on a network to which the user's computer is connected. The user can then obtain information directly related to the part (e.g., maintenance, or troubleshooting information) associated with the hyperlink.

This program was written by Rich Derengowski and Andrew Gruel of ECT International for **Stennis Space Center.**

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

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Refer to SSC-00135, volume and number of this NASA Tech Briefs *issue, and the page number.*

Software for Parallel Computation of 3D Thermal Convection

A computer program solves the differential equations of three-dimensional (3D) thermal convection of an incompressible fluid by use of a parallel-processing, finite volume numerical scheme. The equations of conservation of momentum, and energy are integrated over macroscopic control volumes on a normal, staggered grid. Upwind interpolation functions are used to prevent spurious numerical oscillations at high Rayleigh numbers. The resulting discretized equations, including a pressure equation that demands most of the computation time, are solved by a parallel-processing, multigrid method. The multigrid aspect of the method involves the use of a hierarchy of grids of different mesh sizes to obtain a solution on the finest grid. It has been proven, both theoretically and practically, that the multigrid aspect affords rapid convergence on a solution. The program could be used, for example, to predict oceanic convection currents. The effectiveness of the program has been demonstrated by applying it to test cases on several parallel-computing systems.

This program was written by Ping Wang of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Software category.*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-21147.

Software for Simulating Two-Phase Systems

Møtran (signifying "multi-phase transient") is a package of software for simulating flows in two-phase (gas/liquid) fluid systems like networks of such components as pipes, T junctions, pumps, evaporators, and condensers. The software is based on a two-fluid formulation that can accommodate unequal velocities and temperatures for the two phases. Møtran provides for single-phase, bubbly, slug, stratified, and annular flow regimes. Mechanistic models are used for establishing the boundaries between flow regimes and for constitutive rela-

MEMS

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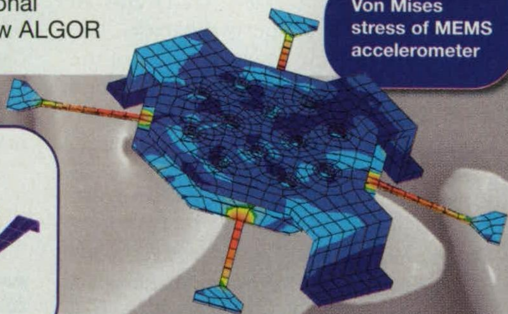
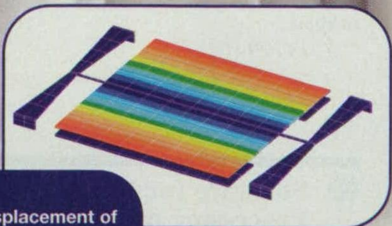


Von Mises stress of MEMS accelerometer

Electric field of MEMS radial comb motor



Displacement of MEMS switch

MEMS switch compared to a penny

WHAT ARE MEMS?

Micro Electro Mechanical Systems (MEMS) are micromachines the size of a grain of salt or the eye of a needle that integrate mechanical elements, sensors, actuators and electronics on a common silicon substrate. MEMS applications include optical switches within telecommunication and networking systems, accelerometers in automotive airbags, inkjets in desktop printers and sensors in medical testing equipment. The emerging MEMS industry promises to make the next generation of electronic products smarter and cheaper.

ALGOR's direct-selling and high-technology business model delivers the best FEA-based simulation value for MEMS simulation in the CAE industry. ALGOR's MEMS solution links electrostatic analysis to structural analysis tools with an easy-to-use graphical user interface that works within many popular CAD systems and includes a precision FEA model building tool.

ALGOR'S MEMS SOLUTION INCLUDES:

- Multiphysics analysis software to simulate the real-world mechanical behavior for several physical factors acting simultaneously, such as:
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  - Structural analysis software that predicts electromechanical effects driven by electrostatic forces
  - Piezoelectric material models for Mechanical Event Simulation and static stress analysis
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- InCAD technology for CAD/CAE interoperability within Autodesk Inventor, CADKEY, Mechanical Desktop, Pro/ENGINEER for Windows, Solid Edge and SolidWorks
- Unstructured brick and tetrahedral meshing
- A midplane mesh engine that automatically converts thin solid parts into plate/shell elements
- A Material Library Manager that controls material property data for all analysis types

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Photos courtesy of Sandia National Laboratories tions that represent wall shear, interfacial shear, wall heat transfer, interfacial heat transfer, and phase change. Constitutive models are provided for each of the flow regimes, and all are selected and calculated dynamically during solution for each grid point in the network. The software is applicable at all levels of gravitation, whether steady or time varying. Møtran includes a state-of-the-art graphical user interface (GUI) and an integrated fluid-property database. The user assembles the representation of the fluid system (which can be of arbitrary topology) through drag-and-drop operations on the GUI. The software predicts pressures, volume fractions, temperatures, and velocities of the phases throughout the system.

This program was developed under the direction of James J. Barry and Christopher J. Crowley of Creare Inc. for **Glenn Research Center.** *For further information, please contact James J. Barry at (603) 643-3800 or via http://www.creare.com/motran/index.html.*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16937.

Fourth-Generation Software for SEU Testing

RBK4 is a computer program for testing electronic components for susceptibility to single-event upsets (SEUs). RBK4 controls the computer on which it is executed to communicate with both the board holding the device under test (DUT), a power supply, and other laboratory instruments including custom circuitry integrated into the computer. Written for the Windows 95, 98, and NT operating systems, RBK4 offers improvements over RBK3, its DOS-based predecessor. RBK4 enables the user to open, change entries in, and save configuration files that set the values of virtually every changeable field in the software. Information in the configuration files includes names and settings of counters, power-supply settings (including voltage, current, and limiting values thereof), soft-programmable switches, and full control over instrumentation displays. Clock circuits on the board can be enabled and disabled while counters integrated into the computer can be monitored and time-tagged. The software provides for full control of the power supply, including the control and monitoring of voltages and currents in the power supply and a variety of error and reset conditions. The data collected during a test run can be stored in the computer with a variety of viewing modes integrated into the software such as text file viewing and graphical plots, providing for easy, quick analysis of the test data.

This program was written by Richard Katz of **Goddard Space Flight Center** *and Igor Kleyner and Ingrid Brill of Orbital Sciences Corp. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Software category.*
GSC-14399

Software for Improved Processing of DRWP Signals

The Automated Adaptive Signal Processing (AASP) computer program extracts wind data from the outputs of Doppler-radar wind profilers (DRWPs). Unlike prior software used for this purpose, AASP does not rely on manual intervention to prevent a DRWP system from locking onto and tracking interfering signals (e.g., signals from side lobes of radar beams). AASP identifies interference signals in the range-gated spectra produced by a DRWP, then tracks the height- and time-continuous atmospheric signal in each radar beam. AASP then combines the radial velocity components from three or five beams and computes the horizontal and vertical wind components. AASP produces high-quality wind profiles within a single radar cycle, without need for averaging for quality control. It also calculates an indication of the level of confidence with each wind estimate. The single-cycle capability enables users to detect temporal shifts in wind earlier and with greater confidence than was possible by use of prior software. AASP comprises two coupled software subsystems: (1) a subsystem that implements signal-processing algorithms and (2) a subsystem that provides a quality-control capability and that generates displays of spectra, of wind estimates, and of the performances of the DRWP hardware.

This work was done by Robin Schumann, Ed Toughlian, Greg Taylor, and Erik Magnuson of ENSCO, Inc., for **Kennedy Space Center**. *For more information, contact the Kennedy Commercial Technology Office at 321-867-6224.*
KSC-12245

Refrigerant Blends Containing Trifluoroiodomethane

Some of these non-ozone-depleting refrigerants can supplant older ozone-depleting ones.

John F. Kennedy Space Center, Florida

Blends of refrigerant fluids have been developed as improved alternatives to conventional chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants, which contribute to depletion of stratosphere ozone. Each blend of this type is a zeotropic or nearly azeotropic mixture of trifluoroiodo-methane (CF_3I) with two or three hydro-fluorocarbon (HFC) refrigerant compounds. In addition to having zero ozone-depletion potential, these CF_3I-containing refrigerant blends are nonflammable, and have low toxicity, low global-warming potential (GWP), and low total equivalent warming impact (TEWI). [GWP and TEWI are two measures that quantify different aspects of contributions to global warming.]

In comparison with prior non-CFC and non-HCFC refrigerants (including blends) that do not contain CF_3I, the present improved refrigerant blends containing CF_3I offer greater energy efficiencies and smaller temperature glides. (The temperature glide of a zeotrope is the range of temperatures over which the zeotrope and its constituents evaporate and condense as the proportions of the constituents vary.) Some of the improved refrigerant blends can be substituted directly for older medium- and high-pressure refrigerants, without need to modify refrigeration equipment. The older refrigerants in question are R-12 (dichlorodifluoromethane), R-22 (chlorodifluoromethane), R-134a (tetrafluoroethane), and R-502 (a blend of chlorodifluoromethane and chloropentafluoroethane).

This work was done by Jonathan S. Nimitz, Edward T. McCullough, and Patrick M. Dhooge of Nimitz, Inc., for **Kennedy Space Center.**

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

Dr. Patrick Dhooge
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E-mail: pdhooge@etec-nm.com

Refer to KSC-12180, volume and number of this NASA Tech Briefs *issue, and the page number.*

Heat-Exchanger Rocket Engine

Engine heat is used to prevaporize liquid oxygen.

Lyndon B. Johnson Space Center, Houston, Texas

The proposed rocket engine includes a combustion chamber actively cooled by liquid oxygen: Heat from the combustion chamber vaporizes the flowing liquid oxygen, and the absorption of latent heat of vaporization contributes to cooling of the combustion-chamber wall. The resulting high-vapor-quality (mostly vapor) two-phase flow of oxygen is then injected into the combustion chamber to burn with the fuel. Vaporization of the majority of the oxygen prior to injection renders the engine insensitive to wide variations of inlet conditions.

The need to reduce the sensitivity of the engine to inlet conditions arises because of a generic drawback of cryogenic rocket-engine propellants: In general, liquid oxygen and hydrocarbon fuels can be stored as propellants for rocket engines. Because liquid oxygen and other cryogenic propellants are very volatile, thermal-control devices are necessary for storing them. During operation of a cryogenic-fluid feed system of a rocket engine, there may be some nonuniformity in the level of subcooling, and/or vapor bubbles may appear in some locations. The resulting fluctuations in the quality of the liquid oxygen [that is, in the liquid fraction of the two-phase fluid] delivered to the engine can lead to malfunctions.

In designing and operating the proposed engine, no attempt would be made to inject liquid oxygen into the combustion chamber. On the contrary, most or all of the oxygen is vaporized prior to injection, in recognition of the fact that for oxygen and other highly volatile propellants, the magnitudes of flow-rate fluctuations are much smaller in the high-vapor-quality (mainly gas) regime than they are in the low-vapor-quality (mainly liquid) regime. As a result, the pattern of injection of oxygen into the combustion chamber, which pattern can be expected to exert a major effect on engine performance, is rendered much less sensitive to inlet quality variations than it would be if one were to attempt to inject liquid oxygen.

The proposed engine, denoted a heat-exchanger rocket engine, includes flow channels in its combustion-chamber wall. Liquid oxygen enters the engine through these channels. The rate of transfer of heat from the combustion process to the liquid oxygen flowing in the channels is adjusted so that most or all of the liquid oxygen is vaporized and the combustion-chamber wall temperature remains low. Mixing devices in the heat-exchanger flow passages enhance heat transfer in two-phase flow. The high-vapor-quality flow of liquid oxygen from the channels is collected in an oxygen-injector manifold and distributed in the combustion chamber through annular gaps at the head end of the combustion chamber.

Fuel is injected radially into the combustion chamber from a central injector extension. The fuel jets are broken up and atomized by the cross flow of gas. The injector configuration is selected to obtain a fuel-rich wall zone and adequate atomization; these features control engine performance and the rate of transfer of heat to the walls of the combustion chamber and nozzle. The fuel injector is adjusted to control the amount of fuel landing on the chamber wall and, therefore, control the gas temperature driving the heat exchange.

In an alternative scheme, the gas flowing from the heat exchanger would be collected in tanks or other accumulators, then fed from the accumulators to the engine. In this scheme, the operation of the engine as a whole would be somewhat decoupled from the operation of its heat-exchanger portion. This scheme may present some advantages at an overall system level.

This work was done by Jacky Calvignac of TRW Space & Technology Division for **Johnson Space Center.** *For more information, contact the Johnson Commercial Technology Office at (281) 483-3809. MSC-23081*

Stable Ohmic Contacts on SiC Devices for High Temperatures

The candidate material — Ti_3SiC_2 — is thermodynamically stable in contact with SiC.

John H. Glenn Research Center, Cleveland, Ohio

Ti_3SiC_2 has been proposed as a material for ohmic contacts on SiC-based electronic and microelectromechanical devices intended to operate at temperatures >600 °C and/or in corrosive environments. Although SiC is stable and devices made of SiC are capable of functioning at elevated temperatures and in corrosive environments, the lack of stable ohmic contacts has been a barrier to the realization of SiC-based devices. Most metals react with SiC at high temperatures, forming metal silicides and/or carbides. At a minimum, these reactions cause contact resistances to change over time, affecting the performances of devices; in extreme cases, entire contact layers can deteriorate through oxidation, melting, evaporation, or balling up on surfaces.

The proposal to use Ti_3SiC_2 was made on the basis of a search of the literature on transition-metal carbides, nitrides and borides; metal and compound contacts for SiC; phase stability diagrams; brazing; and methods of deposition. The properties of Ti_3SiC_2 were found to be exceptionally favorable for making highly stable ohmic contacts on SiC devices for operation at temperatures >600 °C and/or in corrosive environments.

Ti_3SiC_2 is thermodynamically stable in contact with SiC and is one of the products usually formed in reactions between thin Ti films and 6H SiC substrates after rapid thermal annealing. Ti_3SiC_2 has electrical conductivity greater than that of Ti or TiC, plus high thermal conductivity and acceptably large resistance to thermal shock. It is rigid, relatively light, and stable at temperatures up to 2,200 °C. Its coefficient of thermal expansion is roughly twice that of SiC; however, like gold, Ti_3SiC_2 relieves internal stress via motion of dislocations, even at room temperature. Oxidation of Ti_3SiC_2 follows a parabolic rate law over the temperature range of 900 to 1,400 °C in air, with an activation energy ≈4 eV. The oxidation product is a conformal protective layer of TiO_2/SiO_2. On the basis of published data, it has been estimated that after 1,000 hours in air at a temperature of 1,100 °F (593 °C) the thickness of the oxide film on Ti_3SiC_2 would be only ≈11 nm.

Ti_3SiC_2 can be deposited directly on SiC by sputtering, chemical vapor deposition, or pulsed laser ablation. Because of its thermodynamic stability in contact with SiC, Ti_3SiC_2 forms a stable interface with a stable electrical resistance. The one major drawback is that Ti_3SiC_2 reacts with most metals used for electrical interconnections, forming TiC and silicides. Hence, it may be necessary to develop diffusion barriers to enable the use of standard interconnection metals.

This work was done by Harry L. Tuller, Marlene A. Spears, and Richard Mlcak of Boston Microsystems, Inc., for **Glenn Research Center**.

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135.

Refer to LEW-16982.

Mechanics

Improved Lightweight Freeze-Tolerant Tubes

Lyndon B. Johnson Space Center, Houston, Texas

Improved designs have been conceived for lightweight tubes that can withstand the large (as much as 8 or 9 volume percent) freeze/thaw expansions and contractions of typical heat-transfer fluids like water and ammonia. Intended originally for radiators for rejecting waste heat from spacecraft, these designs may also be suitable for such terrestrial applications as freeze-tolerant water pipes in houses and sprinkler systems. Typical prior freeze-tolerant-tube designs are characterized by short operating lives because they rely on compressible polymeric inserts that are degraded by permeability and by embrittlement at low temperatures. The improved designs call for thin tube walls with noncircular (typically oval) cross sections and solid or hollow metal inserts of various shapes, all selected together to obtain specific combinations of limited volume expansion and mechanical advantage such that the stresses in the tube walls remain sufficiently low under all anticipated freeze/thaw conditions.

This work was done by Robert J. Copeland and Mark M. Weislogel of TDA Research for **Johnson Space Center.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category.*
MSC-23120

Mechanisms Facilitate Blowdown of Large Diesel Engines

Blowdown can be performed faster, more easily, and more safely.

Stennis Space Center, Mississippi

Simple mechanisms have been devised to facilitate the blowdown of large diesel engines. As explained below, these mechanisms reduce the amount of time and effort that must be expended to test engines before operating them.

Blowdown is a procedure used to detect fuel or water leaks in diesel-engine cylinders. To prepare for blowdown, a technician opens a valve, known as a Kenny cock, on each cylinder. The engine is then cycled. If fuel or water has leaked into a cylinder, it is ejected through a drain pipe and can be seen. Once blowdown has been completed, the Kenny cocks are closed. If no water or fuel was found during blowdown, the engine can be started.

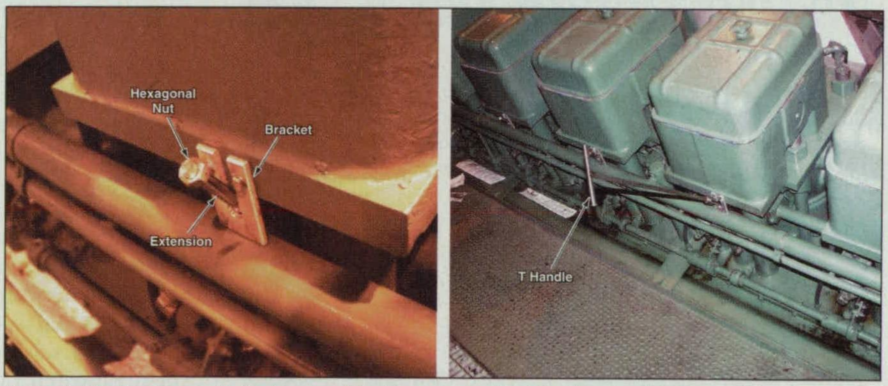
In the setting for which the present blowdown-facilitating mechanisms were devised, the Kenny cocks are difficult to see and reach, and they are opened and closed by turning hexagonal bolts. Before these mechanisms were installed, technicians had to squat or get down on their knees in order to see, open, and close the Kenny cocks. The combination of difficulty and awkwardness of position contributed substantially to the time and effort of the blowdown procedure and increased the risk of injury.

