November 1999

Vol. 23 No. 11

NASA

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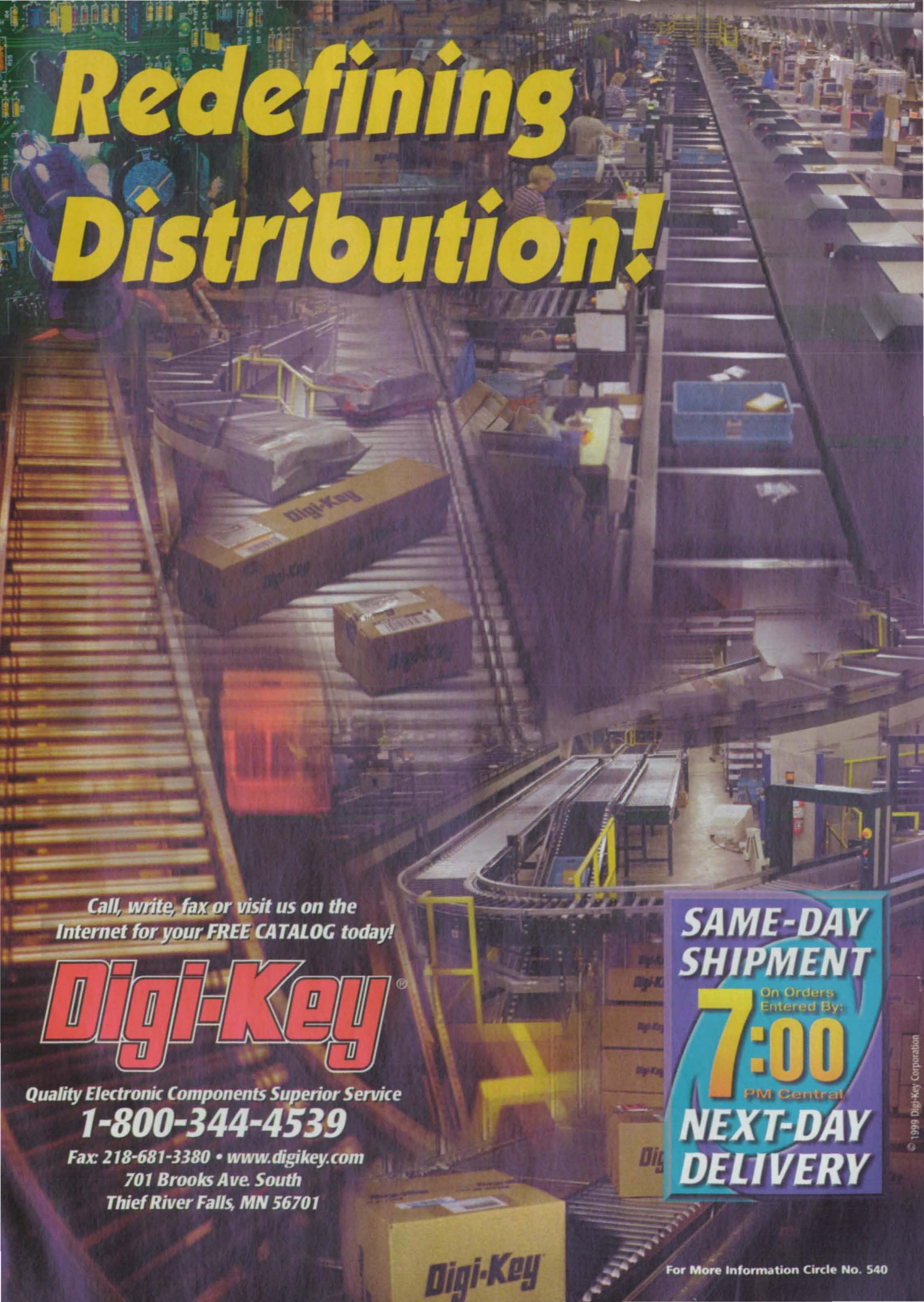
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FEATURES

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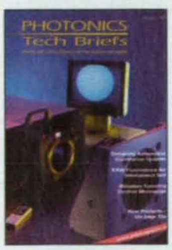
BRIEFS

DEPARTMENTS

SPECIAL SUPPLEMENTS



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PRODUCT OF THE MONTH

Invention Machine Corp.'s CoBrain™ Knowledge Processor creates a structured knowledge database from a variety of external sources.

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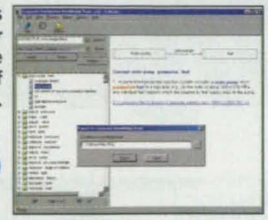

ON THE COVER

Parr Instrument Co. of Moline, IL, designs and manufactures glass pressure vessels and stirred reactors with magnetically coupled agitation. The company created this part with CADKEY® 99 mechanical CAD software from CADKEY Corp. of Marlborough, MA. Learn more about CADKEY 99, and other new software advances, in the Special Coverage on Design and Analysis Software beginning on page 24.

Image courtesy of Parr Instrument Co. and CADKEY Corp.

Standard mail enclosed in versions 2, 3A, 4, 5A, 6A, 7A, 8A

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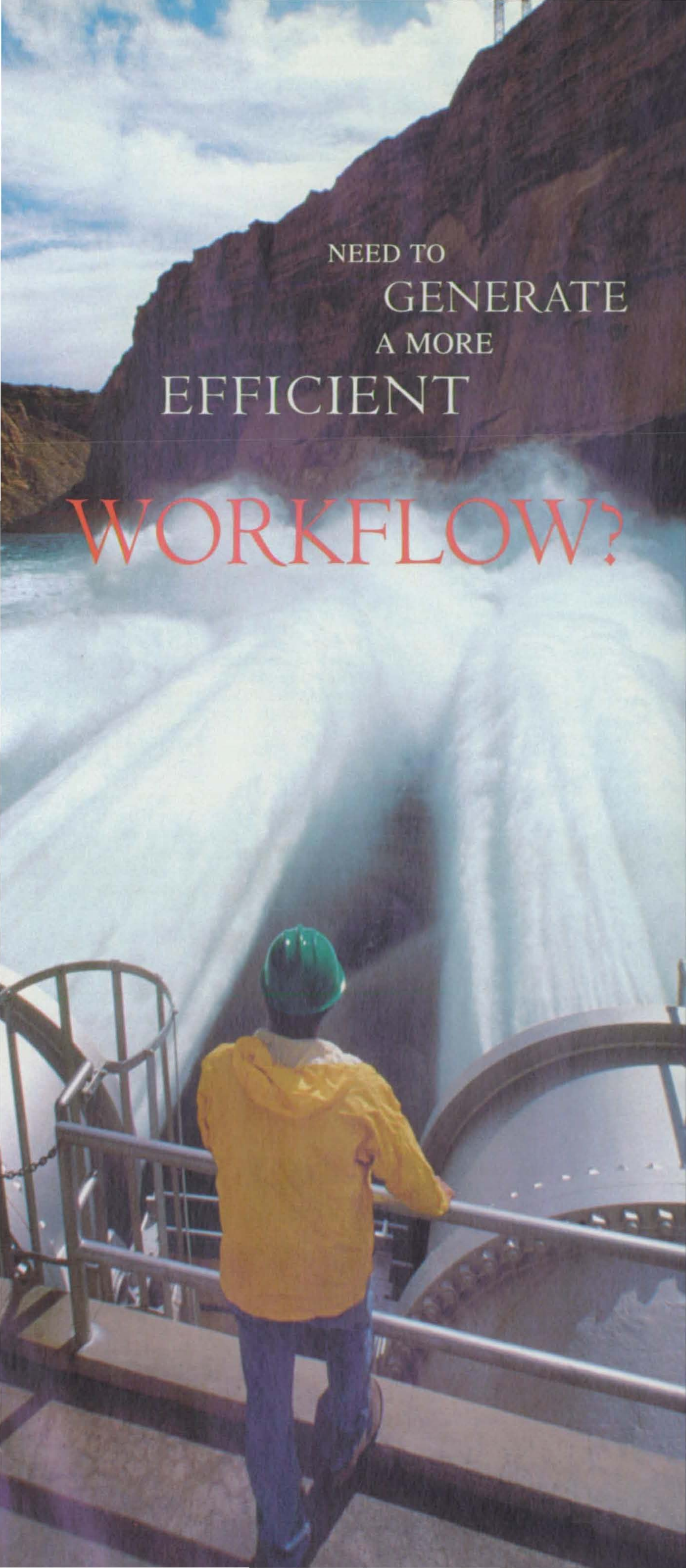

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NASA Commercial Technology Team

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: Fluid Dynamics; Life Sciences; Earth and Atmospheric Sciences; Information, Communications, and Intelligent Systems; Human Factors.
Carolina Blake
(650) 604-1754
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Dryden Flight Research Center
Selected technological strengths: Aerodynamics; Aeronautics Flight Testing; Aeropropulsion; Flight Systems; Thermal Testing; Integrated Systems Test and Validation.
Lee Duke
(805) 258-3802
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Goddard Space Flight Center
Selected technological strengths: Earth and Planetary Science Missions; LIDAR; Cryogenic Systems; Tracking; Telemetry; Command.
George Alcorn
(301) 286-5810
galcorn@gsfc.nasa.gov

Jet Propulsion Laboratory
Selected technological strengths: Near/Deep-Space Mission Engineering; Microspacecraft; Space Communications; Information Systems; Remote Sensing; Robotics.
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merle.mckenzie@ccmail.jpl.nasa.gov

Johnson Space Center
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Hank Davis
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hdavis@gp101.jsc.nasa.gov

Kennedy Space Center
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Gale Allen
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gale.allen-1@ksc.nasa.gov

Langley Research Center
Selected technological strengths: Aerodynamics; Flight Systems; Materials; Structures; Sensors; Measurements; Information Sciences.
Dr. Joseph S. Heyman
(757) 864-6006
j.s.heyman@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.
Sally Little
(256) 544-4266
sally.little@msfc.nasa.gov

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

NASA-Sponsored Commercial Technology Organizations

These organizations were established to provide rapid access to NASA and other federal R&D and foster collaboration between public and private sector organizations. They also can direct you to the appropriate point of contact within the Federal Laboratory Consortium. To reach the Regional Technology Transfer Center nearest you, call (800) 472-6785.

Joseph Allen
National Technology Transfer Center
(800) 678-6882

Ken Dozier
Far-West Technology Transfer Center
University of Southern California
(213) 743-2353

Dr. William Gasko
Center for Technology Commercialization
Massachusetts Technology Park
(508) 870-0042

J. Ronald Thornton
Southern Technology Applications Center
University of Florida
(352) 294-7822

Gary Sera
Mid-Continent Technology Transfer Center
Texas A&M University
(409) 845-8762

Lani S. Hummel
Mid-Atlantic Technology Applications Center
University of Pittsburgh
(412) 383-2500

Chris Coburn
Great Lakes Industrial Technology Transfer Center
Battelle Memorial Institute
(440) 734-0094

NASA ON-LINE: Go to NASA's Commercial Technology Network (CTN) on the World Wide Web at **http://nctn.hq.nasa.gov** to search NASA technology resources, find commercialization opportunities, and learn about NASA's national network of programs, organizations, and services dedicated to technology transfer and commercialization.

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.

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Roger Crouch
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rcrouch@hq.nasa.gov

Granville Paules
Office of Mission to Planet Earth (Code Y)
(202) 358-0706
gpaules@mtpe.hq.nasa.gov

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.

Wayne P. Zeman
Lewis Incubator for Technology
Cleveland, OH
(216) 586-3888

B. Greg Hinkebein
Mississippi Enterprise for Technology
Stennis Space Center, MS
(800) 746-4699

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

Marty Kaszubowski
Hampton Roads Technology Incubator (Langley Research Center)
Hampton, VA
(757) 865-2140

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.

Reader Forum

Reader Forum is devoted to the thoughts, concerns, questions, and comments of our readers. If you have a comment, a question regarding a specific technical problem, or an answer to a question that appeared in a recent issue, send your letter to the address below.

I work with a 3/16" carbon steel tank top located next to LaGuardia Airport in New York City. It is exposed to a salt air, semi-harsh weather environment. The tank top was painted more than 20 years ago with a zinc-rich primer and top coat paint. This coating failed eight years ago, and the tank top was then painted with a Mathys coating (elastomeric). This is showing signs that it is approaching the end of its life. What is the experience of others in painting/coating steel surfaces in such an environment? I am looking for recommendations. Thank you.

Edwin P. Jakubowski
jakubowskie@ConEd.com

Your August issue featured a tech brief on FoilSim software from NASA's Glenn Research Center (page 32). The software teaches students about airfoils, and helps them perform simulated flow experiments. I'm interested in obtaining a copy of FoilSim for my 12-year-old son, who is interested in aerodynamics. How can I find it?

Larry Morton
L_Morton@pacbell.net

*(**Editor's Note:** Larry, you can download FoilSim through NASA's John H. Glenn Research Center's web site at: http://www.grc.nasa.gov/Other_Groups/K12/aerosim/.)*

I'm a project engineer for a company that makes recreational vehicles such as snowmobiles, personal watercraft, and all-terrain vehicles. For a two-stroke engine, the exhaust pipe is a very important part of how the engine performs. I volume-check a certain percentage of the exhaust pipes by filling the pipe with tap water and weighing the pipe. This gives me the volume of water displaced. Is it possible to check the volume of a pipe by using frequency? Does the frequency change if the volume gets bigger or smaller? Thanks for any information you can provide.

Dan Johnson
Djohnjohnson@hotmail.com

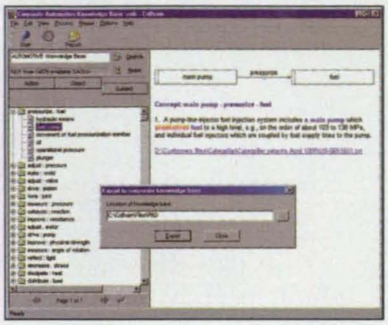
Does anyone have any information on colored lamps for use in high-power applications? We have done tests with several types of colored coatings, but none passed the illumination requirements. We are looking for red, green, blue, and amber lights. Thanks.

Quinton Beyer
qbeyer@worldnet.att.net

Post your letters to Reader Forum on-line at: www.nasatech.com or send to: Editor, *NASA Tech Briefs*, 317 Madison Ave., New York, NY 10017; Fax: 212-986-7864. Please include your name, company (if applicable), address, and phone number or e-mail address.

UpFront

PRODUCT OF THE MONTH

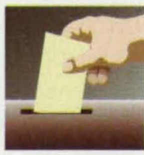


CoBrain™ knowledge processing software from Invention Machine Corp., Boston, MA, allows users to semantically process large numbers of electronic documents from diverse information sources to create a structured corporate knowledge base. CoBrain enables users to capture and process electronic information from internal and external sources, including research reports, patents, conference proceedings, and technical journals. It extracts and presents an index of technical documents displayed in a problem-solution format that enables users to find solutions to engineering and scientific problems. A description of each solution listed in the index is displayed, as well as a direct link to its corresponding source document. The semantic processing technology used analyzes large volumes of text to determine the interaction between words and the meanings of word combinations, divides the content into sentences, and analyzes the sentences according to meaningful functions based on subject, action, and object.

For More Information Circle No. 756

A Century of Innovation

What do you consider the most important technological development of the 20th century? What innovation has had the greatest impact on our society and economy in the past 100 years? Cast your vote for the "Technology of the Century." From the transistor, the integrated circuit, and the laser, to the jet engine, rockets, satellite, and medical advances such as the CAT scan and the polio vaccine, the century has been dominated by technological breakthroughs. Vote for your choice at http://www.nasatech.com/totc/. When you vote, we'll enter your name into a drawing to win free NASA T-shirts. Vote today — the deadline is December 1, 1999. We'll publish the results in January — our first issue of the new century!



Pick the Product!

Next month's issue will include your Readers' Choice Product of the Year ballot. This is your chance to vote for the most innovative product of 1999 — and to win some valuable prizes, too!

Vertical Flight Takes Off

It's the year 2025. Dozens of miniature robotic helicopters measuring only two to three inches in size dart about as you head toward your personal roto-mobile to begin your commute to work. Science fiction? Not according to a group of visionary scientists and engineers at NASA's Ames Research Center in California. Ed Aiken, chief of the Army/NASA Rotorcraft division at Ames, explained that there will be "a significant market potential for two very different classes of vertical flight vehicles: ultra-small-scale vehicles operating autonomously, and larger-scale, 'user-friendly' vehicles capable of carrying a significant payload."

NASA sees enormous potential for miniature robotic rotorcraft, including atmospheric sensing, stealthy urban warfare surveillance, immigration, drug enforcement, and public safety. There also is potential for personal roto-mobiles, which could be built for one or two passengers, have the ability to take off and land vertically, and may be operated autonomously or with car-like controls. These vehicles could be used by the military to bypass land mines, blocked roads, impassable areas of water, or for search and rescue operations.

NASA Ames recently signed a Non-Reimbursable Space Act Agreement with Millennium Jet of Santa Clara, CA, to cooperate in the development of the SoloTrek Exo-Skeletor Flying Vehicle, a one-person air scooter. NASA will support the company's efforts in engineering, technology, and testing.

Michael Moshier, founder and CEO of Millennium Jet, is positioned in the SoloTrek XFV (Exo-Skeletor Flying Vehicle) personal roto-mobile. The company has begun its initial test phase after a three-year development program.

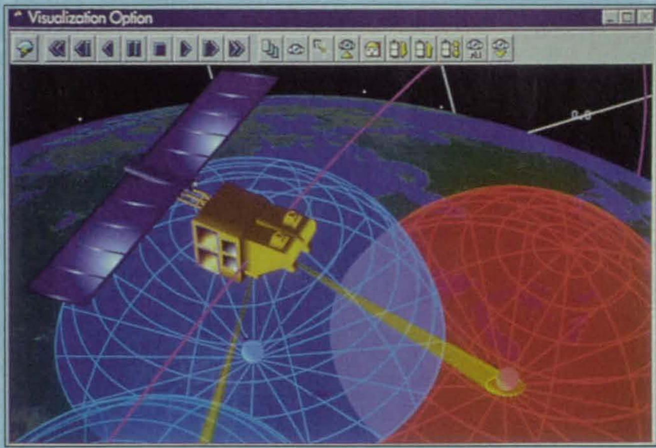
Aiken cautioned that several obstacles still need to be overcome. "The whole concept of miniature flying vehicles is in its infancy," Aiken said. "The concept of the mini-robo-rotorcraft can only become reality once these miniature vehicles are accepted by the public as being of significant value in improving the quality of life."

For more information, contact the NASA Ames Public Affairs Office at: http://ccf.arc.nasa.gov/dx, or phone 650-604-3937.

Application Briefs

Satellite Software Assists Chandra Telescope Project

Satellite Tool Kit (STK)® satellite analysis software
Analytical Graphics
Malvern, PA
610-578-1000
www.stk.com



The $1.3-billion Chandra X-Ray Telescope was launched recently from the Space Shuttle, and is the world's most powerful x-ray telescope. Its mission is to allow scientists to monitor cosmic events that are invisible to conventional optical telescopes. Chandra's images are expected to yield new insight into celestial phenomena such as the temperature and extent of gas clouds that comprise clusters of galaxies, and the superheating of gas and dust particles as they swirl into black holes.

NASA used STK during the mission's design and development, and it is expected to play a crucial role in orbit-transfer operations. The Chandra mission control center uses STK/Visualization Option (STK/VO) as a real-time, 3D visualization display to aid in orbit transfer. After the telescope reached operational orbit, the Chandra mission operations center continues to use the software to aid in mission operations throughout the life of the spacecraft.

STK was chosen by Lockheed Martin in June as part of its solution for NASA's Consolidated Space Operations Contract (CSOC), a program valued at more than $3 billion over ten years that will provide NASA with an infrastructure for space operations into the 21st century.

For More Information Circle No. 742

Metal Seal Helps Keep Space Shuttle Safe

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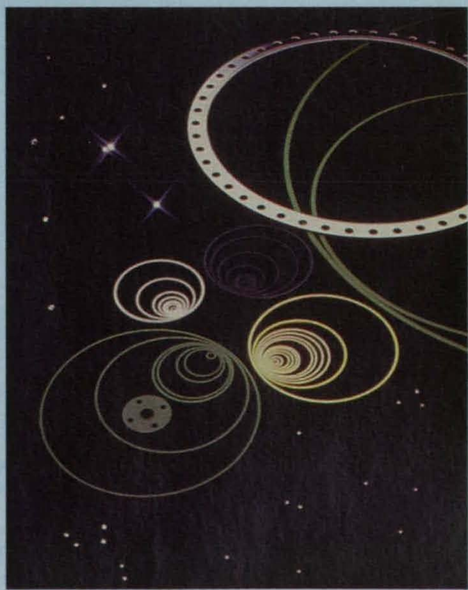


Imagine temperatures reaching 1,347°F. Now imagine the challenge of achieving hermetic sealing at those temperatures — far beyond the capability of rubber or plastic gaskets. Add to that pressures that soar to 7,900 psi. Those are the challenges faced on the hydrogen fuel pump of the Space Shuttle when the main engines fully engage. But thanks to advances in metallurgy, seals made of metallic alloys have proven to be the solution.

Pratt & Whitney Space Propulsion in West Palm Beach, FL, chose metal seals and bellows made by Hydrodyne to meet the critical needs of the Space Shuttle Main Engine (SSME) project. According to Mike Paytas, a development engineer for Pratt & Whitney, NASA needed seals for the turbine housing on the fuel pump side. "The pressures generated were in the thousands of pounds psi, and the metal seals were able to handle it safely. We had them design and manufacture some 'W' seals and bellows."

The choice of material for a metal seal or bellows is based on compatibility with the system fluid and temperatures. Hydrodyne uses, among other materials, Inconel 718, a nickel-chrome alloy, and Rene 41/Waspaloy. Each metal seal has a coating, which is dependent upon the required degree of plasticity. Teflon is a commonly used coating; gold is used for extreme temperatures such as those reached when the shuttle main engines are fired. "We are now looking at Hydrodyne's metal seals for our jet engine side," said Paytas.

For More Information Circle No. 741

Commercialization Opportunities

Tunable, Frequency-Stabilized Diode-Pumped Tm,Ho:YLF Laser

This laser has been demonstrated to operate at a single frequency and to be both tuned and stabilized in frequency. Potential applications are in lidar systems, laser diagnostics, and fiber-optic communication and instrumentation systems.
(See page 38.)

Tailoring Fiber/Matrix Interfaces Through Kirkendall Defects

In a proposed method, fibers would be coated with an element that diffuses readily in the matrix material. Other coatings could be applied either below or above the diffusible layer to further enhance the overall properties of the composite.
(See page 48.)

Composite-Fuselage Concept for Greater Crashworthiness

A design has emerged that calls for a structure made from several glass/epoxy-fabric and graphite/epoxy-fabric laminates plus some other materials. Data from drop tests indicate that a model with a foam subfloor satisfied the impact design requirements.
(See page 51.)

Force-Reflecting, Finger-Position-Sensing Mechanism

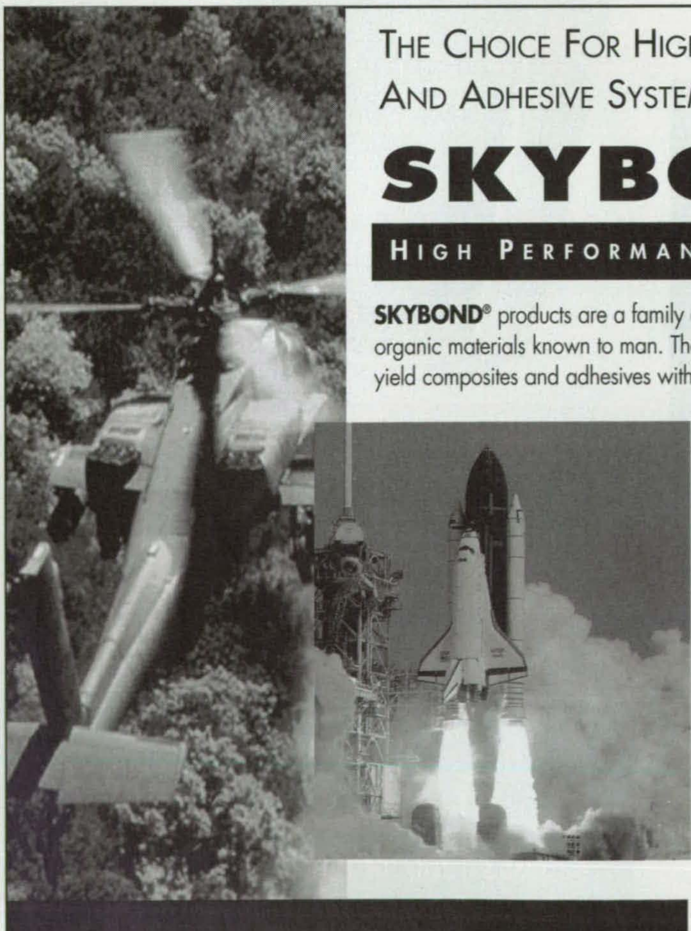
This device called "Dexterous Master" is an exoskeletal mechanism that is worn on a human operator's hand for measuring the positions of fingers relative to the palm and applying feedback forces from a remote robotic manipulator. The design makes it unnecessary to encumber each finger joint with hardware.
(See page 55.)

Loop Heat-Pipe Evaporator With Bidisperse Wick Structures

Improved wick structure helps prevent vapor blanketing that can limit heat-flux capacities to unacceptably low values. Loop heat pipes equipped with the improved wicks have demonstrated good performance at evaporator-wall heat-flux densities up to 100 W/cm^2.
(See page 59.)

Insectile and Vermiform Exploratory Robots

Biomorphic robots are proposed that would be small, mobile, contain microsensors, and feature animallike adaptability and mobility. There are many hazardous applications where they can be deployed. For example, the six-legged variety could be used to search for antipersonnel mines, whereas the legless variety could burrow in earthquake rubble to search for survivors.
(See page 61.)




Books & Reports

Two-Spacecraft Laser Tracking for Detecting Gravitational Waves

A paper proposes a method of mutual coherent laser tracking of two spacecraft for detecting gravitational radiation. Each spacecraft would transmit a laser beam to, and receive a similar laser beam from, the other spacecraft. Each spacecraft would also coherently transpond a laser beam back to the other spacecraft. Comparison of the phases of the various transmitted and received signals would yield four sets of tracking data — two sets of one-way and two sets of two-way Doppler shifts that could be partly attributable to gravitational waves. The data would be time-tagged and telemetered back to Earth for analysis.

This work was done by Massimo Tinto of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "Spacecraft to Spacecraft Coherent Laser Tracking as a Xylophone Interferometer Detector of Gravitational Radiation," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

NPO-20501

Digital PIV Measurements of Flow in a Centrifugal Compressor

A report describes experiments in which digital particle-image velocimetry (digital PIV) was used to measure the flow field in the diffuser of a high-speed centrifugal compressor. In digital PIV, a sheet of pulsed laser light illuminates a flow field seeded with small tracer particles, the positions of the particles are recorded on a digital charge-coupled-device (CCD) camera at each pulse time, and the digitized image data are processed to extract velocities from the displacements of particles between pulses. In the experiments, a special periscope probe was used to introduce the light sheet into the flow plane of interest inside the compressor. Measurements were obtained while the compressor ran at design speed, yielding highly accurate time-averaged velocity-vector maps in much less time than is needed to generate comparable maps by use of laser Doppler velocimetry (LDV).

This work was done by Mark P. Wernet of **Glenn Research Center**. *To obtain a copy of the report, "Digital PIV Measurements in the Diffuser of a High Speed Centrifugal Compressor," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics 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-16878.

Low-Energy Interplanetary Transfers Using Lagrangian Points

A paper summarizes early findings from a continuing study of the dynamics of the transport and distribution of matter within the Solar system. In the study, the stable and unstable manifolds of the periodic and quasi-periodic orbits around the Lagrangian points L1 and L2 of the Sun/planet and planet/Moon subsystems are found to play an important role. (The Lagrangian points are five points, located in the orbital plane of two massive bodies, where a much less massive body can remain in equilibrium relative to the massive bodies.)

This work was done by Martin Lo and Shane Ross of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the paper, "Low Energy Interplanetary Transfers Using the Invariant Manifolds of L1, L2, and Halo Orbits," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category.*

NPO-20377

Telescope/Camera Systems Based on Inflation-Deployed Optics

A report proposes the development of spaceborne telescope/camera systems that would be lightweight, relatively inexpensive alternatives to current systems based on glass mirrors. In a system of the proposed type, the primary reflector (typically a paraboloid several meters in diameter) would be of the membrane-mirror type. The primary reflector would be part of a folded, closed, flexible structure that would be deployed by inflation, then depressurized after being rigidified in the deployed condition. Because the primary reflector would only approximate the required precise reflector surface and because deviations from the required surface would vary with thermal, solar-wind, and microgravitational conditions, the system would also include a two-stage active optical subsystem that would correct wavefront errors in real time.

This work was done by James Breckinridge, Marjorie Meinel, Aden Meinel, and James Bilbro of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Inflation-Deployed Camera," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

NPO-20405

Sun Shields for the Next Generation Space Telescope

A report discusses the design of inflatable Sun shields proposed for use in keeping the primary mirror of the Next generation Space Telescope (NGST) at a temperature ≤60 K. The report summarizes a paper presented at the 33rd Intersociety Energy Conversion Engineering Conference in August 1998 at Colorado Springs, Colorado. The proposed shields would include six parallel layers of thin aluminized polyimide film separated by gaps wide enough to ensure against contact. The layers would be radiatively isolated from each other. The proposed shields would weigh 247 kg less than those of an older proposed design involving multilayer insulation with 10 inner layers, or 388 kg less than those of another older proposed design involving multilayer insulation with 18 inner layers. Relative to the shields of both older designs, the proposed shields would also offer advantages of simplification of packaging, simplification of mechanical structure, and less dependence of telescope temperature on a poorly adherent thermal coating on the Sun side of the outer shield layer.

This work was done by Michael K. Choi of **Goddard Space Flight Center.** *To obtain a copy of the report, "A Practical Thermal Design Concept for Next Generation Space Telescope Sunshield," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

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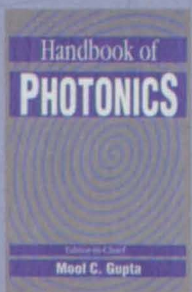

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Technology Forecast

This month's technology forecast for the design and analysis software industry is contributed by Michael L. Bussler, President and CEO of ALGOR, Inc., Pittsburgh, PA. Michael shares his views on the continued evolution of design and analysis software into the next century.

Beginning in the late 1990s, the computer-aided engineering (CAE) software industry began an evolution of products to include CAD/CAE interoperability tools for working with CAD solid parts and assemblies. At the same time, efforts began to integrate finite element stress and kinematic analysis capabilities. In the year 2000 and beyond, these trends will continue, accompanied by shifts in focus to precision finite element modeling and the simulation of multiple, dynamic physical phenomena in a WYSIWYG environment. Such shifts will enable engineers to create more accurate design representations and replicate the dynamic behavior of a product for more reliable virtual testing using just one engineering software product.

Product Design and CAD Solid Models

With the lack of large government engineering initiatives like "Star Wars" in the 1980s, and the automotive emissions crisis in the 1970s, the engineering profession is focusing on refining existing product design cycles instead of designing new products. The CAD solid model has been the focus of refinement efforts because it provides a central Product Data Management point for the entire manufacturing process.

The ideal engineering software enables engineers to maintain the same CAD solid geometry throughout the entire product design cycle, from design conception to manufacture. The continued development of CAD/CAE interoperability tools is key to achieving this ideal CAE product.

Many CAD/CAE interoperability enhancement efforts have evolved through partnerships between CAE software producers and makers of mid-range CAD solid modelers. Through these partnerships, CAE producers provide a limited subset of analysis capabilities that can be run within the CAD system application programming interface through add-in menu commands. ALGOR has taken a slightly different approach with its InCADPlus family of products, which enables engineers to perform all CAD/CAE interoperability, finite element modeling, analysis, and simulation functions from within the CAD solid modeler. More importantly, InCADPlus captures the exact CAD part or assembly in ALGOR without file translation, whether or not CAD and ALGOR reside on the same computer. In addition, InCADPlus works the same for all CAD solid modelers, providing flexibility in today's multi-divisional, multi-system engineering environment, which often requires CAD and FEA professionals in different departments and locations to collaborate.

Michael L. Bussler, President and CEO, ALGOR, Inc.

Accurate Product Representation

Retaining the detail of CAD solid models in finite element modeling is critical to incorporating CAE products more tightly into the product design cycle. In the past, much focus has been placed on feature suppression, or "defeaturing," which eliminates small features from the CAD solid model to enable faster, or "quick and dirty," solid finite element meshing.

In the year 2000 and beyond, less emphasis will be placed on simplification and more emphasis will be focused on the accurate representation of products through the retention of CAD solid model features. As product design processes remain centered around refinement, manufacturers will realize that the elimination of even small features in the finite element model can result in less than accurate stress results. This can translate into design failure, requiring more physical prototype testing and machining costs, and therefore, longer, more expensive times-to-market.

The development of faster, more precise finite element modeling capabilities will enable the accurate representation and reliable testing of a product on a computer. CAE producers will strive to improve current solid meshing capabilities to include the creation of hybrid FEA solid meshes. Hybrid meshes consist of brick elements on the model surface with tetrahedral elements in the model interior. With hybrid meshes, engineers can combine the accuracy of eight- or 20-node brick elements with the speed of tetrahedral elements. In addition, engineers will replace plate elements with thin brick elements to represent slender components of CAD parts or assemblies as the algorithms for solving brick element formulations become more robust. As always, these finite element modeling advances will be boosted by improvements in computer computation speeds.