The blowdown-facilitating mechanisms consist of components attached permanently to the Kenny cocks plus at least one component that a technician carries from cylinder to cylinder. One of the components attached permanently to the Kenny cock on each cylinder is a swivel socket that fits onto the hexagonal bolt. An extension is attached to the swivel socket and is supported by a bracket, through which it protrudes. A hexagonal nut is attached to the end of the extension (see figure).

The component carried by the technician is a T-handle shaft with a hexagonal socket attached to tip of the shaft. The technician simply mates the hexagonal socket with the hexagonal nut and turns the handle to open or close the Kenny cock. Because the hexagonal nut is readily visible, blowdown can be performed in less time and with less difficulty and risk. In the original setting, use of these mechanisms has reduced the time needed to perform blowdown by about 60 percent.

This work was done by Tim Delcuze, Ira Lossett, Todd Pearson, Jerry Quinn, James Seals, Danny Tarter, and Rodney Wilkinson of Lockheed Martin Corp. for **Stennis Space Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechancics category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Stennis Space Center; (228) 688-1929.
Refer to SSC-00132.



A Simple Mechanism — similar to a combination of wrench extensions used to turn a difficult-to-reach nut or bolt on an automobile engine — is installed permanently to bring the point of actuation of a Kenny cock out to a readily accessible and visible location.

Uncertainty Models From Ground Vibration Testing

Test data indicate least conservative errors in model.

Dryden Flight Research Center, Edwards, California

Structural dynamics are often an important consideration when evaluating system characteristics. A concern related to structural dynamics is the analysis of flutter for a flight vehicle. The instability associated with flutter can be quite sensitive to the structural dynamics; therefore, analysis of robustness with respect to error, or uncertainty, is becoming increasingly important for the flight test community. In particular, uncertainty models are needed for μ-method analysis as described in "Characterizing Worst-Case Flutter Margins From Flight Data" (DRC-97-03), *NASA Tech Briefs*, Vol. 21, No. 4 (April 1997), page 62.

Norm	Flutter Speed (knots)
1	317
2	343
∞	359

Robust Flutter Speeds were computed by 1-, 2-, and ∞-norm analyses.

A method of determining optimal uncertainty descriptions for models of structural dynamics has been developed. This method results in the smallest uncertainty descriptions that are needed to account for data measured during ground vibration testing. Consequently, the resulting models generate least-conservative predictions of the flight conditions that are associated with flutter.

A ground vibration test is commonly performed as a preflight check that attempts to evaluate the quality of an analytical model. The basic concept is to excite the structural dynamics and measure responses at locations throughout the vehicle. The responses are then analyzed to estimate a set of modal properties such as natural frequencies and mode shapes. These modal properties are compared with the analytical model to determine the error and uncertainty in the model.

In reality, there are many estimates of modal properties that result from a ground vibration test. There may be hundreds of sensors that indicate slightly different estimates of natural frequencies. Also, the mode shapes are computed by a routine that interpolates responses from many sensors. Different interpolation schemes result in different estimates of modal properties.

The traditional method of analyzing test data is to generate modal properties that are a 2-norm minimization, or average, of a set of property estimates. The new method of analyzing test data is to use an ∞-norm minimization. The ∞-norm approach does not generate the optimal property; rather, it generates the optimal uncertainty set that is associated with the property. In this way, μ-method analysis of the resulting model generates least-conservative predictions of robust stability.

A wing testbed was used to demonstrate this concept. Ground vibration tests of the wing were performed to generate estimates of modal properties. The optimal properties and their associated errors were formulated using 1-norm, 2-norm, and ∞-norm analyses. Robust flutter speeds were computed for models with each set of optimal properties with respect to their associated errors. The results are given in Table 1. These results indicate that the highest, or least-conservative, flutter speed is computed for the model that uses modal properties and uncertainty from ∞-norm analysis.

This work was done by Starr Potter and Rick Lind of **Dryden Flight Research Center**. *For more information, contact the Dryden Commercial Technology Office at (661) 276-3689.*
DRC-01-54

Compressed Symbology — Making Its Mark at NASA

The bar-code concept has been generalized into a powerful method of tracking manufactured parts.

Marshall Space Flight Center, Alabama

Compressed symbology is a product-identification method that was pioneered by NASA for tracking space-shuttle parts and is now being used to mark everything from groceries to automobile parts. Based on a system of two-dimensional marks applied to parts, compressed symbology was developed at NASA's Marshall Space Flight Center in response to the inherent need in the aerospace industry to track parts for configuration management.

The focus at Marshall is on ensuring the quality and safety of products. To be certain of the integrity of a product, each part must be tracked every step of the way — where it was made, who touched it along the way, and when and where it is installed. For NASA, that means tracking millions of parts — even tiny electrical parts no larger than a dime. Since bar codes were implemented in the mid-1980s, they have been used extensively and have saved NASA millions of dollars annually through automatic entry of data from manufacturing work orders and other paper media. However, bar-code labels have not worked well on some parts, especially small ones. Even in cases in which adhesive bar-code labels have been small enough, labels have come off, contaminating processes with glue and paper, and thereby giving rise to additional cleaning processes specifically designed to remove contaminants like glue from space-shuttle parts. In addition, spaceflight is also hostile to bar-code labels.

Another problem that has been encountered is that of compiling information about parts. At the beginning of the space-shuttle program, parts were tracked manually. As the flight rate increased, the amount of data collected was roughly equivalent to the amount of data collected in several large grocery stores each day. This situation created a backlog of paperwork that took as long as three months to catch up with the finished product.

Around this time, a Department of Defense study found that people made errors on one out of every 200 characters entered. For NASA, that meant, theoretically, that one out of every 10 part numbers entered into a data base was affected by a data-entry error. The direction was clear: To ensure the timely flight-worthiness of the space shuttle, it was becoming necessary to develop new techniques for marking parts without damaging them, and to develop an identification system, based on marks, as efficient as that of bar codes.

Because of the inherent limitations of bar codes for direct marking of parts in the aerospace industry, NASA sought a more suitable method of automated identification tracking. In September 1991, Marshall Space Flight Center established the Compressed Symbology Laboratory to investigate marks, roughly equivalent to bar codes, that could be applied directly to parts by use of permanent marking methods. The chosen general form for such marks was that of a two-dimensional matrix symbol that stores up to 100 times as much information as does a one-dimensional, linear bar code in the same area. The matrix symbol is a small square that resembles a checkerboard. The symbol is read by use of a charge-coupled-device (CCD) video camera.

Thirty marking methods were evaluated on more than 60 materials. Included were methods of computer-controlled direct marking by laser irradiation, dot peening, micro-sand-blasting, and machine engraving; these methods worked well on metals. For marking such other materials as ceramics, mica, and graphite it was found necessary to apply permanent inks, precious metals, and ceramic-based coatings, sometimes in conjunction with engraving to penetrate coated surfaces.

Marking of textile products (including clothing, parachutes, tent materials, and other items) was upgraded by use of an automated-embroidery marking method. Gold was marked by depositing a thin liquid film of platinum. To facilitate the non-automated marking, new techniques of stenciling were tried. Some of these techniques were derived from a photographic transfer process, and others from computer-driven cutter/plotters. Finally, a process that closely resembles today's direct hot ink transfer was used in some applications to transfer patterns from film sheets to surfaces of parts.

By 1996, Marshall Space Flight Center researchers felt that many aspects of compressed symbology were ready for introduction into the commercial sector, even though the marking techniques developed to that point had not proven suitable for highly stressed NASA parts or could not provide the resolution needed for small parts. In August 1997, Marshall Technology Transfer formed an alliance with CiMatrix and its parent company, Robotic Vision Systems, Inc., (RVSI) to develop commercial applications for NASA's marking processes for the Data Matrix™, which is the CiMatrix patented version of the matrix symbol. The alliance also enabled development of new marking methods that would satisfy NASA's requirements on stress-critical hardware.

The applications for the Data Matrix™ seem unlimited. Readable symbols have been applied on more than 80 different materials, including metals, plastics, glass, paper, fabric, ceramics, and others. Application processes have been tailored to materials, and some materials can be marked by use of multiple techniques.

Matrix symbols can be applied to aluminum by dot-peening, electrochemical etching, laser marking, or laser bonding; or by ink-jet, silk-screen, stencil, or film deposition. The symbols can be embroidered on cloth or stenciled onto rubber. There is a technique for marking almost any substance or item. Regardless of the technique used, the mark is permanent, is smaller than a bar code, and can be easily read by use of a CCD video camera.

Before compressed symbology was available, manufacturers of computer chips had no way of marking their products, and counterfeit chips flooded the market. The same is true of other small electronic parts. Automobile manufacturers can use compressed symbology to track each piece of an automobile, thereby narrowing the scope of, and simplifying, the recall process. The symbols have already begun appearing on items used every day. Because of their versatility, data-matrix symbols are being used to mark a wide variety of products, including such household items as jars of mustard, deodorant sticks, vitamin jars, and packages of photographic film. Data Matrix™ has now become the symbol of choice for direct marking of parts in the automotive, electronics, and aircraft industries.

But it does not stop there because NASA has part-identification needs that go beyond visible marks. Identification marks might be covered by paint, cork, foam, or a number of other coatings designed to protect parts. Six techniques for reading identification symbols under coatings, through containers, and within an assembly are in the patent process. NASA has engaged partners to develop portable devices to implement these techniques.

Compressed symbology will have untold implications for industry as well as for NASA. New marking techniques within the ambit of compressed symbology, possibly ready this year, should open the door to marking stress-critical hardware.

The 15-year effort to develop these identification technologies has resulted in a NASA preferred standard and handbook. NASA Technical Standard 6002, "Applying Data Matrix Identification Symbols to Aerospace Parts" and NASA Technical Handbook, "Application of Data Matrix Identification Symbols to Aerospace Parts using Direct Part Marking Methods/Technologies" can be found at website http://standards.nasa.gov.

This work was performed by Fred Schramm of **Marshall Space Flight Center;** *Donald L. Roxby of the CiMatrix Symbology Research Center (formerly of Rockwell); Willis L. Pavolini, Terry L. Higdon, and James D. Teed of Rockwell/Boeing; and Ward F. Davis and Robert Sant'anselmo of Veritec.*

Refer to MFS-28960/61/28776/867/974/959/31015 volume and number of this NASA Tech Briefs *issue; and the page number.*

Additionally, Marshall is currently seeking partners for the commercialization of six techniques of reading identification symbols under coatings (patents pending). See Technology Opportunity Announcements at http://www.nasasolutions.com/tech_ops/tec hops.html. For further information, contact Amy Witsil at Research Triangle Institute, (919) 541-6923 or awitsil@rti.org.

Books & Reports

Large-Aperture Telescope Synthesized From Small Mirrors

A report proposes a design concept for synthesizing a reflecting telescope with a large-aperture (diameter ≈100 m) primary mirror from a sparse arrangement of four smaller (diameter ≈10 m) primary mirrors. The telescope would be placed in orbit for viewing Earth with high resolution. The primary and secondary mirrors would be mounted on a lightweight structure that would be deployed in orbit.

This work was done by Philip Moynihan of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Ultra-Sparse Aperture Concentrator with Full-Area Coverage," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

NPO-21103

Spacecraft Nuclear Reactor Would Be Fueled in Orbit

Two reports summarize progress thus far in the continuing development of a spacecraft nuclear reactor, some or all of the fuel rods of which would not be loaded until the spacecraft was in orbit. (Keeping the fuel rods out of the reactor core before and during launch is intended to minimize the risk of release of radioactive material in the event of a launch accident.) The report describes the design and operation of the fueling mechanism, and problems in the design and fabrication of the core. The fuel rods include uranium oxide in rhenium sleeves. The core includes niobium star-cross-section inserts and molybdenum tubes, into which the fuel rods are to be inserted.

This work was done by Peter Ring of Advanced Methods & Materials for **Marshall Space Flight Center**. *For more information, contact the Marshall Technology Commercialization Office at (256) 544-2615.*

MFS-31612

Designs for Safer Launching of Spacecraft Fission System

A report proposes the development of two different mechanisms that would prevent inadvertent startup of reactors in nuclear-fission-based propulsion and power systems in future spacecraft. The purpose of this development is to contribute to safety by ensuring that radioactivity is kept to normal negligible levels before and during launch and in the event of a launch accident. Once the spacecraft was safely in outer space, a motor would actuate a linear screw that would move the fuel section of the rods into the core, enabling the reactor.

This work was done by Thomas Godfroy of **Marshall Space Flight Center.** *For more information, contact the Marshall Technology Commercialization Office at (256) 544-2615.*

MFS-31533

Automated Planning and Scheduling for a Large Interferometer

A report discusses the potential application of artificial intelligence (AI) to planning, scheduling, and control of the optical configuration and other aspects of the operations of a large astronomical interferometer. Scientific demand and technical requirements necessitate streamlining and optimization of the operation of such an interferometer, but it is difficult and often impossible to achieve the streamlining and optimization manually.

This work was done by Andrew Booth, Gregg Rabideau, Leonard Reder, and Steve Chien of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Automated Planning for Interferometer Configuration and Control," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Information Sciences category.*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-21179.

Cooperative Communication by Low-Power Radio Transmitters

A report proposes a method of cooperative modulation between (1) low-power radio transceivers associated with sensors geographically dispersed on a remote planet for relaying information between the sensors and an Earth station. The method, denoted node selection on orthogonal channels (NSOC), would make it unnecessary to include an additional, intermediate-power base station on the planet to effect long-distance communication with the orbiting transceiver.

This work was done by Kevin Quirk, Meera Srinivasan, and Jonathan Agre of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Cooperative Communication Using Node Selection, Orthogonal Channels," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*
NPO-30177

Uplink/Downlink Spacecraft Radio Occultation Measurements

A report proposes a method to increase the accuracy of Doppler measurements made at the beginnings and endings of Earth/spacecraft radio occultations. Such measurements can reveal structural details of occulting objects in outer space. Heretofore, one-way measurements have been used, and have been subject to degradation of accuracy by frequency fluctuations of an onboard oscillator.

This work was done by Massimo Tinto of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Spacecraft radio occultations using multiple Doppler readouts," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*
NPO-30216

Development of Alternatives to Hydrazines as Propellants

A brief report summarizes an investigation of less-toxic alternatives to toxic monopropellant fluids used in launch vehicles, upper stages, and spacecraft propulsion. The toxic fluids in question are (1) hydrazine and its derivatives, used, variously, as fuels or by themselves as catalytically decomposable monopropellants; and (2) nitrogen dioxide, used as an oxidizer for such fuels.

This work was done by Paul E. Penwell, Jeff C. Bottaro, and Mark A. Petrie of SRI International for **Glenn Research Center**. *To obtain a copy of the report, "Development of new High-Performance Ammonium Dinitramide based and Hydrazinium Salt based Monopropellants," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17143.

ASIC for Controlling a Power-Switching MOSFET

A report describes an application-specific integrated circuit (ASIC) for controlling a power-switching metal oxide semiconductor field-effect transistor (MOSFET) in a spacecraft power-supply system. Denoted an SCA (for switch-control ASIC), this ASIC is designed to be radiation-hard and to function over a wide temperature range during a long operational lifetime.

This work was done by Barbara Lam, Clint Kwa, David Zhu, Gene Wester, Gregory Carr, John Bennett, Lauro Franco, David Hogue, Pete Skelly, and Russ Haskell of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Switch Control ASIC," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*
NPO-30280

Controlling the Rubber Production Line

Noncontact laser sensors help the rubber and tire industry guard quality.

More than three decades ago, the company now called LMI Selcom developed the first in a line of noncontact laser sensors to control processes on the rubber tire production line. The company's sensors were among the first to measure fresh uncured rubber from an extruder or calender, among the harshest of environments. As the tire industry grows more competitive, the company strives to enhance automation, lower material cost, and continue to reduce waste on the production line.

Trends in sensor measurement in a variety of rubber and tire applications have grown as the technology to support such products has evolved. The overall reliability and accuracy of sensors in process control can yield millions of dollars in savings over a long-term quality control program.

For all on-line and off-line applications, the basic benefits of using laser sensors for quality control are the same: to increase yield and productivity, to increase quality control by providing one-hundred percent product inspection, to reduce scrap production and rejects, and to improve the work environment. A facility cannot afford high rejection rates in tire uniformity.

Sensors for the rubber and tire industry use the principle of optical laser triangulation to accurately measure objects or systems. A beam of light is projected onto the item to be measured. At some angle to the laser beam, a lens forms an image of this spot in the plane of the detector. By determining the position of the imaged spot and calculating the angles involved, the distance from the sensor to the surface can be determined.

A general rule for best sensor performance is that the spot size on the surface must be small. For large, flat uniform surfaces, this is not a major issue, but for small objects or surfaces of large curvature, spot size becomes very important. The spot size can be no larger than the feature to be measured. If a small feature is precisely positioned beneath the laser beam, the beam must be smaller than the feature. If, however, the sensor is to be scanned over a surface to find a small feature, a good rule of thumb is that the spot size must be less than one tenth the size of the feature.

The challenge for laser sensor manufacturers is to meet the demands of the rubber and tire industry for longer standoff distances without sacrificing accuracy. Standoff distances of up to 400 millimeters are now available for such applications.

The SLS 6000 from LMI Selcom is currently being used in a major southeastern United States tire plant to measure melted green rubber as it comes out of the extruder.

In rubber and tire applications where spot size is important, the sensor should be mounted as close to perpendicular to the surface as possible. If the laser is at an angle to the surface, the spot size on the surface will be elongated, proportional to the angle away from normal.

Rubber measurement has often been a problem for laser sensors because of its inevitable characteristics: hot, sticky, and smoking targets wreak havoc on accuracy. Recent technologies have evolved to handle the situation, with greater accuracy and reliability than in the past.

A number of types of detectors are available; two main types are used in triangulation sensors. Both are fully solid-state integrated circuit chips with rugged construction and reliable performance — even in hostile environments — when properly packaged in a sensor housing.

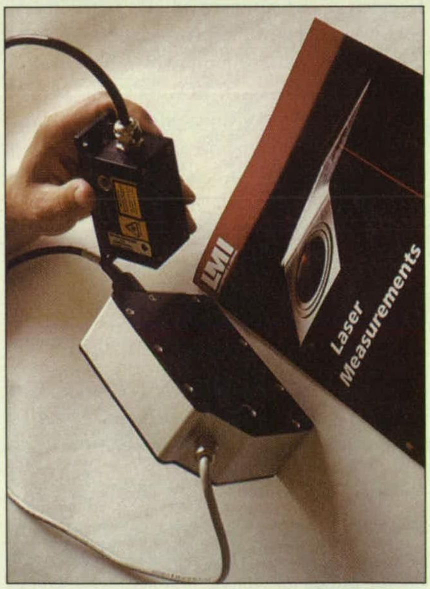
The first type is a position-sensing detector (PSD), also known as a lateral effect photodiode. The second is the charge-coupled device (CCD). The PSD is a single-element detector that converts incident light into continuous position data. Essentially an analog device, it offers advantages in several areas, particularly in speed of reading. Disadvantages include lack of ability to display an image of the detector pattern.