(continued on page 26)

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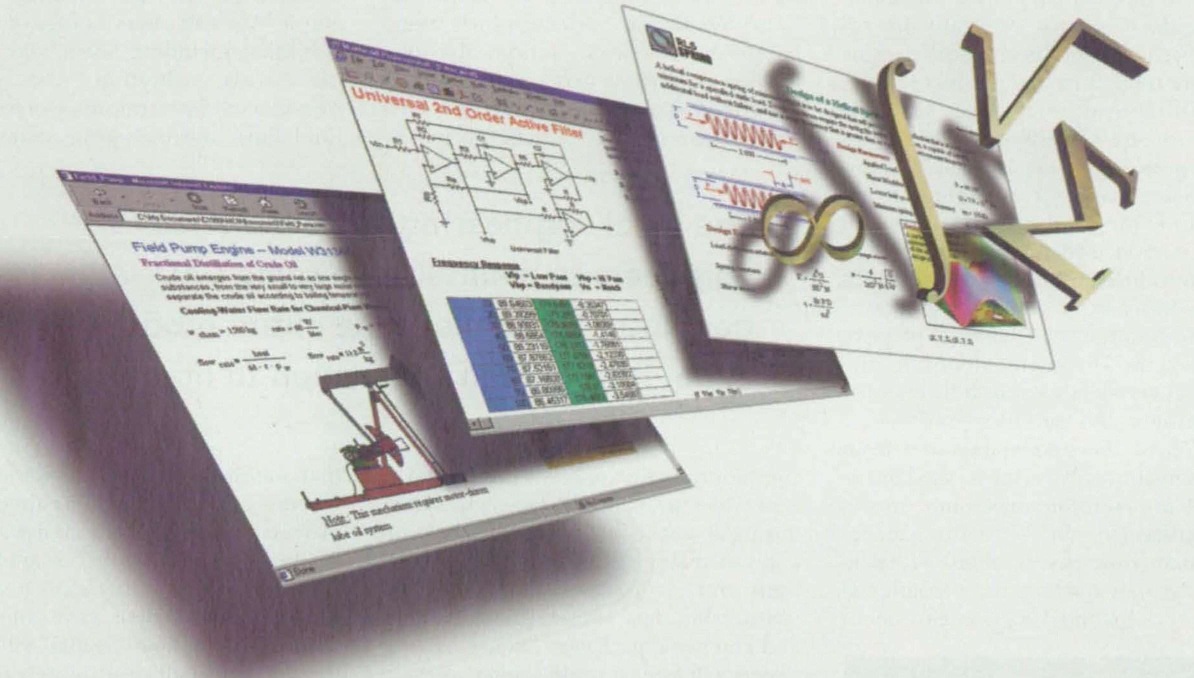

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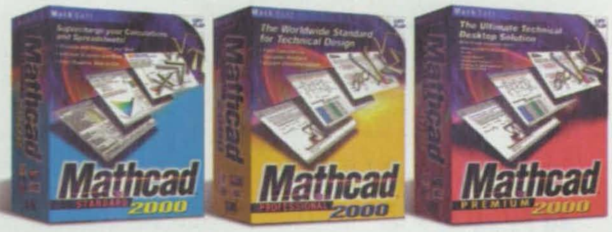

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For More Information Circle No. 502

Replicating Dynamic Behavior

The accurate representation of a design is just a small part of the challenge to provide tools that replicate the dynamic behavior of mechanical designs for more reliable virtual product testing. The widespread integration of kinematic and stress analyses is expected to continue as engineers become increasingly aware that static environments do not exist in the physical world. A process called motion load transfer already has been introduced in the engineering software industry to address this issue.

In the motion load transfer process, engineers use kinematic software to simulate rigid-body motion in fully coupled mechanisms and produce forces over time. Then, the maximum force from the kinematic analysis can be used in static FEA to determine maximum stresses at one instant in time. While this is an improvement over past methods of calculating dynamic loading, the method still relies on an assumed static environment for stress determination. Many CAE producers soon will develop a solution similar to ALGOR's Accupak/VE Mechanical Event Simulation software, which simultaneously simulates motion, dynamic loading and flexing to determine stresses in parts of an assembly of interconnected components during a virtual "event." By combining stress analysis with dynamics, it provides stress results for each instant during an event, and eliminates the difficulty of manipulating stand-alone solutions and errors that can result when transferring data between separate FEA and kinematic packages. Many CAE producers will soon provide similar software tools that offer WYSIWYG environments, which let engineers examine the behavior of the entire mechanical system without physically building a prototype.

As stress analysis and motion simulation are combined, design and analysis software producers will incorporate more sophisticated contact capabilities between separate components, including surface-to-surface contact and sliding friction contact. Software also will include more sophisticated simulation capabilities for flexible-body motion. ALGOR recently invented actuator element technology, which enables engineers to mimic multi-directional expansion and retraction movement over time that is common in such components as solenoids and hydraulic pistons.

In addition to the integration of stress and kinematic analyses into one software product, the consideration for a wider range of physical phenomena — including changes in temperature, fluid flow, electrostatics, and fluid-object interaction — is necessary to accurately portray the physical behavior of a product in its natural environment. Stress caused by motion is not the only way that failure can occur. For example, pressures, significant temperature gradients, or the flow of fluids such as water or air against an object also can induce forces, which can result in motion and stress.

The ideal engineering software enables engineers to maintain the same CAD solid geometry throughout the entire product design cycle, from design conception to manufacture.

Many CAE software producers already offer analysis capabilities for handling multiple physical phenomena. For example, ALGOR offers a range of FEA capabilities, including linear and nonlinear stress, vibration and natural frequencies, heat transfer, electrostatics, fluid flow, and composite materials so that multiple physical phenomena can be considered on the same model — a process known as multiphysics analysis. In the future, multiphysics analysis capabilities will be more tightly integrated into a single analysis environment. In addition, design and analysis software in the future will more accurately simulate the behavior of a more diverse set of materials as additional information on material properties becomes available.

One Consolidated Product

In the near future, additional engineering software products accurately will represent product designs, using the exact CAD solid model geometry with little or no feature suppression. CAE products will further replicate and optimize the dynamic physical behavior of product designs, reducing or even eliminating the need for laboratory testing. Furthermore, PCs with Windows NT processing systems will continue to dominate the engineering field; CAD solid modelers will become even more user-friendly, universal, and inexpensive; and CAD/CAE interoperability tools will proliferate.

These variables will enable FEA software products to become more tightly integrated into the product design cycle, with engineers performing more FEA with CAD solid models. The evolution of design and analysis software toward a singular but multi-faceted product will continue as manufacturers further refine the product design cycle.

For more information, contact ALGOR, Inc., 150 Beta Drive, Pittsburgh, PA 15238-2932; Tel: 412-967-2700; info@algor.com.

Special Coverage: Design and Analysis Software

Computer Program for Analysis of Convective Heat Transfer

Convective heat transfer is calculated without wall functions.

John H. Glenn Research Center, Cleveland, Ohio

Glenn-HT is a computational fluid dynamics (CFD) computer code for the analysis of three-dimensional flow and convective heat transfer in a gas turbine. Glenn-HT has been evolving during the past few years at Glenn Research Center, and at least 35 technical papers relative to this code have been published. The code is unique in the ability to give highly detailed representations of flow fields very close to solid surfaces. This ability is necessary for obtaining accurate representations of fluid heat transfer and viscous shear stresses.

The computation of convective heat transfer in a gas-turbine environment is a very difficult task, but one that must be done with reasonable accuracy in order to design a durable engine. Three-dimensional CFD computer codes are used extensively to determine pressure distributions in turbines, but the determination of heat transfer is a much more complex problem, in which it is necessary to consider details of flow fields very close to solid walls. Glenn-HT has been specifically developed to address this issue. The unique feature of this code is the use of a multiblock grid system that enables the use of high-quality grid structures very close to walls, eliminating the need for wall functions for calculating heat transfer. A conventional aspect of the code is the inclusion of a two-equation k–ω model (a k–ω model is a mathematical model of turbulence in which k denotes the turbulent kinetic energy, while ω denotes the fractional rate of dissipation of the k).

The code has been used extensively to perform cooling-passage-flow and hot-gas-path-flow calculations, including detailed calculations of film cooling and of complex tip-clearance-gap flow and heat transfer. The code has been validated for a number of turbine configurations. Although developed and used primarily as a research tool, the code should be useful for detailed design analysis.

This work was done by James D. Heidmann of **Glenn Research Center**, *Ali A. Ameri and Vijay K. Garg of AYT Corp., David L. Rigby of NYMA/Dynacs, and Erlendur Steinhorsson of OAI.*
LEW-16765

Five Computer Codes for Analysis of Turbomachinery

These codes can be used separately, or together in sequence.

John H. Glenn Research Center, Cleveland, Ohio

A suite of five computational fluid dynamics (CFD) codes has been developed for analysis of flows in turbomachinery. Two of the codes are used to generate two-dimensional (2-D) or three-dimensional (3-D) grids that describe the turbomachinery blade geometry. The other three codes solve the Navier-Stokes equations on those grids to predict the performance of the blades. Three mathematical models of turbulence that include effects of flow transition and roughness are available. The codes are applicable to fans, compressors, and turbines in both axial and radial machines.

The codes include the following:

- GRAPE (Grids About Airfoils Using Poisson's Equation) generates a two-dimensional blade-to-blade periodic grid. GRAPE is used with RVCQ3D, which is described next.
- RVCQ3D (Rotor Viscous Code Quasi-3-D) is a code for quasi-3-D blade-to-blade analysis that includes the effects of rotation, change of radius, and variable stream surface thickness.
- TCGRID (Turbomachinery C-Grid) generates a 3-D grid used with RVC3D and SWIFT, which are described next.
- RVC3D (Rotor Viscous Code 3-D) is a code for 3-D analysis of isolated blade rows.
- SWIFT is a code for 3-D, multiblock analysis that affords grid capabilities additional to those of RVC3D, including the ability to model tip-clearance flows and multistage turbomachinery.

The codes can be used independently but often are used in sequence. RVCQ3D is used to investigate many design parameters quickly in two dimensions, RVC3D is used to predict the performance of isolated blade rows, and SWIFT is used to study a 3-D blade in more detail or in a multistage environment.

RVCQ3D, RVC3D, and SWIFT solve finite-difference approximations of equations of flow by use of an explicit Runge-Kutta scheme. A spatially variable time step and implicit residual smoothing are used to accel-

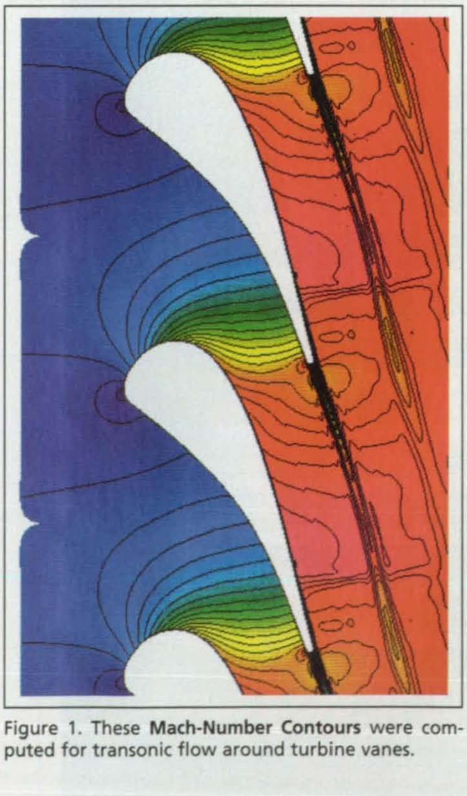

Figure 1. These **Mach-Number Contours** were computed for transonic flow around turbine vanes.

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Figure 2. These **Pressure Contours** were computed for a transonic compressor stage.

erate convergence. Preconditioning can also be performed for low-speed (incompressible) flows.

The codes have been verified with respect to transonic flow around turbine vanes (see Figure 1) and with respect to a transonic compressor stage (see Figure 2). They have also been used to analyze many fan blades, the fuel turbine for the space shuttle main engine, wind-tunnel turning vanes, centrifugal compressors, and a vacuum-cleaner impeller.

The codes are written in Fortran and can be compiled and run on most computers. Blade data are entered by use of a common Glenn Research Center design-code format. Simple namelist input is used for flow parameters. Some printed output is generated. No graphical output is provided, but grid and solution files are in a standard format that can be read directly by most CFD visualization software packages, including FAST and PLOT3D.

This work was done by Rod Chima of **Glenn Research Center**. *Details about the individual codes and sample results may be found on the author's web site, www.grc.nasa.gov/WWW/5810/webpage/rvc.htm.*

For further information, access the Technical Support Package (TSP) ***free on-line at www.nasatech.com*** *under the Mechanics category.*

LEW-16851

Software for Probabilistic Thermal and Structural Analysis

This program is expected to help improve designs of major turbine-engine components.

John H. Glenn Research Center, Cleveland, Ohio

NESTEM is a computer code that is a combination of a heat-transfer-analysis subprogram and a NASA in-house probabilistic-analysis code called "NESSUS" (for Numerical Evaluation of Stochastic Structures Under Stress). NESTEM can be used to analyze a complex combustor thermal environment with uncertainties and to assess the effects of the environment and the uncertainties on the overall responses of components. NESTEM is expected to help in the development of a comprehensive probabilistic methodology for reliable and robust design of such major turbine-engine components as compressors, turbines, impellers, and combustors.

Prior to the development of NESTEM, there was no known program that afforded a capability for perturbing such heat-transfer variables as thermal conductivities of materials, convection coefficients, and radiation temperatures. NESTEM enables one to perform a formal assessment of uncertainties in loads,

variations in properties of materials, and geometric imperfections on the overall structural behavior (as characterized by stability parameters, frequencies, stresses, and other parameters).

In addition to enabling probabilistic heat-transfer analysis, NESTEM makes it possible to generate mathematical models of components by use of selected modules from the NASA in-house Composite Blade Structural Analyzer (COBSTRAN) computer code. Furthermore, the material-property parameters needed to represent ceramic-matrix composites are obtained by use of the NASA in-house Ceramic Matrix Composite Analyzer (CEMCAN) code.

This work was done by B. M. Patel of Modern Technologies Corp. for **Glenn Research Center.**

LEW-16788

A 3D Navier-Stokes CFD Code for Analysis of Turbomachinery

This code can be used to model complex, multiple-path flows.

John H. Glenn Research Center, Cleveland, Ohio

The ADPAC software is a computational fluid dynamics (CFD) code for analysis of flows in turbomachines. The outstanding feature of ADPAC is the ability to solve the Navier-Stokes equations for complex three-dimensional (3D) flow fields that include multiple flow paths, and the modeling of which typically involves multiple computational grid blocks. In addition, ADPAC can handle coupled calculations in which some portions of models are rotating and some are not, as in the case of the rotating blades and stationary vanes of a turbomachine. ADPAC was developed especially for use in analyzing the performances of short-duct, ultrahigh-bypass-ratio turbofan engines, both as uninstalled and as installed; however, ADPAC is applicable to a very broad range of other turbomachines and of other flow systems.

There are now several commercially available computer programs that offer capabilities similar to those of ADPAC. However, when the development of ADPAC began (circa 1989) 3-D Navier-Stokes CFD codes for turbomachinery could handle only single flow paths, and only a few codes could handle more than one component at a time. NASA had a need for a CFD code that could simultaneously handle multiple flow paths (through the core, through the bypass duct, and outside the cowl), multiple blade rows, and tightly coupled components of conceptual ultrahigh-bypass-ratio turbofan engines. Prior to the development of ADPAC, computational simulations of such complex flow fields were done in parts: In a typical case, each flow path and each blade row was split out, gridded, and run separately. Then the data at the interfaces between blocks were adjusted and the individual blocks run again until there was convergence. This decoupled-solution method proved to be inefficient and time-consuming.

The development of ADPAC involved rewriting of a prior 3D, viscous-flow CFD code that was capable of handling a single flow path with a single grid block. The rewriting included the incorporation of multiblock and multigrid capability, extra boundary conditions, and mathematical models of turbulence. The resulting ADPAC code is characterized by the following major features and capabilities:

- *External Inflow*: On-axis or off-axis for configurations at various angles of attack.
- *Internal Inlet*: Uniform (or plug) flow; distortion patterns with mixed radial and circumferential distributions of total pressure and total temperature.
- *Boundary Conditions*: Solid walls bounding inviscid or viscous flow; porous walls with inflow or outflow; and exit planes with constant static pressure or radial equilibrium.
- *Grids*: Multiple blocks; mixed C, H, I, and/or O grids (with some restrictions); mixed axisymmetric and/or three-dimensional grids with single or multiple blade passages; and multiblock binary (Cartesian) grids stored externally as PLOT3D files.
- *Coupling Among Blocks*: All boundary conditions must be given on a common face. Direct patch or interpolation is possible for mismatched grids with no relative movement. Mixing-plane or unsteady interpolation is

possible for blocks with relative movement.

- *Block Periodicity*: Cylindrical (as for turbomachinery) or Cartesian (as for linear cascades or aircraft).
- *Flow Paths*: Multiple.
- *Solver Algorithm*: Finite-volume 4- or 5-stage Runge-Kutta explicit, dual time step implicit, multigrid acceleration, parallelized via message passing, APPL, PVM, or MPI libraries.
- *Turbulence Models*: Baldwin-Lomax with wall functions, restricted to the block with the wall; Goldberg's k-R; and Spalart-Allmaras.
- *Time-Marching Throughflow Capability*: Turbomachinery blade rows represented as 2-D axisymmetric surfaces with body forces to represent flow turning and profile losses.
- *Inverse Design Capability*: Turbomachinery blade row design based on time-marching throughflow simulation with user-specified tangential velocity and airfoil thickness distributions.

This work was done by Christopher J. Miller of **Glenn Research Center** *and Edward J. Hall, Nathan J. Heidegger, Michael L. Koiro, and David A. Topp of Rolls Royce Allison Engine Division. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category.*
LEW-16768

Software for Finite-Element Analysis of Thermoelasticity

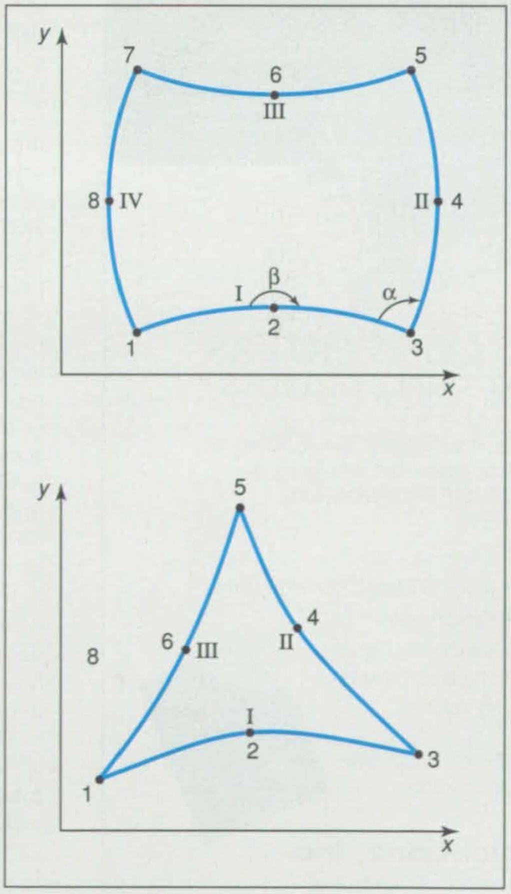
This program utilizes p-version finite elements for accuracy in resolving gradients.

Lyndon B. Johnson Space Center, Houston, Texas

The P-Finite Element Integrated Thermal-Structural Program (PITS 2D) solves the equations for the combined effects of thermal expansion and elasticity in a two-dimensional or an axisymmetric three-dimensional structure. The name of this program reflects the use of *p*-version finite elements, in contradiction to the traditional use of *h*-version finite elements. In comparison with older finite-element programs that utilize the *h*-version, PITS 2D predicts physical response more accurately in the presence of large gradients.

A *p*-version finite element in PITS 2D (see figure) can be either a quadrilateral or a triangle with concave and/or convex curved sides. A quadrilateral element is defined by eight nodes: four of them define the corners, and each of the remaining four nodes defines the approximate midpoint of a curved side. Similarly, a triangular element is defined by six nodes, three lying at the corners and each of the three remaining nodes lying at about the midpoint of a curved side.

In an *h*-version finite element, the displacements, stresses, strains, temperature, and other physical quantities are represented by trial first-order functions of spatial coordinates. The solution that one seeks is embodied in the coefficients of the functions. In a *p*-version finite element, the physical quan-



Eight-Node Quadrilateral and six-node triangular finite elements are used in PITS 2D.

tities are represented by polynomials that can be of orders higher than first. Thus, the polynomials of the *p*-version can fit physical data points more smoothly and accurately than can the linear functions of the *h*-version. In a given case, the error in the solution can be made smaller by using a polynomial of higher order. In PITS 2D, the polynomials can be of any order from first to eighth.

Examples of phenomena that can be analyzed by use of the current version of PITS 2D include stresses and/or temperatures in two-dimensional or axisymmetric three-dimensional structures made of isotropic or orthotropic materials, bending and buckling in thick plates made of isotropic or orthotropic materials, torsion in beams, and potential flow of fluid around a body. Nonlinear effects of thermal radiation (without stress) can be analyzed in cases of isotropy or orthotropy; nonlinear effects of thermal radiation (with stress) can be analyzed in cases of isotropy. Boundary conditions on displacement, stress, temperature, thermal, flux, and convection can include quadratic spatial variations.

PITS 2D is based largely on an older finite-element program called "BUCKY." It was developed and tested on computers running the Linux, HP-UX, and SunOS operating systems. A standard Unix Fortran 77 compiler and linker are necessary for execution.

This work was done by James P. Smith of **Johnson Space Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category.*
MSC-22832

SINDA/FLUINT Augmented To Represent Condensable Species

Lyndon B. Johnson Space Center, Houston, Texas

The Systems Improved Numerical Differencing Analyzer/Fluid Integrator (SINDA/FLUINT) software system has been upgraded by addition of a capability for simulating fluid mixtures that include condensable vapors. SINDA/FLUINT is the NASA standard software system for computational simulation of interacting thermal and fluid effects in arbitrary heat-transfer and fluid-flow networks. Prior to this upgrade, SINDA/FLUINT could represent single-phase vapors, single-phase liquids, and two-phase fluids, but not condensable vapors within mixtures. Now SINDA/FLUINT can also represent a fluid mixture that includes a condensable vapor, one or more noncondensable gas(es), and one or more nonvolatile liquid(s). Inasmuch as condensable vapors are often important constituents of two-phase fluids, the upgraded SINDA/FLUINT is more useful as an engineering software tool in general and for designing and analyzing liquid propulsion and environmental-control systems in particular. In addition, because of the added capability, fewer design iterations should be needed when using SINDA/FLUINT.

This work was done by Brent A. Cullimore of Cullimore and Ring Technologies, Inc., for **Johnson Space Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*
MSC-22816

Special Coverage: Design and Analysis Software

think3™, Santa Clara, CA, has introduced version 4.0 of thinkdesign™ **3D CAD software** that includes features to enable 2D designers to use 3D design software without abandoning 2D legacy data. The release includes 2D drafting and layout tools that enable users to turn a 3D design into a production-quality 2D drawing. A standard parts library management system called thinkparts™ allows teams of designers to create, share, manage, and reuse standard and proprietary components from a central catalog.

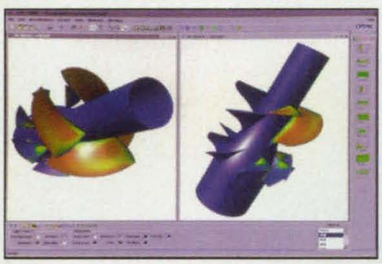
A capture and playback feature enables designers to record, review, and communicate about specific design sessions. The Windows software is built upon a proprietary software kernel, rather than Parasolid or ACIS. It allows integration of 2D design methodology into 3D. From 2D file import, to assembly modeling, and back to layout and drafting, 2D data is handled in the same manner as any type of geometry, whether it is 2D, 3D solids, 3D surfaces, or wireframe.

For More Information Circle No. 731

CADKEY Corp., Marlborough, MA, has announced CADKEY® 99 **mechanical PC-CAD software** that includes solid modeling enhancements such as solid body healing and tolerant edge functionality used to convert less precise imported model geometry to more precise, manufacturable CADKEY solid models. The new version also includes a one-pass IGES translator for import of IGES files, and a Parasolid® file translator for XT files.

Other new features include expanded data capabilities, and a visual feedback tool that highlights areas where modeling operations fail, permitting the designer to modify input parameters to complete freeform modeling tasks. Enhanced blending, sweep and extrude, and shelling capabilities are included, as well as increased speed in trim/split operations between solids and curves, sheet bodies, planes, and other solids.

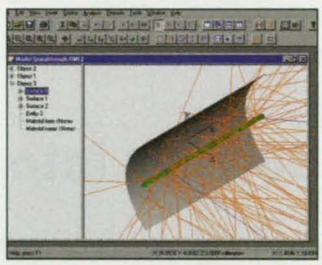
For More Information Circle No. 727



CFD-ACE+ Version 6.0 **multi-physics analysis software** from CFD Research Corp., Huntsville, AL, enables analysis of fluid-structure interaction, fluid analysis problems involving multi-material stress, and problems encountered in MEMS design. It also can be used for free surface flow and surface tension problems.

The software includes modules for Coupled Stress, Multi-Material Heat Transfer, Electro-Physics, and Chemistry. It consists of CFD-GEOM for geometry and automated structured/unstructured hybrid grid generation; CFD-ACE/CFD-ACE(U) flow solvers; and CFD-VIEW for post-processing, graphics, and animation. It is available for UNIX and Windows NT workstations.

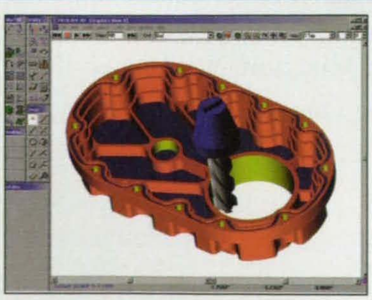
For More Information Circle No. 732



Unigraphics Version 16 **CAD/CAE/CAM software** from Unigraphics Solutions, St. Louis, MO, includes the introduction of Predictive Engineering, a set of technologies that incorporates engineering practices and product life-cycle knowledge into the product development environment. Predictive Engineering has enabled the creation of new tools called Process Wizards and Process Assistants that encode product and process knowledge to improve design and manufacturing productivity.

Other enhancements include a new user interface; controls for assemblies, features, and manufacturing operations; integration of Microsoft Excel spreadsheets for controlling and optimizing parametric data; and new CAM capabilities focused on knowledge capture and process automation. Also included is Design Studio, a new product for conceptual design that provides tools for direct manipulation of surfaces, texture mapping, and interactive analysis.

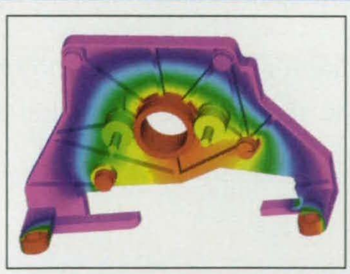
For More Information Circle No. 729



TekSoft, Phoenix, AZ, has introduced ProCAM 99 **2D/3D CAD/CAM software** that generates NC programs for 2D CAD/CAM applications and 3D applications requiring complex surface modeling and machining. The new version includes new finishing strategies for 3D surface machining, such as radial, spiral, and angular.

Other features include fabrication toolpath simulation and verification, groove tool support for turning rough cycle, true-shape automatic nesting for milled and routed parts, 3D surface machining speed increase, and options such as 3D roughing, tapping, and tool management.

For More Information Circle No. 728



FEMAP Version 7 **finite element modeling and visualization software** from Enterprise Software Products, Exton, PA, features new meshing technologies, automotive-specific modeling for crash simulation, and the ability to manage large finite element models. New geometry import functionality includes enhanced interoperability with CATIA.

The software enables users to model and visualize analyses of stress, temperature, and dynamic performance of products and processes. The Windows-native program includes an ABAQUS input file reader, nonlinear support for ANSYS, and improved mapping between multiple nonlinear servers.

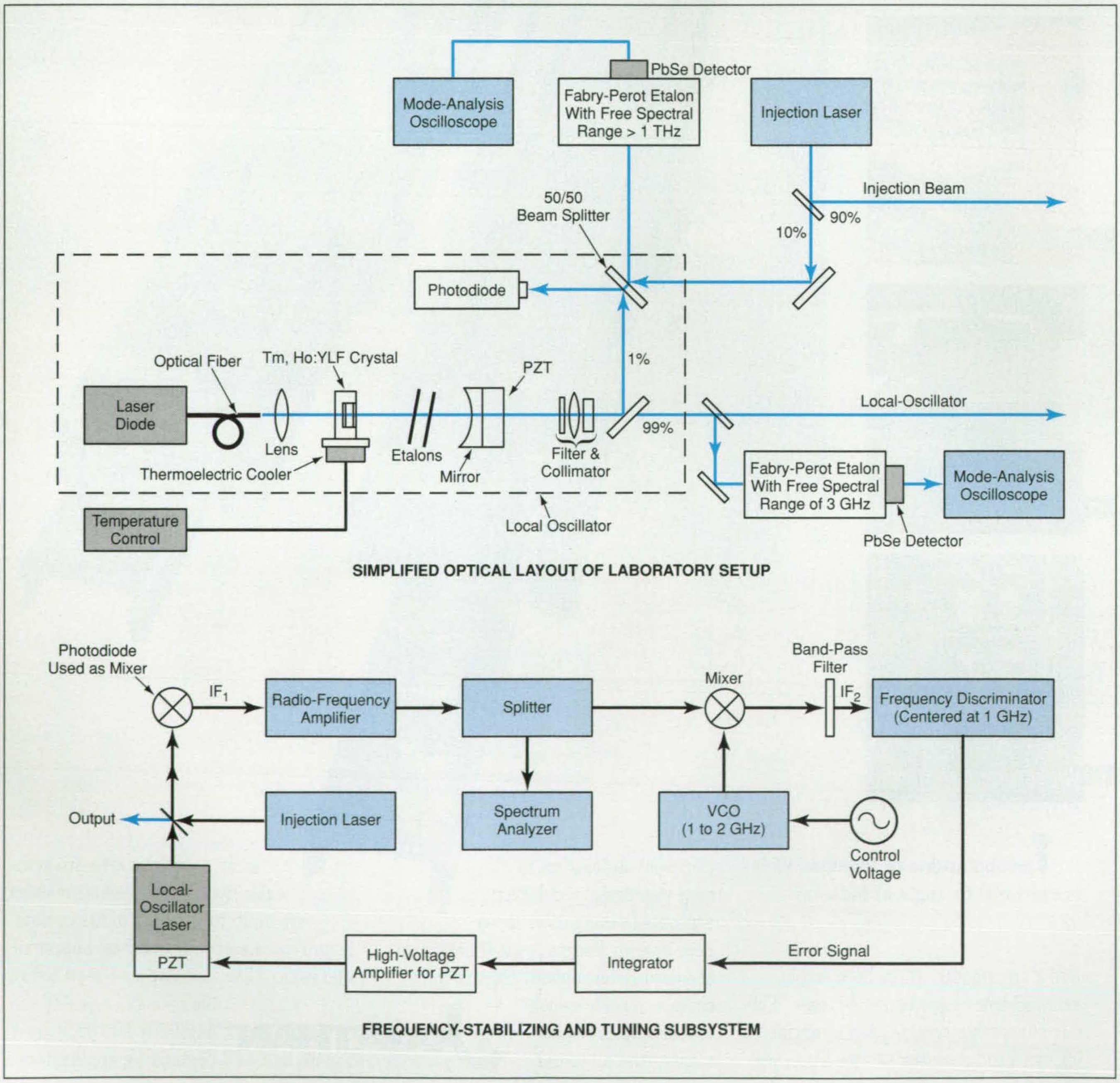
For More Information Circle No. 730

Tunable, Frequency-Stabilized Diode-Pumped Tm,Ho:YLF Laser

Frequency can be swept or adjusted over a range of ±4 GHz.

NASA's Jet Propulsion Laboratory, Pasadena, California

A laser-diode-pumped thulium- and holmium-doped yttrium lithium fluoride (Tm,Ho:YLF) laser that operates at a single frequency and that can be both tuned and stabilized in frequency has been demonstrated in a laboratory setup. This demonstration is a significant achievement in a continuing effort to develop frequency-stabilized, frequency-agile lasers. Such a laser could be used, for example, as a local oscillator in a coherent lidar system, wherein its capabilities would be exploited to generate a signal with a precise nominal frequency plus or minus a time-varying Doppler compensation for the relative motion of the system and its target. There may also be uses for such lasers



This **Laboratory Setup** was used to demonstrate laser-diode-pumped Tm,Ho:YLF laser that can be used as a frequency-agile local oscillator and that can be stabilized in frequency with respect to a similar laser used as an injection oscillator.

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	Dynamic Range		
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Voltage	±200V	±1100V	±60V
Current	±1A/20V	±1A/20V	±3A/20V
	±100mA/200V	±20mA/1100V	±1A/60V
Power	22W	22W	66W

Max system speeds:	
Pass/fail	= 500μs
To memory	= 500μs
To IEEE-488	= 1ms
Range change	= 13ms
Contact check	= 350μs

External interface:
IEEE-488 (SCPI)
RS-232
Digital I/O
Component handler

1 year basic accuracy: (5½-digit resolution)	
Volts	0.01%
Amps	0.02%
Ohms	0.04%

For More Information Circle No. 548

in laser diagnostics, and in fiber-optic communication and instrumentation systems.

The laboratory setup (see figure) includes two identical laser-diode-pumped Tm,Ho:YLF lasers, denoted the injection laser (IL) and the local oscillator (LO), respectively, in correspondence to the role that each would play in a fully developed lidar, communication, or instrumentation system. Each laser comprises a Tm,Ho:YLF crystal pumped by light at a wavelength of 794 nm from a fiber-coupled laser diode. A thermoelectric cooler is used to maintain the crystal at a temperature of −10 °C, where its optical-energy-conversion efficiency is greater than it is at room temperature.

The pumped surface of the crystal is coated for high transmittance at the pump wavelength and high reflectance at a nominal output wavelength of 2,060 nm. The surface opposite the pumped surface (the output surface of the crystal) is coated to minimize reflectance at the output wavelength. The output boundary of the laser cavity is defined by a curved output-coupling mirror that is coated for 98.5-percent reflectance at the output wavelength and is mounted facing the output surface of the crystal. Two etalons are mounted in the laser cavity, between the output crystal surface and the output-coupling mirror; these etalons are angle-tuned to enforce the desired single longitudinal laser mode and broad frequency-tuning range.

In the case of the LO, the output-coupling mirror is bonded to a piezoelectric transducer (PZT). The length of the laser optical cavity, and thus the laser frequency, can be varied by varying the voltage applied to the PZT.