CCD detectors are essentially a form of television camera, and come in both one-dimensional and two-dimensional form. The CCD detector has several advantages. First, the "video" part of the output can be viewed to display light levels and cleanliness of the image, and to show any stray-light effects. Filtering can be applied to the sensor's output to remove noise from the optical image. Disadvantages of the CCD detector are related to speed of operation, which typically is less than can be achieved with a PSD.

In general, laser sensors, as compared to contact devices, are free of probe wear or bounce and collect data at much higher rates. Laser sensors, versus capacitive or inductive devices, have a much greater standoff, or distance to the material being measured. Thus, the former is more likely to receive less physical wear. Unlike most ultrasonic sensors, laser triangulation sensors are available with much higher resolution and accuracy, even with their longer standoff distance.

Specific applications include measurement on- and off-line of product thickness, dimensional and cross-sectional profiles of extruded products, on-line thickness profiling or rubber and calendered rubber sheets, splice detection for rubber sheets, sidewall inspection, and radial runout measurement.

In measuring extruded rubber, the key variables measured and controlled include the weight per unit and the thickness of the sheet. Thickness measurement using laser sensors can be performed either in fixed tracks along the line or in a scanning system that can provide complete profile information. A scanning system using two opposing sensors, one above and one below the material, is eminently suited for obtaining true thickness.



Shown above is the Class II (optional Class IIIb) laser sensor head LSH 2401, a new high-speed machine-rugged laser-based noncontact industrial gauging sensor from LMI Selcom for rubber and tire industry applications.

Unlike ultrasonic sensors, lasers are available with much higher resolution and accuracy.

Laser sensors are increasingly finding themselves as part of the production-line process control. On-line continuous tread profile measurement systems constantly monitor physical dimensions. This application ensures early detection of faults, reduced rework, and fewer downgraded tires. Three techniques are often used. With adjustable measuring points, the thickness error at specific geometric points, such as the outside or inside shoulder, can be identified, and width errors can be detected. Statistical analysis is often used to select the appropriate set of profile measurements and to use software features to calculate and chart average or deviation. Variation due to changes in ambient environment, compound, processing equipment, line settings, and operators will likely be found. Finally, tires with compounded rubber, where one compound contains a certain amount of trapped air bubbles, are measured for porosity variations.

Laser sensors, with their speed, accuracy, and reliability, are playing an increasingly important role in quality control. Laser sensor manufacturers are responding to the demand for more stringent measurement criteria by developing sensors that can meet or exceed expectations.

For more information, contact the author of this article, Mike Snow, at LMI Selcom, 21666 Melrose Ave., Southfield, MI 48075; (770) 888-6586; fax: (770) 888-0734; www.lmint.com; e-mail: mike.snow@lmint.com.

Motorized Rotator for an Ultrasonic Probe

The probe can be positioned more precisely than before.

NASA's Jet Propulsion Laboratory, Pasadena, California

An apparatus has been devised to enable accurate, reproducible angular positioning of an ultrasonic probe used to diagnose the carotid artery. More specifically, the apparatus is intended for use in a clinical setting in which the intima-media thickness (IMT) of the carotid artery is measured by use of information in ultrasound images. The IMT is useful as an indication of the health status of the carotid artery.

Ultrasonic probes are used to obtain longitudinal-view images of the carotid artery. The IMT can then be measured from these images. However, in order to obtain these images, it is necessary first to find the appropriate site with a transverse view and then to rotate each ultrasonic probe 90°. Heretofore, the probe has been rotated manually and without the benefit of a fixed reference.

The present apparatus includes a holder that accommodates various ultrasonic probes, and a cylindrical housing that rests on the patient's neck, acts as an anchor, and provides a fixed reference. A small stepping motor in the housing is coupled to the holder through gears. An electronic control unit sends control pulses to the motor when either a panel switch or a foot switch is pressed. The control pulses cause the motor to turn the holder, and thus the probe, by 90°. A second actuation of the switch causes the motor to rotate the probe back to the original angle.

The advantage afforded by this apparatus is greater (compared to manual rotation) accuracy in returning to a specific site in the carotid artery. The disadvantage is that the apparatus adds weight and bulk to the probe.

This work was done by Helenann Kwong-Fu, Paul L. Lee, and Robert Selzer of Caltech and Howard Hodis of USC for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery/Automation category.*

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

Intellectual Property group
JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-2240

Refer to NPO-21244, volume and number of this NASA Tech Briefs *issue, and the page number.*

Measuring Turbomachine-Blade Deflections in Two Dimensions

John H. Glenn Research Center, Cleveland, Ohio

A report describes a method of simultaneously measuring steady-state axial and tangential turbomachine-blade deflections by use of fiber-optic probes and probe actuators designed specifically for this purpose. Each fiber-optic probe illuminates a small spot and, by measuring a change in the amount of reflected light, detects the passage of a leading or trailing edge of a blade through the spot. Each probe actuator contains a servomotor that produces controlled, small increments of rotation of an eccentric probe mount to adjust the axial and tangential position of a probe. At each rotational speed, the passage of a leading or trailing edge of interest is found by adjusting the position of a probe until the blade-passage output pulse of the probe is just discernible above noise. When this has been done for all probes and/or edges of interest, the edge-passage times are determined in relation to the time of a once-per-revolution master pulse generated by an independent optical sensor. Then the blade deflections at a given speed, relative to those at a reference speed, are determined from the known probe positions and the measured blade-passage pulse times at both speeds.

This work was done by Anatole P. Kurkov of **Glenn Research Center** *and Harbans S. Dhadwal of Integrated Fiber Optic Systems, Inc. To obtain a copy of the report, "Simultaneous Optical Measurements of Axial and Tangential Steady-State Blade Deflections," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery/Automation category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17200.

Magnetoelastic Vibration Dampers

Unlike viscoelastic dampers, these would be highly effective at low temperatures.

NASA's Jet Propulsion Laboratory, Pasadena, California

Magnetoelastic dampers have been proposed for use in suppressing vibrations of large motors and transformers that operate at temperatures below 100 K. [Also see "Progress in Magnetoelastic Vibration Dampers," (NPO-20887) on page 57 of this issue.] These dampers would be made of magnetostrictive materials — specifically, Tb/Dy alloys. It would not be necessary to use the rare and expensive high-purity grades of Tb/Dy; the commercial grade would suffice and may in fact be preferable.

Conventional dampers for such applications are based on viscoelasticity. Because viscoelastic damping involves movements of atoms and these movements become very small at low temperatures, viscoelastic dampers become ineffective at low temperatures.

In magnetostrictive materials, vibrational energy becomes damped through the movement of magnetic domains and the consequent dissipation of vibrational energy as heat. Because this effect is not diminished at low temperatures, magnetostrictive materials can be expected to be effective in damping vibrations at low temperatures. In a recent quasi-static experiment, a Tb/Dy alloy specimen was found to dissipate 30 percent of vibrational energy per stress-and-strain cycle at a temperature of 77 K. Moreover, it may be possible to increase the dissipation factor through the addition of small amounts of N, Ta, and/or other elements to Tb/Dy alloys and through changes in the processing conditions.

This work was done by Jennifer Dooley, Brent Fultz, John Voccio, and Robert Chave of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

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

Intellectual Property group
JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-2240

Refer to NPO-20988, volume and number of this NASA Tech Briefs *issue, and the page number.*

Progress in Magnetoelastic Vibration Dampers

NASA's Jet Propulsion Laboratory, Pasadena, California

A report describes uniaxial-stress-versus-strain experiments that were performed on polycrystalline $Tb_{76}Dy_{24}$ alloy specimens. [Also see "Magnetoelastic Vibration Dampers" (NPO-20988) on page 56 of this issue.] The proposal is to use Tb-Dy alloys as vibration-damping materials at temperatures ≤100 K, exploiting the fact that in Tb-Dy alloys and other magnetostrictive materials, vibrations cause the movement of magnetic domains and the consequent dissipation of vibrational energy as heat.

This work was done by Jennifer Dooley, Robert Chave, Brent Fultz, Art Clark, Nathan Good, and Jason Graetz of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Magnetoelastic damping applications of magnetostrictive TbDy alloys" access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*

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

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Refer to NPO-20887, volume and number of this NASA Tech Briefs *issue, and the page number.*

Equipment for Removal of EDM Water Filters

The risk of back injuries is reduced.

John H. Glenn Research Center, Cleveland, Ohio

An assembly of lifting equipment has been devised to enable the safe removal of water filters used in electrical-discharge machining (EDM). As explained below, this equipment prevents injuries of a type formerly associated with changing the filters.

In the particular machine shop in which the equipment is used, there are seven EDM machines, each equipped with filters located in a water tank at about knee level. The filters must be changed at intervals of operating time that range from 10 to 200 hours, depending on the material being cut. A filter to be removed is full of water and weighs about 50 lb (≈23 kg). The filter must be held in place while the water drains out before completing its removal. Previously, the filters were changed by hand, without the help of any equipment. Some workers suffered back injuries from bending over, lifting the water-laden filter elements, and holding them while the water drained out.

The present lifting equipment prevents these injuries by changing the nature of the lifting operation. The equipment includes a special-purpose tool on one end of a cable, the other end of which is wound on a ratcheting hand crank. The tool includes a part that is mounted on the inner diameter of a filter element on an outlet shaft. The tool also includes lifting arms that are lowered and attached to the outside diameter of the filter. Once the tool has been attached to the filter, the hand crank is actuated to raise the filter partly out of the tank. Once the water has drained out of the filter element, a worker can safely lift the filter element and the tool out of the tank. The filter is then disconnected from the tool and discarded.

This work was done by Timothy G. Schilens of Microcraft Inc. for **Glenn Research Center**.

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16795.

Software for Analyzing Traversability of Terrain

NASA's Jet Propulsion Laboratory, Pasadena, California

Grid-Based Estimation of Surface Traversability Applied to Local Terrain (GESTALT) is a software library that helps a robotic wheeled vehicle choose a safe path across nearby terrain. The input to GESTALT consists mainly of three-dimensional range measurements of the nearby terrain taken by sensors (e.g., stereoscopic cameras or a laser scanner) aboard the robot as it moves along. GESTALT groups the data into grid cells, then geometrically evaluates the cells as separate planar patches, identifying such impediments to traversability as steps, steep slopes, and excessive roughness. Both straight and curved paths from present position of the robot can be evaluated. The safest path that helps the rover move toward its goal is selected. The resulting path evaluations can be used to steer the robot.

GESTALT is an extension of a previously developed algorithm known as Morphin, incorporating additional capabilities: Diagnostic outputs in greater detail are available. Traversability can be evaluated in a direction-specific manner; for example, a hill found to be unclimbable if approached head-on might be found climbable on a sideways approach. Navigation parameters can be reset at any time. Multiple rover configurations can be evaluated in a single map.

This program was written by Mark Maimone of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Software category.*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-21233.

Six-Legged Experimental Robot

This robot would walk to a designated location and perform mechanical operations there.

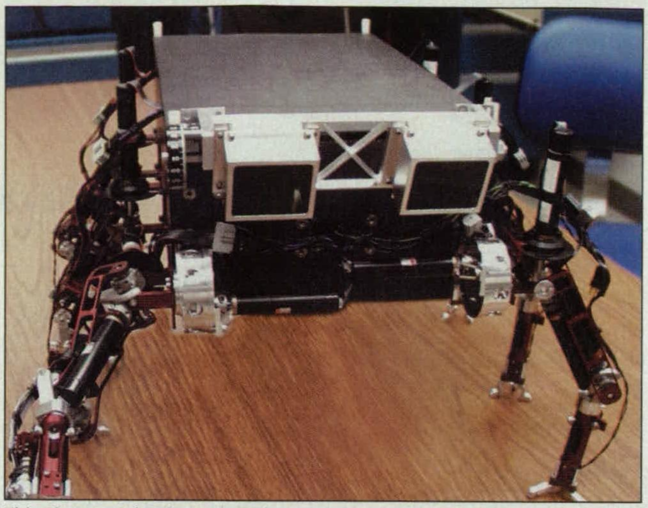
NASA's Jet Propulsion Laboratory, Pasadena, California

The figure depicts the Legged Excursion Mechanical Utility Robot (LEMUR) — a six-legged robot for demonstrating robotic capabilities for assembly, maintenance, and inspection. LEMUR is designed to be capable of walking autonomously along a truss structure and to perform other operations.

LEMUR is equipped with stereoscopic video cameras and image-data-processing circuitry for navigation and mechanical operations. It is also equipped with a wireless modem for remote operations. Upon receipt of a command via the modem, LEMUR would walk along the truss structure toward a mechanical assembly at a prescribed location. Once LEMUR was within a distance of 1 m from the assembly, its artificial-vision system should be able to recognize the image of the assembly and enable the LEMUR to move autonomously toward the assembly. Upon arrival at the assembly, LEMUR would perform simple mechanical operations with one or both of its front legs. It could also transmit images to a host computer.

Each of the six legs of the LEMUR is operated independently. Each of the four rear legs has three degrees of freedom (DOFs), while each of the front two legs has four DOFs. The front two legs are designed to hold, operate, and/or be integrated with tools. For example, the right front leg could be made capable of holding and turning a wrench socket, while the left front leg could be equipped with a hand, which could include an in-line macroscopic camera. The kinematic design of the LEMUR is such that it could support itself on the four rear legs, or, preferably, on three of them. The feet on the rear legs are capable of grappling.

LEMUR includes an on-board computer containing a Pentium (or equivalent or better) processor with a minimum speed of 200 MHz, a dynamic random-access memory of at least 32MB, and an assortment of digital control circuits, digital input/output circuits, analog-to-digital converters for input, and digital-to-analog (D/A) converters for output. Feedbacks from optical encoders in the leg actuators are utilized for closed-loop microcomputer control of the positions and velocities of the actuators. Signals for controlling motors in the actuators are generated by D/A converters and multiplexed through a sample-and-hold circuit. The multiplexed outputs are sent to pulse-width-modulator circuits, the outputs of which would constitute the control voltages applied to the motors.



This **Six-Legged Robot** would be used to demonstrate robotic capabilities for assembly, maintenance, and inspection.

LEMUR contains a rechargeable-battery power supply that could sustain operation for 1 hour. It would also be capable of operation through an electrical umbilical cord. Optionally, the umbilical cord could serve as a bypass for the wireless modem.

This work was done by Gregory Hickey and Brett Kennedy of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery/Automation category.*

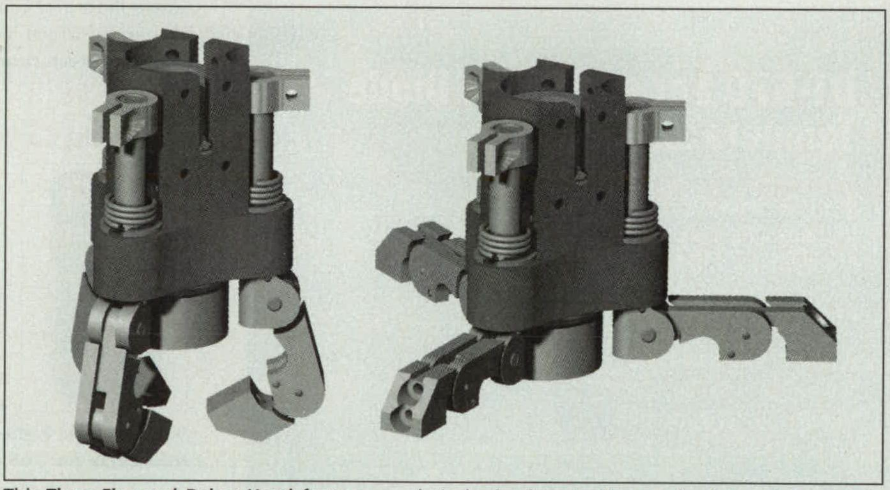
NPO-20897

Three-Fingered Robot Hand With Self-Adjusting Grip

Three fingers are actuated by one motor, tendons, and springs.

NASA's Jet Propulsion Laboratory, Pasadena, California

The figure depicts a tendon-driven, three-fingered robot hand (or foot, depending on one's perspective) designed to be installed on the end of the left front leg of the six-legged robot described in the preceding article. This hand, which was undergoing development at the time of reporting the information for this article, is intended to satisfy the need for a small, lightweight mechanism that can grasp objects of various shapes (e.g., balls or cylinders of differing diameters), without need for an elaborate electronic control system or for multiple actuators. The hand also houses rudimentary sensors: the terminal optics of a fiber-optic camera are incorporated into the palm of the hand, and the housing for the optics doubles as a contact-sensor switch.



This **Three-Fingered Robot Hand** features a relatively simple actuation mechanism, yet it can grip irregularly shaped objects. When fully open, it spans a diameter of about 2 in. (≈5 cm).

Each finger includes two links, with knucklelike joints. The knucklelike joint at the inner end of the innermost link is mounted on a base that pivots around an axis perpendicular to the joint axis, thereby allowing the finger to rotate into conformation with the object to be gripped. The three fingers are spring-biased into planes of action 120° apart, but forces and torques of contact with a gripped object overcome the spring biases, causing the finger to pivot into the aforementioned conformation.

For the sake of simplicity, the tendons that drive all three fingers are, in turn, driven by only one motor. More specifically, the motor drives a winch to which is coupled a set of tendons arranged as finger flexors. When these tendons are drawn in, the fingers close around the gripped object. For opening the fingers to release the gripped object, the fingers are equipped with a second set of spring-loaded tendons arranged as finger extensors. Each flexor tendon is connected to a spring stiffer than that of the corresponding extensor tendon; this provision prevents the full contact of one finger with the object from acting as a hard stop against the further closure of the other fingers, thereby enabling the fingers to conform to an irregularly shaped object.

This work was done by Brett Kennedy of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery/Automation category.*

NPO-20907

New on the MARKET

PRODUCT OF THE MONTH

Mountz, San Jose, CA, offers the Wizard module, which transforms any Handspring™ Visor™ handheld computer into a personal digital assistant (PDA) torque and force analyzer. The module snaps into the Visor and uses 16-bit technology to support all standard Visor functions. Entering force and torque parameters is accomplished by maneuvering through the Visor screens with the touch stylus. Its memory supports up to 25 project folders of 250 readings each. HotSync® Conduit software allows data transfer from the Visor to a PC, automatically synchronizing and restoring data. The Wizard can graph torque and force over time, with adjustable parameters for horizontal and vertical plotting scales, and a torque or force trigger threshold. The module is available alone, or packaged with the Visor.
For Free Info Circle No. 700 or Enter No. 700 at www.nasatech.com/rs

Digital Oscilloscope

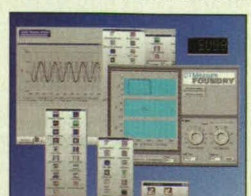
The CSA7404 communications signal analyzer (CSA) is a real-time digital oscilloscope that features data rates of up to 2.5 Gb/s. New capabilities include an optical reference receiver, clock recovery, and serial triggering. The unit is suited for the design of high-speed electrical and optical systems and features 4-GHz bandwidth and a 20 Gs/s sample rate. An integrated optical/electrical converter and a library of optical reference receiver filters also are provided. **For Free Info Circle No. 701 or Enter No. 701 at www.nasatech.com/rs**

Handheld Calibrator

The CL123 handheld multifunction calibrator from OMEGA Engineering, Stamford, CT is a portable device for generating and measuring voltage, current, frequency, and temperature of thermocouples K, J, E, and T (°C and °F). Designed with a 4- and 5-digit display, the instrument has an operating temperature of 0 to 50°C and an operating and storage humidity of <85% relative. It is supplied with a carrying case, 9V battery, external battery pack that holds four AA batteries, type K thermocouple, test leads, and alligator clip. **For Free Info Circle No. 708 or Enter No. 708 at www.nasatech.com/rs**

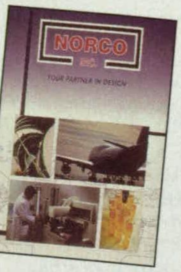
Test and Measurement Software

DT Measure Foundry™ 2.1 from Data Translation®, Marlboro, MA, lets users create automated test and measurement applications using a drag-and-drop approach. By arranging the instrument functions needed to test on a desktop, users can activate the functions by selecting the desired hardware source. The software includes a built-in post-processing package that lets users view, save, and export to an ASCII file for use with packages such as MATLAB®. **For Free Info Circle No. 706 or Enter No. 706 at www.nasatech.com/rs**



New LITERATURE

Power Transmission Products



Norco, Ridgefield, CT, has released a brochure featuring Flennor® power transmission products including reversing actuators, rollnut actuators, timing belt drives, and custom-designed assemblies. Also included are mechanical apparatus such as hold-open supports, locking and coupling devices, and mechanical actuators. **For Free Info Circle No. 722 or Enter No. 722 at www.nasatech.com/rs**

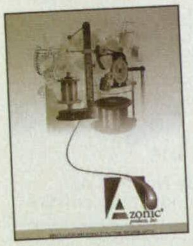
Self-Clinching Fasteners

A six-page product bulletin from PEM® Fastening Systems, Danboro, PA, covers specifications, installation procedures, and performance data for miniature self-clinching fasteners. These non-locking and self-locking fasteners feature a knurled collar that is embedded in the sheet to prevent rotation of the fastener upon installation. **For Free Info Circle No. 723 or Enter No. 723 at www.nasatech.com/rs**

Inductive Components

Prem Magnetics, McHenry, IL, offers a 30-page catalog detailing power and telephony transformers, inductors, and CRT display magnetics. Drum core type ferrite power inductors, slug core PC mounting and bobbin core, wide band shield bead ferrite chokes, and surface mount inductors also are available. **For Free Info Circle No. 724 or Enter No. 724 at www.nasatech.com/rs**

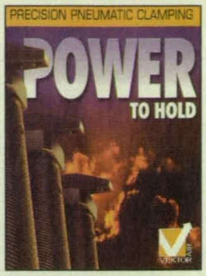
Tensioning Devices and Monitors



Azonic Products, Albion, NE, offers a six-page catalog highlighting its tension controllers and monitors that show actual tension in grams, continuously displayed throughout the winding cycle. Accessories include tension meters and customized multiple tensioning setups using rack mounted Azonic tensioners. **For Free Info Circle No. 725 or Enter No. 725 at www.nasatech.com/rs**

Fiber Optic Bonding Adhesives

A brochure from Loctite Corp., Rocky Hill, CT, describes Loctite® OptiLOC™ adhesives for bonding optical connectors, fibers, lenses, and prisms. The products also can be used in optical alignment applications, and provide chemical and solvent resistance while acting as an electrical insulator. **For Free Info Circle No. 726 or Enter No. 726 at www.nasatech.com/rs**



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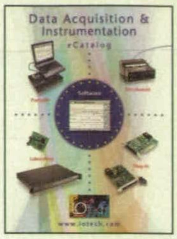

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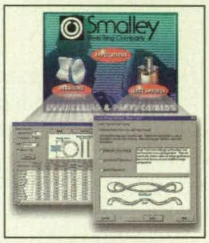

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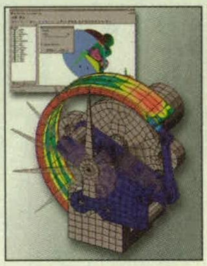

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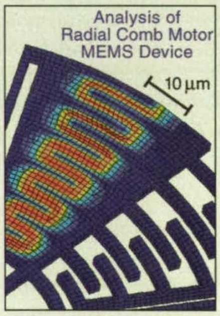

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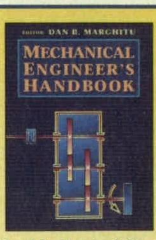

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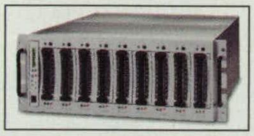

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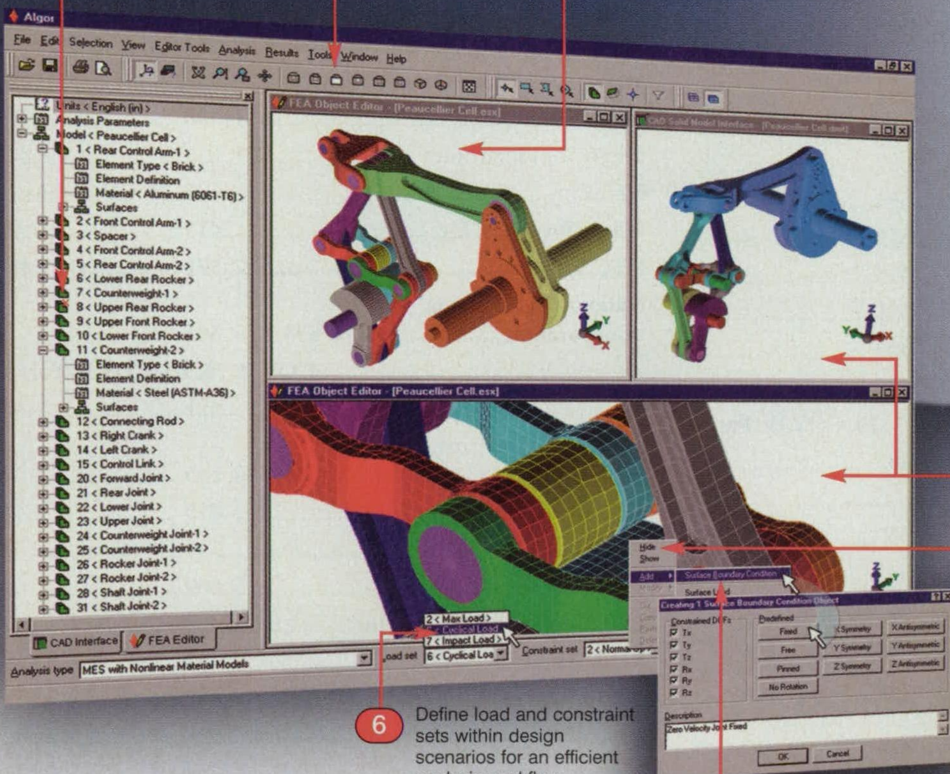

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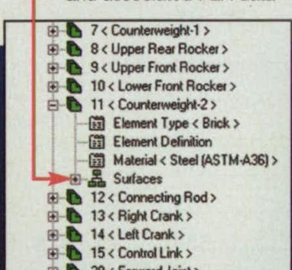
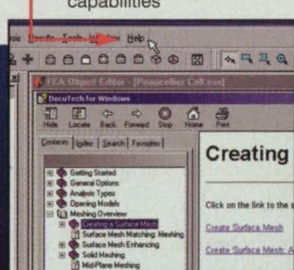
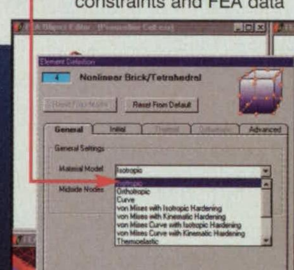


9 HTML compiled help with robust indexing and search capabilities



10 Windows-native input screens for all loads, constraints and FEA data



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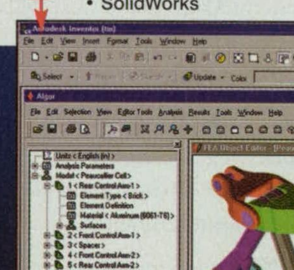

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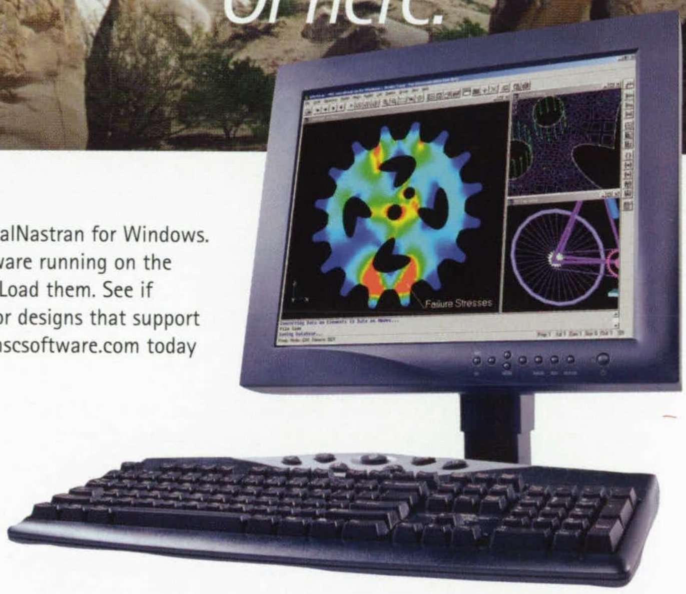

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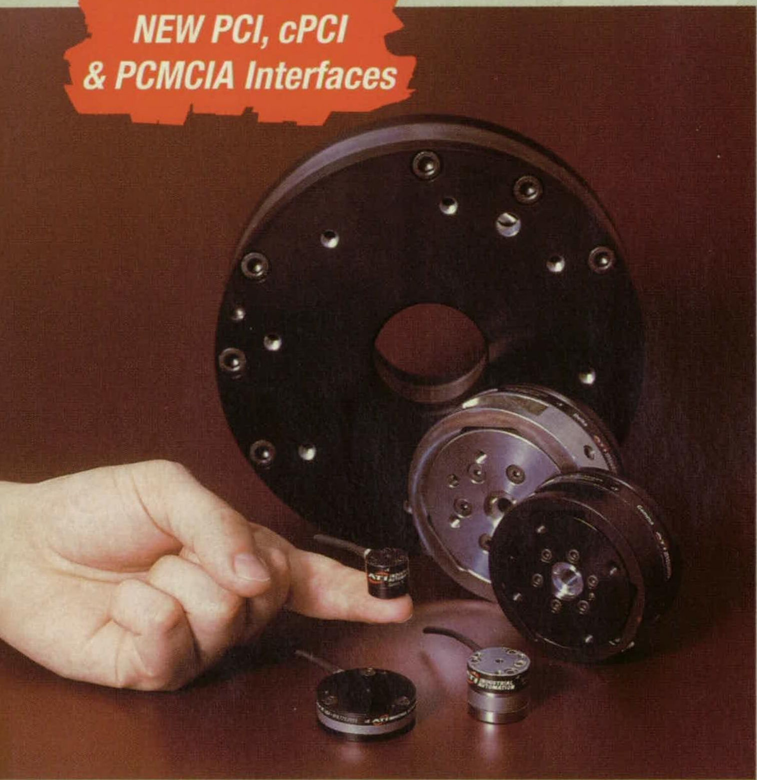

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Technology Years

We put together this 25th anniversary portion of *NASA Tech Briefs* as both a look back and a future view of what the magazine has been about for the past quarter-century — technology. From the first issue in 1976 to this issue, *NASA Tech Briefs* has covered everything from the basic, to the important, to the earth-shattering in technology developments.

Our look back begins on page 72 with "Covering the Cutting Edge: 25 Years of *NASA Tech Briefs*" — a timeline that describes the technology innovations of the past 25 years as they were covered in the pages of *NASA Tech Briefs*. From ferrofluids in the 1970s, to the laptop computer in the 1980s, and an advanced heart pump in the 1990s, you'll read about the products and technologies from NASA and commercial industry that continue to affect our work and our daily lives.

We jump forward into the future with the "Visions of Tomorrow," beginning on page 78. We talked with leaders in ten different industries about, of course, technology — how it has helped to advance engineering industries, and where it will take us in the next 25 years.

In our conversation for this issue, SolidWorks CEO John McEleney said, "Technology years are like dog years." While that at first seemed like a strange comment, it perfectly illustrates how the pace of technology is increasing. Look at the progress of technology developments in the past, John explained, compared to the speed of innovation expected in the future. The equivalent amount of progress made in the past 25 years will take only five to ten years to achieve as we move forward.

We'd like to thank those industry leaders featured in the Visions of Tomorrow for providing their predictions and for helping us celebrate our first quarter-century. We hope John McEleney is right — that the pace of technology development continues to increase. *NASA Tech Briefs* will always be about technology, and we look forward to reporting on the cutting-edge of it for the next 25 years — which is really only five in technology years.

Linda L. Bell
Editor/Associate Publisher

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Covering the Cutting Edge: 25 Years of *NASA Tech Briefs*

Since 1976, *NASA Tech Briefs* has been bringing its growing readership of engineering professionals cutting-edge technologies developed by NASA and commercial industry. In those 25 years, the magazine has covered thousands of technologies and products that have become part of our daily lives. This timeline provides only a sample of the important innovations *NASA Tech Briefs* has covered during the past 25 years; visit **www.nasatech.com** to view an extended version of the timeline.

Fall 1978

The material was developed in the 1970s as a new fabric for astronauts' spacesuits. It's Fiberglas® fabric from Owens-Corning Fiberglas coated with Teflon® fluorocarbon resin from DuPont. Today, it's used to provide a roof for the Pontiac Silverdome sports stadium, and as a permanent roofing material for buildings and stadiums worldwide.

1982

Astronauts working on the surface of the Moon wore liquid-cooled garments under their space suits to protect them from lunar temperatures that often reached 250°F. Developed by NASA's Ames Research Center, the technology is one of the most widely used spin-offs in NASA history. The technology has been adapted to portable cooling systems for treatment of medical ailments such as burning limb syndrome, multiple sclerosis, and spinal injuries.

Fall 1985

Laser angioplasty has been used as an alternative in many cases to balloon angioplasty to deal with coronary artery blockage. Advanced Interventional Systems of Irvine, CA, developed a system called the Dymer 200+, a laser angioplasty system that uses a "cool" excimer laser that won't damage blood vessel walls. The system is based on technology developed by NASA's Jet Propulsion Lab (JPL) for measuring gases in the Earth's atmosphere.

1970s

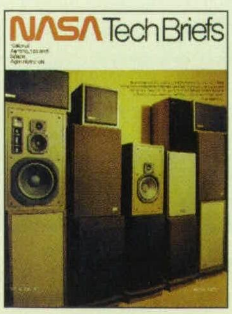
1978

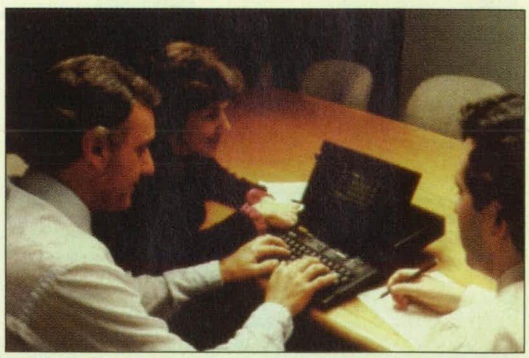
In the early 1970s, NASA's Ames Research Center tried to improve crash protection for airplane passengers. One of the resulting innovations was an open-cell polymeric "slow springback foam" that flowed to match the contour of the body pressing against it, and then returned to its original shape once the pressure was removed. Initially marketed as Temper Foam®, it has become one of the most widely used commercial spinoffs of NASA technology. Fagerdala World Foams of Sweden perfected the invention into Tempur® material, which was used to make a pressure-relieving foam mattress called the Tempur-Pedic Swedish Mattress, introduced in 1991, which has sold millions.

1980s

Winter 1979

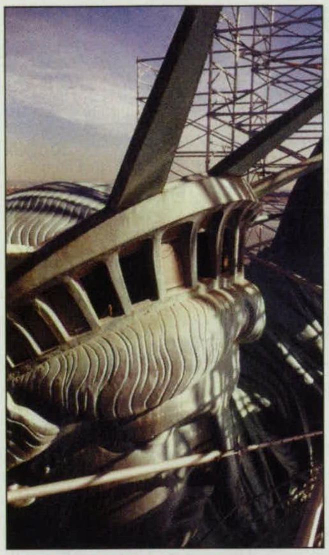
A Lewis Research Center development called ferrofluids is licensed to Ferrofluidics Corp., which grew to be a multimillion-dollar company in its first ten years, making it one of the most successful NASA spinoffs in history. Ferrofluids are magnetic fluids in which tiny particles of iron, nickel, cobalt, or their alloys are suspended. The material can be controlled by magnetic force, making them suitable for applications in semiconductor manufacturing, disk drive seals, coolant for loudspeakers, medical equipment, visual displays, automated machine tools, and as magnetic seals in motors and other machinery.





1983

The Shuttle Portable Onboard Computer (SPOC) made its debut on a nine-day Space Shuttle mission. In the early 1980s, space shuttle needs drove production of the first portable computer, which had the operating and control systems necessary for navigation functions. NASA engineers worked with GriD Systems, a California manufacturer, to develop new technologies and hardware.



Summer 1985

In 1986, the 100th birthday of the Statue of Liberty was marked with a complete refurbishment of the statue to repair a century's worth of wear and tear. A protective coating called IC 531 was used to proivde corrosion protection for the interior of the statue. The coating originated with research on corrosion resistant materials conducted by NASA's Goddard Space Flight Center.