In this setup, the LO can be stabilized and tuned with respect to the IL, by use of the following feedback loop: The outputs of the LO and IL are mixed in a photodiode to generate a beat note denoted intermediate frequency 1 (IF_1). The amplified IF_1 signal is mixed with a signal with a frequency between 1 and 2 GHz generated by a voltage-controlled oscillator (VCO). The resulting beat note is denoted intermediate frequency 2 (IF_2). The IF_2 signal is fed to a frequency discriminator that has a center frequency of 1 GHz. Whenever IF_2 differs from 1 GHz, the discriminator generates an error signal, which is fed to an analog integrator. The integrator output is amplified to a high voltage, which can be applied to the PZT to drive IF_2 toward 1 GHz. If the feedback loop is thus closed, then the system strives to maintain IF_1 (the difference between the LO and IL frequencies) at a frequency that differs by 1 GHz from the output frequency of the VCO.

There are three modes of operation:

- Open-Loop Operation: The feedback loop is not used. Instead, the PZT voltage is controlled at will to tune the LO frequency directly. The tuning range is ±4 GHz.
- Locked Fixed Frequency: The feedback loop is used with the VCO set at a fixed frequency. As a result, the LO is maintained at a frequency that differs from the IL frequency by a fixed amount between 0 and 1 GHz, LO jitter is reduced, and LO drift is eliminated.
- Scanning Locked Mode: The feedback loop is used and a sinusoidal or other suitable waveform with a frequency < 1 Hz is superimposed on the VCO control voltage. As in the locked-fixed-frequency mode, LO jitter is reduced and LO drift is eliminated, but in this case, IF_1 varies with the VCO control voltage. The amplitude of the waveform can be chosen to scan IF_1 over a range of ±1 GHz.

This work was done by Hamid Hemmati, Carlos Esproles, and Robert Menzies 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

Technology Reporting Office
JPL
Mail Stop 122-116
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-2240

Refer to NPO-20444, volume and number of this NASA Tech Briefs *issue, and the page number.*

Inrush-Current-Control Circuit

Voltage is raised gradually from zero to full supply voltage.

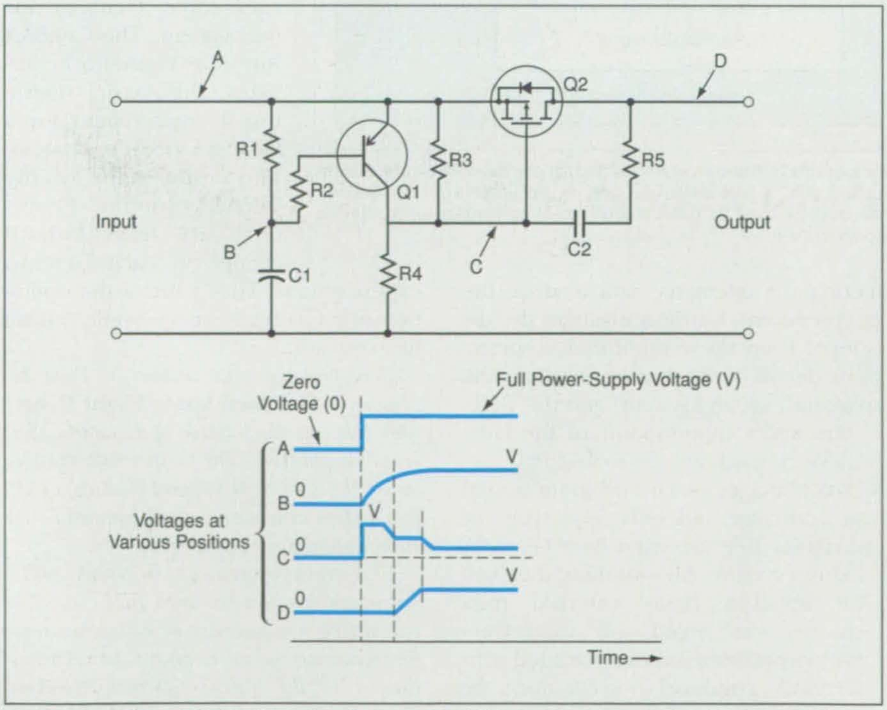
NASA's Jet Propulsion Laboratory, Pasadena, California

The electronic circuit shown in the figure regulates the inrush current that arises upon initial application of voltage to capacitors. This inrush-current-control circuit is intended principally to be incorporated into an electronic instrument in which capacitors are used to filter out current spikes and noise that would otherwise be impressed on the instrument power-supply bus. In the absence of a circuit like this one, voltage would be applied to the capacitors abruptly — typically by closing a relay; the resulting high inrush current could disrupt the power-supply bus and thereby also adversely affect the operations of other instruments connected to the same bus.

Shortly after turn-on, the inrush-current-control circuit causes the voltage on the instrument bus to ramp approximately linearly up to the full power-supply potential, so that the inrush current is constrained to be an approximately square pulse of controlled amplitude. In more detail, the sequence of events is the following:

Before power is applied, all capacitors are discharged. Upon initial application of power to the input terminals, Q1 becomes turned on, and C1 starts to charge through R1. The turn-on of Q1 causes the charging of C2 to full power-supply voltage. When C1 reaches full charge, Q1 becomes turned off; this allows C2 to discharge partially. When the potential on the left side of C2 reaches the threshold voltage of Q2, the output voltage begins to ramp up toward the full power-supply value.

This work was done by Steven Cole 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-20403



The **Output Voltage of This Circuit Ramps Up** to the full power-supply voltage following initial application of power.

Software for Creating Real-Time Monitoring Expert Systems

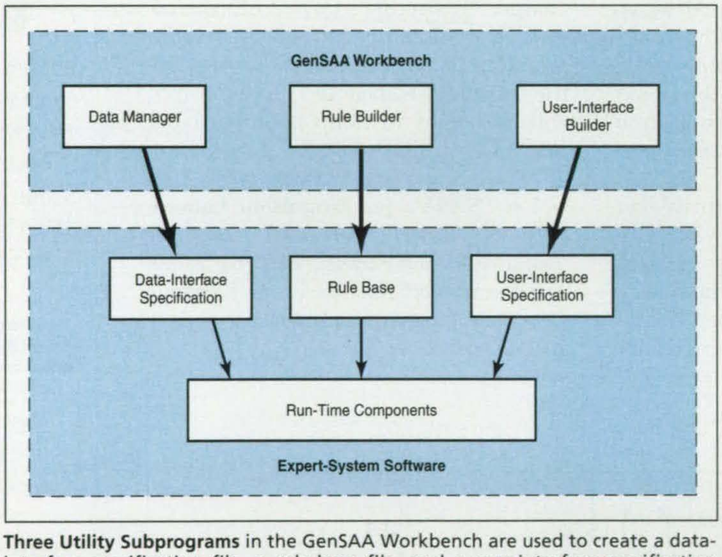
An expert-system developer need not write any program code.

Goddard Space Flight Center, Greenbelt, Maryland

The Generic Spacecraft Analyst Assistant (GenSAA) computer program enables the rapid development of expert-system software for intelligent real-time monitoring and detection of faults in complex systems of hardware and software. The hardware/software systems to which GenSAA expert systems were originally intended to be applied are spacecraft-control centers that feature the Transportable Payload Operations Center (TPOCC) architecture, which is a UNIX-based architecture used at Goddard Space Flight Center. An expert system built by use of GenSAA is a rule-based system that assists spacecraft analysts during operation of a control center; the expert system receives spacecraft telemetric and ground-system-status data, makes inferences and draws conclusions about the data, and generates textual and graphical displays of the data and the conclusions. Continuing development of GenSAA includes generalization of its capabilities to build expert systems for non-TPOCC control centers and for non-spacecraft-control applications, which could include industrial process control, monitoring of networks, and monitoring and control of vehicular traffic.

GenSAA serves as an alternative to commercial expert-system-development software tools, which generally require programming skills beyond those of typical domain experts (human spacecraft analysts in the original intended applications). The effort involved in the use of such tools constitutes an impediment to the rapid development of the desired expert-system software. GenSAA overcomes this impediment, making it possible for domain experts without advanced programming skills to develop monitoring, graphical-display expert systems.

GenSAA comprises (1) the GenSAA Workbench, which is an integrated set of utility subprograms; and (2) the GenSAA Runtime Framework, which is a run-time executive subprogram. The GenSAA Workbench generates a graphical user interface (GUI) that enables the development of an expert system by use of point-and-click and drag-and-drop actions; it is not necessary for the expert-system developer to write any expert-system program code. The expert-system developer uses the Workbench for laying out the GUI of the expert system, defining fault-detection rules, and selecting the telemetry data to drive the expert system. GenSAA insulates the developer from the complicated programming details of the data source (e.g., the spacecraft ground system) and the GUI.



Three Utility Subprograms in the GenSAA Workbench are used to create a data-interface-specification file, a rule-base file, and a user-interface-specification file; these files are later be used by the GenSAA run-time framework to define an executable expert system.

The utility subprograms of the GenSAA Workbench are the following:

- Data Manager — This program is used to construct and edit four types of variables that are used by a GenSAA expert system. All variables that will be received from external data sources, exchanged with other GenSAA expert systems, or associated with GenSAA graphical objects must be specified by use of the Data Manager.
- Rule Builder — This program is used to create the rule base for an expert system. The rule base is a group of rules in "condition-action" ("if - then") format that may infer new facts based on currently asserted facts. A rule contains one or more conditions and one or more actions. An inference engine manages the matching and firing of rules in the rule base during execution of the GenSAA expert system.
- User Interface Builder — This is a powerful tool for creating GUIs. The user interface of a GenSAA expert system consists of a workspace, graphic windows, and graphic objects. These graphical elements can be dynamically created and customized, without programming, by use of mechanisms provided in the User Interface Builder.

The GenSAA Workbench creates a set of files that are used by the GenSAA Runtime Framework (see figure) to define the executable GenSAA expert system. The GenSAA Runtime Framework provides the basic operational environment for a GenSAA expert system. The components of the GenSAA Runtime Framework are used without change in each GenSAA expert system. They control the operation of a GenSAA expert system during its execution.

This program was written by Peter M. Hughes of **Goddard Space Flight Center** *and Edward C. Luczak of Computer Sciences Corporation. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Information Sciences category.*

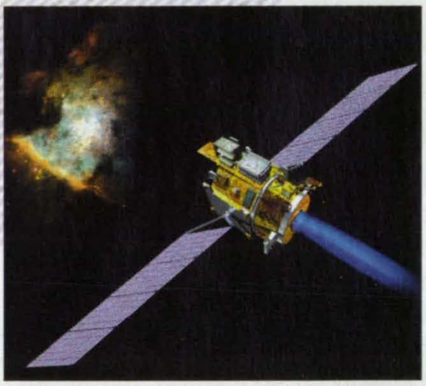
This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center; (301) 286-7351. Refer to GSC-13672.

NASA Selects 1999 "Software of the Year" Winners

Remote Agent, a state-of-the-art Artificial Intelligence system for onboard autonomous control of spacecraft, and Genoa — a software package that predicts aging and failure of materials — have been named co-winners of NASA's 1999 Software of the Year awards. The NASA award, cosponsored by the NASA Inventions and Contributions Board and the NASA Chief Information Officer, is the largest of its kind in the U.S. Winners were selected from a field of more than 150 corporations, universities, and government laboratories. For more information on the awards and the winning software, visit www.hq.nasa.gov/office/codei/swy99win.html.

In the Driver's Seat

For three days last May, scientists relinquished control of the Deep Space 1 spacecraft to Remote Agent, an Artificial Intelligence (AI) system developed at NASA Ames Research Center, Moffett Field, CA, and the Jet Propulsion Laboratory (JPL), Pasadena, CA. According to NASA, the flight experiment and the AI system exceeded expectations. Remote Agent detected, diagnosed, and corrected problems, demonstrating that it can make decisions to keep a mission on course.



Remote Agent, a state-of-the-art Artificial Intelligence system, controlled the Deep Space 1 spacecraft for three days last May. Since its launch on October 24, 1998, Deep Space 1 — part of NASA's New Millennium Program — has validated 12 new technologies, including an ion-propulsion system.

NASA scientists said that the AI used in Remote Agent is a precursor to self-aware, self-controlled, and self-operated robots, rovers, and intelligent machines that may one day explore distant planets.

"The Remote Agent approach to spacecraft autonomy signals the dawn of a new era in space exploration," said Dr. Pandu Nayak, Ames' deputy director of Remote Agent development. "Remote Agent will enable new classes of missions and more effective use of existing resources; and it will enable today's ground-operations teams to operate significantly more missions. Remote Agent and its components are already being considered for a variety of missions across the Agency."

Dr. Doug Bernard, JPL's Remote Agent manager, added that "This technology will allow us to pursue Solar System exploration missions that only a few years ago would have been considered too elaborate, too costly, or too dependent on teams of Earth-bound controllers."

According to Bernard, the Remote Agent system incorporates an onboard planner that had never before been used on a spacecraft. This goal-based planner is designed to create flexible plans that can take advantage of unexpected opportunities. Remote Agent has three main components that work together to control the spacecraft:

- **Planner & Scheduler (PS):** produces flexible plans and specifies the activities that must take place to accomplish mission objectives.
- **Smart Executive (EXEC):** carries out the plan.
- **Mode Identification & Recovery (MIR):** also known as LIVINGSTON, this component monitors spacecraft health and attempts to correct problems as they occur.

To demonstrate Remote Agent's versatility, scientists created four simulated failures. During one of these tests, Deep Space 1's camera appeared to be stuck in the "on" position. Remote Agent responded by formulating and executing a new plan that would preserve the spacecraft's power supply. A failed electronics unit prompted Remote Agent to fix the problem by reactivating the unit, not unlike rebooting a PC when it crashes. Later, when a sensor failed, Remote Agent correctly detected that the sensor had malfunctioned — not the device it was sensing.

In the final test, a thruster was stuck in the "off" position. Remote Agent compensated by switching to another set of thrusters.

According to NASA, using Remote Agent and its onboard planning system reduces the costs of planning/scheduling via communication with the ground-based Deep Space Network (DSN).

Progressive Failure Analysis

Genoa is an integrated structural analysis/design software suite used to model aging and failure in structural materials, including metals, ceramics, concrete, high-tech alloys, and composites. It was developed at NASA's John H. Glenn Research Center, Cleveland, OH, to cost-effectively predict strength, reliability, and durability of aerospace structural components with minimal experimental testing support. NASA said that Genoa's ability to predict material and structural failure can help engineers design and build safer, more durable aircraft fuselages, engines, car bodies, and bridges. The software recently has been commercialized by Alpha-STAR Corp., Long Beach, CA, which now markets Genoa to aircraft manufacturers and others.

Genoa's progressive failure analysis predicts crack initiation, growth, and final failure of monolithic and 2D/3D braided/laminated/stitched/woven composite materials. The software evaluates the structural material response, including degradation of material properties due to initiation and growth of damage under various conditions. Failure prediction takes into account defects introduced by manufacturing, in-service operations and environments, fatigue, and material creep.

Genoa is used to model aging and failure in structural materials, including high-tech alloys and components.

Genoa applications include automotive, chip manufacture, sporting goods, biomedical, virtual manufacturing, turbo machinery, and seismic retrofit for bridges, freeway columns, and buildings.

Runners-up in NASA's 1999 Software of the Year competition are:

- Virtual Interactive Imaging and Cybersurgery for Distant Healthcare, Ames Research Center, Moffett Field, CA;
- Generic Inferential Executor (Genie), Goddard Space Flight Center, Greenbelt, MD;
- Enigma Software Tools, Johnson Space Center, Houston, TX.

Three additional software packages received Honorable Mention:

- NPARC Alliance Flowfield Simulation System, Glenn Research Center, Cleveland, OH;
- ASPEN: Automated Scheduling and Planning Environment, Jet Propulsion Laboratory, Pasadena, CA;
- Ring Buffered Network Bus Data Management System, Dryden Flight Research Center, Edwards, CA.

Ceramic $Si_wB_xC_yO_z$ Fibers From Organic Si/B Polymer Precursors

Some of these fibers are stable at temperatures up to 1,300 °C.

Ames Research Center, Moffett Field, California

Improved formulations and processes have been invented for manufacturing ceramic fibers that exhibit structural stability and retain tensile strength at temperatures up to 1,200 °C, or even 1,300 °C in some cases. The final compositions of these fibers are given in the following table:

Element	Weight Percent
silicon	30 to 60
boron	2 to 8
carbon	18 to 40
oxygen*	<20

* Alternatively, as explained in the text below, fibers can contain nitrogen instead of oxygen.

These fibers are more stable at high temperatures than are the silicon carbide- and silicon nitride-based fibers made by the older processes described next.

Fibers containing the same elements in proportions different from those listed above have been made by older processes that involve (1) synthesis of precursor organic polymers, (2) extruding (melt-spinning) the polymer masses into fibers, and (3) treating the fibers by curing, sintering, and/or pyrolysis. In cases in which the polymer fibers are pyrolized directly, the fibers can deform or even melt during pyrolysis; this is a disadvantage in engineering applications in which fibers of specified shape are required.

The improved process includes the same basic steps as those described above. In addition, the improved process includes a step in which the precursor polymers are cured (their molecules are cross-linked) to prevent melting or deformation during the subsequent pyrolysis.

In a typical case, the improved process begins with heating a reaction mixture of an organoborohalide and an organohalosilane to synthesize a polyorganoborosilane, which is the precursor polymer. The polymer is then heated to a temperature between 80 and 200 °C (chosen to be somewhat above the softening or melting temperature of the polymer). The heated polymer is extruded into fibers by use of a standard spinneret, and the fibers are spun onto spools.

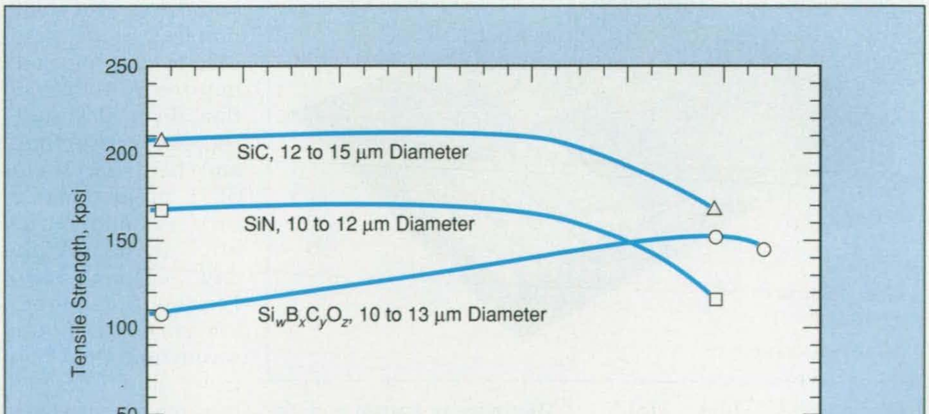
The precursor polymer fibers are cured in one of the following three ways:

- The fibers are oxidized slowly in air, starting at room temperature, gradually heating up to 150 °C during 3 or 4 days, and holding at 150 °C for about 1 day. Cross-linking is effected, and the level of oxygen incorporated in this step is between 5 and 25 weight percent.
- A better and faster oxidation-and-curing procedure involves irradiation of the fibers with ultraviolet light in air for 1 to 48 hours.
- A procedure for curing in the absence of oxygen involves exposure of the fibers to hydrazine vapor, preferably under a dry nitrogen or argon atmosphere for about 16 hours, followed by irradiation with ultraviolet light for 6 to 16 hours. In this procedure, nitrogen (instead of oxygen) is incorporated into the polymer.

The cured fibers are pyrolized by heating them from ambient temperature to about 1,300 °C in an inert atmosphere (argon or nitrogen). After initial heating, the fibers are held between 1,000 and 1,300 °C for as much as 1 hour. The products of pyrolysis are black fibers. The figure summarizes results of tensile tests of representative $Si_wB_xC_yO_z$ fibers made in this process and of commercial silicon carbide- and silicon nitride-based fibers, showing that the fibers of this invention retain tensile strength better at high temperature.

This work was done by Salvatore R. Riccitiello, Ming-ta S. Hsu, and Timothy S. Chen of **Ames Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*

This invention has been patented by NASA (U.S. Patent No. 5,223,461). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Ames Research Center; (650) 604-5104. Refer to ARC-11956.



Tensile Tests Were Performed on representative fibers of this invention and of commercial SiC and SiN-based fibers. Unlike the other fibers, the fibers of this invention were found to grow stronger with increasing temperature up to about 1,200 °C.

Reducing Damage to Alumina Fibers in Metal-Matrix Composites

Precoating the fibers by sputtering may increase the retention of strength.

John H. Glenn Research Center, Cleveland, Ohio

Coating alumina fibers with sputtered metal has been proposed as a means to enable the fibers to retain more strength when the fibers are incorporated into metal-matrix composites. If the alumina fibers could be made to retain more strength, then it would be possible to manufacture such composites with high volume fractions (20 to 40 volume) percent of fibers to obtain high-temperature properties suitable for such demanding applications as nozzles in engines of supersonic airplanes.

A metal-matrix composite of the type in question is formed by hot pressing or hot isostatic pressing of alumina fibers with a foil or powder of the metal that is destined to become the matrix. The issue of retention of strength arises because it has been observed, in the case of iron- and nickel-base alloy matrices, that the alumina fibers become degraded from their original strength of 425±25 kpsi (2.9±0.2 GPa) to mean strengths <150 kpsi (<1 GPa).

In preliminary experiments to test the proposed strengthening technique, alumina fibers were coated to a thickness of 4.7 μm by sputtering from a target of MA956 alloy. The coatings of some of the fibers were removed, and then the strengths of the fibers were measured and found to be about 360 kpsi (2.5 GPa). Other fibers were heated in a vacuum at a temperature of 1,200 °C prior to removal of coatings, and their strengths were found to be 310 kpsi (2.1 GPa). The sputtered coatings appeared to have resulted in only minimal strength-reducing damage to the fibers. Scanning electron micrographs of the fibers after removal of the coatings showed a surface appearance very different from that typically seen on fibers damaged by incorporation into metal-matrix composites.

Some caution in interpreting the observations in these experiments is in order, in part because the fibers were not rotated during sputtering and therefore the coatings did not extend around their entire circumferences. The fibers were also not coated along their full lengths. Moreover, it is not known whether the partial-strength-preserving effect of sputter coating is repeatable. Further experiments are planned to investigate the effects of full-circumference and full-length coating, to determine repeatability, and to learn more about the chemical and microstructural details of damaging versus nondamaging deposits. Another question to be addressed is whether alternative sputtering-target compositions and alternative coating processes could contribute to retention of strength.

This work was done by M. F. X. Gigliotti, Jr.; M. R. Jackson; and A. M. Ritter of General Electric Co. for **Glenn Research Center**. *For further information, 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-16735.

Tailoring Fiber/Matrix Interfaces Through Kirkendall Defects

Microporosity would be induced in thin interfacial layers.

John H. Glenn Research Center, Cleveland, Ohio

In a proposed method of tailoring some of the mechanical properties of metal-matrix, oxide-matrix, and ceramic-matrix composite materials, Kirkendall defects (microscopic pores as described below) would be introduced into thin interfacial layers between the fibers and the matrices. This method could be used in addition or as an alternative to an older method in which one seeks to tailor the mechanical properties of a composite by coating its fibers one or more layer(s) of material(s) distinct from the matrix and fiber materials.

The coatings of the older method are applied as diffusion barriers to isolate the fibers from chemically reactive components of the matrix during processing or service, to protect the fibers from the effects of consolidation into the composite, to provide adequate bonding so that loads can be transferred from the matrix to the fibers, and/or to provide for deflection of cracks or for toughening the composite. In the case of multilayer coatings, each layer is applied in the effort to provide a beneficial effect that will contribute to the overall attainment of the protective effects listed in the preceding sentence.

In the proposed method, the fibers would be coated with an element that diffuses readily in the matrix material. Typically, such an element would be one that has a small atomic radius. The element must be one that is compatible with the matrix material at concentrations to be used.

Examples of techniques for depositing such elements include chemical vapor deposition (CVD), sputtering, and electron-beam physical vapor deposition (EB-PVD). During the thermal processing that is typically done to consolidate the composite, the coating material would diffuse away into the matrix as interstitial contaminants, leaving a porous interface behind. The resulting interfacial pores are instances of the classical metallurgical phenomenon known as "Kirkendall defects."

The initial coating and the subsequent porous interface would provide many of the protective effects mentioned above. In comparison with a composite that lacked the Kirkendall defects but was otherwise identical, the composite would be toughened because the porous interface would have a reduced cross-sectional area and would therefore be weaker.

The initial thickness of the diffusible coating, in conjunction with the processing parameters, would determine the extent of porosity created and, therefore, the degree of toughening. Other coatings could be applied either below or above the diffusible layer to further enhance the overall properties of the composite.

This work was done by Theodore R. Grossman of General Electric Co. for **Glenn Research Center**. *For further information, 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-16733.

November 1999

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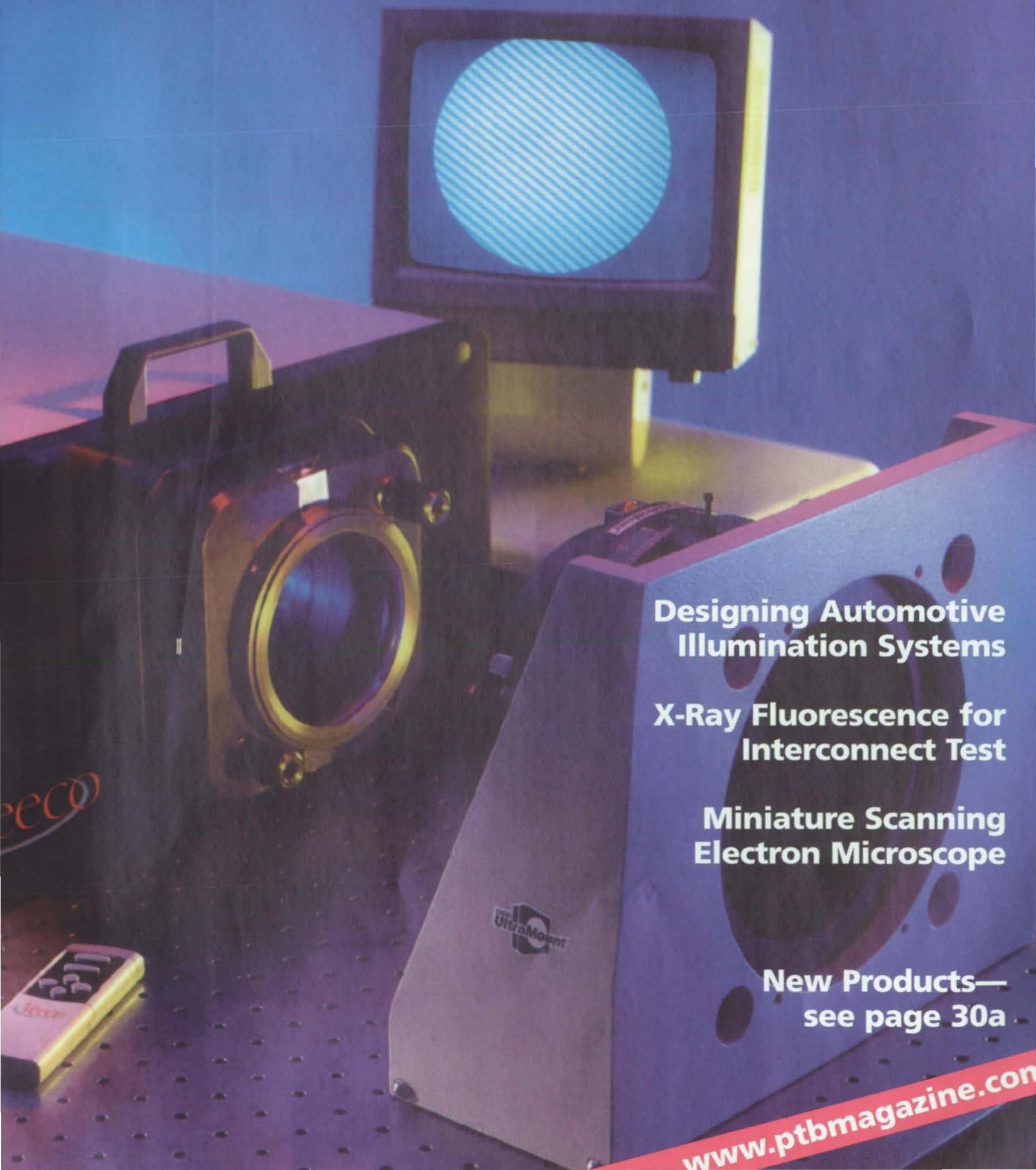

Designing Automotive Illumination Systems

X-Ray Fluorescence for Interconnect Test

Miniature Scanning Electron Microscope

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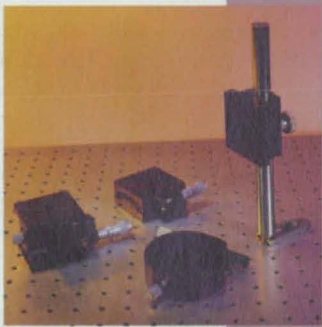

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Designing Advanced Automotive Illumination Systems

Powerful software improves system performance and cuts development costs.

Most automobiles use backlighting to illuminate dashboard displays, such as speedometers, gauges, indicators, sound systems, and climate control. This approach provides excellent aesthetics and enhanced readability, which is a positive safety factor. Historically, the design of backlit dashboard displays was largely a trial-and-error process. But the newest generation of illumination design and analysis software reduces design cycle time and cost, and also enables the production of more sophisticated and efficient systems.

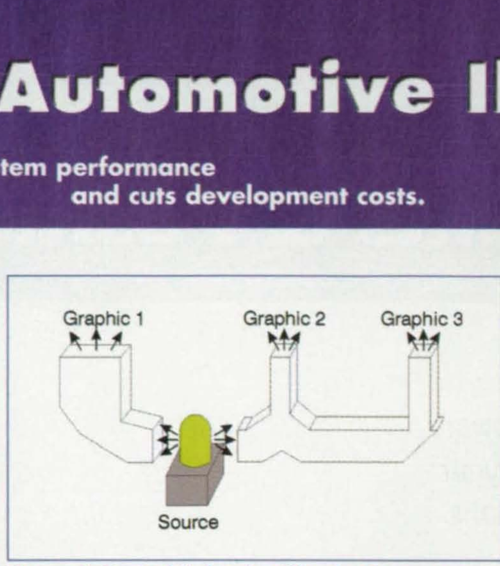

Figure 1. Typical light pipe illumination system.

Light Pipe Operation and Design

In a typical automotive display illumination system, the output from a light source is coupled into one or more thick plastic light pipes, which direct the light to various graphics (Figure 1). The light pipes are fabricated from a clear plastic—typically polycarbonate or acrylic—by injection molding. An efficient design utilizes total internal reflection (TIR) to confine the light within the light pipe, eliminating the need for any optical coatings. At present, color-filtered incandescent bulbs are most commonly used. Light-emitting diodes (LEDs) are now becoming popular because they offer higher electrical efficiency (with the exception of white LEDs), unfiltered colored light, lower heat generation, and a longer lifetime.

The ability to illuminate several graphics with a single source is the primary advantage of light pipes, since this minimizes the number of light sources required. This is not an insignificant consideration, given that many automobiles now have more than 100 different light sources. Light pipes allow the source output to be steered around various mechanical obstacles within the dashboard. They can also be used to alter the luminous distribution of the source, so as to achieve greater illumination uniformity, or specific light levels on a given graphic.

Unlike imaging optics, which generally have been designed and optimized with sophisticated computer ray-tracing programs for about 30 years, the design of plastic light pipes has traditionally been performed by trial and error. The initial design was generated using basic geometrical concepts (angle of incidence equals angle of reflection) to ensure that incidence angles were high enough to meet the TIR condition, and flat "fold mirror" surfaces were incorporated when needed to change propagation direction. Then an actual plastic prototype part was produced by either injection molding or a combination of machining and hand polishing (polishing is required to produce a surface smooth enough to support TIR that is also free of significant scattering). Finally, this prototype was tested to validate the design and indicate where improvement was needed.

Both injection molding and machining/polishing are time-consuming processes. Furthermore, injection molding tooling can cost $10,000-$40,000. Because of these time and cost constraints, a light pipe would typically undergo only two or three design iterations before going into production. Limited analysis together with a small number of prototype cycles resulted in systems that were not highly optimized.

Using Computing Horsepower

Computer modeling of an illumination system is based on the same basic principles as imaging optical system design. Specifically rays are traced through the system, and either reflect, refract, or both (*i.e.*, a beamsplitting surface) at each material interface. This changes the direction and flux of each ray as it propagates to the next surface. The analysis and optimization of most imaging optical systems is accomplished by tracing several hundred or several thousand rays at a limited number of field positions. In contrast, performing a useful analysis of a relatively simple illumination system, such as the light pipes under discussion, may require the tracing of millions of rays. Thus it is only with the recent advent of powerful desktop computers and software that computer-aided illumination system design has become commonplace.

LightTools®, by Optical Research Associates, is one illumination system design and analysis software package that takes advantage of inexpensive and fast computing horsepower. Unlike traditional imaging optical design programs, where systems are specified surface by surface, LightTools' CAD-like interface enables the user to build three-dimensional models quickly from a toolbox of common shapes (Figure 2). Boolean operations, including intersection, subtraction, and union, and trimming facilitate the creation of complex geometries. Both optical and nonoptical components, such as mounts and mechanical constructs, can be included and ray-traced in the model. The program also models complex surface and volume-emitting light sources.

Once a light source or input ray bundle is defined, LightTools uses nonsequential Monte Carlo ray tracing to determine the path of the light through the system. The optical effects at every surface a ray encounters are taken into account; thus even the interaction of light with component edges and mechanical structures is analyzed. Polarization, scattering, and surface reflection effects, as well as the performance of thin-film optical coatings, can also be considered. Simulation output consists mostly of plots of the illuminance or intensity dis-

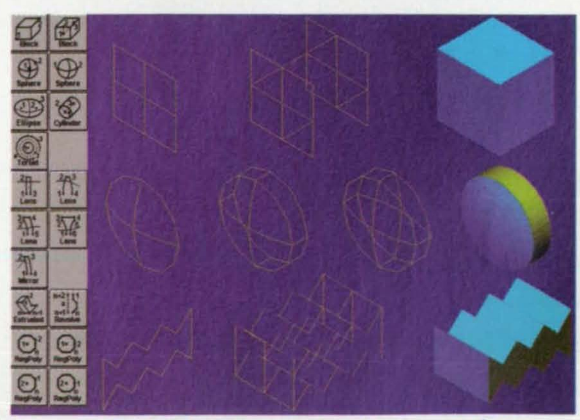
Figure 2. LightTools system construction screen shot.