March 1987

NASA's aeronautical research program has spun off many technologies, one of which is the winglet, an upturned wing tip that is seen on all types of commercial airliners today. Originally developed at NASA's Langley Research Center, it has been in service since the 1970s. A vertical extension of the wing, the winglet is a lifting surface that produces a degree of forward thrust, much like a boat sail. It also results in greater fuel efficiency.

May 1994

The first in a series of tech briefs from Marshall Space Flight Center describes an automatically locking/unlocking orthotic knee joint. The original device locked and unlocked automatically, at any position within a range of bend angles, without manual intervention by the wearer. Revised versions of the joint were featured in May 1995 and December 1995. The technology was licensed in 1998 to Horton's Orthotic Lab to manufacture the Selectively Lockable Knee Brace to provide freedom of movement to patients suffering from lower extremity weakness due to stroke or accident.

February 1987

In 1986, Tylenol capsules were removed from store shelves because of cyanide poisoning. The Food and Drug Administration (FDA) needed to find the cyanide-laced capsules quickly, without having to subject each capsule to chemical analysis. The screening device they used was the Lixiscope, developed at Goddard Space Flight Center. It showed the tampered capsules as black images against a green background. A license was granted in 1982 to Lixi, Inc. to manufacture the x-ray imaging device, which has been used to determine the condition of injured athletes on the field at the Olympics and the Super Bowl, check PC boards, and scan the contents of mailed packages.

1990s

October 1987

The C Language Integrated Production System (CLIPS) from Johnson Space Center enables research, development, and delivery of artificial intelligence on conventional computers. The rule-based language, developed a year earlier, is featured again in NTB in November 1987 as the basis for a new computer-based expert system called Airline Operations AI, which evaluates current and past weather, runway length, aircraft weight, and other conditions to provide "intelligent" recommendations for pilots.

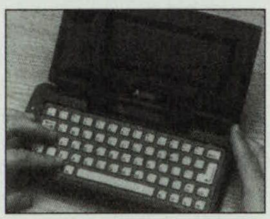
April 1994

The 1994 NASA Invention of the Year was awarded to the Regenerable Biocide Delivery Unit developed by three engineers at Johnson Space Center. The system passes water through an anion exchange bed that has been treated with iodine. The resin bed is regenerated *in situ* using small amounts of elemental iodine, significantly extending its life. The system was designed to serve as an emergency backup system during floods, droughts, power shortages, and other natural disasters.

more

October 1987

An early report in NTB discusses the evolving project known as the Space Station. As that issue went to press, contractors were still vying for the four major work packages comprising the design and development of what is now the International Space Station (ISS). In July 1998, NTB featured a special section on the technologies and commercial products used in the development and deployment of the ISS, the largest cooperative international space project in history.



November 1989

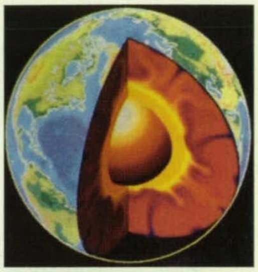
"New on the Market" in NTB is the Portfolio™ from Atari Computer, the first "palmtop" personal computer. The one-pound PC is slightly smaller than a VHS videotape, and is MS-DOS-compatible. It includes a built-in Lotus 1-2-3® file-compatible spreadsheet, word processing software, a calculator, an appointment book program, and a phone/address directory, as well as typewriter-style keyboard.

September 1994

A new way of cleaning up oil spills by "bioremediation" was invented by Joseph A. Resnick, chief scientist at Petrol Rem in Pittsburgh, PA. The Petroleum Remediation Product, or PRP™, incorporates technology reported in NTB related to fabrication of beeswax microcapsules developed by Marshall Space Flight Center and Jet Propulsion Laboratory. Petrol Rem developed the Bio-Boom™ to be used in conjunction with PRP for oil spill cleanup. The boom is an oil containment system with a floatation device that keeps it on top of the water.

1995

The Ultra® 500 Series golf ball from Wilson Sporting Goods has 500 dimples arranged in a pattern of 60 spherical triangles, a design that incorporates NASA aerodynamics technology. A design engineer formerly associated with NASA programs researched and tested dimple patterns, and the result was a ball with 60 triangular faces, compared with the usual 20. The result is a ball with a symmetrical surface that sustains initial velocity longer, and produces stable ball flight for accuracy and distance.



February 1995

Research Systems of Boulder, CO — a Kodak company — develops software for analysis and visualization of scientific data. The company's IDL® (Interactive Data Language) is used for mathematical analysis and graphical display in physics, remote sensing, test and measurement, and medical imaging. IDL's origin dates back to a software predecessor developed for NASA's Mars flyby spacecraft in the late 1960s and early 1970s. The commercial version of IDL was introduced in 1982, and is still a successful commercial product today.

June 1995

A hybrid power system uses flywheel technology to power a Chrysler open-cockpit race car called the Patriot Mark II. The hybrid car replaced the standard lead-acid battery with a carbon-composite flywheel energy storage system that converts latent electric energy to rotational energy. Chrysler worked with Marshall Space Flight Center on the use of space shuttle-based insulation materials for use in the Patriot's fuel system.

November 1996

The concept of microencapsulation of drugs is reported by Johnson Space Center. The technology involves drugs stored in inactive forms in time-released microcapsules that are injected, and the drugs then are activated by exposing the target sites to suitable forms of penetrating energy that may include electromagnetic radiation, ultrasound, or heat. The drugs then diffuse out of the microcapsules. The technology holds potential for cancer tumor treatment and other medical applications.

1990s

October 1995

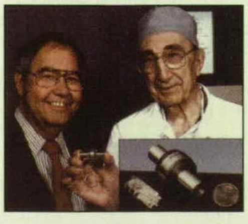
The first Active Pixel Sensor (APS), developed at Jet Propulsion Laboratory, features the ability to store all of the components necessary to produce an image on a single computer chip. The camera-on-a-chip technology enabled the development of small imaging systems. The innovation was quickly commercialized with applications in PC visual communications, advanced television, electronic still cameras, laboratory-based cameras, medical and nuclear instruments, toys, automobiles, and space-based surveillance systems.

August 1995

Following the bombing of the Murrah Federal Office Building in Oklahoma City, Lifeshear, a pyrotechnic-based cutting tool, was used to cut through debris, including concrete, piping, electrical conduit, and reinforced bar. The tool was developed through a NASA program in conjunction with the manufacturer — Hi-Shear Technology Corp. — and the city of Torrance, CA. The unit operates on NASA-developed pyrotechnics called initiators. Originally designed to sever automotive brake and clutch pedals, use of Lifeshear at the Oklahoma City site drew the attention of Federal Emergency Management Agency (FEMA) officials, who ordered 36 cutters. Today, the cutters are used by Urban Search and Rescue groups across America.

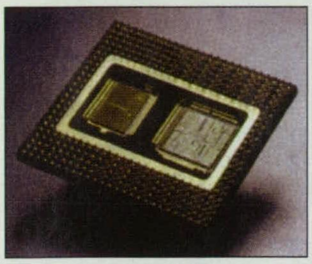
June 1995

The Left Ventricular Assist Device (LVAD) is used to supplement the heart's pumping capacity in the left ventricle. David Saucier of NASA's Johnson Space Center teamed with Dr. Michael DeBakey of the Baylor College of Medicine to develop the device with tools and techniques used by NASA in spacecraft propulsion system component design. The device can maintain the heart in a stable condition in patients requiring a transplant until a donor is found, which can range from one month to one year. In some cases, the need for a transplant may be negated by permanent implantation of the LVAD.



November 1995

The opening of the new Denver International Airport in February 1995 marked the first major commercial use of an air-traffic control system developed by Ames Research Center in the late 1980s. The Center TRACON (Terminal Radar CONtrol) Automation System (CTAS) is a software-based technology designed to manage and control arrival traffic at multi-runway hub airports by automating the process. CTAS was awarded the 1998 NASA Software of the Year, and is in use at major airports such as Dallas/Ft. Worth. Estimates indicate that it could save airports as much as $800 million per year.



December 1995

Intel introduced the Pentium™ Pro, a 150-MHz processor that achieved twice the performance of the original Pentium in 32-bit high-end visual computing applications, including CAD and 3D animation. The dual-cavity construction allowed additional CPUs or high-speed I/O channels to be connected to the processor's bus with no loss in system performance.

August 1996

Stock car driving can be a hot job — literally. Temperatures inside a race car's cockpit can soar to 160°. Boeing North America (formerly Rockwell Space Systems) and BSR Products, under a Space Act Agreement, are using space shuttle Thermal Protection System (TPS) material to insulate the race cars. BSR Products manufactures insulation kits for race car teams around the world at a cost of $1,300 apiece. The insulation is used under the driver's seat, between the floorpan and the exhaust system on the driver's side, under the driver's feet, and for insulating the oil tank, the ignition system, and the side of the transmission tunnel, resulting in temperature reductions of up to 90°.

February 1996

The first annual *NASA Tech Briefs* Readers' Choice Product of Year is awarded the to co-winners SolidWorks — for SolidWorks 95, the first release of its mechanical design software — and Autodesk for its Mechanical Library CD-ROM. The 2001 Product of the Year will mark the seventh consecutive year that the award has been presented to the most innovative new product released to the engineering community during the year.

September 2001

The development in 1986 of a bioreactor for growing cell cultures led to commercialization of a bioreactor-based system for manufacturing recombinant human protein drugs. The bioreactor is a cell-culturing apparatus with a rotating cylinder developed at Johnson Space Center during research to simulate the way cell cultures grow in weightlessness. The system's rotation and shape produce high-density cell cultures that would not otherwise grow in the body. Synthecon of Houston, TX, began producing recombinant human protein drugs in its Rotary Cell Culture System™ based on the Johnson bioreactor.

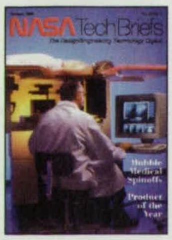
October 1997

NASA's 1997 Software of the Year was awarded to a Jet Propulsion Laboratory program called DARTS (Dynamics Algorithms for Real-Time Simulations), a multibody dynamics simulator used for real-time testing of spacecraft flight software. DARTS was used to keep the Mars Pathfinder spacecraft on course during its historic journey to the Red Planet in 1997.

2000s

February 1996

The LORAD Stereo Guide™ Breast Biopsy System from LORAD Corp. incorporates charge-coupled devices (CCDs) based on those developed at Goddard Space Flight Center for the Hubble Space Telescope's Imaging Spectrograph. The CCDs, marketed by Scientific Imaging Technologies (SITe), are part of a digital camera system that "sees" a breast structure with x-ray vision. SITe applied the technology to manufacture CCDs for the digital mammography market. The resulting device images breast tissue more clearly than conventional x-ray film technology. The LORAD system allows a radiologist to extract a tiny sample with a needle. The new technique, which is replacing surgical biopsy, is saving women time, pain, scarring, radiation exposure, and money.



July 1999

FutureFlight Central, the world's first full-scale virtual reality air traffic control tower, is installed at Ames Research Center. Using data sources such as satellite imagery, digitized photographs, and architectural data, the system can render any airport in the world in realistic, 360-degree, high-resolution virtual reality through the tower's 12 tempered-glass windows. Computer-generated images simulate weather conditions, seasons, time of day, and the movement of up to 200 aircraft and ground vehicles. In 2000, San Francisco International Airport (SFO) selected FutureFlight Central to evaluate new tower positions, runway configurations, and aircraft movements before beginning new construction.

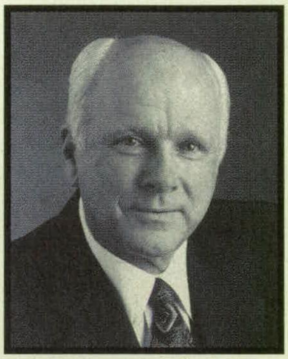
June 2000

Scientists at Pennzoil-Quaker State began basic research on a family of synthetic lubricants in the mid-1980s that resulted in Pennzoil Synthetic with Pennzane, a commercial synthetic motor oil. The basis of the product is Pennzane X2000 synthesized hydrocarbon fluid, the result of a decade-long research and development project to produce synthetic lubricants that meet space conditions. Its original commercial use was in 1987 when Pennzane was shipped to NASA contractor TRW, which began using it for equipment deployed in outer space.


know innovate design analyze realize

Materials

Fabrics and fibers, plastics and adhesives, coatings and films, all make up the ever-widening world of engineering materials. Companies like DuPont, Dow, Bayer, Phillips Plastics, 3M, BASF, Union Carbide, and thousands of smaller players have been, and probably will continue to be, in the forefront of materials innovation and development. But along with these industry giants, NASA has been one of the most prolific and innovative research entities in materials of all types.


Robert Cervenka of Phillips Plastics sees great opportunity for the use of magnesium.


DuPont Vespel's Michael Paparone sees an explosion in a new generation of materials and the development of brand new chemistries.

In the past 25 years, plastics have enjoyed increased utility in many industrial applications and everyday use. Plastics today are used to make our cars, planes, electronics, homes, clothing, and medical devices. Plastics offer a variety of functions at a lower cost than most other materials. Such widespread use of plastics over the past quarter-century has resulted from improvements in manufacturing, molding, and durability, as well as a reduction in cost.

Cost has become a huge factor in choosing plastics and other materials — in some cases, more of a factor than a material's properties. "The amount of time engineers are devoting to innovation and new design has really taken a back seat to the amount of time they're devoting to cost-reduction programs," said Michael Paparone, global business manager for the VESPEL Parts & Shapes business of DuPont Engineering Polymers.

"Looking for materials to be innovative is secondary in many cases, compared to looking for materials to be cheaper substitutes. Many times, it's getting away from a superior material to one that's good enough," Paparone added.

Environmental concerns will dictate how plastics and adhesives are manufactured in the future. More stringent regulations to reduce emissions from volatile organic compounds (VOCs) will require that plastics and adhesives manufacturers change some of their processes and the manner in which they dispose of waste.

According to Robert F. Cervenka, chairman and chief technology officer of Phillips Plastics Corp., advancements in molding will enable the use of a variety of materials, including magnesium.

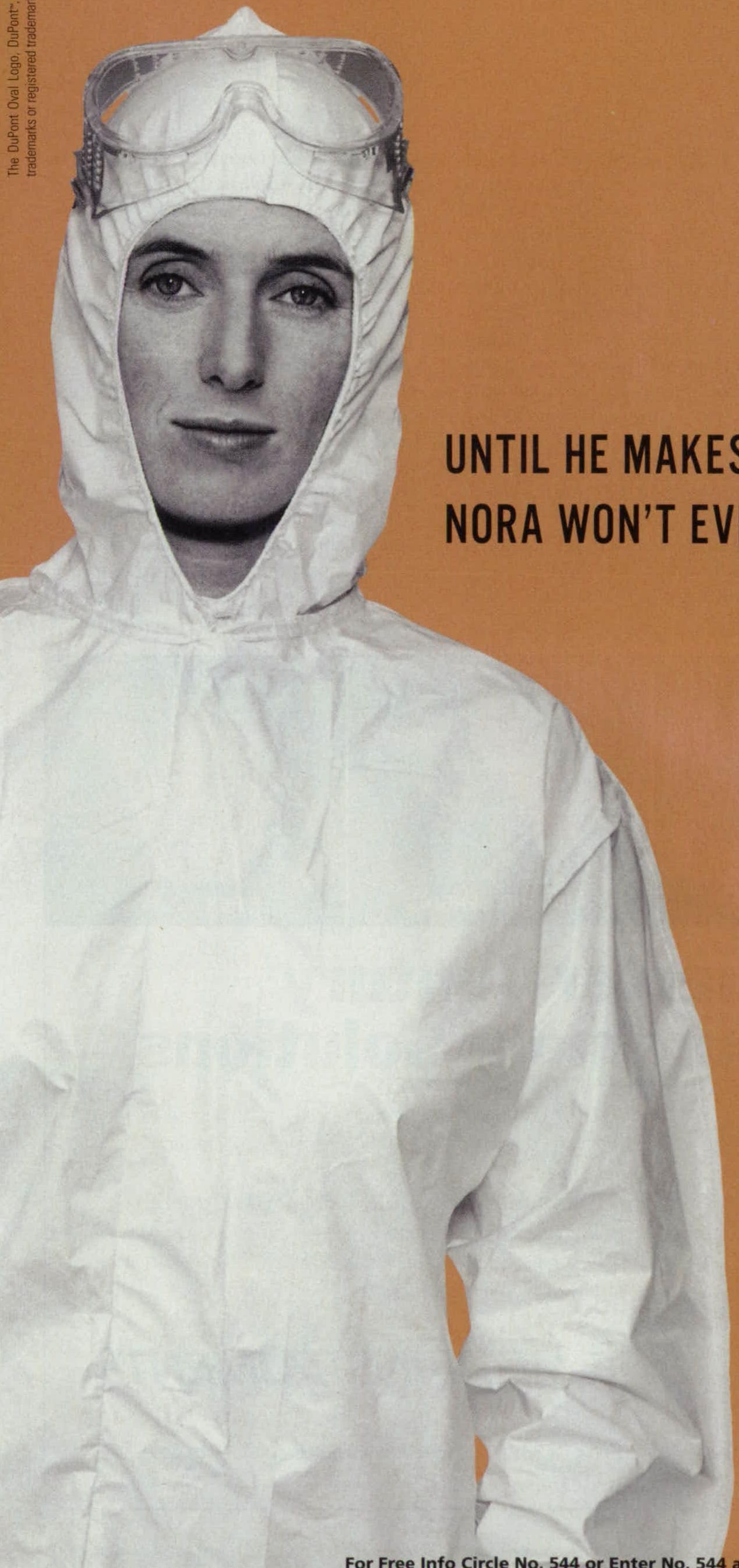
"We see great opportunity for the use of magnesium because of the advancements being made with the magnesium injection molding process. This single-step, semi-solid molding process combines the best of plastic injection molding and die-casting," Cervenka explained. "The use of magnesium is beginning to expand rapidly in a wide array of markets, including the automotive and consumer electronics fields. Products made with this metal are lightweight, strong, environmentally friendly, recyclable, and beneficial in conserving energy."

The automotive industry perhaps is benefiting more than any other from the proliferation of new, lightweight, paintable plastics. Components such as doors and bumpers that previously were made only of steel are now made with plastics that can be painted in a myriad of colors and textures. These new components help to increase fuel efficiency due to lighter weight, and are available at prices comparable to steel.

"If you have a more heat-resistant, lighter, better-wear material," said Paparone, "it's accentuated as we get into the automotive industry with lighter cars and more energy-efficient cars. While these trends might have been on the table for a long time, there is a step change in the kinds of materials that are needed." The challenge faced by DuPont, said Paparone, is to come up with the next generation of plastics.

In the plastics industry, in particular, the future will not be one of creating new applications for existing materials. It will be finding new materials that will work in existing applications. "We're seeing the embryonic development of brand new chemistries that can do things nothing else has ever done before," Paparone said. "In the next few years, you'll see an explosion in this new generation of materials."

Continued on page 80



A new horizon for plastics is the area of tiny electronic devices, predicted Paparone. Plastics, he said, have the ability to make dimensionally stable, high-performance parts that work in extremely small cell phones, disks, and other areas. Those materials will then spill over to applications in other industries.

"If you have a material that's dimensionally stable for electronics at a very micro-sized scale, there is tremendous implication in what it can do in fuel systems for automobiles, for example. It wasn't developed for automotive, but it has applications in automotive," Paparone explained.

The development of new materials has been, and continues to be, an important focus of many of the NASA field centers. Most of these materials developed in the past 25 years have been spun out of the Space Shuttle and International Space Station programs into widespread use in industrial and commercial areas. Inventions ranging from reflective packaging and thermal insulation to spring-back foam can all trace their roots to NASA materials research.

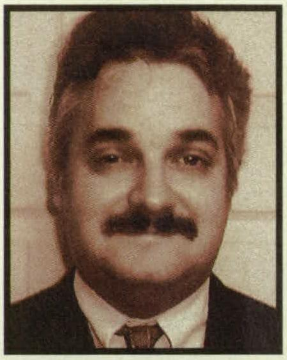
One of the most important materials research projects conducted at NASA began in the mid-1990s on a material that originally was developed in the 1930s. Aerogel is a remarkable, nearly transparent material made principally from silica. It is the world's lightest solid — only three times the density of air. A block of Aerogel the size of a human weighs less than one pound, yet is able to support the weight of a compact car.

Aerogel has tremendous insulating capabilities — it dissipates heat throughout its complex structure. According to Raymond Cronise, a member of the Aerogel research team at NASA's Marshall Space Flight Center, Aerogel has so many sides and surfaces, "if you could unfold a sugar cube-sized portion of Aerogel, it could cover a basketball court."

There have been more than 800 cited product applications for Aerogel, ranging from spacecraft to computers. These products include windows and skylights, oven door panels, refrigerators, picnic coolers, and surfboards. Currently, and in the coming years, the Marshall team will investigate ways to make Aerogel not only on a production-level basis, but as a transparent material. When made on Earth, Aerogel is hazy or smoky in appearance; when made in space, it is transparent.

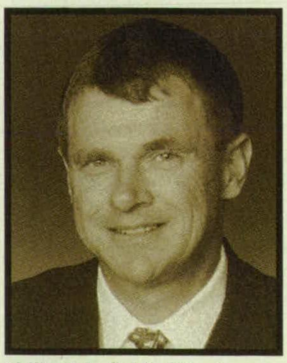
"To make Aerogel clear is a challenge," said Dr. David Noever, the principal investigator on the Aerogel team. "Once you make it clear, it becomes a whole new product and it opens up a whole new world of applications. We're trying to advance technology through space research and then pass on the results to American industry for ground production." ■

Electronics



Hamamatsu's David Leinwand: Organic electronics will be inexpensive and disposable.

Dr. Marla Perez-Davis of NASA sees a need for more technology breakthroughs in batteries and fuel cells.



Philip Schofield of Stratos Lightwave: Improvement in bandwidth will enable access to new applications.

In the burgeoning world of electronics, many of the trends for the foreseeable future have already taken clear shape: smaller feature sizes on semiconductor integrated circuits; miniaturization and nanotechnology (or, if you prefer, microelectromechanical systems or MEMS); 300-mm and larger wafers with space for far more etched circuits than before; the rush to networking over the Internet, Ethernet, MANs and LANs; and the surge of wireless stimulated by the Bluetooth standard. There's also the looming possibility that one day in the not too distant future all voice, data, and video information will be delivered to the user's computer over a single strand of high-transmission-rate optical fiber.

Over the next decade, the wireless boom is expected only to accelerate. The research firm Allied Business Intelligence predicts that by the end of 2004, the number of subscribers to wireless services is expected to reach 1.1 billion worldwide. This development will go far beyond the cell-phone phenomenon, for it is expected to include not just voice communications, but laptops, personal digital assistants (PDAs), and other portable devices. Already some organizations, such as the armed services, NASA, banks, and hospitals are using wireless connections in their daily routine. The hospital of the future could have patient beds bearing screens linked to a central digital database that doctors and nurses could use to get to medical records using handheld devices.

The wireless revolution is getting, and will continue to get, a boost from Bluetooth, the technology developed by a consortium of international vendors including 3Com, Ericsson, Motorola, Intel, IBM, Lucent, Microsoft, Nokia, and Toshiba. Bluetooth is a low-cost, low-power, short-range wireless radio technology that can link a host of devices including mobile phones, PDAs, laptops, and other portable devices. It operates worldwide on the 2.45-GHz frequency, so it is a truly global development. According to the Bluetooth Special Interest Group, more than 2,000 manufacturers have agreed to offer Bluetooth-enabled products.

Parallel to this growth will be a similar growth in networking, from the office and home to metropolitan and local area networks. "Deployment of metropolitan area networks will significantly accelerate over the coming decade and beyond," according to Philip W. Schofield, chief operating officer of Stratos Lightwave. "This will occur by driving down the operational costs that service providers must rationalize in expanding network access." Schofield sees vast improvement in bandwidth-provisioning velocity turning the balance-sheet metrics for return on capital invested in favor of the carrier, thus perpetuating service access to applications yet unknown.

The coming decades are sure to see a surge in "smart cards" of all kinds, beyond credit and debit to medical profiles, personal data, and — in our age of heightened security concerns at airports, transportation facilities, military bases, and factories — for identification and certification. One system already installed at the Amsterdam airport presages the future. Called Privium, it is an iris scanner that matches data on a smart card in the traveler's possession with the characteristics of his iris as recorded on a small camera at the security point. The process begins with an analog camera taking a detailed picture of the iris, which can have 250 or more identifiable characteristics peculiar to the owner, as opposed to a fingerprint, which can have only 40. This picture is converted into a digital code, which is transferred to a plastic card. Privium members go to a separate gate, run the smart card through a slot, and look into a camera for a few seconds. If the encoded data matches that recorded by the camera, the gate is opened and the passenger passes through.

According to David Leinwand, general manager of Hamamatsu, the coming decades will see the introduction of organic chemistry-based electronics. "Organic chemistry-based electronics will be printed, making them very inexpensive and disposable," Leinwand said. "They will be incorporated into clothing, office walls, and even the daily newspaper." Their low manufacturing cost will make them available to rich and poor nations alike, he believes. "Inexpensive medical sensors based on organic electronics will make it easier to prevent and diagnose disease."

Though the electronics industry will strive to deliver devices that can run on lower and lower electrical power requirements, demand for power is certain to grow. Researchers will pursue practical goals in the development of superconducting materials in the next couple of decades, and their deployment will make power delivery quicker and more efficient.

Another power technology receiving much attention by scientists is the fuel cell. Both fuel cells and lead acid batteries are electrochemical power sources, but fuel cells have several advantages over batteries in size, weight, length of life, and environmental friendliness. Most devices used today are hydrogen fuel cells, but a competing technology called a zinc-air fuel cell holds significant promise. Hydrogen fuel cells are about ten times as expensive as prototype zinc/air cells; hydrogen is explosive, and takes up much more space for the same amount of energy. The zinc-air cells have the additional attraction of being regenerative: the reactant is recycled and used over and over. Metallic Power, a California company developing the technology, says no pollutants are emitted and the product is environmentally safe. Current configurations can produce between one and ten kilowatts, making them suitable for telecommunications backup power.

NASA also is taking an active role in electrochemical technologies that result in high-energy-density and long-life batteries and fuel cells. The Electrochemistry Branch at Glenn Research Center in Cleveland is involved in the development of nickel-hydrogen batteries. According to Dr. Marla Perez-Davis, chief of the Electrochemistry Branch, there are many future commercial applications for such technologies. "One of the big commercial areas is portable, wireless electronics like cell phones and laptop computers that need longer battery life. You get on a plane and want to have your laptop run for a while without having to charge your battery."

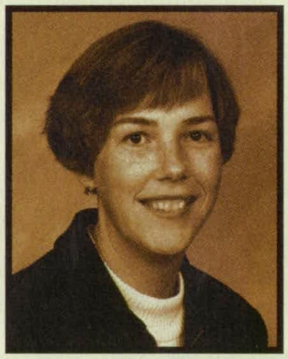
Perez-Davis adds that with fuel cells, "You want to look at different types of fuels, their efficiencies, and how to use devices where the impact to the environment is reduced. That could also mean a reduction in the amount of fuel you need to power a device," she added.

New materials also will play their part in the changes in the electronics field over the coming decades. It seems unlikely silicon will lose its primacy in integrated circuit manufacture, the result of its plentifulness and low cost. But it is wavelength-limited, and newer materials for electronic components, such as gallium nitride and indium phosphide, will take their places in electronics devices of the future.

Electrically conductive polymers will also find their uses. One seems foreshadowed in a recent report in MIT's *Technology Review*. Photolithograpy, the technique for etching the features into the silicon surface of an integrated circuit chip, is running into trouble as feature sizes move deeper into the submicron domain. But two Harvard scientists came up with an idea they called "soft lithography": using flexible rubber-like stamps to make devices with micro- and nanoscale features. Expect to see the technique used in the future to encode data on charge-based smart cards or to create waveguides for optical telecommunications switches.

It is only a matter of time before all the functionality now contained in discrete components will reside on a single chip. According to Hamamatsu's Leinwand, "Integrated circuits will be designed in three dimensions. Data will be sent by photons — both the detectors and light sources being part of the integrated circuit. Quantum computing will replace conventional computers in tasks such as searching large databases and decoding encrypted messages." ■

Imaging



Eastman Kodak's Helen Titus: Looking forward to unprecedented inventiveness in imaging.

Indigo Systems' Jeff Frank sees an explosive growth in nonvisible imaging.

It is not hard to predict that the coming decades will see advances in all varieties of digital imaging, from the x-ray band to the infrared realm. These advances will affect integration, resolution, frame rate, pixel size, dynamic range, and reduction of image blur and noise. "Camera-on-a-chip" will become not a single achievement, but a common phenomenon, and scalability will characterize the industry. Product maturity and a growing market will parallel a reduction in costs, which will foster applications at the high-resolution end of the market that the present probably cannot conceive of.

Improvements in the technologies combined in the complementary metal oxide semiconductor (CMOS) image sensor could lead in time to further inroads into the current primacy of the charge-coupled device (CCD) in digital cameras. The differences between the CCD and the CMOS technologies currently result in a series of tradeoffs for designers. CMOS devices use less power, and are therefore suitable for handheld devices with smaller batteries or whenever smaller means better. The level of integration is greater with CMOS devices, which approach the camera-on-a-chip domain. These factors, coupled with economies of scale in fabrication, make CMOS the technology of choice where cost and high-volume production are issues.

CCDs have two current advantages over their CMOS counterparts: they are capable of much higher resolution, and because they have much less noise and dark current than what the CMOS manufacturing process imposes on the latter, CCDs have much better dynamic range. Thus CCDs are suitable for applications where image quality is the most important factor: camcorders, spy satellites, and medical applications such as advanced mammography. CMOS technology finds its niches in such low-end devices as consumer cameras and machine vision, where high resolution is secondary to cost and ease of integration. Some predict that CMOS will very shortly dominate the consumer digital camera market. In time, as fabrication standards improve for CMOS, this technology probably will cut further into the CCD market.

Helen Titus, a manager at Eastman Kodak's Image Sensor Solutions division, views the future of the two technologies this way. "The vectors for CCD/CMOS image sensor technology and applications in days to come are clear. The scalable semiconductor processes used to manufacture sensors will bring denser, larger, and more highly integrated imaging components that will drive performance up and cost down for legacy cameras using conventional formats and legacy lenses.

"Further out," she explained, "the continuing advance of sensor technology will enable new generations of legacy-free cameras that, in combination with advanced support electronics and sophisticated image processing algorithms, will deliver performance and functionality beyond anything we see today."

One application that is certain to be affected by the expansion of imaging technology in the coming decades is medicine and surgery. Even today, many envision an all-digital hospital in which all records are kept on digital files so that the results of an x-ray done two years ago and those of a blood test done an hour ago are instantly available to a doctor, either in a central computer-file storeroom or at the patient's bedside on a handheld display. Nurses and technicians could update records remotely. Remote imaging and telemedicine, both advanced in recent years by NASA, already have invaded the operating room, and their use will grow in the fu-

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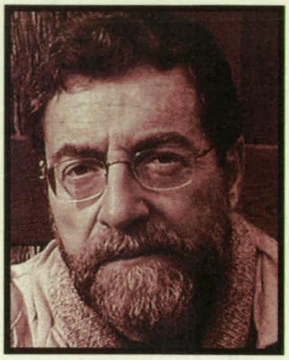

Lenny Lipton of StereoGraphics: Stereoscopic visualization will become even more widespread.

ture. In the coming decades, with increasing bandwidths and decreasing costs, the use of such technology for surgery and other medical procedures, as well as for remote surgical and medical training, will grow.

Strides in technology will hasten the widespread advent of 3D imaging. Already service providers can deliver 3D simulations of diagnostic scans to doctors' offices over the Internet. In the coming decades, such high-definition volumetric displays will be found in a variety of settings, particularly where design of solid objects is being done.

Lenny Lipton, founder, chairman, and chief technology officer of StereoGraphics Corporation, a maker of stereo viewing devices, predicts a bright future for 3D displays. "Our expectations are that the next decade or so will witness the growth of electronic stereoscopic displays in a rich variety of applications. Stereoscopic visualization of information is widespread in science, industry, and medicine. Acceptance of the medium will become even greater, adding additional professional uses, and even broadcast television, if future systems are excellent and don't require the use of glasses."

Out beyond the visible spectrum lie many possibilities for the imaging domain. The future is likely to see increased use of the quantum well infrared photodetectors, known as QWIPs. Advances in the technology of the growth of gallium arsenide led to the development of QWIPs in the late 1990s by NASA's Jet Propulsion Laboratory's Center for Space Microelectronics Technology, and Amber, a Raytheon company. The handheld camera, employing highly sensitive arrays of these detectors, responds to heat energy in the 8- to 12-micrometer wavelength range. A quantum well is a small well with electrons in it at rest. When these electrons are invaded by photons, they jump out. By measuring the current produced, the camera can indicate the amount of infrared light coming from the source. As further refinements are made to gallium arsenide growth technology, the QWIP should be even more prominent in such applications as night vision, early warning systems, medical imaging, navigation, flight control systems, fire fighting, weather and environmental monitoring, and security and surveillance.

Jeff Frank, vice president of business development at Indigo Systems Corporation, is enthusiastic about nonvisible imaging. "In 2011," he said, "we will look back at the first decade of the new millennium as a period of explosive growth in nonvisible imaging technologies and marvel at the countless applications that were not just improved upon, but created because of the inherent possibilities."

Frank expects sensor arrays that provide man and machine the ability to "see" wavelengths outside of the visible spectrum to be prolific in all aspects of our lives. "From the key-ring thermal imager you use to check the parking lot at night before going to your car, to the imaging spectrometer at the grocery store that helps you select only ripe, unbruised produce, they will be everywhere."

Eastman Kodak's Titus looks ahead to a period of unprecedented inventiveness. "It will be the system designers themselves who will bring us the most significant developments, by cleverly applying new technology to products that will meet evolving market needs." ■

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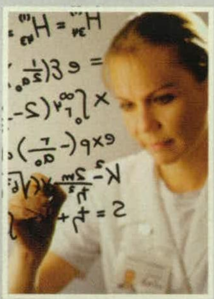

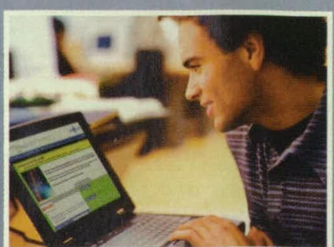

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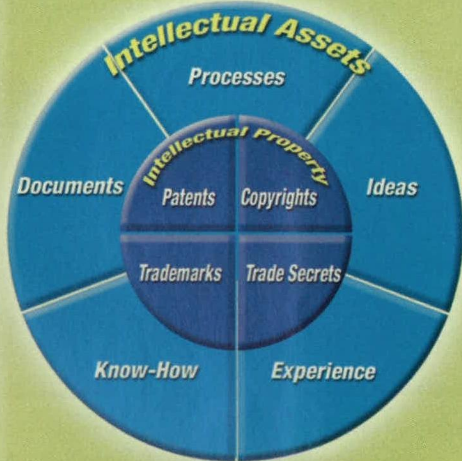

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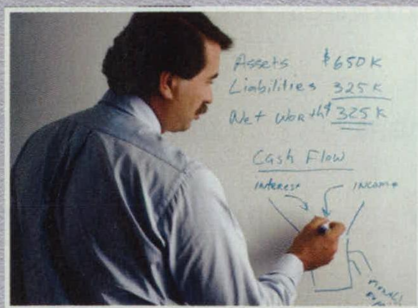

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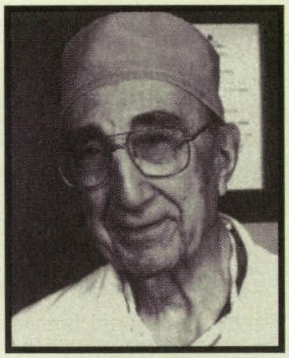
Medical



Dr. Michael DeBakey used NASA turbopump technology to develop the Left Ventricular Heart Assist Pump.

Perhaps no industry has come farther, faster, in the past 25 years than the medical industry. Innovations such as artificial hearts, magnetic resonance imaging (MRI) machines, virtual surgery, pacemakers, and countless other technologies have evolved into the realm of the commonplace. And in today's environment of feared bioterrorism, the medical industry has been forced to advance even faster with new detection techniques and treatments for airborne bacteria and poisonous gases.

Medical devices such as those mentioned above — as well as surgical equipment and thousands of other devices — make up a $43 billion market in the US, according to the marketing firm Frost & Sullivan. The US is the largest medical device market in the world, and also leads in advanced medical technologies.

Along with industry, federal, and university laboratories, NASA has consistently been in the forefront of innovative medical developments. Ingestible thermometers, microencapsulated drugs, insulin delivery systems, cool vests, laser angioplasty, and heart pumps can all trace their roots to NASA-developed technologies.