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More Sophisticated Design

A coauthor, Dr. John Van Derlofske, has used LightTools for the past five years at DaimlerChrysler and currently at the Lighting Research Center at Rensselaer Polytechnic Institute, in the design of light pipes for dashboard illumination. During that time the software has been found to produce computer models of sufficient accuracy to largely eliminate the expensive and time-consuming step of constructing physical prototypes. Typically, five to 20 iterations of a design are run on the computer before producing a prototype for final verification.

In addition to providing time and cost savings, nonimaging optical design software has also enabled the exploration of more sophisticated design forms for light pipes, particularly that of aspheric surfaces.

To understand the benefit that an aspheric surface can deliver, consider a simple light pipe designed to perform the commonly required task of redirecting an incandescent source through a 90° angle to provide illumination evenly over an extended area.

The most obvious design approach is a light pipe with a 45° fold surface (Figure 3). This design efficiently performs the basic function of redirecting the light, since most of the source's output meets the condition for TIR. It does not, however, transform the nonuniform input flux distribution into one that is more uniform. Thus the illuminated graphic appears much dimmer at the edges than in the center. Replacement of the flat fold surface with a curved surface results in a component that can both bend the light and alter the input flux distribution to produce greater uniformity.

To create and optimize designs built around aspheric surfaces, the shape of the curve is defined using a standard polynomial expansion. Changes to surface curvature, position, tilt angle, conic constant, and fourth-order deformation coefficient are then input to optimize the design. Light-source modeling proceeds along similar lines. The structure of the source is first built inside the program, and the source model is compared to either measured or manufacturer-specified characteristics, or both.

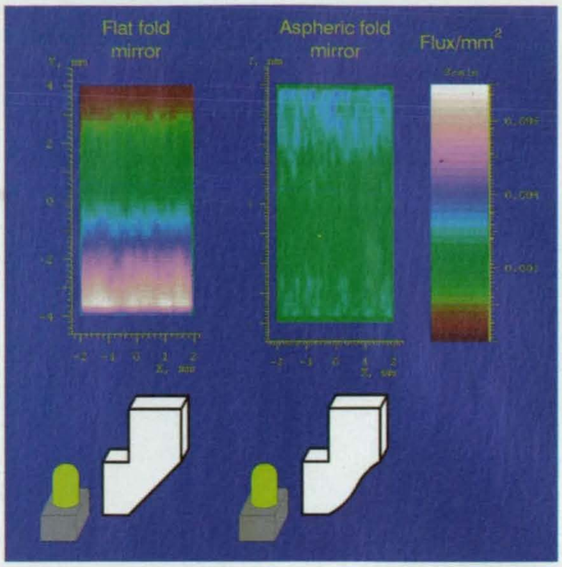


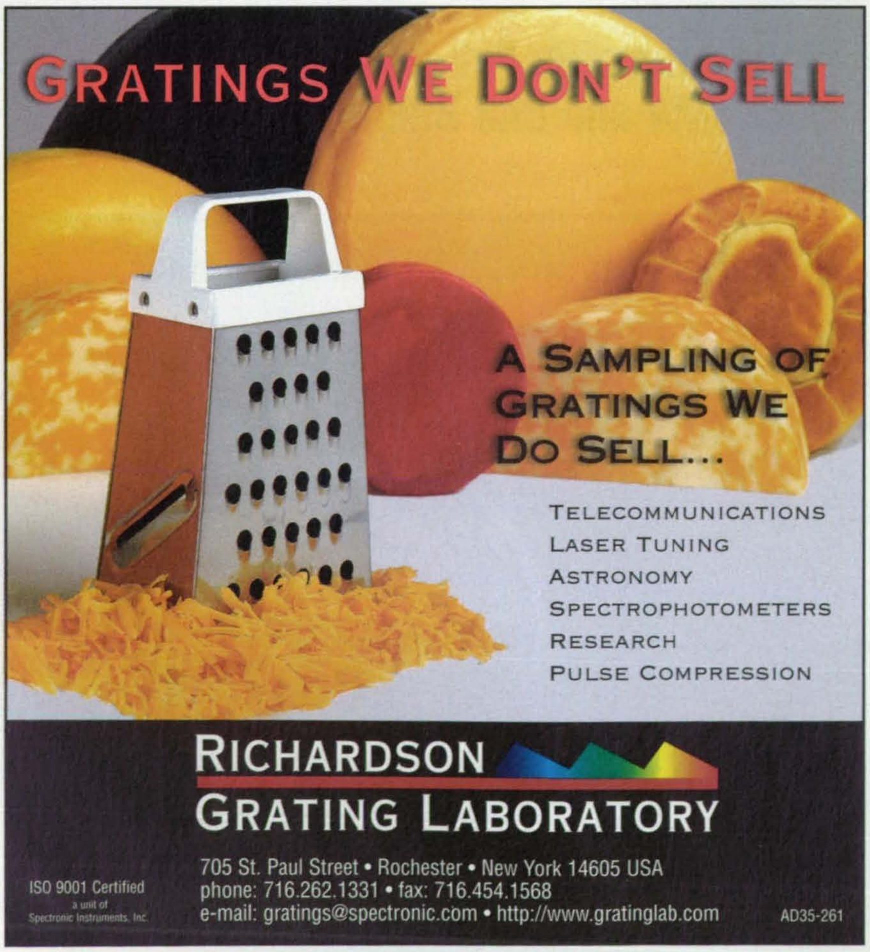
Figure 3. Right-angle light pipe analysis shot, showing the flux difference between a flat fold mirror and an aspheric fold mirror.

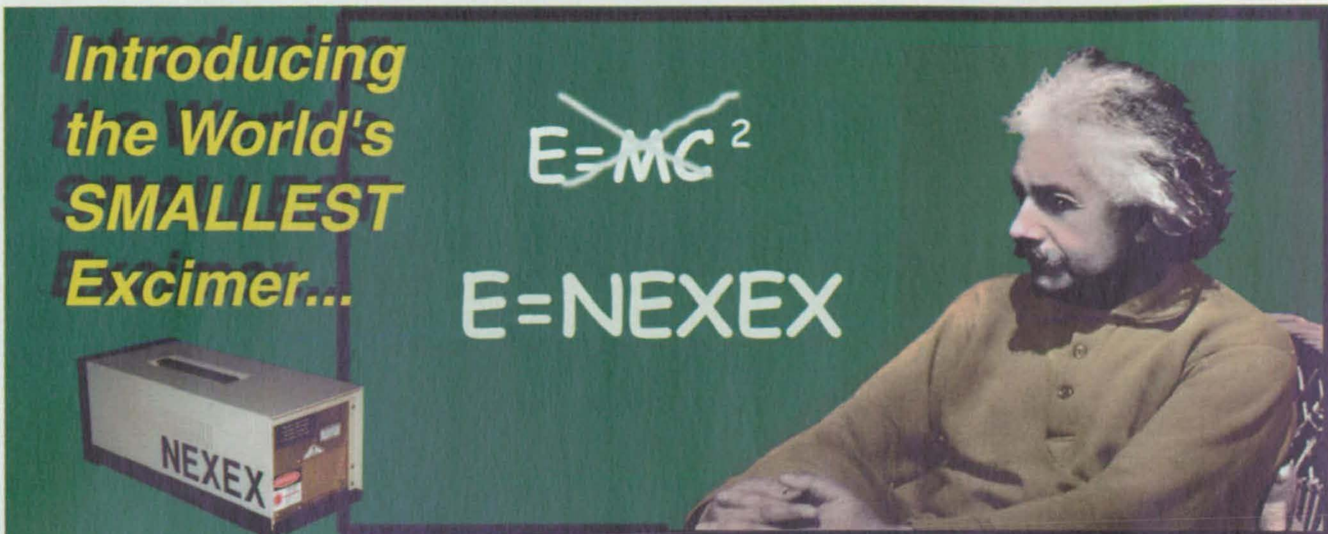
The results comparing the output of a light pipe using a flat fold surface and an optimized aspheric surface are shown in Figure 3. Two million rays were traced to produce this output, which clearly shows the superior uniformity of the aspheric system. The output also demonstrates that a small amount of overall throughput was sacrificed to achieve this critical goal, because the curved shape of the surface causes TIR to fail for a greater number of rays than the flat surface does.

Previously various surface parameters were modified manually, and then a ray-trace was performed to assess the impact of changes. Automated optimization techniques using LightTools' newly added macro programming, however, are now being developed. The first step in this process is to use the desired final flux distribution to define a performance merit function. Macro commands are then used to alter surface parameters and perform ray-tracing to optimize the design's merit function iteratively.

A trial-and-error approach has long been used to design optics for illumination systems, such as film and video projectors, flat-panel displays, interior vehicle lighting, architectural lighting, segmented mirrors, sign lighting, machine vision systems, and medical imaging systems. Now a new generation of illumination system design and analysis software enables a much more rigorous and analytical approach to be taken.

For more information, please contact the coauthor of this article, John Van Derlofske, Ph.D., the Head of Transportation Lighting at the Lighting Research Center at Rensselaer Polytechnic Institute, 877 25th St., Watervliet, NY 12189; (518) 276-8717. Coauthor David W. Kuntz is a managing partner at TMS, 171 High St., Laguna Beach, CA 92651; (310) 377-5393.





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Focusing on Better Interconnect Measurements

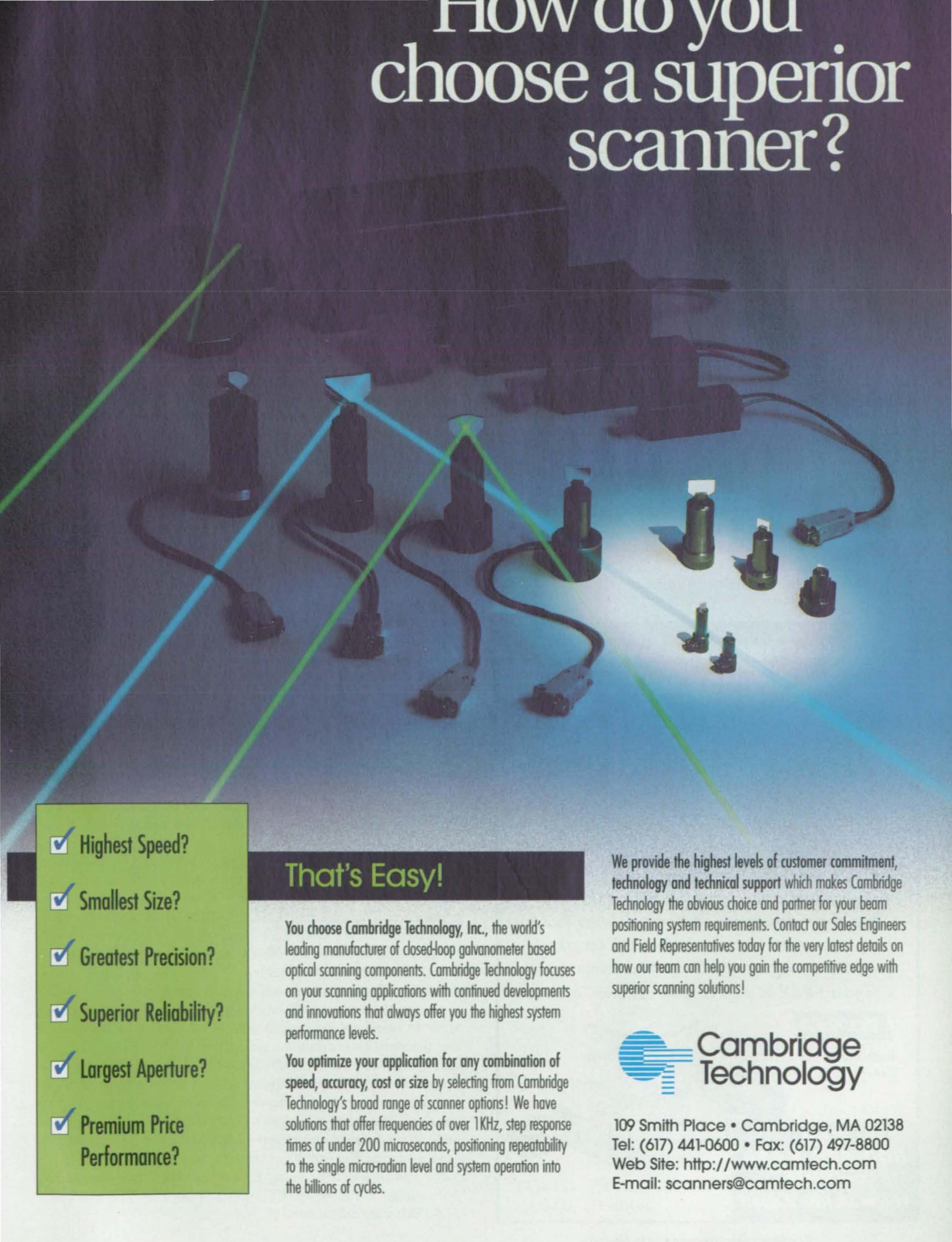
A new method of collimation improves the speed and precision of x-ray fluorescence tools for evaluating interconnect metallizations.

A worker loads a printed circuit board into a Veeco Industrial Measurement Division MXR x-ray fluorescent measuring tool, incorporating its innovative optical collimator technology.

Continued advances in microelectronics manufacture—including increasing clock speeds, reductions in device size, impedance and capacitance factors, and thermal management issues—have intensified the demand on the packaging and interconnect segments of the industry to provide smaller, faster, and more electrically and thermally conductive interconnect schemes. Sub-100-micron interconnect structures used in ball grid arrays (BGAs), flip chips, and wire bonding techniques on wafers, packages, and substrates are common now, and these structures will continue to decrease in size and increase in density.

This trend creates the need for better opaque film metrology tools. A new focusing method enables x-ray fluorescent (XRF) measuring tools, commonly used to determine the thickness and composition of interconnect metallizations in microelectronic and data storage devices, to measure in much smaller areas. Long the preferred tool for such measurements in the electronics industry, this method relies on the principle that any element, when exposed to a source of high-intensity x-rays, will emit x-rays or fluoresce at energy levels unique to that element. To obtain a measurement, the XRF system uses an x-ray source to produce a spectrum that is directed at a sample to induce the fluorescence.

Since the XRF is used to measure very small sample areas, small x-ray beams are required. Erroneous measurements will be obtained if the beam size is larger than the sample, or if the beam is mispositioned in such a way that its perimeter extends beyond the edge of the sample. Most XRFs use collimators, essentially pinhole apertures, to direct the beam. The collimator blocks all but a very small frac-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tion of the generated x-rays, passing through only those traveling in a path coincident with the opening. They emerge in a cone-like beam whose initial diameter is equal to the diameter of the collimator's opening.

The XRF detects x-ray emissions from the sample and converts them to electronic pulses. Each pulse is then sorted according to its energy level and delivered into a memory location, or channel, in the XRF's multichannel analyzer, which also counts the number of pulses stored in each channel. A computer uses the data to generate a frequency distribution or histogram, displaying channel-number or energy-level information along the x-axis and number of pulses along the y-axis. To arrive at a measurement level, the instrument can either compare the spectral data from a sample to a previously stored calibration spectrum or use fundamental parameters to evaluate the sample. By these methods the instrument can calculate the thickness and composition of the sample.

XRF is a powerful tool but has until recently been taxed to provide fast and precise results on structures smaller than 100 microns, because the collimators used have been mechanical. With mechanical collimation, as the machined openings become smaller to resolve smaller interconnect structures, less of the primary beam can reach the sample. Since XRF systems are counting devices, their precision is proportional to the number of x-rays generated at the sample and subsequently fluoresced back from the sample to the detector. Thus, smaller beams mean reduced precision, longer measurement times, and reduced throughput.

Enter optical collimation

Recently a new method has been devised to improve the precision of XRF instruments. Optical collimation, as it is called, rather than governing the flow of primary x-ray beam photons, redirects them down to a point. This is accomplished by a device called a focusing element that utilizes a monolithic polycapillary optic in conjunction with a beam input array and an exit filter to deliver unprecedented x-ray intensities in areas as small as 50 microns. Count-rate gains on the order of 100 times and precision gains of an order of magnitude can be achieved with this new technology. The use of a focusing element allows for a micro-beam x-ray analysis of structures as small as 50 microns.

Typical applications for the new technology include analysis of solder-bump composition (Sn-Pb), three-layer under-bump metallurgy thickness measurement (such as Au/Ni-P/Cu and Cu/Cr/Ti), wire-bond-pad metallurgy (Au/Ni/Cu) thickness measurement, ball-grid-array and flip-chip metallurgy, package-to-substrate interconnects, and current-carrying metallurgy.

When the Industrial Measurement Division of Veeco Inc., of Ronkonkoma, NY, first integrated the optical collimator into its XRF tools, the company faced a challenging task in commercializing this technology. The biggest obstacle was the fact that the optical collimator is considerably more complicated from a mechanical standpoint, yet Veeco wanted the new instrument to be exactly the same size as the old one. The primary complexity is the need for two-axis positioning of the focusing element. At the same time engineers wanted to fit the case inside the existing product structure because of tight space requirements in the clean rooms where the devices are normally used and because of the need to reduce design and manufacturing costs.

Veeco engineers selected the R201XY roller slide positioning stage from Del-Tron Precision Inc. of Bethel, CT, because it was the smallest linear motion device they could find that fit their requirements. This stage easily fit within the confines of the existing product packaging. The stage also meets the accuracy requirements of the application without difficulty. It incorporates a spring-loaded micrometer drive that allows precise repeatable adjustments with low friction and zero backlash. The slides provide accuracy to 0.0001 in./in. of travel and repeatability of 0.0001 in. More than 60 models support load capacities to 160 lb.

The device also features a positive locking capability consisting of a steel shim and an extended micrometer bracket secured by a screw mounted to the side of the stage carriage. This allows the user to lock the position of the carriage during use. Locking micrometer heads are also available to lock the micrometer setting. Del-Tron makes more than 60 models of its ball slide positioner with load capacities of up to 60 pounds. These slides can be used for gauging and positioning light and medium loads; applications include measuring instruments and optical assemblies.

Veeco incorporated the slide into its MXR XRF metrology tool that delivers 40 to 300 times the x-rays and 10 times the precision of mechanically collimated XRF systems with equivalent beam sizes. The detection column of the MXR instrument features an electrically cooled solid-state detector for optimum sensitivity required for thin (100-500-angstrom) depositions, multilayer metal stacks, and elemental peak overlap applications. Veeco has also introduced a VXR instrument that utilizes vacuum technology to extend the elemental measuring range of the MXR to elements from aluminum to scandium, in addition to the titanium-to-uranium range of the MXR. This instrument also incorporates an evacuated-conduit design that allows measurement of the sample in the air while retaining the accuracy of vacuum measurement. Since chamber evacuation is not required, throughput is dramatically improved. Both of these instruments have experienced excellent success in the market, demonstrating the validity of this new technology.

For more information, contact Ed Keane at Del-Tron Precision, Inc., 5 Trowbridge Drive, Bethel, CT 06801; (203) 778-2727; fax: (203) 778-2721; www.deltron.com.

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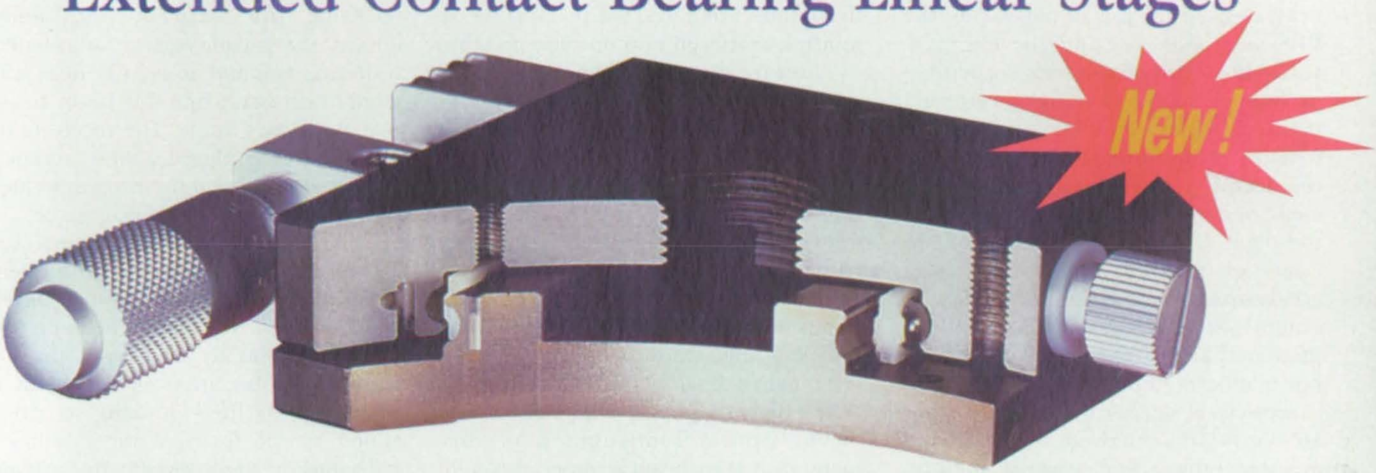

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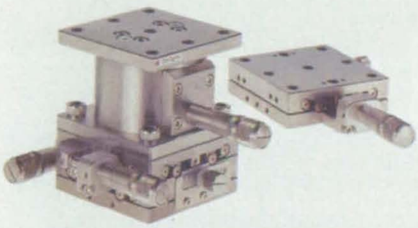

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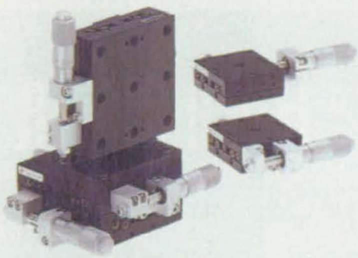

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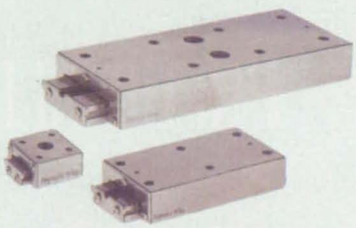

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Multiple Scattering Suppression in Laser Light Scattering

Sizes of particles in solutions can be determined over a wide range of concentrations.

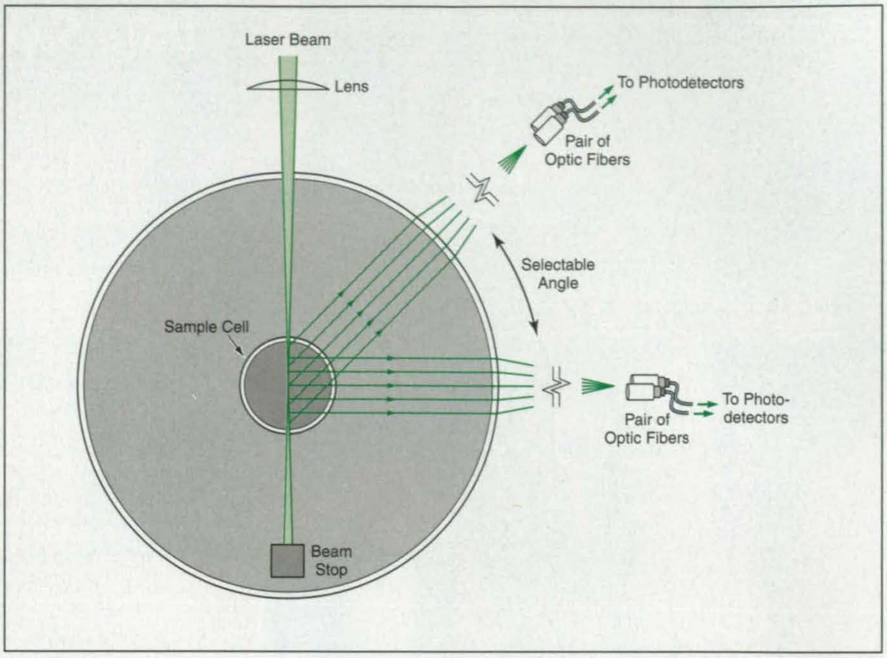
John H. Glenn Research Center, Cleveland, Ohio

A laser-light-scattering method that includes cross-correlation processing of photodetector output signals has been devised for use in measuring the Brownian motions, and thereby indirectly the sizes, of particles suspended in liquids. Older laser-light-scattering methods for determining particle sizes from cross- or autocorrelation of photodetector outputs entail various deficiencies and difficulties, which include the need for precise alignment of two lasers of different wavelengths in a cross-correlation method, inability to obtain useful data at concentrations greater than 0.5 percent in one autocorrelation method, restriction to measurements at shallow depths in another autocorrelation method, and restricted angular range. The present method requires only one laser, can be used at various depths (for example in general liquid vessels or eye lenses), and yields useful data at concentrations >0.5 percent. This method can be used to determine typical particle sizes from 30 Å to 3 μm.

Singly scattered photons are needed for determining particle motions and sizes. As the concentration of particles in solution increases, the proportion of multiply-scattered photons also increases, altering photodetector outputs significantly. In autocorrelation processing, there is no way to distinguish between singly- and multiply-scattered photons arriving at the photodetector; therefore, as concentration increases, interpretation of autocorrelation signals becomes increasingly problematic. In the present method, cross-correlation is used to discriminate against photons multiply scattered from a single illuminating laser beam.

The figure depicts a simplified version of the optical configuration of this method. A laser beam is aimed through a vertically oriented cylindrical sample cell containing the particles of interest suspended in a liquid. Optionally, the cell can be placed in a vat of another liquid, the index of refraction of which approximates that of the liquid in the cell. The laser beam is focused to a waist at the middle of the cell or at any other desired depth within the cell. Two optical fibers are positioned with their receiving tips adjacent and aimed toward the beam waist (the nominal scattering volume) to receive light scattered horizontally from the beam axis to a single chosen angle. The receiving tip of one fiber is placed a short distance above the other and the two are located above or below the scattering plane.

Only a narrow waist beam generates the tall speckles which span both fibers. The width of the beam waist (typically ≈80 μm), the separation between the fiber tips (typically ≈250 μm), the distance of the fiber tips from the scattering volume (typically ≈170 mm, as determined by the focus of the cylindrical cell), and the laser wavelength (typically ≈0.5 μm) are chosen so that the relative sizes of time-dependent speckle arising from single and multiple scattering can be used to discriminate against signals from multiple scattering. The proper choice of dimensions is one for which (1) speckle from single scattering of pho-



Scattered Laser Light enters two adjacent optical fibers attached to photodetectors. The separation between the receiving tips of the fibers is made smaller than single-scattering speckle but larger than multiple-scattering speckle, so that the cross-correlation (as a function of differential time) of the fluctuations in the outputs of the two photodetectors suppresses contributions by multiple scattering of photons.

tons from the same scattering volume is large enough to encompass both fiber tips while (2) speckle from multiple scattering, which results from a beam of larger diameter, is significantly smaller than the distance between fiber tips, so that (3) the single-scattering components of the outputs of photodetectors fed by the two fibers are correlated with each other, while (4) the multiple-scattering components of these outputs are not correlated with each other. Thus, cross-correlation of the two photodetector outputs is nearly equivalent to a single-photodetector autocorrelation, and can be inverted to obtain the desired particle-motion and particle-size data.

This work was done by William V. Meyer and Padetha Tin of Ohio Aerospace Institute; David S. Cannell of the University of California, Santa Barbara; James A. Lock and Thomas W. Taylor of the Cleveland State University; and Anthony E. Smart for **Glenn Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences 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-16517.

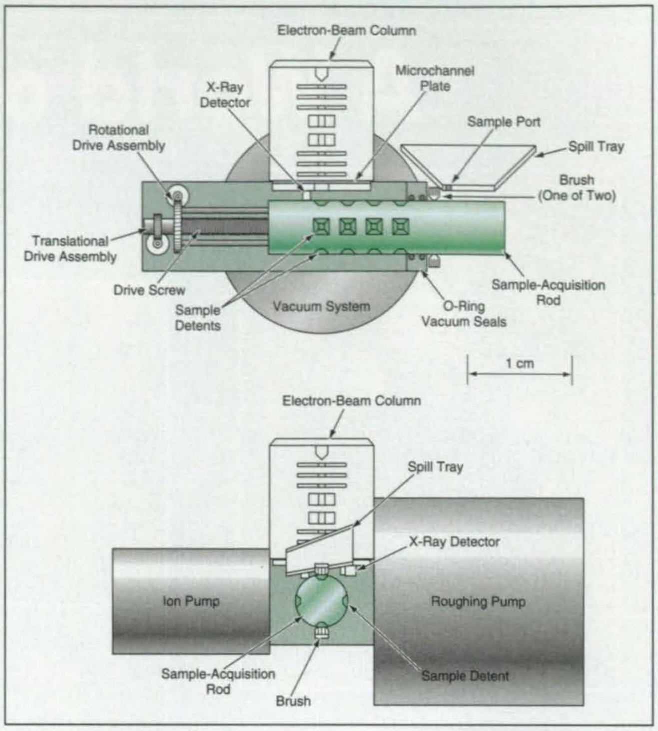
Miniature Scanning Electron Microscope

This instrument could be used to analyze specimens in the field.

NASA's Jet Propulsion Laboratory, Pasadena, California

A miniature scanning electron microscope (SEM) with a capability for x-ray microanalysis has been proposed. This SEM would be particularly suitable for analyzing samples of dust, soil, drill tailings, and other finely divided solids collected in various environments. Designed for use in the robotic exploration of remote planets, asteroids, and comets, this instrument could also be used on Earth, where it could be operated in the field as well as in the laboratory.

The miniature SEM (see figure) would include an electron-beam column comprising a highly integrated assembly of electrostatic electron optics; as a result, this electron-beam column would be much smaller and less complex, in comparison with the electromagnetic-optics-based electron-beam column of a conventional laboratory SEM. An



The **Miniature SEM** would have dimensions of only a few centimeters and would consume much less power than does a conventional SEM.

electrostatic deflection system in the column would be used to raster-scan the electron beam across a sample.

A coaxial microchannel plate would be used to detect secondary and back-scattered electrons. A small, highly pure, deeply depleted silicon detector, with sensitivity from <1 to >10 keV, would be used to analyze the electron-beam-induced x-rays emitted by the sample, for identification of chemical elements in the sample. The field of view of the SEM would measure about 100 by 100 μm, and the spatial resolution would be about 10 nm.

The vacuum needed in the interior volume of the electron-beam column and sample chamber would be provided by a dedicated vacuum system comprising a small sputter ion pump and roughing pump. Samples would be brought into the chamber by a sample-acquisition system that would include (1) a rod equipped with O-ring vacuum seals near its outer end and with detents on its side to hold samples and (2) drive assemblies that would rotate and translate the rod. A typical sample-acquisition sequence would begin with extension of the rod to expose the detents. Sample material would be dropped into upward-facing detents, optionally with the help of a spill tray containing holes to guide the samples into the detents.

The rod would then be retracted to bring the sample-filled detents into the chamber. The rod could be further translated and rotated to bring a desired sample or part of a sample into registration with the electron-beam column. To prevent sample material from fouling the O-ring vacuum seals, small brushes would remove any sample material protruding from the detents and the rod would be made slightly narrower in the detent region than in the vacuum-sealing outer region. Once the samples had been analyzed, the rod would be extended, then rotated to dump the samples from the detents and to bring a set of empty detents to the top to receive the next set of samples.

This work was done by John L. Callas 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.*
NPO-20499

Improved Optical Sensor for Monitoring Dissolved Oxygen

Oxygen induces a reduction in the fluorescence lifetime of indicator molecules immobilized in an oxygen-permeable polymer.

John F. Kennedy Space Center, Florida

An optical sensor for measuring the partial pressure of dissolved oxygen in water is based on the effect of oxygen quenching on the fluorescence lifetime of an optically excited ruthenium complex immobilized in a recently developed polymer. In the operation of this sensor, the fluorescence lifetime and thus the degree of quenching and partial pressure of oxygen are measured by a phase-sensitive detection method described below. This sensor is a prototype of improved oxygen-concentration transducers, which are needed for monitoring critical oxygen concentrations in bioreactors and chemical plants.

The predecessors of this sensor include electrical (galvanic and polarographic) sensors and similar fluorescence-quenching sensors. The electrical sensors are subject to spurious responses due to ambient electrical noise, calibration drift arising from electrolyte depletion and/or fouling followed by reductive oxygen consumption, and poor sensitivity at low oxygen partial pressures. Among the older fluorescence-quenching sensors are versions in which the immobilizing polymers are made of silicone rubber and in the operation of which oxygen levels are deduced from measurements of fluorescent intensity. These older fluorescence-quenching sensors are subject to long-term calibration drift resulting from indicator photobleaching, and frequently require complicated multipoint calibrations because of their nonlinear Stern-Volmer response.

The deviation from linearity with the older optical sensors is partly attributable to electrostatic binding of the indicator molecules — particularly cationic ruthenium complexes — to anionic silanol groups on the surface of silica particles that are added to the silicone polymers to increase tear resistance. This binding reduces the degree of quenching by oxygen for a portion of the polymer-immobilized fluorophores, resulting in a negative deviation from a linear response. Tests of the solubility of the ruthenium complex in traditional silicones lacking silica particles showed the indicator material to be insoluble and, therefore, poorly suited for the construction of oxygen sensors.

The recently developed polymer used in the present sensor is a highly oxygen permeable fluoropolymer possessing slightly polar aromatic chain segments. These polar groups were found to solubilize the indicator complex in the polymer without affecting the degree of accessibility by oxygen. The hydrophobic nature of the fluoropolymer imparts a degree of selectivity in the sensor response by excluding nongaseous water-borne quenchers from the sensing membrane. The polymer is also inherently tear resistant by virtue of microscopic crystalline domains formed from aromatic polymer chain segments.

Unlike the response of older sensors made with silicone rubber, sensors made with the new membrane polymer exhibit a linear Stern-Volmer response that has been attributed to the greater homogeneity of the oxygen-quenching environment created around the ruthenium complex within the sensing membrane.

This linear Stern-Volmer response to oxygen should make it possible to use a one- or two-point calibration procedure.