One of the most important innovations of the past two decades was developed by world-famous heart surgeon, Dr. Michael DeBakey, of the Baylor College of Medicine, who is known for having performed the first successful multi-organ transplants. Having previously developed a crucial component of the heart-lung machine and having paved the way for open-heart surgery, Dr. DeBakey teamed with NASA for another invention in the 1990s.

Armed with NASA-developed turbopump technology and capabilities in computational fluid dynamics analysis, David Saucier and his Johnson Space Center colleagues teamed up with Dr. DeBakey to devise the Left Ventricular Heart Assist Pump. The small turbine pump helps the heart circulate blood through the body, keeping a patient with a diseased heart alive until the organ recovers or is replaced by a transplant. It can also allow patients who are not transplant candidates or whose hearts may not recover the chance to live a normal life. The device is 25% more efficient than other clinically available devices. An estimated 60,000 patients per year in the US are in need of an implantable heart pump.

NASA has continued to develop the technologies behind telemedicine and robotic surgery in the past six years. In 1995, NASA demonstrated a telemedicine system with the University of Texas Health Science Center at San Antonio (UTHSCSA), VTEL, and Sprint in which a live consultation took place between physicians in Chicago and South Texas. Telemedicine is used to treat patients in medically underserved areas where there is no access to specialists. It can provide direct visual examination of x-rays, blood smear samples, and bone marrow aspiration slides.

Just this summer, telemedicine and robotic surgery were combined to enable surgeons in New York to remove the gallbladder of a woman in France. Dr. Michel Gagner of New York's Mt. Sinai Hospital's School of Medicine, and Professor Jacques Marescaux of the European Institute of Telesurgery in France, used robotic surgical equipment from Computer Motion, which initially developed the system through a grant from NASA in the early 1990s.

Dr. Gagner manipulated the arms of the computer system in New York, and the instructions were transmitted via high-speed fiber-optics. He operated the laparoscope while receiving pictures from inside the patient's body. The technology also can be used to teach doctors who work in underdeveloped areas.

"We can now extend the reach of the surgeon so that an expert can intervene any place in the world," said Marescaux. "I felt as comfortable operating on this patient as if I had been in the room."

Other areas of research in the medical field are conducted by NASA's Biotechnology and Earth-Based Applications Program — part of The Office of Biological & Physical Research at NASA Headquarters. The Program focuses on the elements of cellular, macromolecular, and exploration biotechnology research. Biotechnology merges biological science, engineering, and biochemistry to provide biomolecules, cells, tissues, and other bioproducts to enhance human health.

The Program already has made significant contributions in the area of artificial growth of human cartilage, cardiac muscle, and kidney tissue. The National Institutes of Health (NIH) has applied NASA's biotechnology capabilities to study how HIV is transmitted, and currently is developing human tissue models to study other infectious diseases. The same tissue models will be used as a platform for testing drugs against these infectious diseases.

The development of new drugs has propelled the US pharmaceutical industry into a leadership position in the global market. The US pharmaceutical industry has produced almost half of the important new drugs introduced globally over the past 20 years. Diseases such as heart disease, HIV/AIDS, and Alzheimer's are still killing millions of Americans each year, so development of drugs and vaccines continues to be an important priority for pharmaceutical companies.

Raymond V. Gilmartin, chairman, president, and CEO of New Jersey-based Merck & Co. spoke about his vision of the pharmaceutical industry at the National Congress on the Future of Genomics, Biotechnology and Pharmaceuticals in Medical Care late last year. Gilmartin stated that many of the right conditions have existed to enable the pharmaceutical industry to prosper. These include market-based competition in the US, access to global markets, and significant investments in basic research.

"No one can deny that we are in the midst of a great biomedical revolution," Gilmartin said. "The sequencing of the human genome, along with other advances in science and technology, means that researchers can begin to understand the secrets of human health and disease at a more fundamental level than any of us might have imagined a decade ago."

Future success for companies in the pharmaceutical industry, Gilmartin explained, "will depend on their ability to translate cutting-edge science into breakthrough research." ■

Computers

Dr. Eng Lim Goh of SGI: Users' computational needs have been outpacing the industry's ability to improve single-processor performance.

Twenty-five years ago, an entire desktop computer's processing power handled less data than today's Palm Pilot™. Computers required highly skilled operators. The idea that practically every American would have a computer on his or her desk someday was utterly unbelievable, let alone the fact that one day computers would be carried in your briefcase, or even in your shirt pocket. The Internet, e-mail, computer-aided design, and countless other everyday tools would not exist without the computer.

Mammoth supercomputers that originated in the mid-1970s with Cray Research's Cray-1, also have shrunk in size and grown in capacity. IBM, regarded often as today's supercomputer leader, has produced systems with computational capability of more than 12.3 teraflops. Current supercomputers often consist of clusters of PCs wired into a network.

At the forefront of supercomputing are SGI and NASA. They teamed up early this year to install a 512-processor system based on SGI's Origin™ 3800 system at NASA's Ames Research Center. The supercomputer is being used by NASA to develop spacecraft, and perform computational fluid dynamics, global climate modeling, and computational astrobiology.

Today, computers define generations. The PC and the advent of the Internet have revolutionized the world, providing the ability to communicate with virtually anyone, anywhere, who has access to a computer. There are no barriers, no borders.

The key to the growth of the computer industry has been the development of universal ease of use and the accumulation of processing power, countered with a decrease in size. Portability became key in 1986 when IBM introduced its IBM PC Convertible laptop, which inspired many clones, thus initiating the modern-day laptop market.

Over the years, laptops have become lighter, smaller, and more powerful, revolutionizing the way in which — and where — engineers and designers can do business. Containing the same processing power as conventional PCs, engineers are able to collect data and work directly in the field. Palm, Compaq, and other manufacturers of handheld computers have provided even smaller computers with enough flexibility to become mainstream computing devices.

Virtual reality is one of the fastest-growing computer-based technologies. While popular in consumer applications such as video games, simulators, and entertainment, the most innovative uses of virtual reality have been in the military, aerospace, and industrial engineering fields. Cutting-edge software, display technologies, and lightning-fast computers have made virtual reality an immensely important tool for flight simulators and pilot training. NASA has pioneered the use of virtual reality in the medical field for everything from diagnostic imaging to virtual surgery.

Display technology in the form of monitors and flat-panel units has helped to advance the utility of computers. One of the latest display innovations that should have a major impact on most graphics-intensive computing applications is the Helios 3-D volumetric display from Actuality Systems. It allows high-resolution color images to appear to hover in three-dimensional space. The spherical monitor is shaped like a 20"-diamter globe, and lets users move around the display to view images from any angle across a full 360 degrees. No 3D glasses are needed, and the display has a resolution of about 100 million volume pixels, or voxels. The applications for the display are many and varied, ranging from medical imaging and pharmaceutical design, to aerospace and defense, to electronics.

Because expansion of the computer industry has accelerated and evolved so rapidly in the last 25 years, how do manufacturers keep up with customer demand for faster, smaller, and cheaper computers?

Dr. Eng Lim Goh, senior vice president and chief technology officer at SGI, believes that "for an increasing number of high-end users, computational needs have been growing well in excess of the industry's ability to improve single-processor performance." Consequently, the industry, Goh said, is "seeing such users employing scalable multi-processor systems with increasingly higher processor counts."

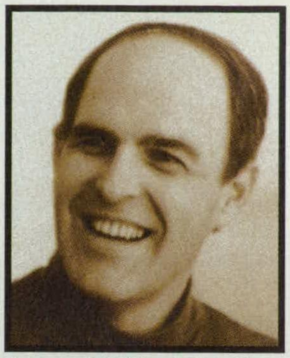
To keep up with customer demand, Dr. Goh proposes three fundamental system performance factors that will aid improvements in designing scalable systems — computational power, bandwidth, and latency. "Computational power will continue to improve as it has in the past, and bandwidth will also continue to increase, particularly when it has multiplexing techniques working for it." Overall, Dr. Goh said, the most powerful computer may have to be the densest.

To keep up with the market demand, competition between computer manufacturers is also growing, and is beginning to result in consolidation. To maintain viability in such a fierce market, the industry is seeing companies like Compaq and Hewlett-Packard attempting to merge. By trying to create a company second in size only to IBM, Compaq and Hewlett-Packard are hoping to become a doubly dominant presence in this large business.

In the latest issue of Compaq's *Inform* news magazine (Fall/Winter 2001/2002), chairman and CEO Michael Capellas stated that he has met with hundreds of customers since the beginning of the year, and has learned that they want "an IT partner who can reduce complexity and the number of moving parts. Customers want someone who delivers creative, new approaches for getting the most value and flexibility out of IT investments." Capellas believes that the combined companies "will deliver a new cost and value model for the enterprise — a model grounded in the companies' commitment to open, market-unifying standards."

With so many industries depending on and benefiting from computing technology, defining a clear path for the computer industry is challenging. "We believe that the proliferation of handhelds and other access devices — and the services that users will demand — is going to place increasing demands on the Internet infrastructure," Capellas predicted on his Web site.

After all, it wasn't that long ago that people were impressed by the capabilities of a simple calculator, not knowing the scope and speed at which the computing industry was to expand. ■



Compaq's Michael Capellas believes the proliferation of handhelds will put increased demands on the Internet infrastructure.

Sensors

Omron's Rob Loomis sees a growing demand for specialty and custom sensors.

Michael Horton of Crossbow Technology sees networked MEMS sensors as a means toward automation.

"Before there is information, there must first be a sensor." Rob Loomis, vice president of Omron's Industrial Automation Division, could not have provided a more straightforward explanation of the importance of sensors in many manufacturing industries. Sensors have developed into such a sophisticated medium of communication that they are able to control the entire functioning process of a mechanism.

Position sensors, proximity sensors, pressure sensors, heat sensors, flow sensors — there are sensors for the detection of virtually any parameter you can imagine. Automobiles, in particular, contain dozens of different types of sensors. The smoke alarms in your home could not function without sensors. In the healthcare and medical industry, sensors are used in everything from pacemakers and blood pressure monitors, to dialysis machines and heart monitors. Photoelectric sensors are standard components in the machine vision industry.

Michael Horton, president of Crossbow Technology, believes that the success of the sensors industry is due, in part, to the integration of sensors "with processing and communications, often wirelessly, making deployment rapid and easy. Micromachining and materials technology breakthroughs are creating a broad range of sensors at low cost."

As an example, Horton cites the integration of inexpensive sensor/GPS (Global Positioning System) modules into handheld packages. "Data collection devices are emerging for vehicles, new and retrofit construction, and video and camera circuitry in security and surveillance monitoring applications."

A growing trend in the sensors industry will continue to be the use of smart sensors, which integrate new sensing methods with computing capability and digital communications. They can automatically adapt their behavior under changing conditions, making them "smart."

According to the marketing firm Frost & Sullivan, the smart sensor will be used to monitor environmental conditions such as traffic congestion, air pollution, or magnetic fields, and also will be used for disaster mitigation by monitoring the motion of buildings during an earthquake. They can be networked to monitor many different parameters and systems in one location. For example, a network of wireless smart sensors can monitor the lighting and temperature of an entire building, reducing energy costs significantly.

With so many applications, predicting the future of this versatile industry is challenging, but industry insiders are tracking the application of MEMS (microelectromechanical systems) technology as the next step in sensor evolution. MEMS refers to any technologies that integrate mechanical elements, sensors, actuators, and silicon-based electronics with micromachining technology, frequently producing system-on-a-chip technology.

While MEMS technology has been around for almost 40 years, it wasn't until the early 1990s that companies began commercializing the technology and producing MEMS-based products. Benefits of MEMS technologies center around their exceptionally small size, and since they are also low in mass and very reliable, they can be applied in areas such as accelerometers, disc drives, telecommunications, aircraft, printers, and optical switching.

Because of integrated circuit processing methods, thousands of MEMS can be mass-produced on a six-inch silicon wafer, slashing production costs when

Endevco's Len Maier: Wireless networked sensor systems will benefit applications requiring portability.

compared to the production of conventional parts. MEMS technology is still being developed, but is anticipated to play a huge role in networked sensor technology.

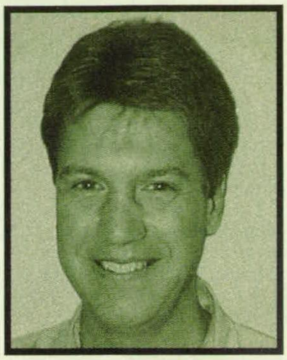
Horton sees networked MEMS sensors as a means toward automation. "Networked MEMS sensors with wireless communications capability can now relay room temperature, humidity, and light data to a central computer. All of these developments mean sensors interact directly with the world, without human intervention," he explained.

Len Maier, president of Endevco Corp., also believes that MEMS will be a significant contributor to the development of networked sensor systems. He expects "the vibration and measurement market to benefit from the development and refinement of network sensors. Flight test and structural test applications previously requiring large bundles of cables, making installations expensive and cumbersome, will be replaced with two-wire networked measurement systems," he said.

Maier envisions that the two-wire measurement systems "will consist of smart sensors with digital outputs, a transducer bus interface module (TBIM), and a transducer bus controller (TBC). These systems will also lend themselves to permanent monitoring applications where transducer location and communication — in addition to installation costs — are of high importance," he predicted. "Silicon and piezoelectric sensor technologies that merge MEMS will play an important part in the next generation of networked sensor systems. Wireless networked sensor systems will follow closely behind and will be especially beneficial in applications requiring portability."

The broadening role of sensors will be a major factor in their continuing development. New applications will dictate new sensor capabilities. "As the information age moves to the production floor," said Loomis, "the role of sensors will expand exponentially. In addition to its role in regulating and controlling the process, information pertaining to repeatability, quality, mechanical wear, predictable failure, and yield will need to be detected, reported, and managed. The demand for specialty sensors and custom sensors will be in response to the growing need to know. Research is another emerging area of significant growth." ■

Manufacturing & Motion Control



Philip Hollingsworth of California Linear Devices: End users are getting the best state-of-the-art equipment as it's developed.

George Blackwell of Cognex expects the drive toward networked machine vision to accelerate.

Delta Tau Data Systems' Dimitri Dimitri: More commodity-type motion control solutions will be available.

"The motion control industry is changing. Current trends include direct drive motors, a move to electrical solutions, open architecture, and standard communications and interfaces," said Philip Hollingsworth, director of engineering at California Linear Devices. These trends are bound to persist over the next decade and more.

To respond to ever-increasing competition, motion control system designers will continue to seek ways to reduce system costs by eliminating or consolidating the number of system components. Frank P. Monteleone, senior director of worldwide sales for Thomson Airpax Mechatronics, cites an instance of trend. "An example is the increased use of sensor technology for simplified position feedback. Reducing the number of system components also decreases the assembly time, and improves reliability. Since there are fewer components, there will be less system maintenance and increased mean time between failure (MTBF) ratings for the customer's product."

Prominent among trends in the coming years will be the growth of the use of microelectromechanical (MEMS) devices in motion control instrumentation. Marketing firm Frost & Sullivan estimates that the total MEMS market, now at $1.4 billion, will increase at a compound annual growth rate of 17 percent through the year 2004, when the market is expected to exceed $3 billion. Automotive applications such as airbag inflation sensors currently make up one third of the total market, followed by the medical market, which uses MEMS in products like disposable blood pressure sensors.

But there are numerous applications that are certain to reach the market in the coming decades. These could include smart munitions that can alter their paths after firing, metering nozzles for inkjet printers, drug delivery systems, accelerometers used in antilock braking systems, and sensors for measuring fuel level, tire inflation, and oil pressure. Applications in the photonics industry abound, including reliable telecommunications switching devices.

MEMS-based designs can produce systems on a chip in which a transceiver, batteries, sensors, and microprocessors are all on a single component not much larger than a postage stamp. They are rugged — many will be made of silicon, which is many times stronger than steel — and can operate for long periods with little power. The challenge for the years ahead is to create components able to endure internal heat buildup and withstand excessive structural loads, ambient temperature swings, and severe shock and vibration. But few doubt that these devices have a bright future.

The near future will see changes in encoders as well. Already in evidence are optical encoders that use fewer components, yet provide better reliability and performance at lower cost.

According to Edward Burk, technical sales manager at Renco Encoders, "Component reduction is being done by incorporating the optical sensors and conditioning circuitry into a single, application-specific integrated circuit (ASIC). By reducing component count on the encoder, you open up valuable printed circuit board space, allowing additional capabilities to be integrated with the encoder. Future developments will add memory to contain encoder data, user data, or both, and a communication bus to transfer this data to external devices."

Thomson's Monteleone sees a similar push toward integration in the world of motors and controllers. He notes a trend away from high-torque, closed-loop multiple device systems with separate motor, control electronics, power supply, and feedback devices, toward "having everything necessary to perform all of the functions required in one package." He added that "surface-mount, field-effect transistors are a driver of this trend. Power needs can be scaled down to a lower level. The older servo systems were very expensive."

Nick Johantgen, manager of engineering at Oriental Motor USA Corp., said his company will continue to migrate toward all-inclusive solutions. "The customer will simply input a description of the mechanical system and motion profile he would like to achieve. The solution would then provide the proper motor, driver, and/or controller, and cause these components to execute the motion upon command. This technology will be applied to both rotary or linear motion products with minimal effort required by the user."

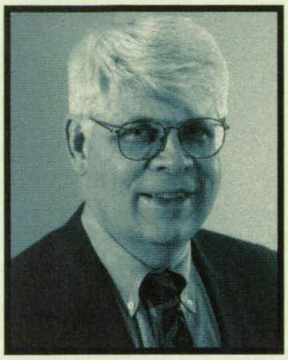
In the world of machine vision, George Blackwell, senior manager of marketing at Cognex Corp., expects the drive toward networked machine vision to accelerate. "To catch defects earlier in the manufacturing process and improve process control, companies will distribute vision systems at even more points along the production line. Ethernet will likely continue to serve as the basis for networking the sensors, together with an emergence of new types of industrial networking protocols."

Dimitri Dimitri, president of Delta Tau Data Systems, sums up the changes coming in motion control. "During the next decade, the number of motion control solutions will continue to grow. We'll see a continuation of distributed and centralized architecture, and while old technology solutions are not disappearing, the real growth will be in new technology, resulting in much higher resolutions that increase accuracy. Single-chip solutions will be available for volume applications," he said. "The biggest issues for customers," predicted Dimitri, "will continue to be price performance, simple wiring, and easy setup without sacrificing performance and flexibility. As a result, more commodity-type motion control solutions will be available."