In operation, oxygen from solution diffuses freely into the polymer, where it efficiently quenches the photoexcited ruthenium complex, reducing the lifetime of the fluorescence process. Excitation light energy is provided by a light-emitting diode operating in sinusoidally driven amplitude-modulation mode at a fixed angular frequency, ω. The resulting fluorescent signal is amplitude-modulated at the same frequency, but phase shifted relative to that of the excitation. The average fluorescence lifetime, τ, of the indicator complex is calculated from the observed phase shift, θ, occurring to the expression $\tau = \tan(\theta)/\omega$. Fluorescence lifetimes for the polymer-immobilized indicator were shown to be inversely proportional to the solution partial pressure of oxygen over the range 0 to 400 mm Hg.

This work was done by James A. Kane of Polestar Technologies, 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

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220 Reservoir Road
Suite 28B
Needham Heights, MA 02194
Tel No.: (781) 449-2284
E-mail: polestar@ix.netcom.com

Refer to KSC-11998, volume and number of this NASA Tech Briefs *issue, and the page number.*

Spectrometer/Radiometer for Measuring Heights of Cloud Tops

Three instruments with a common field of view produce complementary measurements.

Goddard Space Flight Center, Greenbelt, Maryland

A spectrometer/radiometer now undergoing development is designed to be used aboard a spacecraft to measure the heights of cloud tops on Earth. The spectrometer/radiometer performs functions of three instruments — two spectrometers and a radiometer — that share a common field of view. Each of these instrument techniques implements a technique that has been used before, by itself, to measure the heights of cloud tops. By combining the three techniques in a single instrument package, the design of the spectrometer/radiometer makes it possible to determine cloud-top heights more accurately than can be done by use of one of the techniques alone. Moreover, the three techniques are complementary, so that at least one of the techniques can yield a useful measurement under conditions in which the other two techniques are deficient.

The three techniques are the following:

1. *Thermal-Infrared Technique*

The spectral radiance of a cloud top viewed from above is measured at a wavelength of 11 μm, and the temperature of the cloud top is inferred from the measured radiance. Then the height of the cloud top is inferred from the climatological temperature-versus-altitude profile of the atmosphere, under the assumption that the cloud is in thermal equilibrium with the atmosphere. This technique fails in the presence of an isothermal atmosphere or of a convective cloud, which is not in thermal equilibrium with the atmosphere.

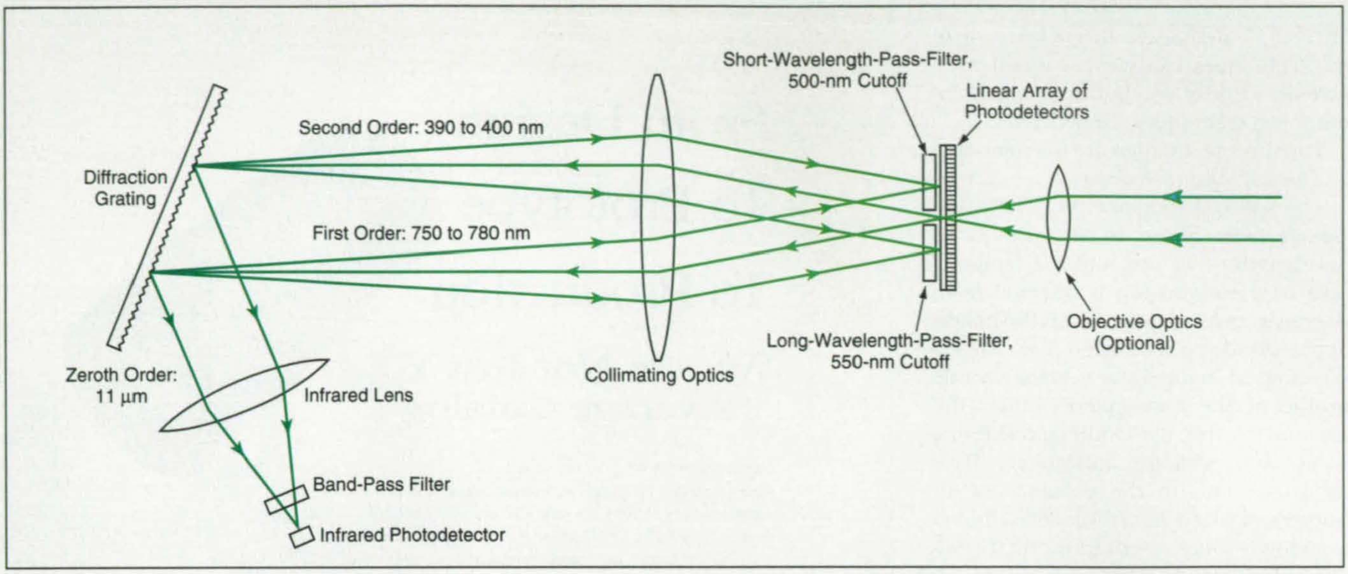
2. *Molecular-Oxygen "A"-Band Absorption*

Back-scattered sunlight is spectrally analyzed to determine the amount of absorption of light in oxygen molecules in the wavelength range from 750 to 780 nm. The depth of the atmospheric column above a cloud (and thus the height of the cloud top) is inferred from the differential absorptions in this wavelength range. This technique is vulnerable to errors in that the accuracy of the inferred cloud-top height depends on accurate correction of nonoxygen absorption at the cloud boundary layer.

3. *Fraunhofer-Line Filling-in Effect (Ring Effect)*

The Fraunhofer Ca, H, and K lines (which are absorption spectral lines in the solar spectrum) in the wavelength range of 390 to 400 nm are partially filled in by scattering in the terrestrial atmosphere due to the frequency shift in rotational Raman scattering. The measured spectrum of back-scattered sunlight in this wavelength range is compared with the corresponding extraterrestrially measured spectrum of light coming directly from the Sun to determine the amount of filling in of the Fraunhofer lines. Then the depth of the atmospheric scattering column above the cloud top (and thus the height of the cloud top) is inferred from the amount of filling in. This technique is not vulnerable to the boundary-layer inaccuracy of the molecular-oxygen "A"-Band technique, but its accuracy depends on high spectral resolution.

In the spectrometer/radiometer (see figure), wavelength dispersion is achieved by use of a diffraction grating. The spatial period and orientation of the grating are chosen to diffract the three wavelength bands of interest in different orders that emerge in different directions. Filters provide additional spectral selectivity for sorting the orders.



This **Spectrometer/Radiometer** diffracts light in three different orders to measure spectral properties of light scattered by cloud tops and by the atmosphere above cloud tops in three wavelength bands.

The 11-μm radiation is diffracted in the zeroth order of the grating, goes through a band-pass filter, and impinges on an HgCdTe photodetector cooled by liquid nitrogen. The 750-to-780-nm radiation is diffracted in the first order of the grating, goes through a long-wavelength-pass filter with a cutoff wavelength of about 550 nm, and impinges on part of a 1,024-pixel linear array of silicon photodiodes on a focal plane. The 390-to-400-nm radiation is diffracted in the second order, goes through a short-wavelength-pass filter with a cutoff wavelength of about 500 nm, and impinges on another part of the linear array of photodiodes. The spectral resolution is 0.4 nm in the first order and 0.2 nm in the second order.

This work was done by Hongwoo Park of **Goddard Space Flight Center**, *Peter F. Soulen of the University of Maryland, and Coorg R. Prasad of Science & Engineering Services, Inc. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*
GSC-14022

Continued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Robot Would Inspect Hanging Cables

John F. Kennedy Space Center, Florida

A proposed automated apparatus would travel along a hanging cable, optically inspecting it all around. The proposal was made to eliminate lowering human inspectors in baskets along emergency-egress slidewires at Kennedy Space Center launch pads. The apparatus would include a motor drive system, a video camera configured with mirrors for a 360° view of the cable, a data-capturing system, a laser micrometer, a video transmitter, and a radio transceiver for command and data signals. The apparatus would be placed on a cable at one end, then the inspection process would be initiated. During the process, the apparatus would operate under the control of a compact, rugged, onboard computer. Upon reaching the far end of the cable, the apparatus would automatically reverse itself and return to the starting end. An electronic neural network could be used, either on board the apparatus or in the command station, to analyze the inspection data to determine the integrity of the cable.

This work was done by Robert L. Morrison, Kenneth M. Nowak, Terence J. Ross, Eduardo Lopez del Castillo, Michael D. Hogue, and Tom Bonner of and Gabor Tamasi formerly of **Kennedy Space Center**.

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Technology Programs and Commercialization Office, Kennedy Space Center, (407) 867-6373, or for information regarding commercially available application of this technology contact: Halkin International at Halkinl@aol.com or telephone (303) 344-9592 (a nonexclusive licensee).
Refer to KSC-12023.

Miniature, Rugged Infrared Spectrometer

Variants could serve as engine-exhaust, chemical-process, and atmospheric chemical monitors.

John H. Glenn Research Center, Cleveland, Ohio

The figure shows a first-phase prototype of a miniature, rugged long-wavelength infrared (LWIR) spectrometer that incorporates recent advances in the design and fabrication of microelectronic and integrated optical devices. Initial development efforts have been directed toward the intended use of the instrument in measuring the concentrations of certain chemical constituents (e.g., CO_2, hydrocarbons, NO_2, N_2O, and HCl) in aircraft turbine exhaust streams. The instrument would be small and rugged enough to be mounted aboard an aircraft for diagnostic engine monitoring or even for feedback engine control. The basic instrument design could be varied to obtain automotive engine monitors, chemical-composition monitors for hot industrial processes, hand-held meters for identifying unknown chemicals or for measuring deviations from the nominal composition or purity of known chemicals, and mounted or hand-held instruments for detecting toxic or otherwise hazardous gases in outdoor or indoor air.

One especially notable component of the instrument is a unitary silicon chip that performs all of the functions of a conventional infrared analyzer. Optical elements of the analyzer — a diffraction grating, mirrors, apertures, and beam dumps — are micromachined directly onto the chip. The main body of the chip is also an important optical element in that it has a high index of refraction and acts as a slab waveguide; the use of a high-index slab waveguide reduces (in comparison with the use of simple propagation of light through air) the needed optical path length and makes it possible to design a smaller instrument. By virtue of its unitary construction, the micromachined infrared analyzer is rugged and permanently aligned. It is insensitive to vibration and to thermal transients. It is also opaque to visible light and other interference.

Another especially notable component of the instrument is a micromachined, silicon-based linear array of 64 thermopile-type photodetectors — one for each of 64 channels that span the wavelength range from 2.8 to 5.6 μm with a resolution (bandwidth per channel) of about 0.04 μm. Each photodetector is 1.5 mm long with a pixel pitch of 75 μm. Each photodetector comprises a 0.6-μm-thick silicon nitride membrane with eleven (Bi-Te)/(Bi-Sb-Te) thermocouples.

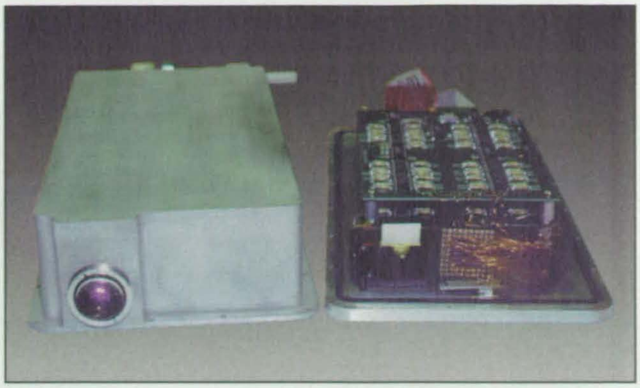
Thermopiles typically operate over a broad temperature range (including room temperature) and are insensitive to drifts in substrate temperature, so that it is not necessary to provide for either cooling or stabilization of temperature. Thermopiles are passive devices that generate voltage outputs, without need to supply bias voltage. Thus, in comparison with other infrared detectors in the same class (bolometers, pyroelectric devices, and ferroelectric devices), thermopiles consume less power and can be supported by simpler readout circuits. Moreover, if thermopiles are read out with high-input-impedance amplifiers, they exhibit negligible 1/frequency noise because there is negligible readout current. Moreover, thermopiles typically exhibit highly linear response over many orders of magnitude of incident infrared power.

It is necessary to process the thermopile readouts to extract chemical-composition information from overlapping spectral peaks. In the case of the first-phase prototype of the instrument, the outputs of the thermopiles are amplified, multiplexed, and digitized, then processed in an external laptop computer. A planned second-phase prototype would incorporate a digital signal processor that would perform neural-network processing to extract the required information.

This work was done by Edward A. Johnson and James Daly of Ion Optics, Inc., for **Glenn Research Center.** *No further documentation is available.*

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-16828.



This **Prototype of a Miniature, Rugged LWIR Spectrometer** was tested and found to satisfy signal-to-noise and spectral-resolution requirements to justify further development into an on-board aircraft engine exhaust-gas monitor.

INDUSTRY LEADERS

Profiles Of Pathsetting Companies Serving The Engineering Field

MELLES GRIOT PHOTONICS COMPONENTS

Melles Griot manufactures and distributes a complete line of optics designed specifically for ultraviolet applications. These optics include mirrors, beamsplitters, lenses, polarizers, and harmonic separators that are used in a wide variety of applications ranging from micromachining and annealing of TFT devices to photoradial keratotomy and video-disk mastering.

Currently Melles Griot is featuring mirrors and windows, tailored specifically for high-energy argon-fluoride and krypton-fluoride excimer lasers that have been proven in demanding photolithography applications. The computer-optimized multilayer dielectric coatings used on these components are immune to corrosive gases, making them suitable for either intracavity or extracavity applications, and they exhibit damage thresholds as high as 5 J/cm^2 at 248 nm and 2.5 J/cm^2 at 193 nm. Mirror coatings are available for either normal or 45°-incidence angles.

Melles Griot uses only UV-grade fused silica and calcium fluoride for its UV optics. Only this grade of material undergoes the special processing and selection steps necessary to deliver the combination of transmission, high damage threshold, resistance to color-center formation, low fluorescence, high homogeneity, and low stress birefringence required for the most demanding deep-UV applications.

All of our UV components are available in custom sizes and OEM quantities.

For more information contact Melles Griot Photonics Components, 16542 Millikan Ave., Irvine, CA 92606; (949) 261-5600, (800) 835-2626; fax: (949) 261-7790; e-mail: mgsales@irvine.mellesgriot.com; www.mellesgriot.com.

Circle No. 780

DEPOSITION SCIENCES INC.

Durable Coatings for Ultrahigh-Temperature Applications

Deposition Sciences Incorporated (DSI) now offers custom cold mirror and color filter coatings for extremely high temperature applications, such as those using high-intensity discharge lamps. These coatings are produced using the company's patented MicroDyn® microwave-assisted sputtering process. This unique method enables the uniform coating of flat, highly curved, and cylindrically shaped parts, and yields thin films with exceptional mechanical durability and a heat-handling capacity in excess of 1300 °C.

This high-temperature capacity allows these coatings to be used in very novel ways. For example, DSI's cold mirror coating can be applied directly to part of the curved envelope of an HID lamp, thus acting as an integrated reflector. Similarly, a color filter can be put right on almost any type of lamp envelope or burner to alter its output spectrum; for example, a blue blocking filter would yield a yellow fog lamp. The coatings are also useful for the glass and ceramic reflectors, such as parabolas and ellipsoids, that are used with high-intensity sources.

DSI is a manufacturer of optical thin-film coatings for heat, color, and color-temperature management in lighting systems utilizing high-intensity discharge, tungsten, halogen, and other types of illumination sources.

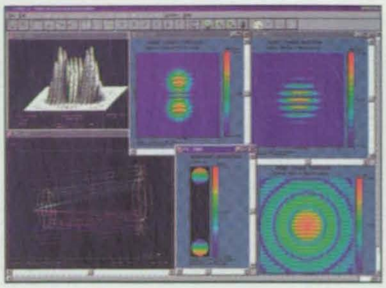
For more information, contact the Industrial Lighting Products Business Unit, Deposition Sciences Inc., 386 Tesconi Court, Santa Rosa, CA 95401; (707) 573-6700; fax: (707) 573-6748; www.heatbuster.com.

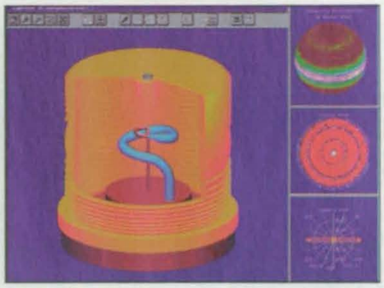
Circle No. 781

OPTICAL RESEARCH ASSOCIATES

ORA's CODE V and LightTools Software

Optical Research Associates' CODE V® is the industry's leading software for the design, analysis, and tolerancing of optical systems, enhancing user productivity throughout the design and fabrication cycle.





CODE V has unique lens design capabilities in MTF-based tolerancing, Global Synthesis®, environmental analysis, partial coherence analysis, gradient index and DOE/HOE support, polarization ray tracing, and lens cost appraisal. It supports user-defined surfaces and a powerful high-level Macro-Plus language for creating user-generated applications. The optimization and tolerancing capabilities are uniquely powerful.

LightTools®, an illumination design software offering, uses Monte Carlo ray tracing techniques to determine illuminance and intensity information based on a precisely defined and visualized 3D interactive solid model description of an illumination system (sources, refractors, reflectors, receivers).

Applications include the design of fiber light engines, refractors, interior and exterior vehicle lighting, complex light guides, projection systems, machine vision systems, etc.

All users receive comprehensive support from a dedicated staff of experienced optical designers.

For more information, contact Optical Research Associates at (626) 795-9101 or at service@opticalres.com. Visit our home page at www.opticalres.com.

Circle No. 782

UDT SENSORS

UDT Sensors' new 76-page photodetector catalog features more than 80 new products including general-purpose photoconductive and photovoltaic planar diffused photodiodes; soft x-ray, UV-enhanced, high-breakdown voltage detector/amplifier hybrids; detector/filter combinations; multielement arrays; position-sensing detectors; low-cost molded packages; and dual emitter/detector combinations.

Our new avalanche photodiodes use internal multiplication to achieve high gains from impact ionization, resulting in high responsivity and high-gain bandwidth with superior sensitivity, compared with conventional PIN detector/amplifier combinations. They are manufactured using a double-implanted "reach-through" structure for good gain and temperature stability combined with low noise and dark current.

Our large-active-area fiber optic silicon detector/amplifiers achieve bandwidths >1.25 GHz with a single 3.3-V supply for 850-nm short-haul Gigabit Ethernet receiver applications. They exhibit superior performance over existing detector/amplifiers for high-speed communication.

For more information, contact UDT Sensors Inc., at 12525 Chadron Ave., Hawthorne, CA 90250; (310) 978-0516; fax: (310) 644-1727.

Circle No. 783

CORNING OCA

A world leader in optical products and technologies

For more than 35 years, Corning OCA has been a world leader in design, development, and manufacture of OEM optical systems. We are experts at manufacturing optical components in sizes ranging from 1 mm to 1 meter. We fabricate cylindrical, aspheric, flats, and spherical optics to the most demanding specifications. In addition, Corning OCA offers high-performance thin film coatings for applications in the ultraviolet, visible, and infrared wavelengths. Our assembly and integration capabilities range from lens assemblies to complex opto-mechanical and electro-optical assemblies. Corning OCA offers a complete package of integrated capabilities serving our customer needs from concept and design through prototype and production.

Projection system modeled in ASAP. Courtesy of Breault Research Organization.

Corning OCA recently introduced Visicor™ illumination optics for projection illumination systems. A custom Visicor system will improve performance by as much as 20 percent over standard projection illumination systems. Superior performance is achieved through the use of specialty glass combined with proprietary thin-film coatings technology. A Visicor system replaces a three- to four-element projection illumination system with one or two elements. Performance improvement results from fewer optical surfaces that generate light loss. Fewer system elements and mounting fixtures lead to significant cost savings and weight reduction. Visicor elements can be formed into shapes ranging from traditional optical components to multielement monolithic lens arrays.

For more information, contact Corning OCA, 7421 Orangewood Avenue, Garden Grove, CA 92841; (888) 329-2114; fax: (714) 898-0587; e-mail: corningoca@corning.com; http://www.oca.com.

Circle No. 784

COHERENT SEMICONDUCTOR GROUP

High-Power 770-nm Fiber-Coupled Laser for Optical Pumping Experiments

Coherent's Semiconductor Group (CSG) now offers a high-power fiber-coupled diode laser at 770 nm designed for optically pumping potassium vapor to generate polarized ^{3}He, ^{21}Ne, or ^{129}Xe via spin exchange. The polarized gases can then be used in applications ranging from physics and material science experiments to high-resolution imaging.

To date rubidium has been the primary alkali metal used to generate polarized noble gases. However, the potassium/noble gas spin exchange interaction is significantly stronger than the rubidium/noble gas interaction. As a result, using potassium allows researchers to polarize helium, for example, several times faster than similar experiments using rubidium. Alternatively, experiments involving potassium can produce a volume of polarized helium equal to experiments using rubidium, while requiring a small fraction of the laser power.

To coincide with this research, CSG has developed a high-power CW fiber-coupled package (FAP™) at 770 nm—potassium's D1 transition. For the simplest delivery of the high-power light, CSG's FAP device produces an output of 16 W through an 800-µm fiber with an NA of <0.16. Spectral width is <2 nm FWHM, and drive conditions are 2 V at 31 A.

For ease of use in a host of spin-exchange experiments, CSG offers a standalone microprocessor-controlled FAP-System™. Using the CSG FAP device as the system's engine, the FAP-System allows researchers to swap out different wavelength laser diodes to support both rubidium (795-nm D1 transition) and potassium (770-nm D1 transition) spin exchange.

For more information, contact Coherent Inc. Semiconductor Group, 5100 Patrick Henry Drive, Santa Clara, CA 95054; 408-764-4983.

Circle No. 785

EASTMAN KODAK CO.

Kodak offers high-quality, 2000-fps color imager for product design.

The Kodak EktaPro™ CR imager, Model 2000, is a self-contained imager designed to provide engineers and scientists with a user-friendly way to record high-speed images for video playback at variable speeds and as a data source for computerized motion analysis.

The CR imager, Model 2000, enables users to record 24-bit color or eight-bit monochrome images at frame rates up to 2000 frames per second. A 512-×-384-pixel sensor captures the high-resolution images needed for demanding applications. Electronic shuttering helps eliminate motion blur, and an anti-blooming feature prevents image degradation under intense lighting conditions. As a result, recorded images are consistently sharp and clear.

The new imager can be operated with an attached handheld keypad, or remotely from a PC via 100-BaseT Ethernet communications. An x-y reticle provides an electronic crosshair for basic motion analysis. Digital images can be downloaded from the imager in either compact (Bayer) or industry-standard TIFF format onto a PCMCIA hard drive or solid-state memory card. Images can also be downloaded directly to a PC over Ethernet for future detailed analysis. By attaching a video recorder to the imager, a user can also capture and archive NTSC or PAL video onto tape.

For further information, contact: Motion Analysis Systems Division, Eastman Kodak Co., (619) 535-2909, or visit the MASD website at www.masdkodak.com/pub.

Circle No. 786

OPTOSIGMA CORP.

OptoSigma offers more than 3500 off-the-shelf optics and high-performance optical coatings. All optics and coatings are designed and manufactured to extremely tight specifications and tolerances for the highest-performance off-the-shelf solutions.

Catalog optics include high-power laser and broadband mirrors; beamsplitters; windows; spherical and achromatic lenses; micro-optics; prisms; polarizers; and filters. Sizes range from 2 mm to over 6 inches in diameter. Lens focal lengths vary from several to thousands of millimeters. Lenses are available in BK7 or fused silica with antireflection coatings for broadband, laser-line, or super-low-loss applications.

OptoSigma's coating factory in Santa Ana, CA, is automated to ensure highly repeatable coatings. This capability provides the consistent run-to-run performance required by most OEM applications. In addition, use of ion-assisted deposition in our coating process ensures more densely packed thin-film coatings that are extremely durable and are capable of withstanding very high laser fluence.

OptoSigma's metrology laboratory is sophisticated and complete, thus ensuring that your specifications are met every time. Computer-controlled spectral and interferometric instrumentation allows us to provide optical performance data to you in several convenient electronic or paper formats.

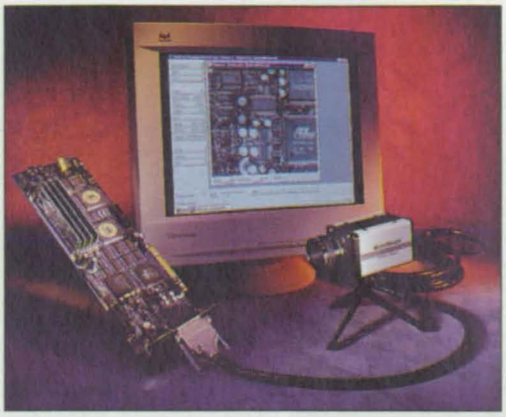
For more information, ask for OptoSigma's product catalog, or contact OptoSigma at 2001 Deere Avenue, Santa Ana, CA 92705; (949) 851-5881; fax: (949) 851-5058; e-mail: optosigm@ix.netcom.com; www.optosigma.com.

Circle No. 787

REDLAKE IMAGING

Redlake Imaging is the manufacturer of the *Motion*Scope® high-speed imaging product lines. The *Motion*Scope series is based on the premise that high-speed imaging for motion analysis should be affordable, small, and easy to use. *Motion*Scope models range from stand-alone systems and PC peripherals to network-based cameras that record up to 8000 images per second (shutter up to 10 microseconds).

The *Motion*Scope PCI series is a plug-and-play PC peripheral for capturing high-speed digital images directly into a PC. With the "point & click" Windows-based application software, the PCI series gives you more motion analysis capabilities in a full digital environment. Images are easily archived in the Microsoft .AVI file format, extending the functionality of the system by interfacing to many third-party analysis software packages.



The e/Cam series is a network-based (Ethernet) high-speed digital imaging system for motion analysis applications that require many cameras to be controlled by a PC. Designed for motion analysis applications such as research & development, automotive crash testing, and military and aerospace research, these capabilities make the *Motion*Scope the ideal tool. *Motion*Scope PCI board-level products are also available for OEM and integrator applications that require high-speed continuous image acquisition.

Redlake Imaging Corporation, 18450 Technology Drive, Suite A, Morgan Hill, CA 95037; (408) 779-6464; (800) 453-1223; fax: (408) 778-6256; e-mail: sales@redlake.com

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AVIMO PRECISION POLYMER OPTICS

Avimo Precision Polymer Optics (APPO) is a leading manufacturer of precision molded plastic optics used in a wide range of commercial markets including medical disposables; bar-code, security, and fingerprint scanners; motion and presence sensors; CCD cameras; and laser collimation. With diamond-turning capabilities and a state-of-the-art mold-making shop, APPO produces aspheric, diffractive, hybrid, and conventional optics, including a stock line of collimating lenses for laser diodes. Our expertise in precision plastic optics and molding techniques allows us to offer cost-effective polymer optical solutions ranging from quick-turnaround prototype fabrication to production runs of millions of components, consistently and reliably.

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For more information, contact Avimo Precision Polymer Optics, 560 West Terrace Drive, San Dimas, CA 91773; (909) 599-9341; fax: (909) 592-2780; e-mail: joeatappo@aol.com; or see us on the web at www.polymeroptics.com.

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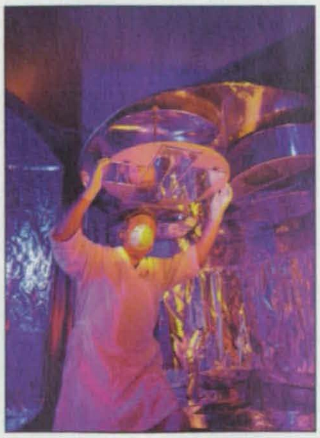

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Circle No. 790

NEW PRODUCTS

PRODUCT OF THE MONTH

Carbon Dioxide Laser Marking Head

The new FH Series of carbon dioxide laser marking heads from Synrad, Mukilteo, WA, is a component-level galvanometer-based scanning head featuring digital fiber optic technology. Marking at speeds of up to 180 characters per second, it is designed to work with Synrad lasers from 10 to 125 W. The company supplies all the components (except for a standard PC) needed to assemble a complete laser marking system, including marking software, focusing lenses, mounting assemblies, and power meters. The series is fully CE compliant, and includes a built-in test mark function.

For More Information Circle No. 765

Blue Laser Diode System

The new blue/violet laser diode system from Coherent's Auburn Group, Auburn, CA, is based on an indium gallium nitride diode that emits at a center wavelength of 405 nm and has output power of 4 mW. The system uses Coherent's patented Alignlock™ technology to mount the diode chip and the optics together in the same module housing, similar in size to a HeNe laser tube (44.5 mm in diameter and 222 mm long). To extend the life of the raw diode, the laser is thermoelectrically cooled to a temperature of 20 °C. Beam diameter is 1.9 mm × 4.5 mm, and beam boresight is ±1.2 mrad.

For More Information Circle No. 766

Windowless Avalanche Photodiodes

Advanced Photonix, Camarillo, CA, introduces the 5X0 windowless series of large-area avalanche photodiodes (LAAPDs). The company says windowless operation enables the detector to contact the scintillator or fiber-optic bundle directly for maximum collection efficiency. Windowless operation also enhances performance in the UV, and allows direct detection of soft x-rays. The LAAPDs offer quantum efficiencies of up to 90 percent, and have active areas as large as 5, 10, and 16 mm. Three spectral enhancements are available to optimize usage across the wavelength range of 250-1000 nm.

For More Information Circle No. 767

Single-Emitter Diode Laser

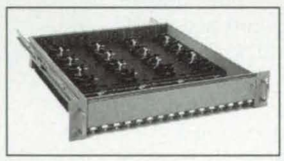
Opto Power Corporation, Tucson, AZ, says that its new H02-A001-830-FC/60 single-emitter diode laser has the highest power yet coupled to a 60-µm-core optical fiber. The laser produces 700 mW at 830 nm, and the fiber core has a numerical aperture of 0.22. The company says that the system's higher power enables faster writing speeds in graphic arts applications, and that the combination of small core size and low numerical aperture permits the laser output to be refocused to a small spot size with a relatively large depth of field, translating into higher image resolution.

For More Information Circle No. 769

Three-Chip Color Linescan Camera

DALSA INC., Waterloo, Ontario, Canada, introduces the Trillium color linescan camera specifically designed for high-end color imaging applications, such as print inspection, web inspection, and high-resolution machine vision. Trillium uses prism beamsplitting technology with dichroic interference filters and three DALSA-designed IL-CC sensors, providing three color signals (red, green, and blue) from a common optical axis. With 1024 or 2048 resolution, the three channels transmit LVDS data at 25 MHz each, resulting in up to a 21-kHz line rate, with 8-bit output from 10-bit digitization.

For More Information Circle No. 770



16-Channel Laser Diode Mount

ILX Lightwave Corp., Bozeman, MT, announces the LDM-4616 rack-mountable 16-channel mount for butterfly-packaged laser diodes. The zero-insertion-force sockets, user-configurable pin headers, and interchangeable fiber optic connectors on the front panel make the unit compatible with most butterfly-packaged lasers. Slide rollers provide easy access to the entire mounting tray. Each socket has electrical connections for laser drive current, photodiode feedback, TE cooler current, and thermistor sensor signals. Standard cables connect to any ILX Lightwave current and temperature controller.

For More Information Circle No. 772

Large Thermal Disk Laser Probe

Molectron Detector, Portland, OR, offers the PM5K-200, the world's largest-area radial flow thermal disk laser probe, according to the company. With a 200-mm diameter, the water-cooled probe is intended for large laser diode arrays and high-divergence beams, and for measuring the power of a large collimated laser beam from UV to far IR. The probe can measure power levels as high as 5 kW using Molectron's power instruments such as the EPM1000, EPM2000, PM5100, and PM5200.

For More Information Circle No. 773

2/3-Inch Analog CCD Camera

Sony Electronics, Park Ridge, NJ, introduces the XC-ST70 black-and-white analog video camera, featuring the "next-generation" 2/3-inch interline CCD with HAD technology. The camera has a minimum sensitivity of 0.3 lux, for what Sony calls improved detection of faint signals or the need for less gain when detecting faint signals. Signal-to-noise ratio is 60 dB. The unit can be used with the newer high-bit-depth (greater than 8-bit) framegrabbers, according to the company. Electronic shutter speeds range from one one-hundredth to one ten-thousandth of a second.

For More Information Circle No. 774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Mechanics

Additive Beam for Modeling Dynamics of the SR-71 Fuselage

Computational simulations are more accurate.

Dryden Flight Research Center, Edwards, California

Mathematical models to approximate the dynamics of aircraft are often generated by considering aircraft structures to be rigid bodies. These models may be unsuitable for evaluating the maneuvering responses and flight characteristics of flexible aircraft. Computational simulations of the dynamics of a flexible aircraft by use of a model that does not account for the elasticity may indicate inaccurate tracking performance, handling qualities, and response bandwidth, especially in evaluations of responses to pilot commands.

It is necessary to account for the elastic as well as the rigid-body dynamics of the SR-71 airplane (see Figure 1) in order to simulate its overall dynamic responses accurately. In particular, a submodel of elastic dynamics must represent the first bending mode of the fuselage. This mode can significantly affect responses because large-amplitude oscillations in this mode are easily excited during standard pilot maneuvers. Thus, it is necessary to model this mode accurately for closed-loop analysis and pilot simulations.

Flight data can be used to generate mathematical models that account for rigid-body and elastic dynamics, according to the method described in "Calibrating Aircraft-Vibration Models from Flight Data" (DRC-95-05), *NASA Tech Briefs*, Vol. 21, No. 11 (November 1997), page 78. In this method, one considers a general theoretical model and analyzes flight data by use of parameter-estimation algorithms to determine the optimal coefficients for that model. Models of the SR-71 airplane were developed by introducing a simple uniform beam to represent the mode shape of the fuselage in a general model. An optimal model resulting from analysis of flight data was found to be capable of simulating responses much more accurately than did rigid-body models; however, there were some errors in the simulated dynamics of the fuselage.

An additive-beam model has been conceived for use in representing the mode shapes of the elastic dynamics of the fuselage; in other words, the bending shapes of modes of vibration of the fuselage. This additive-beam model is formulated by superimposing the responses of a uniform beam with no fixed ends and a uniform beam with one fixed end. The resulting beam is not restricted to be symmetric about a midpoint and, consequently, can represent complex mode shapes.

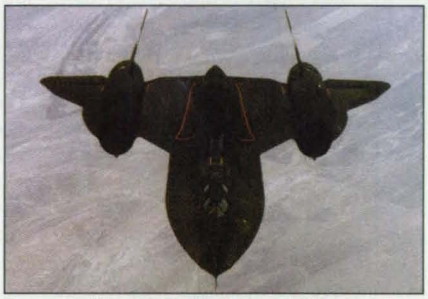


Figure 1. **The SR-71 Airplane** exhibits fuselage-bending vibrations that affect its overall dynamics and that must be taken into account to obtain accurate computational simulations of responses to pilot commands.

A model of the SR-71 is generated by analyzing flight data according to the parameter-estimation method and utilizing a general model that includes the additive beam. Figure 2 presents an example of flight data — acceleration measured near the pilot station during a pitch maneuver — along with the corresponding simulated responses of a rigid-body model and the model that includes the additive-beam submodel. Responses from the additive-beam model are very similar to the flight data and are clearly more accurate than are the responses from the rigid-body model. Thus, the additive beam has been shown to represent accurately the first bending mode of the fuselage.

The additive beam is particularly useful for modeling the fuselage of the SR-71 be-

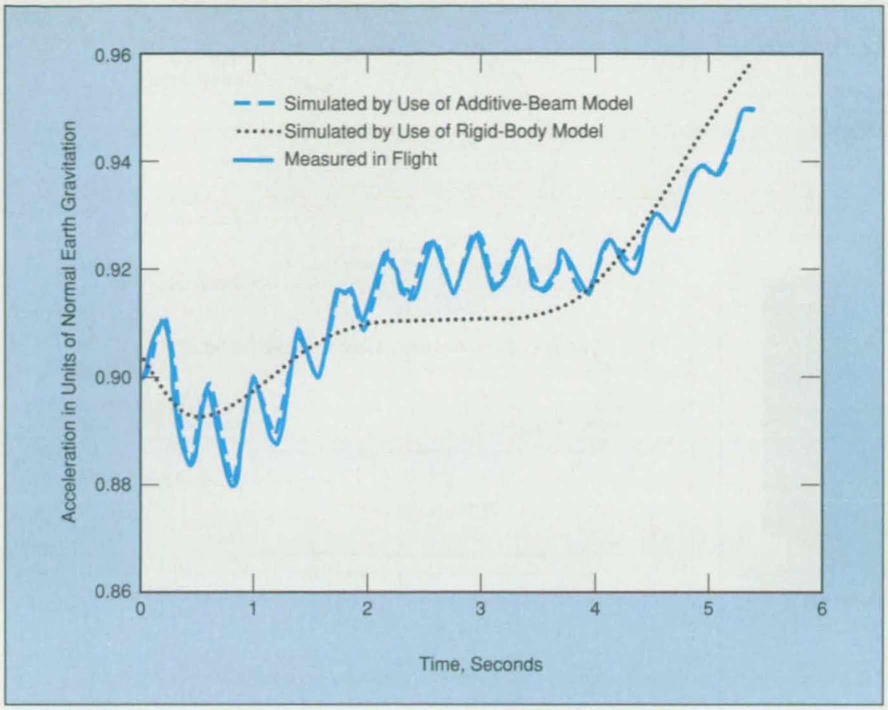


Figure 2. **Acceleration Near a Pilot Station** on the SR-71 airplane, in response to a pilot command, was measured in flight and simulated by use of two different mathematical models.

cause of the resulting complicated mode shape. This shape accounts for the variations in structural stiffness that occur along the fuselage as a result of wings and engine mountings. Similarly, additive-beam models can be included in models of other aircraft that have complicated mode shapes. For example, many long-endurance, high-altitude airplanes with long wing spans are affected by low-frequency bending modes with complicated mode shapes that cannot be accurately modeled by simple uniform beams.

This work was done by Rick Lind of **Dryden Flight Research Center** *and Carla Iorio of West Virginia University. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category. DRC-98-36*

Composite-Fuselage Concept for Greater Crashworthiness

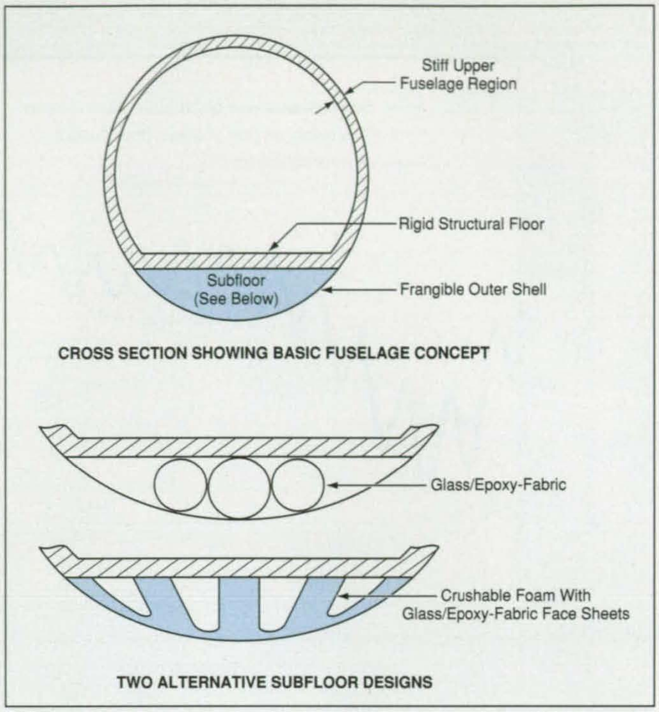
The fuselage is designed to protect occupants and absorb impact energy.

Langley Research Center, Hampton, Virginia

A continuing program of research is directed toward the development of crashworthy composite-material fuselages for small aircraft. These fuselages are required not only to withstand flight loads and exhibit the required aerodynamic characteristics, but also to protect occupants during crashes more effectively than do conventional fuselages. The design goal for protection against crashes is to limit loads applied to occupants to survivable levels in vertical impacts onto rigid surfaces at a speed of 31 ft/s (9.4 m/s). This vertical impact speed exceeds that specified in current regulatory criteria for small aircraft, but it is a realistic, potentially survivable, impact velocity that has been observed in crashes and in crash tests performed at Langley Research Center.

The design concept that has emerged from this research calls for a structure made from several glass/epoxy-fabric and graphite/epoxy-fabric laminates plus some other materials. The fuselage is divided into four regions, as indicated in the figure. Each region is designed to satisfy a different set of requirements:

- The upper region is made of a stiff sandwich comprising a polyurethane foam core between glass/epoxy-fabric face sheets. This region is designed to enclose and protect the occupants in the event of a crash.
- The outer shell is made from a relatively compliant glass/epoxy-fabric layer that



Different Regions of the Fuselage are designed to perform different roles to protect occupants during a crash.

is wrapped around the entire fuselage, enclosing an energy-absorbing structure (the subfloor) beneath a rigid structural floor. The outer shell is designed to have the required aerodynamic shape and to tolerate damage. The outer shell is intended to become deformed upon impact; this deformation, in turn, is intended to initiate crushing of the subfloor.

- The subfloor, described in more detail below, is designed to dissipate kinetic energy through stable crushing, and to maintain adequate post-crash structural integrity.
- The stiff structural floor is designed to react the loads generated by crushing of the subfloor, and to provide a stable platform for attachment of seats and restraints.

Two alternative subfloor designs have been selected: In one design, the main structural components of the subfloor are three laminated glass/epoxy-fabric tubes placed lengthwise along the fuselage. The sizes of the tubes, the number of layers of glass/epoxy fabric, and the orientations of the fibers in the layers must be chosen to optimize the absorption of energy by transverse crushing of the tubes upon impact.

In the other subfloor design, the space below the stiff structural floor is filled with closed-cell polymethylimide foam covered by glass/epoxy-fabric face sheets. The geometry of the foam subfloor was chosen to achieve and to maintain the desired crushing stress level.

The concept has been implemented in 1/5-scale models that have been evaluated in drop tests. The models were dropped from a height of 15 ft (4.6 m) to obtain vertical impact at a speed of 31 ft/s (9.4 m/s) onto a concrete surface. Floor-level accelerations of 125 times normal Earth gravitational acceleration (g) were obtained. (This impact requirement corresponds to a 25-g floor-level acceleration in a full-scale fuselage.) The data from the drop tests indicated that the model with a foam subfloor satisfied the impact design requirement. The results of a finite-element simulation of the impact behavior were found to be well correlated with the corresponding results from the drop tests.

This work was done by Karen E. Jackson and Edwin L. Fasanella of the Vehicle Technology Center of the U.S. Army Research Laboratory for **Langley Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category. L-17835*

Better Densification of Cryogenic Liquid Rocket Propellants

Supercooling would enable reductions of size and weight.

Lyndon B. Johnson Space Center, Houston, Texas

An improved system for densifying (by cooling) the liquid hydrogen and liquid oxygen used as propellants for the space shuttle has been proposed. These propellant liquids are cooled to minimize the sizes of tanks needed to store them and to reduce maximum operating pressures. The proposed system would densify these liquids 7 to 8 percent more efficiently than does the present propellant-densification system, and would reduce the absolute vapor pressure from about 15 psi (≈0.1 MPa) to about 1.5 psi (≈10 kPa). Sizing analysis indicates that the combination of the increase in density and the decrease in vapor pressure would reduce the weight of the space shuttle by 10 to 20 percent. Similar reductions in the required volumes and weights of tanks for storing cryogenic liquids could be beneficial in any industry in which the sizes of such tanks are cost factors.

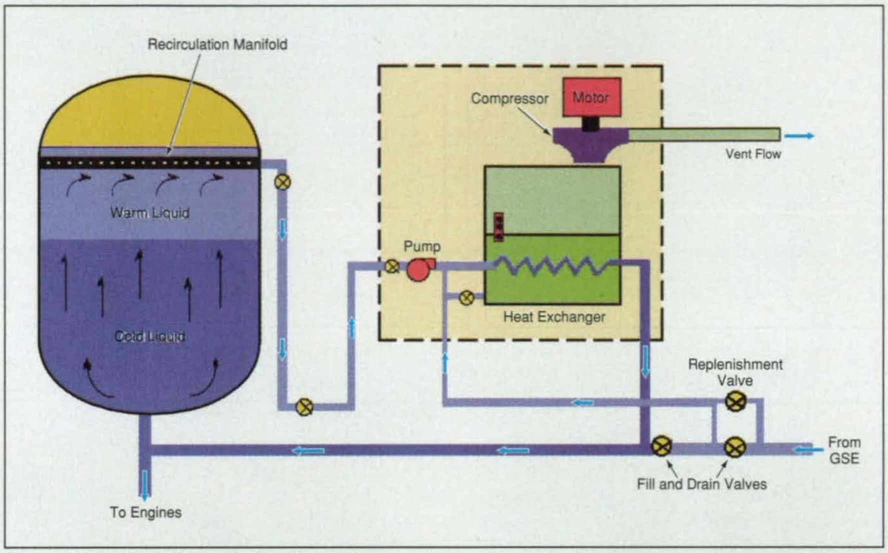


Figure 1. **The Tank Recirculation Subsystem** would continuously circulate the warmer cryogenic propellant liquid from the tank along with a supercooled stream of the same liquid.

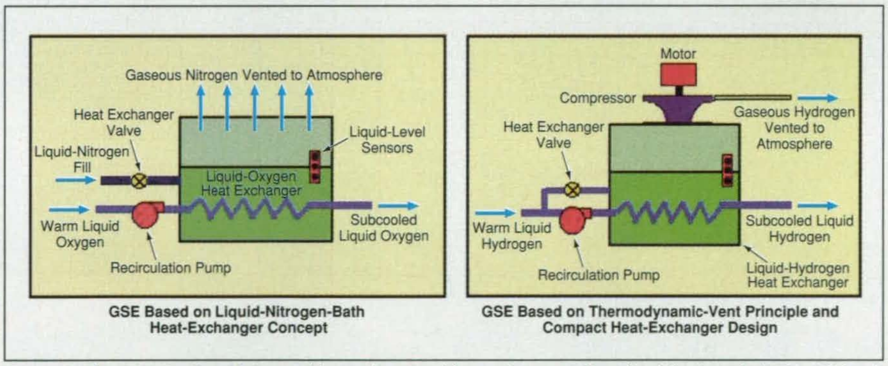


Figure 2. **The GSE Cooling Unit** would vent heat and keep the propellant liquid subcooled. The GSE unit could be designed according to a heat-exchanger-bath concept or a thermodynamic-vent principle.

Densification of the space-shuttle propellant liquids is done during stable replenishing operations. Heretofore, these liquids have been cooled through surface-evaporation heat transfer and convective mixing. This method of cooling, while simple, is time-consuming and constrains the tank pressure to one atmosphere (≈0.1 MPa). The proposed system — a product of research at Rockwell International — would supercool the liquids to lower temperatures and vapor pressures than does the present system, and in a fraction of the time. An added advantage of the proposed system is that a vent valve would be relocated from the flight vehicle to the ground, with consequent further reduction in vehicle weight and simplification of design.

The proposed system (more precisely, a pair of systems — one for each liquid) would comprise two subsystems: (1) a tank recirculation subsystem (see Figure 1), which would continuously recirculate the initially warm liquid in the affected propellant tanks with subcooled liquid; and (2) a ground support equipment (GSE) cooling unit (see Figure 2), which would vent heat and keep the liquid subcooled. The GSE unit could be designed in one of two ways: as a simple heat exchanger or based on the thermodynamic-vent principle. The heat-exchanger design would involve use of a liquid bath as a boiling liquid medium. In the thermodynamic-vent version, a fraction of the recirculation fluid would be expanded to a lower pressure without changing its internal heat content. This throttling of the liquid, or moving from high pressure to low pressure, would cause the liquid to flash to a low temperature. The flashing, in turn, would cool the recirculating fluid. The low pressure on the colder side of the heat exchanger would be maintained by a compressor/blower unit, which would reject the vented gas from the low pressure to ambient pressure.

The GSE design would be determined by the thermodynamic properties of the liquid being recirculated and by cost constraints. The heat-exchanger GSE design, while less effective, would be less costly to build, especially for a fixed-structure system like the space shuttle. The thermodynamic-vent GSE design would be most beneficial in a new system because the vehicle could be designed according to the reduced volume and weight requirements associated with the improved cooling system.

This work was done by Tibor I. Lak, Steve P. Petrilla, and Martin E. Lozano of Rockwell International for **Johnson Space Center.**

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act {42 USC 2457 (f)}, to The Boeing Co. Inquiries concerning licenses for its commercial development should be addressed to

Danielle Bartoli
The Boeing Co.
Canoga Park, CA 91309-7922
Tel. No. (818) 586-1367

Refer to MSC-22723, volume and number of this NASA Tech Briefs *issue, and the page number.*

Force-Reflecting, Finger-Position-Sensing Mechanism

This exoskeletal device is part of a hand-operated apparatus for controlling a robotic manipulator.

Lyndon B. Johnson Space Center, Houston, Texas

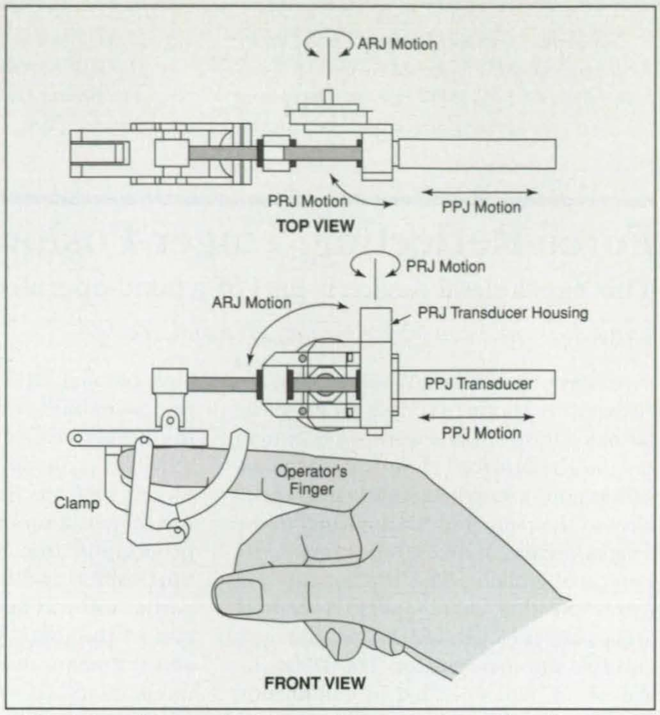
An electromechanical device called the "Dexterous Master" (DM) is an exoskeletal mechanism that is worn on a human operator's hand for (1) measuring the positions and orientations of the fingers relative to the palm and (2) applying, to the fingers, feedback forces from a remote robotic manipulator. The DM is part of a force-reflecting, hand-operated control apparatus through which the operator controls the manipulator. The DM is installed on, and operated in conjunction with, another mechanism that measures the position and orientation of the hand and reflects forces to the hand in the six degrees of freedom that determine the position and orientation of an end effector (robot hand) on the manipulator.

The DM has nine passive parallel degrees of freedom (DOFs) and six actuated parallel DOFs. It includes five finger assemblies, which are mounted on the dorsal surface of the hand to minimize the probability of collisions among fingers and mechanisms. The design of the finger assemblies is based on the proposition that it suffices to measure the position and orientation of each fingertip, with no need to measure the angles of the joints between the fingertip and the palm; this proposition makes it unnecessary to encumber each finger joint with hardware.

A control computer calculates real-time coordinate transformations between (1) the positions and orientations of the operator's fingertips and (2) the positions and orientations of fingertips or other corresponding parts on the robotic end effector. This control scheme renders master/slave kinematic similarity unnecessary, thereby enabling the slaving of a variety of multilink robotic arms and hands.

The six actuated DOFs (two for the thumb, one for each of the other four fingers) are implemented by use of six identical servo-controlled actuator units. The actuators are small electric brushless motors connected to synchronous belt-drive trains.

With the exception of the thumb, each finger assembly includes one actuated revolute joint (ARJ), one passive prismatic joint (PPJ), and a passive revolute joint (see figure). The thumb assembly is similar except that it includes two ARJs. The particular revolute/prismatic arrangement was chosen primarily because it offers an optimum solution to



A **Finger Assembly** contains joints and joint transducers that allow natural finger motion and measure the position and orientation of the fingertip.

the problem of transducing the position of three DOFs per finger while actuating only one.

Each ARJ consists of the bull gear from one of the synchronous belt-drive trains and a radial ball-bearing set. Each PPJ consists of a length of a steel slider bar in a linear recirculating-ball-bearing set. Each PRJ consists of a radial ball-bearing set; it allows revolute motion of the slider bar about an axis perpendicular to both its axis of linear travel and the axis of the actuated revolute joint. The motion of an ARJ (other than the second thumb ARJ) corresponds approximately to the inclination/declination of the proximal joint of the affected finger. The motion of a PPJ corresponds approximately to extension/retraction of the tip of the affected finger with respect to the palm. The motion of a PRJ corresponds approximately to adduction/abduction of the affected finger.

The position of a slider rod along a PPJ is transduced by a linear variable-differential transformer (LVDT) in which the slider bar serves as the transformer core. The angle of a PRJ is measured by a shrouded light-emitting-diode/photoreceptor pair aimed at a rotary polytetrafluoroethylene target. The angle of an ARJ is measured by use of a shaft-angle encoder on its motor. The ARJ, PPJ, and PRJ, through their respective transducers, together provide sufficient data to define the location of the fingertip in spherical coordinates. At the same time, servoing the motor presents the required haptic feedback to the fingertip. Separate actuation of the sliding rod is unnecessary because when the gear is held in place by the application of torque, the sliding rod is positioned so that it cannot be slid freely along its path without a very unnatural motion of the finger.

The tip of each finger assembly is equipped with a mechanism designed specifically for clamping the fingertip. The finger clamp is sprung closed, and a cam action is used to ensure effective clamping while accommodating a large variance in operator finger sizes. The DM superstructure is held stationary, relative to the palm, by means of a fingerless glove with hook-and-loop straps for donning and dofing.

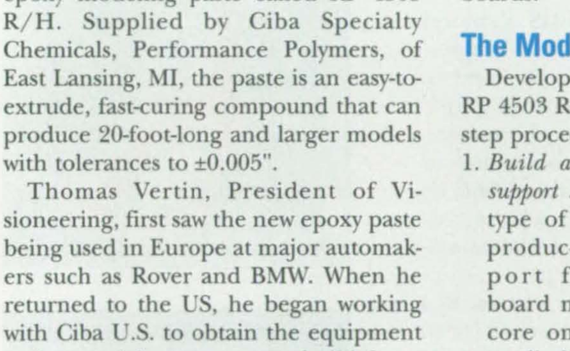
This work was done by Vikas K. Sinha, Eric W. Endsley, Alan J. Riggs, and Brian K. Millspaugh of Cybernet Systems Corp. for **Johnson Space Center**. *No further documentation is available. MSC-22846*

Rapid Product Development

Aircraft Modeling Costs Cut With New Epoxy Paste

To produce large, dimensionally accurate master models at one-third the cost of using conventional materials, Visioneering of Fraser, MI, has chosen a new, machinable, seamless epoxy modeling paste called RP 4503 R/H. Supplied by Ciba Specialty Chemicals, Performance Polymers, of East Lansing, MI, the paste is an easy-to-extrude, fast-curing compound that can produce 20-foot-long and larger models with tolerances to ±0.005".

Thomas Vertin, President of Visioneering, first saw the new epoxy paste being used in Europe at major automakers such as Rover and BMW. When he returned to the US, he began working with Ciba U.S. to obtain the equipment and material necessary to build large extruded epoxy models. Visioneering generated its first paste model in January 1998 for a Boeing aircraft model. Since then, the company has produced 30 to 40 large models from the paste system, perfecting the application and machining of the material to optimize performance and results.



The paste is extruded to build up a machinable shell on an undersized core. The material adheres to underlying layers without visible seams.

"With the new low-shrink paste, we use less material and less labor on large automotive and aerospace modeling projects," said Vertin. "As a result, we significantly cut costs while, at the same time, getting greater accuracy than with traditional modeling boards."

The Modeling Process

Developing a model with RP 4503 R/H paste is a three-step procedure:

1. *Build an undersized core/support structure.* The same type of structure typically produced as a back support for conventional board models is used as a core onto which modeling paste is applied.
2. *Extrude paste over the core.* With a high-output meter/mix machine, the two-component epoxy paste is dispensed onto the substructure. The product provides for fast, clean, and virtually odor-free application. At Visioneering, technicians built up a 3/4" thick layer of material onto the core and let it cure overnight before machining. Other paste users may apply from 1 to 1-1/2" of paste for their model surface. Layer thickness can be controlled according to project requirements by adjusting the dispensing nozzle and its displacement speed. Each successive strip of material adheres to the surface below without voids or visible bond lines.
3. *Machine the model.* Finally, the cured paste surface is machined to the desired contour. Visioneering found that the modeling material is easy to cut with two- or four-flute hardened steel or carbide cutters at speeds of 150" per minute and 1,800 rpm. During machining, the product generates little dust and produces a smooth, seamless surface.

Laser-based coordinate measuring equipment checks surface tolerances on the paste model for a single-engine jet called the Visionaire.

The paste exhibits a cured hardness of Shore 60D, flexural strength of 2,175 psi, heat deflection temperature of 111°F, compressive strength of 2,320 psi, and coefficient of thermal expansion of 32×10^{-6} in./in./°F. Depending on project requirements, surfaces may be sealed before the model is put into production.

As Vertin explained, "When building large models, the paste process is significantly less expensive than cutting up and gluing together multiple boards to produce a rough model structure. And, because the milling machine does most of the work, we can spend less time training our staff. Once completed, machined models need little, if any, finishing and provide the accuracy we need for precision aerospace and automotive projects. The epoxy paste has helped us save as much as $30,000 on a single modeling project."

For more information, contact Ciba Specialty Chemicals, Performance Polymers, at 4917 Dawn Ave., East Lansing, MI 48823-5691; Tel: 517-351-5900.

Visualizing the Better Shoe

Data visualization software helped Nike understand and detail foot morphology for better shoe design.

Basketball fans may be missing Michael Jordan's jump shots, but the people at Nike still have Mark Johnston on their team. Johnston is a project manager on Nike's Advanced Research and Development (AR&D) Team, which is instrumental in helping Nike customers make their own jump shots. The team's goal is to improve broad-based systems and technologies, rather than creating specific designs for next season's shoes.

To meet their goals, Nike's AR&D Team studies all aspects of footwear, from materials, to design, to manufacture. The team is comprised of experts from a wide range of disciplines, including biomechanics, design, mechanical engineering, and computer science. Their goal is to ensure that foot morphology — not manufacturing constraints — drives Nike's design and manufacture.

In 1995, the Nike team began using IRIS Explorer™, a 3D data visualization research tool from Numerical Algorithms Group, Downers Grove, IL, to understand and detail foot morphology and topography in a visual programming environment. The program helped them perfect the shape that represents a foot in action. Within six months of initiating research with Iris Explorer, Nike began successfully designing products using the results.

Shoe design involves several components: An outsole, a midsole, and an upper are assembled around a footlike support unit called a last. In real life, human feet may swell or otherwise change shape during the day, further complicating the fitting process. Data visualization must be sensitive enough to discern whether a bump is an abnormality in the dataset or in the foot itself.

"Because of the nature of our research, we rarely know ahead of time what the best solution will be," said Johnston. "We need tools which are flexible enough to allow for changes and refinements 'on the fly.' IRIS Explorer allows us to do that."

IRIS Explorer is designed to provide non-programmers with an intuitive approach to developing customized visualization applications on a broad range of platforms. It uses a dataflow model in which users can interactively create an application in the form of a map of modules. Each module is a software routine that performs some specific function on its input data and produces some output.

Users create a map interactively using a point-and-click utility. They can try out a range of solutions to a problem, simply by adding or replacing modules until the desired effect is achieved.

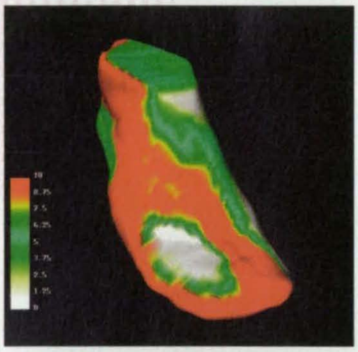
Each module is a software routine that users select from IRIS Explorer's library. New modules can be written to extend IRIS Explorer's functionality using a native language such as C, C++, or Fortran. This type of customization was key to Nike's success. "Having all of IRIS Explorer's pre-built graphic and processing libraries is a boon," said Johnston, "but being able to quickly and easily incorporate our custom routines into the application has proved invaluable."

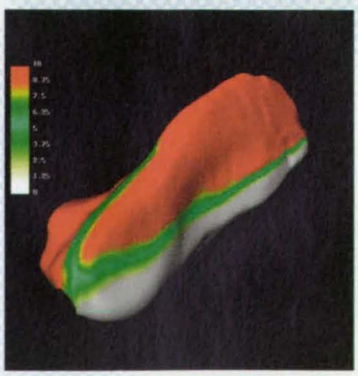
According to Johnston, before Nike began using the program, "Our data analysis was done by hand or at best, a spreadsheet. We were constrained to much smaller data sets. IRIS Explorer allowed us to build a robust, graphic-based application without the need of programming all of the overhead graphic handling and interface routines. Instead, we concentrated on the two or three very specific custom algorithms we needed. If we had to write all the routines ourselves, it would have taken several months longer than it did."

Nike runs IRIS Explorer on an SGI Indigo2 Extreme UNIX box (R10000 processors with 384 megabytes of RAM and a 6-gigabyte hard drive). The team's datasets range in size from 4 to 20 megabytes, based on foot scans producing 300,000 points in x-y-z spatial datasets. If a foot changes shape, IRIS helps the team identify, examine, and compare the differences.

The somewhat amorphous nature of the human foot generally breaks the rules of traditional mechanical-engineering and CAD packages. Nike's AR&D Team exports data to CAD packages only after they have used IRIS Explorer to pre-process and view results in a visually understandable form. The team can also create screen captures and embed them into presentations and documents.

The author of this article is Tony Nilles, Sales and Marketing Manager for Numerical Algorithms Group (NAG), 1400 Opus Place, Ste. 200, Downers Grove, IL 60515-5702. Inquiries can be forwarded to the IRIS Explorer Center North America; Tel: 630-971-2367; e-mail: IRISexplorer@nag.com. The Center provides free evaluation of IRIS Explorer to qualified engineers and scientists investigating the benefits of 3D data visualization for their research efforts. IRIS Explorer is a trademark of SGI.





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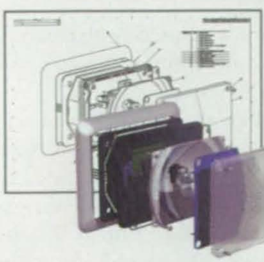
Case Study #1
Weldon Technologies



For over 30 years, Weldon Technologies has been providing lighting and control systems for specialty vehicles like ambulances, school buses and fire trucks. Faced with increasing competition and industry consolidation, they needed a way to streamline their design process. They chose SolidWorks solid modeling software. "It's a very tightly integrated package for complex modeling," said Sean Tillinghast, Weldon Vice President of Engineering, after being disappointed with several other software solutions. "With SolidWorks, we were able to create the first combination halogen/strobe lamp for the EMS market while reducing our design cycle 25%."

For More Information Circle No. 601

Advanced Controls for High-Speed Milling

High-speed milling controls can increase 3D milling productivity by 10 times or more.

Creative Technology Corp., Arlington Heights, Illinois

Work at Creative Technology Corp. installing new controls on existing machines has shown the importance that the controller plays in achieving high speed. Simply changing the control on a machine, retaining its existing drive system, can actually increase productivity by 10 times or more.

High-speed milling offers great benefits for 3D molds, dies, patterns, and prototypes. Some of the key factors in high speed are:

- Look-ahead, the intelligence to analyze geometries before milling them to prevent gouges and overshoots;
- Accurate control at more than 400-inch-per-minute feedrates;
- DCN (direct CNC networking) as opposed to DNC (distributed numerical control), or getting the data into the control for high-speed performance;
- DSP (digital signal processing), the processor that has miniaturized high-performance digital electronics;
- Open-systems architectures;
- Multiprocessor strategies that take CNC beyond machine control.

The most dramatic demonstrations of high-speed benefits come in 3D contouring. For one example, a part that formerly took 3 hours and 43 minutes to mill accurately on a Leblond-Makino MH65 machining center with a Fanuc 11M CNC controller was milled more accurately in 17 minutes after a control retrofit.

In a broader sense, high speed creates many other benefits. Improved accuracy, fit, finish, and cutter life are the most commonly reported peripheral benefits. Tools last longer because their chipload is more consistent.

The evolution of CAD/CAM into a powerful tool for 3D surface creation has brought about high-speed milling for molds and dies. Computer-aided design (CAD) works with entities and surfaces. Points, lines, arcs, cylinders, spheres, planes, etc. all join in CAD to create surfaces. Computer-aided machining then translates those surfaces into point meshes (see Figure 1) or wire frames of data for machines. Once the data is passed to the CNC, it executes one point at a time to reconstruct the surface.

But though the figure shows a uniform gridwork of points, CAM typically creates points with various distances between them. This is done by sorting points based on "chordal deviation." An example of a slice with points sorted by chordal deviation is shown in Figure 2. The deviations to the surface vary. An arc milled by single-point moves really becomes a series of line segments that deviate from the arc by the value of the chordal deviation. This value is set in the CAM system to define what the acceptable deviation from surface or tolerance is. The result is a series of chord segments now commonly referred to as point departures, the distances between successive point-to-point moves.

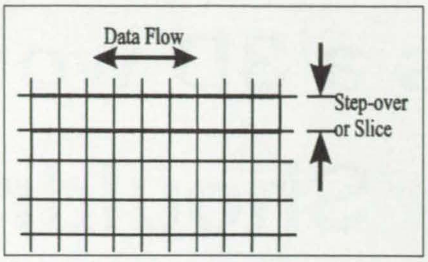


Figure 1. Gridwork of data, or **Point Mesh**.

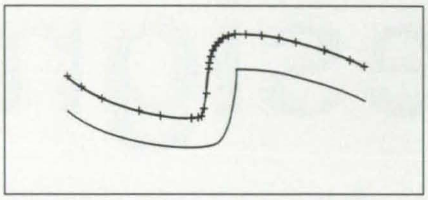


Figure 2. Slice of part, with points sorted by **Chordal Deviation**.

Chordal deviation must be properly set to balance productivity with required job accuracy. Stating a deviation value that is too tight can result in enormous file sizes and high data density that can be difficult to handle. High-speed milling enables smaller chordal deviations and thus higher accuracy by executing the resulting mass of data more efficiently.

Look-ahead is a fairly new feature found in only a few controls. With the success of CAD/CAM, CNC has been used with increasing success to develop 3D surface contours. In this application, the cutter must flow through the points without dwelling. Most numerically controlled milling machines take from 0.100 in. to 0.200 in. to stop from a move at 100 inches per minute. If a CNC control and machine are instructed to flow through data at high feedrates, yet point departures are short, gouges can result at points of abrupt change in the contour. Without look-ahead, the CNC might be surprised by the abrupt change in direction over a short move of only 0.010 in. If the feedrate is too high to stop in that distance, the result will be an overshoot.

Another important factor is servo cycle time, the amount of time a CNC control takes for each measuring and command cycle. If the control's servo cycle time is 20 ms, then the axis positions are measured and a new direction commanded by the control 50 times a second. Servo cycle times over 4 ms are considered inadequate today. The table shows a few sample servo cycle times, measuring speeds, and distances at feedrates. This table demonstrates that to mill as accurately at 1200 inches per minute as at 100 inches per minute, the control must indeed be very fast.

Distances moved at given feedrates and servo cycles.

Time/ ms.	Cycles/ Second	Distance Travelled 100 IPM	400 IPM	1200 IPM
20	50	.0333"	.1333"	.4000"
10	100	.0166"	.0667"	.2000"
3	333	.0050"	.0200"	.0601"
1	1000	.0016"	.0066"	.0200"
.4	2500	.0007"	.0026"	.0080"
.1	10,000	.0002"	.0007"	.0020"

Another dilemma is how to get the program information to the CNC fast enough to avoid data starvation. The most common communications in use for CNCs today is DNC, or distributed numerical control. But at a common data rate of 9600 baud, it is just to slow for high-speed milling. Direct CNC networking or DCN offers a much better solution. While Ethernet is the most common network architecture in use today, Arcnet, Token Ring, and Fast Ethernet are other alternatives. Ethernet's performance of 10 Mb/s translates to 1 million characters per second, about 1000 times faster than most DNC. Networking architectures are already commonly available with data rates of 100 Mb/s or more, some 10 times faster than standard Ethernet.