The major trend that affects manufacturing in general — the actual production of parts — is rapid prototyping. Being able to produce prototypes of parts before they are put into production reduces product development costs, time to market, and the chance of producing defective products.

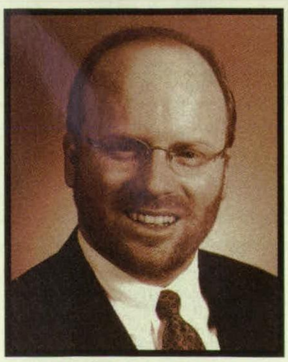
Although still a rather young technology, rapid prototyping has developed quickly in the past decade. 3D Systems introduced the first commercially available rapid prototyping machine in 1987, with a limited choice of materials. The first systems were used primarily in the automotive and aerospace industries, but over the past 15 years, it has become more of a staple in the manufacture of all types of products, from cell phones and medical devices, to computers and consumer products.

Today's rapid prototyping systems incorporate CAD/CAM software with many types of materials such as plastics and resins to construct, layer by layer, a working prototype of a product or part. Using techniques such as injection molding, stereolithography, and high-speed machining, rapid prototyping machines are available from many manufacturers, including DTM, Stratasys, and 3D Systems. Desktop-sized machines, called 3D "printers," also are becoming more commonplace in today's manufacturing environments. As prices for this equipment come down, the use of rapid prototyping could continue to replace conventional methods such as hand carving in many industries. ■



Michael Bussler of Algor: The major CAE trend is toward full virtual capability.

Frank Perna of MSC sees simulation software still in its very early stages.



SolidWorks' John McEleney sees 95% of people using 3D in the next five years.

Engineering Software

There is perhaps no other industry that has been more deeply affected by the progress of the computer than engineering software. The innovations in computer hardware and operating systems in the past 25 years have mapped the course of where software is going, and how quickly it will get there.

The use of computer-aided design (CAD) and computer-aided engineering (CAE) software 25 years ago was limited to what Tony Affuso, president of PLM Solutions, EDS, calls "highly trained engineers working in dark rooms on very expensive, yet primitive, CAD systems to design products." The software that was available often exceeded $100,000 for a seat — well beyond what most companies could afford.

Said Frank Perna, chairman and CEO of MSC Software, 25 years ago the CAE user was a "very highly trained, highly educated engineer or computer scientist who could take the information and do a computer model, and answer important questions relative to the performance of a structure or product." However, when that information was put in to the digital domain, it became more accessible.

While Perna sees the simulation software market as still being in its very early stages — "where CAD was 25 years ago" — the growth of the computer industry has been a factor in the software's ease of use. "You can see that now with Windows and the use of the mouse — years ago there was just a keyboard related to the computer, and there was a limited number of people interacting with the computers," Perna explained. "Today, with the use of the mouse and touchscreens, that population — no matter what the discipline — uses computers on a regular basis."

Engineers and scientists in particular are reaping the benefits of advanced computer technology as it affects the technical software they use. "We've always believed that computers fuel innovation in engineering and science through algorithms," said Jack Little, president and CEO of The MathWorks. "In that sense, software today is at the beginning of a new era in its ability to help scientists and engineers in their most creative work."

Powerful PCs and Windows technology have helped to bring ease of use to CAD/CAE software. "In the UNIX world, you had one person who could set up a machine," said John McEleney, CEO of SolidWorks. "Today, everybody can set up a machine. Five years from now, people will look back and say, 'Do you remember when people used to install their own software?' The whole notion of being a slave to the system will start to remove itself."

Michael Bussler, president and CEO of ALGOR, Inc., said that there has been a continuously changing computing environment ever since the first computer was introduced, and there is no reason to expect that the environment will stop changing. "Hopefully, each of these changes is for the better in that they enable software to do things that couldn't be done previously. There have been two classes of computing environment changes," Bussler added, "the class that affects the speed of computation, and the class that impacts what you can do from a human interfacing standpoint."

The impact of computing technology on CAD/CAE is continual democratization — "the trend of highly specialized, expensive, and sparsely adopted applications to become less specialized, cheaper, and more broadly adopted," explained Scott Borduin, chief technology officer of Autodesk. "By 1990, 32-bit processing became widely available on the PC, enabling new classes of applications like true 3D design and solid modeling."

The computing environment continued to change through the 1990s. By 1994, solid modeling had become a viable technology. Once 3D solid modeling became a product for the "masses," software vendors may have thought the migration from 2D software would be swift, to say the least. While migration is happening, it's occurring slowly.

"Over the next three to five years," predicted McEleney, "a predominant number of people will be doing design in 3D. Today, 20 to 25% are using 3D, and 75%

of the world is still using 2D." That, he believes, will change drastically in just the next five years, when 95% will be using 3D. "It's getting easier to use, their competitors are using it, and it has reached critical mass."

The most significant trend in the CAE software market, according to Bussler, "will be the trend toward a full virtual capability — the technology that is not dependent on the computing environment. It's a whole different type of technology unto itself," he explained. "That's where I see the most important growth happening."

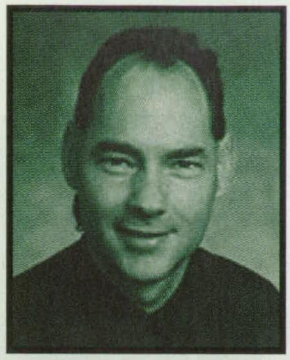
One of the trends that will be a factor in the success of the engineering software industry is the Internet. "Moving design information in purely digital form has been the Holy Grail of the CAD industry for the last two decades. The Internet provides the universal computer networking infrastructure to make this possible — and probable — in the next 20 years," said Borduin.

Robert Bean, president and CEO of CADKEY Corp., agrees. "I strongly believe that the distinction between users on the Internet and the 'person in the next office' will disappear very soon. Design teams will function with seamless communication around the world."

Those types of capabilities will only increase, according to EDS's Affuso. Today, all members of the manufacturing enterprise, for example, have access to technology that lets them collaborate over the Internet. "Practical limits to the type and amount of information that can be shared over the Internet will be eliminated, thanks to dramatic increases in network bandwidth." Affuso added that use of the word "collaboration" in the manufacturing industry will fall off dramatically, "not because organizations will stop collaborating, but because it will be assumed in the same way that access to a PC, the Internet, or e-mail is assumed today."

The Web also will continue to bring other types of engineering software besides CAD to a larger audience. Interactive mathematical content is being brought to the Web today, and that trend will continue, according to Chris Randles, chairman and CEO of MathSoft Engineering and Education. "MathML, the XML standard for describing mathematical expressions, already has been integrated into mathematical software such as our Mathcad package. Over the next few years, we'll see much more math-related material — commercial, scientific, and educational — being shared over the Web," Randles predicted.

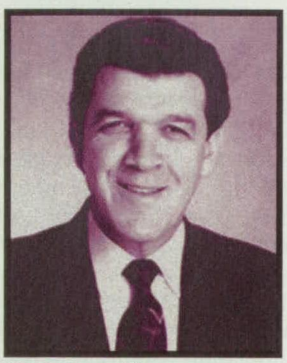
The expensive, programming-intensive engineering software of the past is long gone, being replaced by easy-to-use, collaborative tools that are made for all levels of technical expertise. "With tomorrow's software," said Little, "Technical people will be released from the shackles of programming in traditional languages. They will be free to explore and manipulate data, models, images, and real-time phenomena to achieve insights and discover solutions." ■



Autodesk's Scott Borduin looks to the Internet to change the definition of CAD.

Robert Bean of CADKEY: Design teams will have seamless communication via the Web.

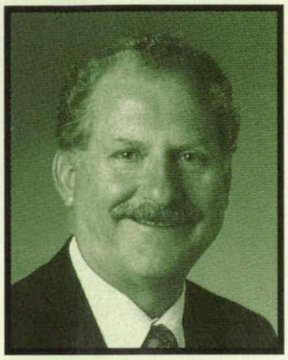
The MathWorks' Jack Little: Tomorrow's software will fuel engineering innovation.



EDS's Tony Affuso: Collaboration will be assumed the way e-mail is assumed today.

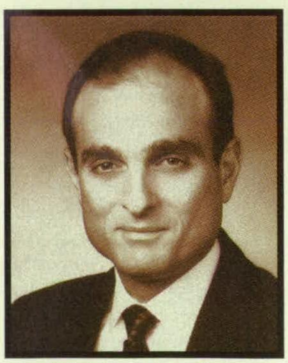
MathSoft's Chris Randles sees more math-related material shared over the Web.

Test & Measurement



National Instruments' Dr. James Truchard: The PC marked the advent of a competitive alternative to traditional instrumentation.

Joseph Keithley of Keithley Instruments sees the Internet being used for secure test control and measurement data-sharing anywhere on the globe.



IOtech's Tom DeSantis: The cost of data acquisition equipment is coming down as less pre-process hardware is required.

Every industry relies on test and measurement to make certain its products and processes operate effectively. Precise measurements are vital for engineers who design, develop, and automate. Comprising everything from handheld portable devices to large test stands and software, the test and measurement industry has undergone many changes in the ways in which data is collected and dispersed.

Twenty-five years ago, most measurements were taken manually, using oscilloscopes and other basic meters. With the advent of personal computers came a much more accessible way to automate the test and measurement process. Dr. James Truchard, president, CEO, and co-founder of National Instruments, recalled how that process began to change.

"The first step in the process was taking off-the-shelf, general-purpose computers and dedicating them for measurement and automation applications. That process started in the late 1970s and early 1980s. With the advent of PCs, we ultimately got a very competitive alternative to traditional instrumentation, in terms of processing power, I/O capabilities, and user interfaces," explained Truchard. "The computer has played a key role in shifting users' perspectives in the way that they look at measurement and automation systems."

Joseph P. Keithley, chairman, president, and CEO of Keithley Instruments, agrees that computers have had, and will continue to have, a profound impact on how we collect data and make measurements.

"In the past 20 years, test and measurement professionals have gained tremendous resources stemming from the personal computer and associated technologies," said Keithley. "The open PC architecture has allowed creation of hardware and software that makes high-quality measurements faster, easier, and more widely available than ever."

Along with the continued growth of computer-based measurement techniques came the required software that accompanied these systems. LabVIEW, National Instruments' graphical programming language for test and measurement applications, was introduced in 1986, and soon engineers and scientists were using it to automate and build measurement systems on their PCs. The evolution of the Windows platform will help make such software easier to use. According to Keithley, Windows has "given rise to software packages such as Testpoint and others that enhance the programmability of instruments, even for 'non-programmers.'"

With faster computers, more choices in easy-to-use software, and plug-in data acquisition cards, taking measurements and collecting data has never been easier. "The cost of data acquisition equipment is coming down, as less hardware is required to pre-process that data before sending it to the PC," explained Tom DeSantis, president and CEO of IOtech. "Now that there is more processing capability available due to increased PC/microprocessor bandwidth, new waveform capture data acquisition equipment is eliminating the DSP [digital signal processing] circuitry, and allowing the PC to perform all of the processing of the sampled time-domain data."

One technology that will affect the future of the test and measurement industry is the Internet. Web-based communication of data will become more commonplace and more important to engineers as they are required to share such information. "With the Internet, faster data communications, and standardized Web interfaces," said Keithley, "the PC can now be used to create tightly integrated systems for secure test control and measurement data-sharing anywhere on the globe."

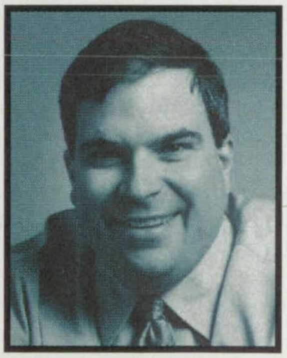
TestMart, a test and measurement information and commerce marketplace, is a Web-based business. However, Peter Ostrow, TestMart's president and CEO, sees the Internet as only one of the three major factors that will greatly affect the test and measurement industry.

"First, the continuing consolidation among manufacturers is going to continue to narrow product choices. Secondly, the increased requirements generated by technological innovation and advancement around telecommunication and networking applications is going to greatly increase the obsolescence rate of the equipment that tests against these applications. Product innovation, therefore, will respond more quickly to these changes." Finally, and perhaps most importantly, said Ostrow, "the Internet as both a sales tool and a separate sales channel will continue to drive down costs and increase productivity."

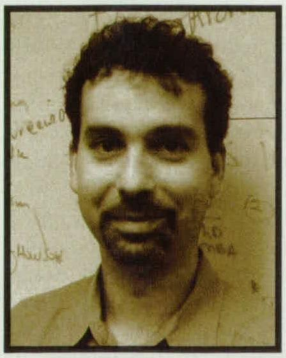
According to Truchard, the Internet not only automates measurement procedures, but also allows the information to be shared on a global scale. "Experiments can be done remotely, users can share information across the world, and they can achieve efficiency that had not existed before. Information becomes available much more quickly now with the globalization of business and the Internet."

Internet-based technologies will become the standard in test and measurement, said Jim Lico, president of Fluke Corp. "Wireless and Web capabilities, something our industry is only tinkering with at present, will become the standard, and portability will expand the universe of what we can measure and manage," Lico added.

Truchard predicts that the Internet — the most accessible method of communication — will have the biggest impact on this industry. "Communication technology will facilitate distribution of measurements and more wide use of measurements. You'll see more integration of measurements into our everyday activities." ■

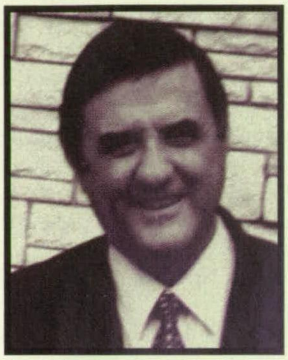


Fluke's Jim Lico: Portability will expand the universe of what we can measure and manage.

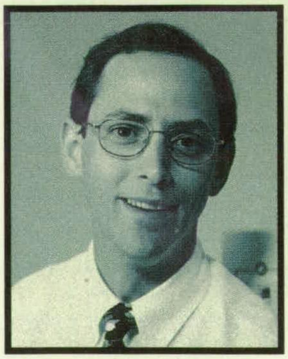


Peter Ostrow of TestMart believes the Internet will continue to drive down costs and increase productivity.

Photonics


Dr. Iulian Petrescu-Prahova of High Power Devices forecasts improvements in edge-emitting devices.


Spectra Physics' Steve Macomber sees a steady rise in semiconductor laser power in the next ten years.


Edmund Industrial Optics' John Stack sees a closer tie between optical component design and fabrication.

The factors at work in today's — and tomorrow's — fiber optics market relate principally to the quest for all-optical components and systems, taking the place of the hybrid optical-electronic instrumentation in the existing installations. In the decades to come, high-speed dense wavelength division multiplexing (DWDM) equipment will employ optical devices to do switching, and all-optical amplifiers will supplant the former reliance on electronic amplification.

Vertical-cavity surface-emitting laser (VCSEL) technology already is moving into broad areas of the industry, going beyond fiber optics, bringing along high beam quality and the capacity to be stacked side by side in two-dimensional arrays for transmitting multiple wavelength division multiplexing (WDM) channels over a single fiber. CoreTek of Burlington, MA, is working to combine VCSEL technology with microelectromechanical technology to achieve access of 1,800 different wavelengths over a 30-nm tuning spectrum.

At Spectra Physics, Steve Macomber, manager of semiconductor lasers research and development, and Alfred Feitisch, vice president and general manager of active telecommunications systems, see a bright future for semiconductor lasers in general. In terms of technology, they see the refinement of materials, structures, and process control steadily raising output power and reliability of semiconductor lasers over the next ten years and beyond. Automation and increased wafer-level integration also will enable commercialization of advanced designs, they predict. Gallium nitride lasers with blue output will affect optical storage, video, and data displays, and telecommunications needs will accelerate performance improvements of VCSEL and edge-emitter technology across the 1.2 to 1.7-micron wavelength regime, according to the Spectra Physics team.

Dr. Iulian Petrescu-Prahova, senior scientist at High Power Devices, also forecasts improvements in edge-emitting devices. "Power and brightness will continue to increase for single-mode, multimode, and multiple-stripe bar arrays, based on improvements in crystal quality, increased device length, and enhanced thermal management. Improved coherence will allow efficient and simple schemes for direct doubling. The basic wavelength range from 630 to 1260 nm will be extended to shorter wavelengths, into the ultraviolet. The next breakthrough will be reached when coherent arrays at the power level of present bars enter the market."

As for industrial lasers, Dave Clarke, president of Synrad, believes that, in the industrial laser market — cutting, marking and drilling — advances in laser technology will continue at a steady pace. But he has quite a different take on what one or two decades will bring. "I firmly believe that the major changes in the industrial laser market will come in the type of companies selling laser technology. In the past, companies owning the 'laser knowledge' have driven the marketplace. But with industrial lasers developing into commodity items — the example of the light bulb is often used — market and customer knowledge and sales and marketing channels will become more important," he said.

New materials processing methods using ultrafast lasers already are showing promising results. Ultrafast materials processing makes the machining of subwavelength feature sizes possible. Ultrafast amplifiers can be used to process a wide range of materials, including fused silica and steel, so there is likely to be a variety of ultrafast industrial lasers on the market tomorrow.

It is a notorious fact that much optical fabrication today relies upon techniques developed decades ago. John Stack, president of Edmund Industrial Optics, thinks that coming years will create forces for change. "In the future," he said, "optical component design and fabrication will be tied more closely together than ever before. The need to

Continued on page 106

completely understand the fabrication process while doing the design should lead to a component that will be efficient to fabricate, as well as optimized for the solution. The need to reduce costs and design and assembly times, and to increase the available volumes, links these two areas," he said.

"Making the integration of optical components by professional engineers of other than optical disciplines easier will increase the opportunities to design products around optical technologies," Stack continued. "The requirement to fit the components into real systems with real constraints demands that the designer understand and execute this goal the first time through. The ability to optimize the component with the illumination and ambient surroundings in the model is a must."

Kevin Thompson, vice president of optical engineering for Optical Research Associates, echoes Stack's concerns from a different angle. "Commercially viable computer-aided optical design is 25 years old this year. In that period, computers for optical design have become simultaneously ten-to-the-third-power faster and ten-to-the-third-power less expensive. Optical design, however, is a long way from real-time, accurate modeling and prediction of the performance of photonics systems," Thompson predicted.

"With products like LightTools bringing 3D visualization to complex geometries and CODE V providing accurate modeling of gradient index and birefringent materials, we are seeing the beginnings of a new paradigm for predicting the behavior of photonics systems before they are built in the laboratory," Thompson said. "In 25 years, the laboratory prototype may finally be a thing of the past." ■

Kevin Thompson of Optical Research Associates: In 25 years, the laboratory prototype may be a thing of the past.

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