The technology that allows PCs to act as high-performance CNC controls is digital signal processing (DSP). DSP is the key to fast servo cycles. There are many varieties of DSP, and they give control builders priority choices for control functions. Another great benefit is that the PC's main central processing unit is still free to perform other tasks. *Continued*

A PC teamed with DSP is actually a multiprocessing computer. Multi-processors offer another level of performance for high-speed milling, allowing the operators to perform multiple tasks quickly and efficiently at their machine control workstation.

Finally, open systems architectures are crucial to further development of high-speed milling. Open architecture implies two key components: an ability to be serviced and an ability to be changed without proprietary parts and/or knowledge. Open architecture can help keep maintenance down and sustain capabilities current with the unfolding state of the art.

For more information, contact Todd J. Schuett, president of Creative Technology Corp., Arlington Heights, IL, and the author of this article; (847) 818-0055; fax: (847) 818-0194.

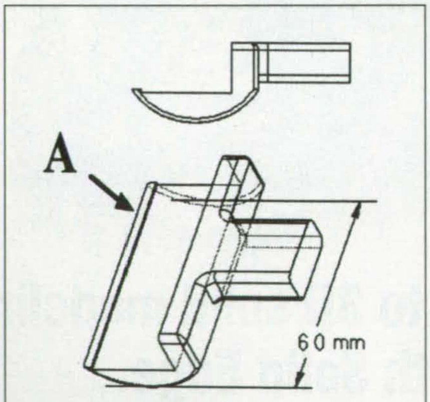
Evaluating Stereolithography Pattern Removal Performance

Six epoxy-based photopolymers are tested for survival of the pattern removal process.

Johnson & Johnson Professional Inc., Raynham, Massachusetts, and DuPont Somos, New Castle, Delaware

Stereolithography (SL) is increasingly being used by investment casting foundries for the creation of complex cast parts. But the SL QuickCast™ patterns constitute only a small percentage of foundries' production, so they are handled using materials and processes developed for traditional wax patterns.

The traditional approach for removing standard wax patterns from investment casting shells involves an autoclaving cycle followed by a high-temperature mold preheat/burnout cycle. But the poor humidity stability and the resulting volume expansion of SL resins is a problem. Many foundries choose to avoid autoclaving and go directly to a flash-fire cycle. But investment casting refractory materials are not designed to withstand the thermal expansion stresses autoclaving imposes, and the oxygen-poor environments in high-temperature furnaces necessitate long mold preheat and burnout times to remove all traces of SL resin. Fortunately improvements in materials are making SL patterns more amenable to traditional practices.



Test part geometry.

An experimental study presents a test procedure that shows the differences in the behavior of six popular stereolithography resins under autoclaving and flash-firing conditions. The observations show the number of ceramic shell layers required for shell survival during pattern removal for a given geometry. Three popular DuPont Somos® resins (6110, 7100, and 7120) and three popular Ciba-Geigy Cibatool® resins (SL 5170, SL 5180, and SL 5190) were evaluated.

Minimum number of shell layers needed for pattern removal process survival

Resin	Autoclave (only)	Flash-Fire (only)	Normalized Minimum Shell Thickness		Comments
			Autoclave	Flash-Fire	
Somos® 7100	6	6	(1)	(1)	
Somos® 6110	7	7	1.16	1.16	
Somos® 7100a	8	7	1.33	1.16	0.05" layer offset depth
Somos® 7120	10	8	1.66	1.33	7120 patterns not well drained
Cibatool® 5180	10	8	1.66	1.33	
Cibatool® 5170	11	8	1.83	1.33	
Cibatool® 5190	12	8	2	1.33	

The evaluation method consisted of two parts:

- Determination of the behavior of SL materials during autoclaving conditions; and
- A comparison of SL pattern behavior within a ceramic investment casting shell, during autoclaving and flash-fire conditions.

The figure shows a test geometry developed to evaluate SL behavior. The edge of the part indicated at A represents a geometry prone to causing shell failure during pattern removal. Regardless of the process, autoclaving or flash-firing, shell failure, when it occurs, is always initiated at this edge, and may range from a fine hairline crack that would not preclude the pouring of metal into the shell, to complete shell disintegration.

Fourteen test patterns were produced in each of the six resins. All were built using a 0.25-in. QuickCast hatch spacing and a 0.1-in. layer offset depth. An additional set of Somos® 7100 patterns (7100a) were built using a 0.05-in. layer offset depth. Six patterns of one resin were affixed to one side of a wax investment casting tree, and six patterns of another were affixed to the opposite side. Resins were arbitrarily paired by SL machine type.

The assembled trees were dipped twice into a fine ceramic slurry-&-sand (called prime coats, which impart detail but little strength to the shell), then dipped in a strength-building slurry-&-sand three more times (backup coats). Dipping was done again, but limited to only the bottom five pairs of patterns. Another dip was limited to four pairs, and so on, The result was an investment casting shell increasing incrementally in thickness from five to ten layers (a sealing coat not counted).

Using the above approach, two sets of three different trees were created. One set was subjected to flash-firing at nearly 1100 °C for several hours. The other was subjected to autoclaving and then flash-firing, the latter performed within eight hours of the autoclaving. All of the patterns, with the exception of the Somos® 7120 patterns, were well drained after centrifuging and cleaning. Part quality was good for all of the patterns.

The table lists the various resins according to the fewest number of shell layers required for shell survival during both autoclave and flash-firing processing. Also shown is the shell thickness, normalized to the "best" performing resin, required for shell survival. The trees subjected to autoclaving were subsequently flash-fired for pattern removal. In no case was there additional shell failure after the flash-firing was complete. Trees subjected only to flash-firing developed cracks along the length of the tree.

All of the resins evaluated build parts of excellent quality and accuracy. A difference in the results of the experiments on the set of parts built in Somos® 7100 and

Somos® 7100a—those with reduced layer offset depth—sets demonstrates that build parameters can have a strong effect on the number of shell layers required to prevent shell failure. The poor drainage of the Somos® 7120 patterns used may have "artificially" increased the shell strength requirements reported. SL patterns which are inadequately drained during post-processing can also adversely affect shell strength requirements. Excess resin inside SL patterns undergoes thermal and water-absorption-induced expansion.

The experience of the experimenters of the Johnson & Johnson and DuPont Somos® Solid Imaging Materials Group shows that the behavior exhibited by the parts used in this study are consistent with behaviors of parts made from the same resins built at other times, with various laser powers, and on other hardware. They assert that the best indicator of resin foundry performance is the normalized minimum shell thickness requirements presented in the table. Other data suggest that there is no correlation between pattern strength at elevated temperatures (high Tg) and occurrence of shell failure during burnout. This is an important result, since high-temperature strength is a desirable feature of SL resins for many other applications.

Many foundries have taken to skipping the autoclaving process for two reasons. First, openings to the patterns must be created in the shell prior to autoclaving to allow equilibration of pressure across the shell during the process. Second, as the results in the table show, for some resins a thicker shell is typically required for shell survival in the autoclave vs. flash-firing. Increasing shell thickness adds materials, labor, and time to the shell creation process, and may limit the number of patterns that can be affixed to a tree.

There are, however, some compelling reasons to use autoclave processing when handling SL patterns. If autoclaving is eliminated, rapid heating of the tree during flash-fire burnout results in thermal expansion of the wax, which can crack the shell. Also, the large volumes of smoke generated by the burning wax can disrupt foundry operations. High-temperature furnaces typically have oxygen-poor atmospheres; when much of the available oxygen is consumed by burning wax, SL pattern combustion is inhibited. Longer or repeated burnout cycles may then be required for complete pattern removal.

The present testing has shown that the greatest differences in foundry performance between the SL resins evaluated are exhibited during autoclaving. It seems that some resins are better suited to the use of the autoclaving process than others. The pros and cons associated with autoclaving or flash-firing a specific job should be weighed against the type of resin from which the pattern is built. The effect of factors such as time, materials, and labor costs must be considered when determining how to process SL patterns.

There appears to be a strong correlation between the coefficient of thermal expansion and flash-fire performance of the resins evaluated: the higher the CTE, the more shell layers are required to survive the process. This correlation may allow prediction of foundry performance of new or existing resins, not evaluated here, based solely upon CTE data. A very simple test to determine the volume expansion of a bulk resin under autoclave conditions can also be performed. Combined with CTE data, results of such a test may be used to predict the autoclave behavior of a resin as well.

A foundry which is sensitive to the differences between various SL resins has several advantages over one which treats all resins equally. It can improve process reliability by interfacing with pattern providers to discuss build parameters and resin types.

For more information, please contact the authors of this brief, Christopher S. McDowell, Johnson & Johnson Professional Inc., 325 Paramount Drive, Raynham, MA 02767, and Suresh Jayanthi, DuPont Somos Solid Imaging Materials Group, 2 Penn's Way, Suite 401, New Castle, DE 19720.

For More Information Circle No. 602

NEW PRODUCTS

Digitizing Software

RevWorks™ CAD-driven reverse engineering software for SolidWorks from Design Automation, Raleigh, NC, creates CAD models from physical parts. All SolidWorks functions remain available during data collection. Features include data visualization for immediate assessment of part characteristics, establishment of a new coordinate system for a part by touching its features, and the ability to align parts to an existing model by touching the actual part features. The software allows direct communication between SolidWorks and 3D digitizers, enabling users to copy physical parts and capture design intent. **Circle No. 737**

Urethane Casting Resin

Smooth-On, Easton, PA, offers Smooth-Cast 325 ColorMatch fast-cast urethane resin that is color-neutral and accepts liquid color pigments. The resin blends with a variety of fillers and is used to create marble (with calcium carbonate) and wood grain (with pecan flour) finish effects. It accepts metal powders such as bronze and copper for creating metal cold castings. Mixed viscosity is 100 cps; pot life is 2.5 minutes; and demold time is 10 minutes. Cured castings of the resin are machinable and waterproof. **Circle No. 733**

Custom Plastic Parts

Custom-engineered plastic parts machined from Teflon® and other engineering plastics are available from Engineering Plastics, Westboro, MA. The parts are fabricated to customer specifications in sizes ranging from 1/2" to 60" in diameter. They feature one-piece construction and can incorporate multi-diameter surfaces, precise hole locations, and dimensional tolerances to 0.005". The parts can be made of PTFE Teflon, CTFE, Delrin®, nylon, Vespel®, Lexan®, PEEK, and HDPE. **Circle No. 735**

Cost-Estimating Software

Manufacturers Technologies, West Springfield, MA, offers the Costimator® computer-aided cost estimating system that provides a means for determining manufacturing costs. The system's IQBuilder Database includes a Feature-Based Estimating section that enables engineers to predict the cost of manufacturing virtually any part, even if they are not familiar with manufacturing operations and machine times. Users choose appropriate manufacturing features, design features, and product types from a knowledge database of manufacturing standards and costs, and the system estimates manufacturing times and costs. Feature and product data can be entered for custom parts, allowing "what-if" comparisons of costs of using different processes or materials. **Circle No. 738**

Product Development

Industrial and mechanical design, reverse engineering, drawing conversion, and concept design services are provided by Product Development Technologies, Lincolnshire, IL. Reverse engineering is achieved by using point clouds generated through laser scanners to construct parametric solid models. The integrity of the resulting geometric data is verified against the original part using CAV® Computer-Aided Verification. CAV provides engineers and parts designers with a graphic, color report that identifies all geometric deviations in a part relative to its 3D CAD database. Other services include structural/mold flow analysis, die cast tooling, and injection mold tooling. **Circle No. 734**

Metal Castings

NEST Technologies, Studio City, CA, has announced the availability of PRECICAST™ technology for production of intricate metal castings. The process provides product manufacturers with a method of obtaining complex metal parts without producing a die-cast mold. The process produces components with geometric complexities such as thin walls, tall pins and fins, and deep, narrow pockets such as those found in hydraulic systems, engine parts, and electrical housings. A sand and ceramic molding machine applies a very thin layer of ceramic material onto the tool in order to create a rigid and smooth casting surface. Once the ceramic layer is deposited, it is backed-up with a compressed sand and resin mixture. **Circle No. 736**

Rapid Prototyping Services

Bastech, Dayton, OH, offers engineering and rapid prototyping services such as CAD engineering, stereolithography, selective laser sintering, plastic and metal reproductions, prototype tooling, and short-run injection molding. CAD information can be manipulated in multiple file formats and from multiple platforms, including Unigraphics and Pro/ENGINEER. The company's model shop provides custom finishing, painting, and assembly of SLA and SLS models to RTV silicone molding. **Circle No. 739**

Rapid Prototyping System

Stratasys, Eden Prairie, MN, has introduced the FDM3000 rapid prototyping system with a build envelope of 10 x 10 x 16". The system incorporates a support removal system for use with ABS modeling material called WaterWorks. The machine is based on the Fused Deposition Modeling technology, and allows virtually hands-free production of concept models, precision prototypes, and tooling patterns and masters. With WaterWorks, a completed model with supports is immersed in a water-based solution and after a brief time, the supports wash away. The WaterWorks solution dissolves the support material, leaving a model with smooth surfaces. **Circle No. 740**

Breathing Apparatus Stores Cold Supercritical Air

Disadvantages of liquid-air packs are overcome.

John F. Kennedy Space Center, Florida

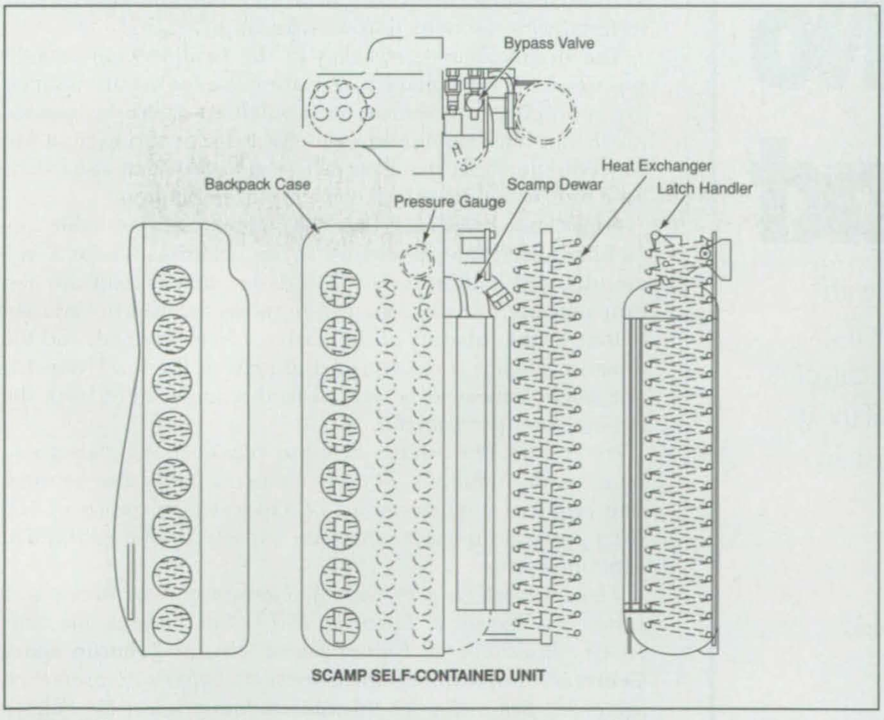
The supercritical air mobility pack (SCAMP) is a prototype self-contained breathing apparatus designed for use in rescue and fire-fighting operations (see figure). The SCAMP is based on the storage of air at supercritical pressure in a temperature range slightly above that of liquid air. Like breathing apparatuses based on the storage of liquid air ("liquid-air packs," for short), the SCAMP offers the advantages of compactness and light weight. In addition, the SCAMP offers the following advantages, as explained below:

In the SCAMP, air is stored essentially as a supercold compressed gas by maintaining its pressure above the critical level of 560 psia (3.86 MPa absolute). In the supercritical condition, the stored air behaves as a single-phase fluid, with no differential boiling or other separation of constituents and thus no change in chemical composition during storage. Because of the feature, the SCAMP is not susceptible to oxygen enrichment. Thus, air may be added to the vessel after storage, rather than emptying and refilling the vessel as required by current liquid-air pack technology. Moreover, there are no separate liquid and vapor volumes in the single-phase fluid; instead, the single-phase expands to occupy the entire volume of the storage vessel, making it possible to position the open end of the supply tube anywhere in the vessel to withdraw the fluid in any orientation.

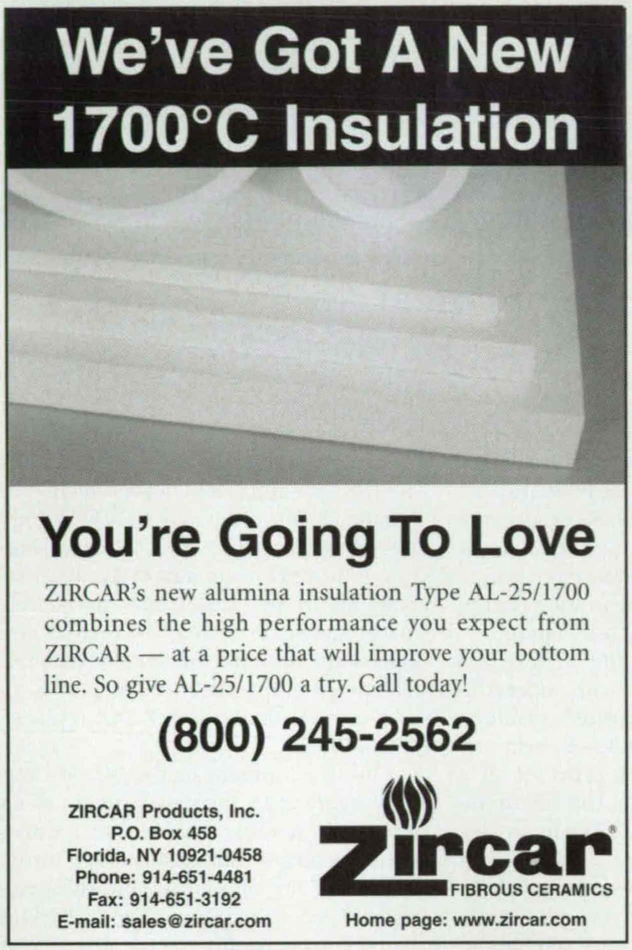
The storage vessel of the SCAMP is a Dewar tank that is filled with supercritical cold air, then mounted inside a molded plastic backpack. A heat exchanger in the backpack provides for a limited flow of heat from the surroundings into the vessel to expel air for breathing. Another heat exchanger in the backpack warms the expelled air to ambient temperature to make it breathable. The heat exchangers operate in conjunction with a pressure-actuated bypass valve; together, the heat exchangers and valve maintain the stored air at a pressure of 750 psia (5.17 MPa absolute) during expulsion at ambient temperatures from –40 to 120 °F (–40 to 49 °C), at flow rates from 10 to 150 standard liters per minute.

A standard self-contained-breathing-apparatus pressure regulator and face mask are used to control and deliver the flow of breathable air to the wearer. A light-emitting-diode device on the backpack harness indicates the amount of stored air remaining in the vessel and an audible alarm is generated when less than 25 percent of the nominal full amount remains. The nearly empty vessel can be rapidly removed from the backpack and replaced with a full one.

The development of the SCAMP was accompanied by the development of an automatic loading system that reduces the difficulty of filling the storage vessel. About the size of a household refrigerator, the system requires a Dewar flask of liquid nitrogen plus electrical power of



SCAMP Self-Contained Unit uses a heat exchanger to warm the expelled air to make it breathable. The apparatus is designed for rescue and fire-fighting operations.



less than 100 W for operation. The system takes about 5 minutes to load a vessel rated for 1 hour.

This work was done by Harold L. Gier and Richard L. Jetley of Aerospace Design & Development, Inc., for **Kennedy Space Center**. *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

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Refer to KSC-11683, volume and number of this NASA Tech Briefs *issue, and the page number.*

Ion-Mobility Spectrometric Determination of Hydrazines

The use of 5-nonanone as the ion former reduces sensitivity to ammonia.

Lyndon B. Johnson Space Center, Houston, Texas

Hydrazine, monomethylhydrazine, and unsymmetrical dimethylhydrazine can be detected and measured at concentrations as low as 10 parts per billion in the presence of ammonia at concentrations as high as 10 parts per million (greater than the odor threshold concentration of ammonia, approximately 5 ppm) by modified use of a portable, commercially available ion-mobility spectrometer. The modification consists in the substitution of 5-nonanone for acetone as the ion-forming compound in the drift or source region of the ion-mobility spectrometer. Previously, when acetone was used and ammonia was present in the sampled atmosphere even at ppm levels, chemical reactions between the ammonia and the acetone formed ion adducts that had mobilities comparable to those of monomethylhydrazine and that, consequently, interfered with the detection of hydrazines.

The simplicity and sensitivity of the modified ion-mobility spectrometric assay make it very attractive for use in monitoring atmospheres in vehicles and buildings where hydrazines, which can have serious adverse effects on health even at low concentrations, are being used. The modified assay also can be used to detect ammonia at concentrations $\geq$ 5 ppm.

Experience has shown that the commercially available ion-mobility spectrometer remains at top performance for 2 to 3 months, and modifications of its design may extend the performance lifetime to 12 months or more. Safety is not a factor as long as the integrity of the analyzer is maintained, and the nonanone vapor is not considered toxic at the low levels that one might expect to be vented to the atmosphere from the ion-mobility spectrometer.

Heretofore, the source of vapor has been clay adsorbent coated with nonanone, but other sources might also be used. The required concentrations of vapor are in excess of 100 parts per billion; exact values are expected to be established experimentally.

This work was done by Gary A. Eiceman of New Mexico State University, Thomas F. Limero of KRUG Life Sciences, Inc., and John L. Brokenshire of Graseby Ionics, Ltd., for **Johnson Space Center.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category. MSC-21966*

Loop Heat-Pipe Evaporator With Bidisperse Wick Structures

Bidisperse structures help prevent vapor blanketing of wicks.

Goddard Space Flight Center, Greenbelt, Maryland

Improved evaporators for loop heat pipes have been developed by incorporating bidisperse structures (in place of older monodisperse structures) into evaporator wicks. As explained in more detail below, the bidisperse structures feature two distinct pore sizes (see Figure 1), which helps to prevent vapor blanketing that can limit heat-flux capacities to unacceptably low values.

Loop heat pipes are important parts of systems for cooling electronic components that dissipate heat at flux densities up to 100 W/cm^2. Loop-heat-pipe evaporators of older design do not work at heat-flux densities in excess of 12 W/cm^2 because vapor blanketing of the wicks in those evaporators blocks the flow of heat-transfer liquids into the evaporators. These wicks have monodisperse micron-size features.

The present improved evaporators are designed (see Figure 2) to prevent vapor blanketing of the wicks. The wicks in these evaporators include bidisperse structures at the interfaces between the heated evaporator walls and core wicks. The bidisperse structures contain both micron-size pores for the liquid supply and larger pores for venting of vapor. The bidisperse structures are in contact with the core wicks, which contain monodisperse micron-size pores. In a given evaporator, the bidisperse structures can be sintered in circumferential grooves in the evaporator wall and/or sintered in circumferential grooves on the outer surface of the core wick.

Because vapor can leave the wicks through the larger pores, vapor blanketing of the wicks does not occur, even at evaporator-wall heat-flux densities greater than 12 W/cm^2. Tests of loop heat pipes equipped with the bidisperse wick structures demonstrated good performance at evaporator-wall heat-flux densities up to 100 W/cm^2.

This work was done by John H. Rosenfeld, David B. Sarraf, Dmitry K. Khrustalev, Peter J. Wellen, and Mark T. North of Thermacore, Inc., for **Goddard Space Flight Center.** *GSC-14225*

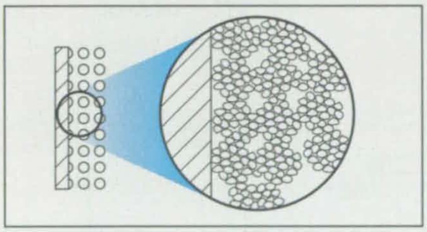


Figure 1. **Bidisperse Wicks** exhibit two distinct pore sizes.

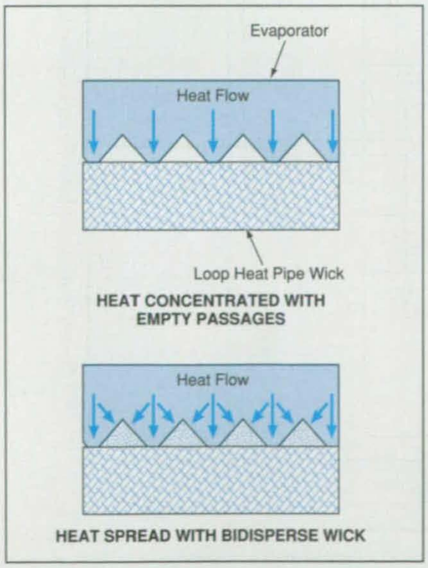


Figure 2. In the **New Design**, the circumferential grooves of the evaporator body are filled with sintered bidisperse wick. Effectively, this creates an efficient extended surface evaporator because bidisperse wick and the triangular groove lands both function as fins.

Watchdog Timer and Reset Control Circuit

This circuit provides several modes of reset for a microcontroller.

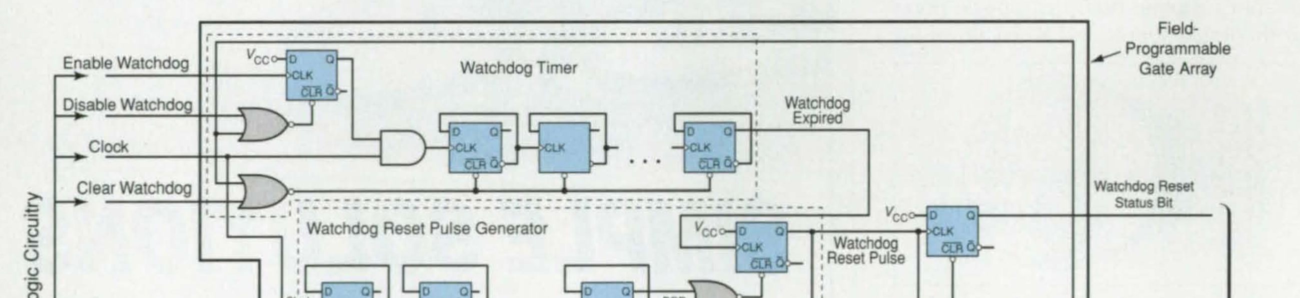
Goddard Space Flight Center, Greenbelt, Maryland

A watchdog timer and reset control circuit has been designed for use with a microprocessor or microcontroller (hereafter "microcontroller" for short) that would otherwise lack the protection afforded by such a circuit. The circuit also has a register to remember the cause of a reset.

A watchdog timer is a safety feature that prevents runaway software; when it times out, it stops a microcontroller from executing meaningless code, a situation that arises from an electrical or programming error. More specifically, if the software is not being executed properly, it fails to clear the watchdog timer; if the watchdog timer is not cleared for a specified interval, the watchdog timer causes the microcontroller to reboot and execute software from a known place.

The circuit (see figure) is implemented mostly as a field-programmable gate array. In operation, the FPGA receives signals from the microcontroller and from address-decoding logic circuitry. The outputs of the FPGA are fed to the microcontroller and to a data bus. For simplicity, in the figure, all signals are represented in positive logic. Inasmuch as microcontroller input signals (e.g., the master reset input signal) are often asserted negatively, inverters can be added as needed, within or without the FPGA.

The watchdog timer consists of a ripple counter and enabling circuitry. The enabling circuitry makes it possible for software to decide when to put the watchdog timer into operation. The software can enable and disable the watchdog timer by writing to the "enable" and "disable" memory addresses. At bootup and master reset of the system that includes the microprocessor and all associ-



Notes on Flip-Flop Terminals and Signals: CLK = Clock Input, CLR = Clear Input, D = Data Input, Q and $\bar{Q}$ = Complementary Outputs

This **Watchdog Timer and Reset Control Circuit** includes a register that the microcontroller can read to determine the cause of a reset. The durations of reset pulses are precise because these pulses are generated by digital circuitry, in contradistinction to analog circuitry, which generates pulses with imprecise durations.

ated circuits, the watchdog is disabled; that is, periodic software writes to the "clear" memory address are not necessary to prevent reboot.

The interval between "clears" to keep the enabled timer from expiring is set by the clock frequency and the number of flip-flops in the ripple counter. For example, if the clock frequency is 12 MHz and 24 flip-flops are strung together in the watchdog timer, then the software must cause the microcontroller to write to the "clear" memory address at intervals of no more than $(2^{24}-1)/(12\ \text{MHz}) = 699$ ms, or else the watchdog timer will expire.

When the watchdog timer expires, the reset control circuitry generates a pulse that becomes the master reset pulse. The pulse generator should be designed so that the duration of the pulse satisfies the reset-pulse-duration requirements of the microcontroller and all other circuits in the system. The master reset pulse also resets and disables the watchdog timer.

Other pulse generators in the FPGA create a master reset pulse for reasons other than watchdog timer expiration: A master reset pulse can be caused by software writing to a reset address or by a push on a reset button on test equipment. In addition, when power for the system is first turned on, the subcircuit comprising the resistor, capacitor, and inverter depicted at the lower left corner of the illustration generates a pulse that becomes the master reset pulse.

The circuit includes a register that records status bits. The microcontroller can read the status bits to determine the cause of a master reset. All the status bits are cleared when software writes to a "clear status bits" address. All status bits except the power-on-reset status bit are cleared by a power-on reset.

This work was done by Kenneth W. Wagner of **Goddard Space Flight Center**. *No further documentation is available. GSC-13925*

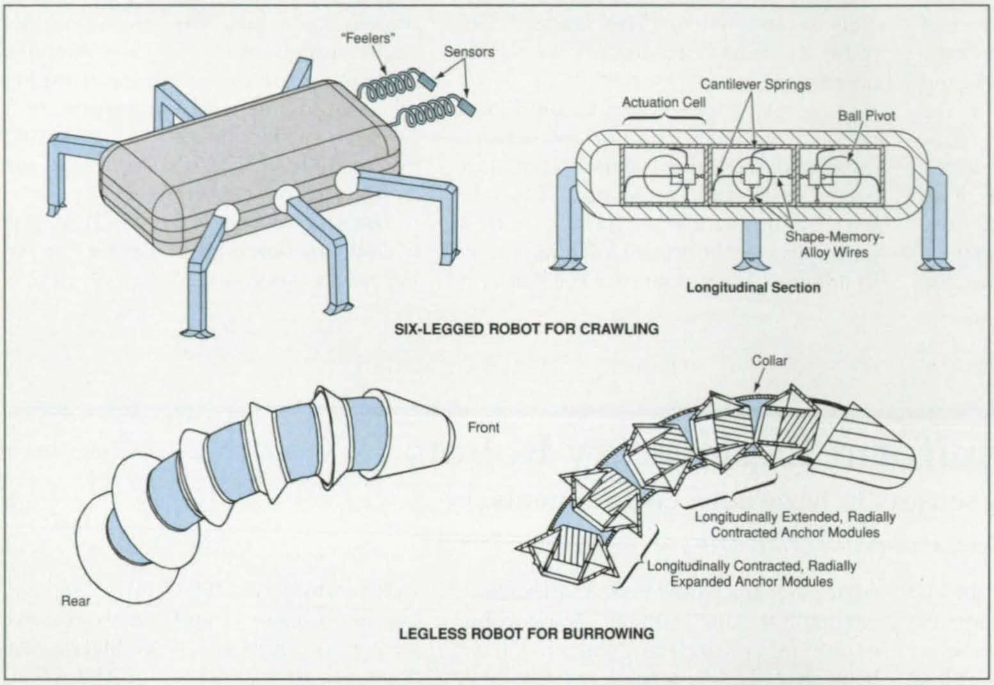
Insectile and Vermiform Exploratory Robots

These robots would carry sensors in hazardous environments.

NASA's Jet Propulsion Laboratory, Pasadena, California

A six-legged robot resembling an insect and a legless segmented robot resembling a worm (see figure) have been proposed as prototypes of biomorphic explorers — small, mobile, exploratory robots that would be equipped with microsensors and would feature animallike adaptability and mobility. Biomorphic explorers and related concepts have been described in several previous articles in *NASA Tech Briefs,* the most relevant being "Biomorphic Explorers" (NPO-20142), Vol. 22, No. 9, (September 1998), page 71 and "Earthwormlike Exploratory Robots" (NPO-20266), Vol. 22, No. 6, (June 1998), page 11b.

Depending on the specific environment to be explored, a biomorphic explorer might be designed to crawl, hop, slither, burrow, swim, or fly. Biomorphic explorers could be used for such diverse purposes as scientific exploration of volcanoes, law-enforcement surveillance, or microsurgery. Another potential use for biomorphic explorers is detection of antipersonnel mines; there is a pressing need for robots that could be deployed in large numbers to detect antipersonnel mines left on and in the ground after armed conflicts. The proposed six-legged robot would be designed with a view toward that application. There is also a need for burrowing robots that could search earthquake rubble for survivors; the proposed vermiform robot would be suitable for this purpose.



Robots That Look and Move Like Small Animals would be developed for use in a variety of exploratory tasks. Six-legged robots could be developed into a mass-producible, mass-deployable units to search for antipersonnel mines. Legless robots similar to the one depicted here could burrow in earthquake rubble to search for survivors.

The proposed six-legged robot would be capable of traversing various types of terrain. The legs would be attached to a main body at shoulder ball pivots. Rotations at the shoulders would result in translations of the feet. The legs would feature telescoping segments that could be lengthened or shortened to suit the direction of motion and the terrain. For example, the legs could be shortened to obtain greater mechanical advantage for climbing, or lengthened to increase speed in level or downhill travel over smooth terrain. The legs would be tipped with footpads that could be configured to suit the terrain. For example, a scissorlike arrangement of footpad members would be use on hard terrain (e.g., rocks), while the footpad members would be spread out to form a larger contact area on soft terrain (e.g., sand). The legs and footpads would be actuated by springs paired with shape-memory-alloy (SMA) wires; within each actuator, the spring would pull or push in one direction, while the SMA wire would pull in the opposite direction by an amount that would be changed momentarily by passing a momentary electric current through the wire to heat it momentarily above its shape-memory transition temperature.

The proposed vermiform robot would be capable of both anchored rectilinear motion similar to peristalsis and a transverse motion, based on the motions of *Amphisbaenia* — a legless order of reptiles that burrow with notable efficiency. The anchored rectilinear motion would be effected by anchor modules that would look like cones paired base to base. Within each anchor module there would be a piston-like assembly actuated by pairs of springs and SMA wires. The assembly could be actuated to either (1) shorten the module longitudinally and expand the outer cone radially to anchor in the wall of the burrow or (2) lengthen the module longitudinally and retract the outer cone from contact with the tunnel wall. For example, suppose that all anchor modules were initially in the minimum-diameter, maximum-longitudinal-length configuration. The foremost module could be expanded radially to anchor the head end, then the next module could be expanded, and so forth, in sequence from front to rear. The longitudinal shortening accompanying the radial expansion of each module would draw the trailing modules forward.

The anchor modules would be connected by collars of a flexible material in which SMA wires would be embedded at multiple circumferential positions. The SMA wires would be oriented longitudinally. The wires could be energized selectively to bend the collar; in this way, part or all of the robot body could be arched.

In both robots, artificial neural networks would receive inputs from sensors and would respond by issuing commands for the SMA actuators to effect complex combinations of motions to achieve the overall lifelike mobility. Artificial neural networks were chosen for this application because they appear to offer the maximum potential for achieving a desired combination of capability for learning, adaptability, fault tolerance, composability (ability to smoothly integrate various primitive motions into complex motions and other activities), and generality to enable application to future biomorphic explorers.

This work was done by Sarita Thakoor, Brett Kennedy, and Anil Thakoor 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-20381*

Video-Based Active Alignment System

Reflected images of a flashing LED are used to align two objects.

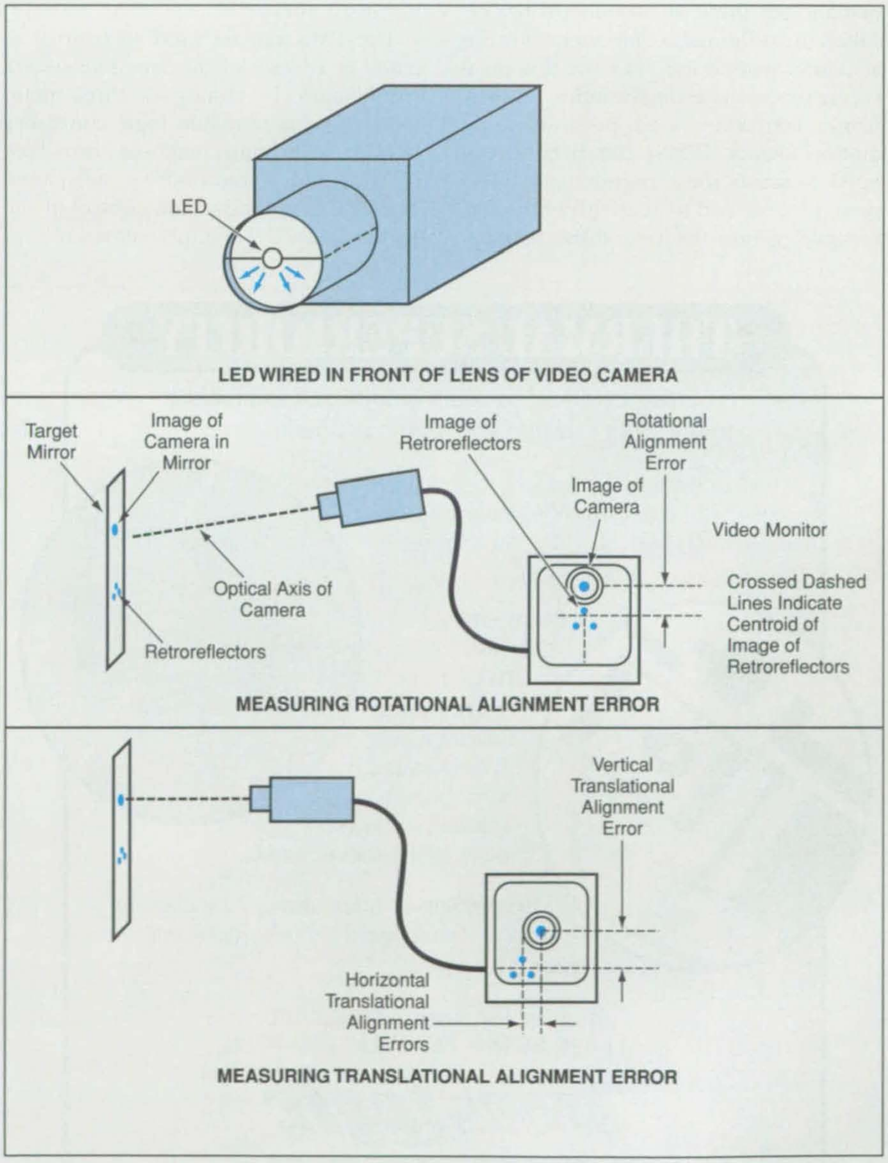
Lyndon B. Johnson Space Center, Houston, Texas

An optoelectronic system senses rotational and translational misalignment between two objects. The system might be used in such diverse applications as aligning construction equipment, mating parts of prefabricated buildings, and aligning vehicles for docking. It could replace more-expensive alignment systems like laser theodolites.

In an experimental version of the system, a video camera is mounted on the end effector of a robot, which is to be aligned with a fixture to which a reflective target is attached (see figure). A light-emitting diode (LED) is positioned at the center of the camera lens, aimed away from the camera. The target includes an ordinary mirror and several retroreflectors, which reflect light from the LED back to the camera, regardless of the orientation of the target.

Typically, the optical axis of the camera is not perpendicular to the mirror plane at the beginning of an alignment sequence. Such misalignment is sensed when the reflection of the LED in the mirror appears off center on a video monitor connected to the camera. To bring the optical axis into alignment with the perpendicular to the mirror surface, the robot is commanded to turn the camera until the video image of the LED appears at the center.

Translational misalignment in a plane parallel to the mirror surface is corrected next. Such misalignment is sensed when the video image of the retroreflectors appears displaced from the video image of the LED. The robot arm moves the camera until the centroid of the image of the retroreflectors coincides with the centroid of the image of the LED.



The **Video Camera Observes** a target that includes an ordinary mirror plus retroreflectors. Processed video images are used to adjust the orientation and position of the camera with respect to the target.

In processing the video-image data to compute the centroids of the LED and retroreflector images, it is necessary to eliminate data on such background features as the manipulator and the camera lens. For this purpose, a picture is taken with LED off, then quickly followed by a second picture taken with the LED on. The data processor then effectively subtracts the first picture from the second picture and performs a binary threshold operation. Only the images of the LED and the retroreflectors remain and are used to compute the centroids.

This work was done by Leo Monford of **Johnson Space Center** *and Robin Redfield, Michael Bradham, Louis Everett, and Jeffrey Pafford of Texas A&M Research Foundation. For further information, access the Technical Support Package (TSP)* ***free on-line at*** ***www.nasatech.com*** *under the Electronic Components and Systems category.*
MSC-21977

Programmable Motion System for Positioning Flow Probes

Advantages include flexibility, speed, expandability, and compatibility with data-acquisition and control systems.

John H. Glenn Research Center, Cleveland, Ohio

The validation of computational-fluid-dynamics (CFD) software used for the design and analysis of turbomachinery has made it necessary to resolve measurement of the flow field more finely by recording more points per survey. The demand for these measurements has resulted in additional requirements for the actuation systems used to move flow-measuring probes in testing facilities. An electronic computer-based programmable motion system (PMS) has been developed to satisfy these requirements. The system is designed to be user-friendly and versatile, giving the user many features not available in older probe-positioning systems. Although originally developed to control probe actuators, the PMS can also be used to control the actions of movable stator vanes, laser tables, or other devices that accept velocity control signals from −10 to 10 Vdc.

The PMS can be used to control as many as 18 axes of motion. The system (see Figure 1) comprises three main parts: a programmable logic controller (PLC), a human/machine interface (HMI), and a motor-drive subsystem. The PLC is used for main control of the system. The HMI is implemented in software on a personal computer. The motor-drive subsystem includes motor-drive circuits and dc brushless motors.

The PLC, HMI, and motor-drive subsystem all operate together to effect control of speeds and positions for the various axes. The position control loop for each axis is implemented in the PLC. The velocity control loop for each axis is implemented in the motor-drive subsystem or in motion modules in the PLC, depending on the application. Commands from the user are sent to the PLC via the HMI program. The interface to the data-acquisition system is implemented in the PLC. The interface to motion profiles specified by the user resides in the HMI program.

The PMS enables its user to control the speed, position, and other parameters of motion for each axis (see Figure 2). The user can also create and edit motion profiles and cause the execution of the motions by use of the Microsoft Excel program. The system can interact with standard data-acquisition systems at Glenn Research Center and with other data and control systems.

In its initial application, the PMS is used to control three sets of circumferential, radial, and yaw probe actuators in an aeronautical test facility at Glenn Research Center. The standard modes of operation for positioning, characterized in terms of motions, are: move to a specified absolute position, move a specified positive or negative increment from the present position, find the home position, and jog (positive or negative). In addition, a yaw probe can be moved in a nulling mode, in which its position is adjusted in response to the output of a differential-pressure transducer. The versatility of the system makes it suitable for a variety of applications.

The PMS has the following advantageous features:

• For the researcher, one of the best

res of the PMS may be that it
tions with minimal (relative to
r probe-actuation systems) com-
ication overhead and, as a result,
measurement time is relatively
rt at 6 seconds per data point.
: PMS is electrically clean; that is,
electronic circuitry does not affect
h instrumentation as pressure
nsducers and hot-wire probes.
al-time editing of axis parameters,
egrated profile programming, and
int-and-click mouse input serve to
nplify operation.
he system can accommodate auxil-
ry positioning devices on the driven
nds (in contradistinction to the driv-
ng ends), and in operation, the sys-
em maintains continuous communi-
ation with the data-acquisition
ystem used in the initial application.
These features are helpful for obtaining accurate and repeatable results.

- Functions specific to a test can be programmed in the field.
- The system is independent of specific motor-drive circuits or motors.
- Troubleshooting is easy.
- The system can be upgraded or expanded.

The PMS gives the user more flexibility than do older probe-actuation systems. Initial tests have shown that data-taking time is 30 to 40 percent shorter. Copies of the PMS are scheduled to be installed in at least four other aeronautical test facilities at Glenn Research Center.

This work was done by Brent C. Nowlin and L. Danielle Koch of **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.* *LEW-16690*

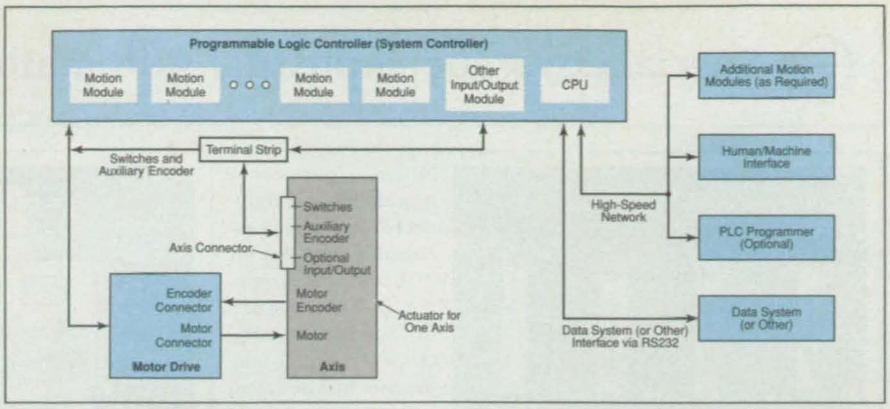


Figure 1. The **Programmable Motion System** offers enhanced capabilities for controlling as many as 18 axes of motion. For simplicity, only one actuator is shown here. A dedicated motion-control module, motor drive, and motor are needed for actuation on each axis.

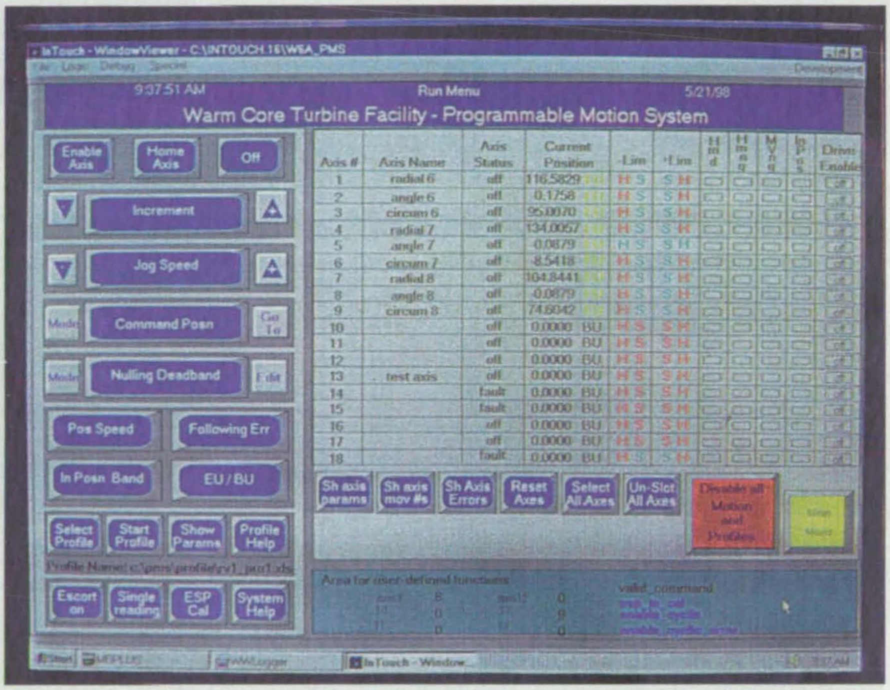


Figure 2. The **Run Menu** is a display, generated by the human/machine interface, through which the user controls motions along or about the various axes. The run menu includes an axis control panel, an access display, and an area for functions defined by the user.

Continuous Electrolytic Generation of Hydrogen Peroxide

Faradaic efficiencies of nearly 100 percent can be achieved.

Lyndon B. Johnson Space Center, Houston, Texas

Electrolytic cells for the continuous generation of hydrogen peroxide in streams of water have been developed. Cells of this type could be incorporated into wastewater-treatment systems based on advanced oxidation processes that utilize hydroxyl radicals. In addition to H_2O_2-generating cells, such a treatment system would include catalysts for the decomposition of H_2O_2 and the formation of hydroxyl radicals as decomposition products. The hydroxyl radicals would oxidize organic contaminants, thereby removing them from the wastewater.

An electrolytic cell of this type includes an anode and a cathode in direct contact with a polymeric electrolyte membrane. Oxygen is supplied and dissolved in the wastewater stream, which is then circulated over the cathode. Under suitable conditions of oxygen pressure, flow rate, and electric-current density, H_2O_2 accumulates over the cathode with nearly 100-percent faradaic efficiency. Multiple cells could be stacked to multiply the rate of production of H_2O_2.

This work was done by James H. White, Michael Schwartz, and Anthony F. Sammells of Eltron Research, Inc., for **Johnson 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 MSC-22835, volume and number of this NASA Tech Briefs *issue, and the page number.*

National Instruments, Austin, TX, has introduced four **signal conditioning modules** for PC-based data acquisition that are designed to automate large channel count or multisensor measurement and control systems. The SCXI-1112 is an eight-channel module with minithermocouple connectors on the front end for signal connection without a terminal block.

The SCXI-1125 is an eight-channel, programmable, isolated analog input module that scans analog input channels at up to 333 kS/s. The SCXI-1142 and 1143 are programmable, low-pass filter modules. The SCXI line is a signal conditioning and instrumentation system for PC-based data acquisition, instrumentation, and control.

For More Information Circle No. 744

The RTI-6520 **automated v inspection and test system** fro Technology, Laguna Niguel, allows inspection of large pri circuit boards up to 18 x 20" w still inspecting parts as smal 0402s with typical scan times of parts per minute. The system be installed over an existing p duction line without disassembly shut-down.

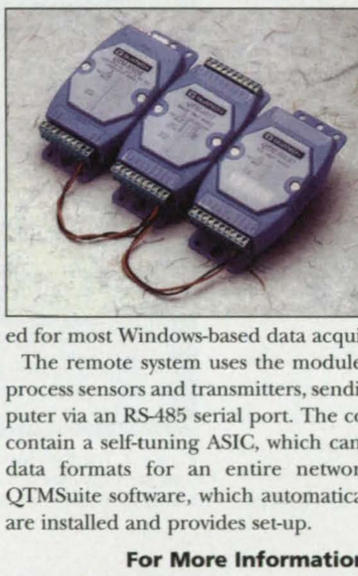
The system features four hi resolution cameras that allow t user to check solder, verify pa installation, and confirm that th correct part numbers are listed. It suitable for both surface moun and traditional board inspection. The system self-learns a PCB b extracting part information from a CAD file and automatically step ping through a known good board.

For More Information Circle No. 743

Balluff, Florence, KY, offers the 6K subminiature **optical sensor** that can be remote-activated via an automatic PLC-signal, "self-teach" cycle. The sensor is able to learn the difference between target and background, even when the target is moving at line speed. The self-teaching mode can be activated remotely for a group of sensors automatically by the machine control.

The sensor is available in sensing modes such as diffuse, retroreflective, and through-beam. Background suppression models use triangulation distance measurement to eliminate the influence of shiny backgrounds; clear object detection is enhanced by low hysteresis and microprocessor-controlled adjustment. It uses a bright red light source for alignment, and to detect a wide range of colors.

For More Information Circle No. 745



Quatech, Akron, OH, has introduced the QTM-8000 Series of **remote data acquisition and signal conditioning modules** that provide conditioning and protection for industrial control signals in a single system. The modules can be wall-mounted near the computer, or mounted on a DIN rail in the field. Support is provided for most Windows-based data acquisition software.

The remote system uses the modules to sample data from remote process sensors and transmitters, sending the information to the computer via an RS-485 serial port. The converter and repeater modules contain a self-tuning ASIC, which can auto-tune the baud rates and data formats for an entire network. The modules come with QTMSuite software, which automatically determines which modules are installed and provides set-up.

For More Information Circle No. 747

The NCA 1000 **non-contact ultrasonic analyzer** from SecondWave Systems, Boalsburg, PA, measures thickness, density, velocity, viscosity, defects, microstructure, mechanical properties, and surface characteristics. After routine calibration, the tasks are performed automatically under ambient environment with no contact with the test medium.

The analyzer features dynamic range greater than 140dB, and TOF accuracy of ±1 ns under closed, and ±20 ns under open ambient conditions. The device is applicable for polymers, ceramics, metals, composites, paper, food, and pharmaceuticals. It can be integrated into factories and laboratories for on-line and off-line testing.

For More Information Circle No. 748

The ME-1000 **remote-controlled data recorder** from Merlin Engineering, Div. of TEAC, Palo Alto, CA, records multiple channels of instrumentation data in severe environments. It logs up to 9 GB of operational or test data, and features a maximum continuous recording rate of 16 Mb/second. The system records data on standard PCMCIA FLASH cards and downloads via SCSI-2.

Remote control is through discrete and serial control status lines. Slots accept up to nine modules for a recording capacity ranging from 990 Mb to 9 GB. Interface set-ups are made via dip switch settings or programmable settings through an RS-232 data port using a proprietary software package.

For More Information Circle No. 746

Custom Couplings

Zero-Max, Minneapolis, MN, offers custom versions of its Schmidt Offset and In-Line couplings. Customizations include special sizes, unusual bore requirements, clamp-style hubs, and special materials and finishes. Schmidt Offset couplings are gned to provide constant velocity between two offset parallel shafts. lications include paper manufacturing, metal forming, food process- and printing. In-Line couplings provide constant angular velocity parallel misalignment from 0 to 1/4, depending on application ed. They can be used in compactors, printing presses, feeders, bossers, and similar types of equipment. **Circle No. 715**

eflex Sensor

SICK, Bloomington, MN, has troduced the WL 12G photo- ectric reflex sensor, which is esigned to detect transparent bjects or small parts. It has a ensing range of over 6 feet and an sense any clear material such as plastic, film, or glass. Features include automatic sensitivity adjustments for changing conditions, such as the build-up of dust on the lens. The sensor is enclosed in a diecast metal housing and can be used in virtually any reflex applications. **Circle No. 717**

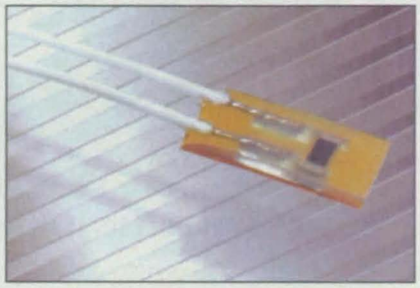
Pressure Transducers

PX2150 Series pressure transducers from OMEGA Engineering, Stamford, CT, are designed for accuracy in high-purity environments. The 0.2 to 5.2 Vdc output assures compatibility with most process controllers and computer-interface equipment. The sensor is isolated from the pressure fitting, which eliminates torque effect. Each part is leak tested by mass spectrometer to 1 x 10-9 ATM.CC/sec. Applications include gas delivery systems, semiconductor process tools, pharmaceuticals, and biotech processes. **Circle No. 718**

Adhesive Film

The 5025E adhesive film from Emerson & Cuming Specialty Polymers, Billerica, MA, is designed to provide electrical and thermal conductivity in microwave and heat-sink applications. The silver-filled, unsupported epoxy is electrically conductive in the x, y, and z axes. It allows bonding of "hot" components onto heat sinks in applications that do not require electrical insulation. When used to bond microwave substrates into packages, the film provides RF/EMI shielding. It is available in die-cut preforms and sheet stock. **Circle No. 722**

Temperature Sensor

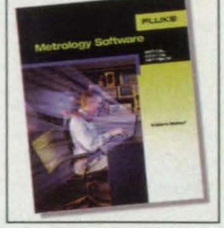


Minco Products, Minneapolis, MN, has introduced the Thermal-Tab™ thermal sensor that consists of a platinum resistance temperature detector (RTD) packaged in a flat body suitable for mounting on surfaces or for assembly into probes. The sensor is insulated and has Teflon-insulated leadwires in a standard length of 40 inches. Standard element types include 100 and 1,000 ohm platinum; other curves, including NTC or PTC thermsistors, are available. Temperature range is -50 to 130°C. **Circle No. 719**

Portable Hygrometer

The Cosa Portable Dewpoint Meter XPDM from Cosa Instrument Corp., Norwood, NJ, is a microprocessor-controlled analyzer designed for moisture measurements to -100°C. The digital instrument features automatic calibration and dry sensor storage. The meter also includes a pressure-correction function, temperature measurement, electropolished stainless steel sample system, and optional analog/RS-232 outputs. **Circle No. 724**

New on DISK



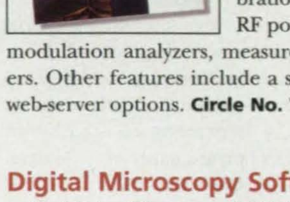
Calibration Software

MET/CAL® Plus Version 6.0 calib software from Fluke Corp., Everett, WA mates calibration and manages and r measurement assets. The core of the sys MET/BASE, an industry-standard SQL designed to provide secure storage for bration information. The software sup RF power meters, counters, signal genera modulation analyzers, measurement receivers, and distortion an ers. Other features include a synchronization/replication option web-server options. **Circle No. 708**

Digital Microscopy Software

Carl Zeiss, Thornwood, NY, has introduced AxioVision 2.0 modular image acquisition and archiving system for digital microscopy that permits interactive measurement of object distances, angles, and areas in the image; acquisition of optical sections (Z-stacks); and automatic recording of multichannel fluorescence images. An automatic focusing control allows recording of a specimen in different focal planes. Two operating modes are available: a user mode for routine appli cations and the expert mode for research. The program can be used with all Zeiss motorized microscopes. Applications include biomedical, mate rials science, and quality control. **Circle No. 709**

Problem Tracking Via the Web



teamshare™, Colorado Springs, CO, offers teamtrack Web-based problem-tracking software as a managed application hosting service called teamtrack on-line. This service allows development organizations to "rent" the teamtrack application as an alternative to purchasing and managing the application. In delivering the hosted application, teamshare provides customers with complete network services, including security, monitoring, data center services, implementation, and operation. Organizations using teamtrack online can track and prioritize defects, system requirements, and other issues arising during complex software-development projects. **Circle No. 710**

Digital Image Archiving

Lockheed Martin Missiles & Space, Sunnyvale, CA, has released Intelligent Library System (ILS) Version 1.0, an interactive digital archiving and analysis solution. The software allows the management, retrieval, and distribution of over 10 million gigabyte-plus imagery and data files from remote-sensing satellites or other sources. Smart tools are integrated into a turnkey system that can acquire, track, and disseminate files from a variety of sources and formats, online and on tape storage, totaling 5,000 terabytes or more. The program is optimized for geographic information systems (GIS), and can be configured for medical images, CAD files, videos, and multimedia. **Circle No. 711**

ew TERATURE

-Locking Studs

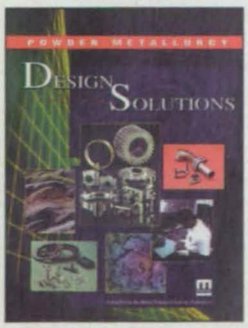
curate Automatic Parts, New Berlin, WI, s a brochure describing its In-Thread® ocking studs that feature a direct-interg thread to provide permanent 360° al-to-metal set. They can be inserted with dard driving tools. Sizes range from #10 ugh 3/4" in SAE grades 2, 5, and 8 as well tainless steel. Metric sizes are also avail- e. **Circle No. 700**

Control Components

The Control Components Master Selection Guide from Omron Electronics, Schaumburg, IL, provides information on relays, switches, optical switches, and card readers. The 36-page guide comes with Omron's CD Resource, a CD-ROM catalog containing more detailed descriptions of control component and industrial automation products, including photoelectric sensors, limit switches, temperature controllers, and timers. **Circle No. 701**

Acrylic/PVC Sheet

An eight-page selection guide from Kleerdex, Mount Laurel, NJ, details 25 grades of KYDEX® acrylic/PVC sheet for thermoforming, membrane pressing, laminating, and fabricating applications. A chart rates each grade by application (general, aircraft, mass transit, building product, weatherable), fire certification, properties, and features. The color-selection page depicts 34 standard and 10 granite colors. **Circle No. 702**



Powder Metallurgy Design

The Metal Powder Industries Federation, Princeton, NJ, offers a 24-page brochure of powder metallurgy design solutions. It includes property information on steels and stainless steels, magnetic iron, copper, brass, bronze, and nickel silver. Design details cover tooling, design rules, and dimensional tolerances. A section on near-fully dense P/M products explains powder forging, cold and hot isostatic pressing, metal injection molding, and spray forming. **Circle No. 703**

Bus Communications

A brochure from Baldor Electric, Fort Smith, AR, highlights bus communications capabilities, including connectivity to various industrial communications networks as well as solutions for DeviceNet, Profibus DP, and Modbus Plus. Options include both external gateways and network expansion boards that are located within the motor control. **Circle No. 704**

Editorial Index

Use the phone numbers listed below to obtain more information from the following companies featured editorially in this issue.

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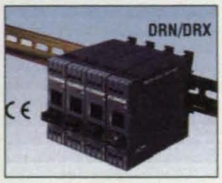
New Products and Services for* NASA Tech Briefs *readers. For more information, write i the corresponding number on the Free Information Request Card (following page 40).



DRN/DRX SERIES PROGRAMMABLE SIGNAL CONDITIONERS/ TRANSMITTERS

The DRN/DRX Series DIN rail mount signal conditioners represent state-of-the-art signal conditioning technology, ideal for all process and power monitoring applications. The intelligent microprocessor-based modules provide a wealth of features.

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HOT/COLD BLACKBODY CALIBRATION SOURCES

The BB701 Blackbody Calibrator is a high-performance, rugged, portable calibrator for infrared pyrometers. The BB701 Hot/Cold model has a range of 0 to 300°F. Its ability to provide a stable, repeatable cold calibration point allows the user to calibrate or test most infrared pyrometers quickly and accurately without having to prepare an ice bath.

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For More Information Circle No. 606

HANDHEL INFRARED PYROMETE SERIES

The OS530 Ser has built-in las sighting and the mocouple inpu The new por able, rugged OS530 infrared pyrometers offer solu tions for many non-contact temperature-measure ment applications up to 2,500°F. Emissivity i adjustable in 0.01 increments. A custom backli LCD displays both current and max, min, diff, or average temperatures simultaneously.

OMEGA Engineering Inc.

For More Information Circle No. 607

MICRO-PROCESSOR-BASED TEMPERATURE/ RELATIVE-HUMIDITY RECORDERS

The new Model CT485B self-contained temperature/relative-humidity recorder is microprocessor based to accurately measure, indicate, and record temperature and relative humidity. This rugged unit comes standard with integral relay contact alarms.

OMEGA Engineering Inc.

For More Information Circle No. 608

INDUSTRIAL NON-CONTACT INFRARED PYROMETER/ TRANSMITTERS

OMEGA's new OS550 Series industrial high-performance, economical pyrometer/ transmitter offers a wide choice of temperature ranges, optical patterns or fields of view, and three outputs (1mV per degree, 4-20 mA, and 0-5 Vdc) to feed directly into panel meters, recorders, temperature/process controllers, dataloggers, data acquisition systems, or other process instrumentation.

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For More Information Circle No. 609

THE TEMPERATURE HANDBOOK™

OMEGA's new Temperature Handbook features more than 2,200 full-color pages with complete specifications and pricing for the latest probes, sensors, thermocouple wire, connectors, instrumentation, and calibration equipment for process temperature measurement and control. It also includes hundreds of technical articles, charts, graphs, conversion tables, and application notes.

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For More Information Circle No. 610

THE DATA ACQUISITION SYSTEMS HANDBOOK™

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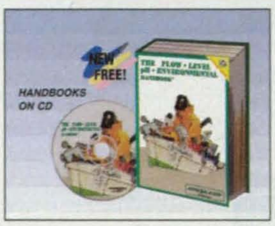

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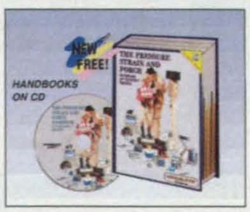

21ST CENTURY™ OMEGA® PRESSURE, STRAIN AND FORCE HANDBOOK

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National Instruments

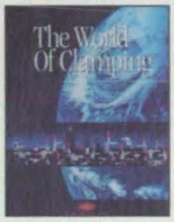
For More Information Circle No. 616

TOOLING COMPONENTS AND CLAMPS

This 500-page catalog contains an assortment of components including toggle clamps, modular fixturing, clamping devices, power workholding, chuck jaws, pins, knobs, drill bushings, leveling feet, and ›uch more. Carr Lane Manufacturing Co., 4200 ›arr Lane St., PO Box 191970, St. Louis, MO ›3119-7970; Tel: 314-647-6200; Fax: 314-647-5736.

Carr Lane Manufacturing Co.

For More Information Circle No. 617



WORLD OF CLAMPING

The World of Clamping catalog covers DE-STA-CO's line of approximately 500 toggle clamps, and features expanded dimensional and application information. DE-STA-CO's toggle clamp line includes hold-down, latch, straight-line, and squeeze-action clamps. The catalog also contains DE-STA-CO's pneumatic and hydraulic clamping systems, and line of spacing products. (Catalog 197 REV 1). DE-STA-CO Industries, 2121 Cole St., Birmingham, MI 48009; Tel: 248-594-5600; e-mail: cust.serv@destaco.com; http://www.destaco.com

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National Electrostatics Corp.

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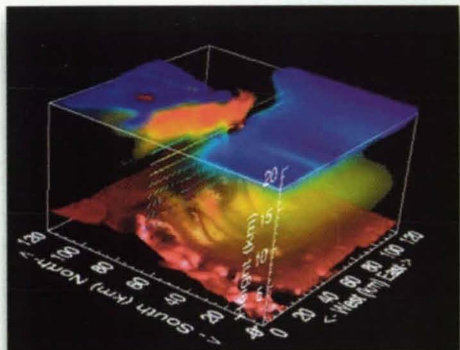

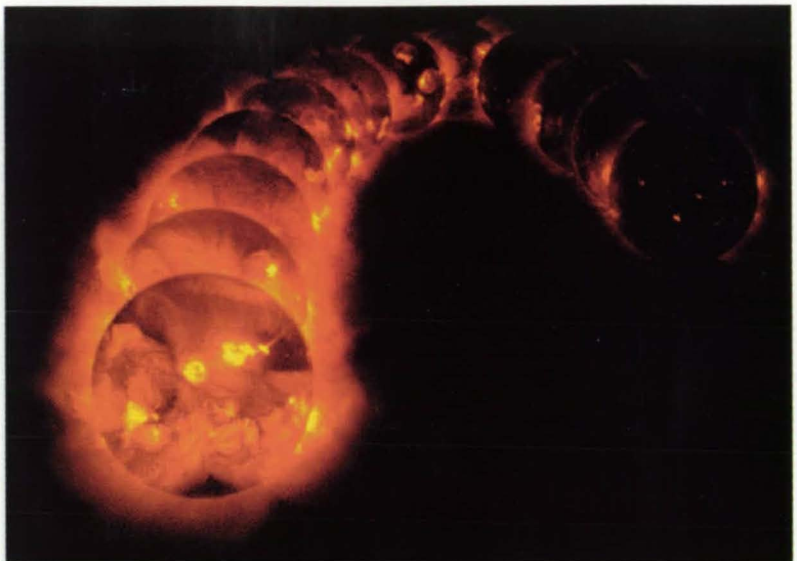

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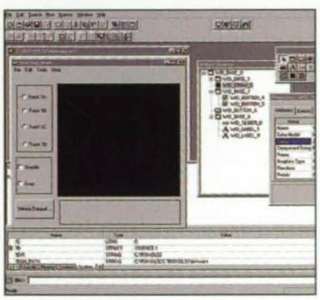

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