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TECH BRIEFS

ENGINEERING SOLUTIONS FOR DESIGN & MANUFACTURING

Advances in CAD/CAE/PDM

Automotive Technology

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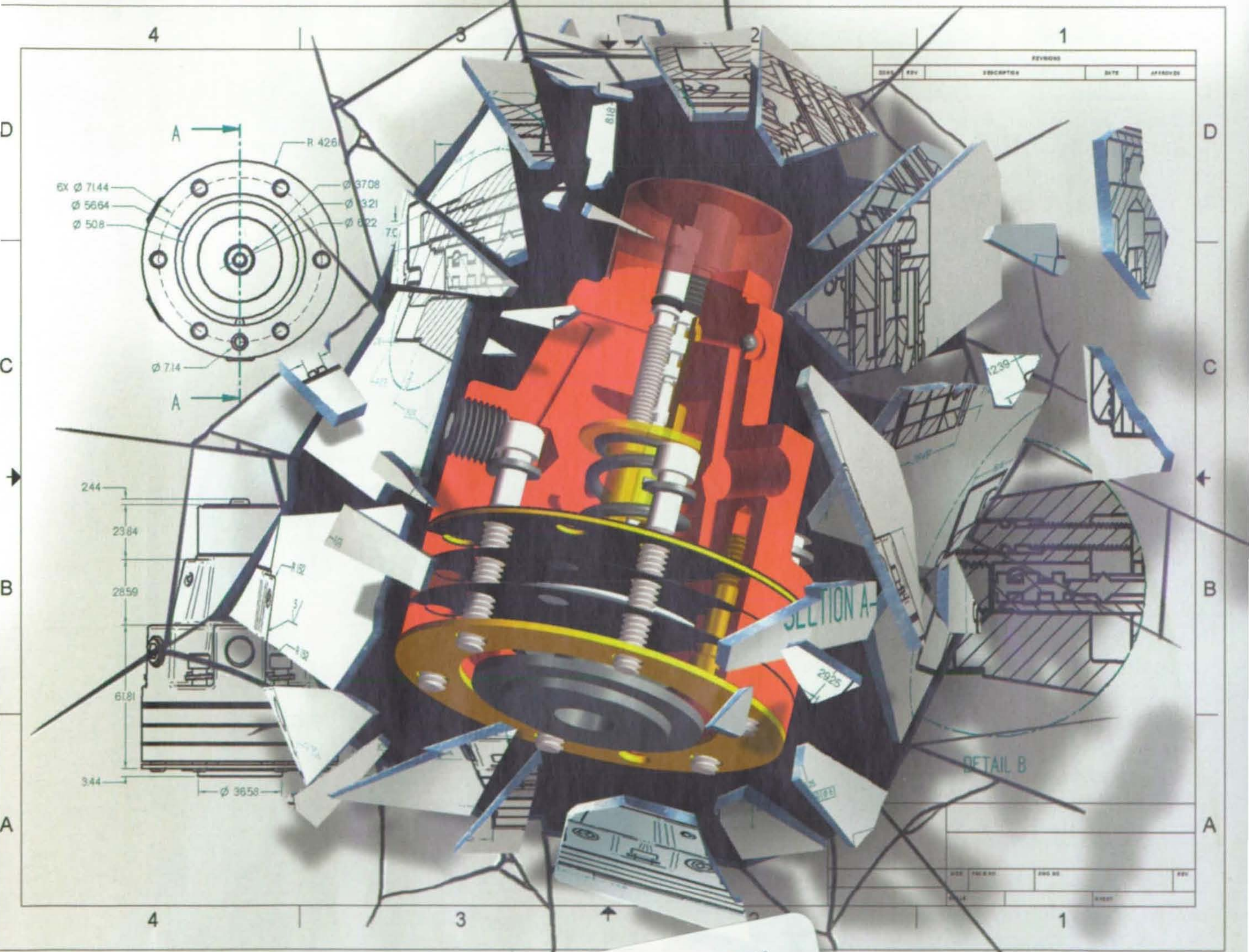

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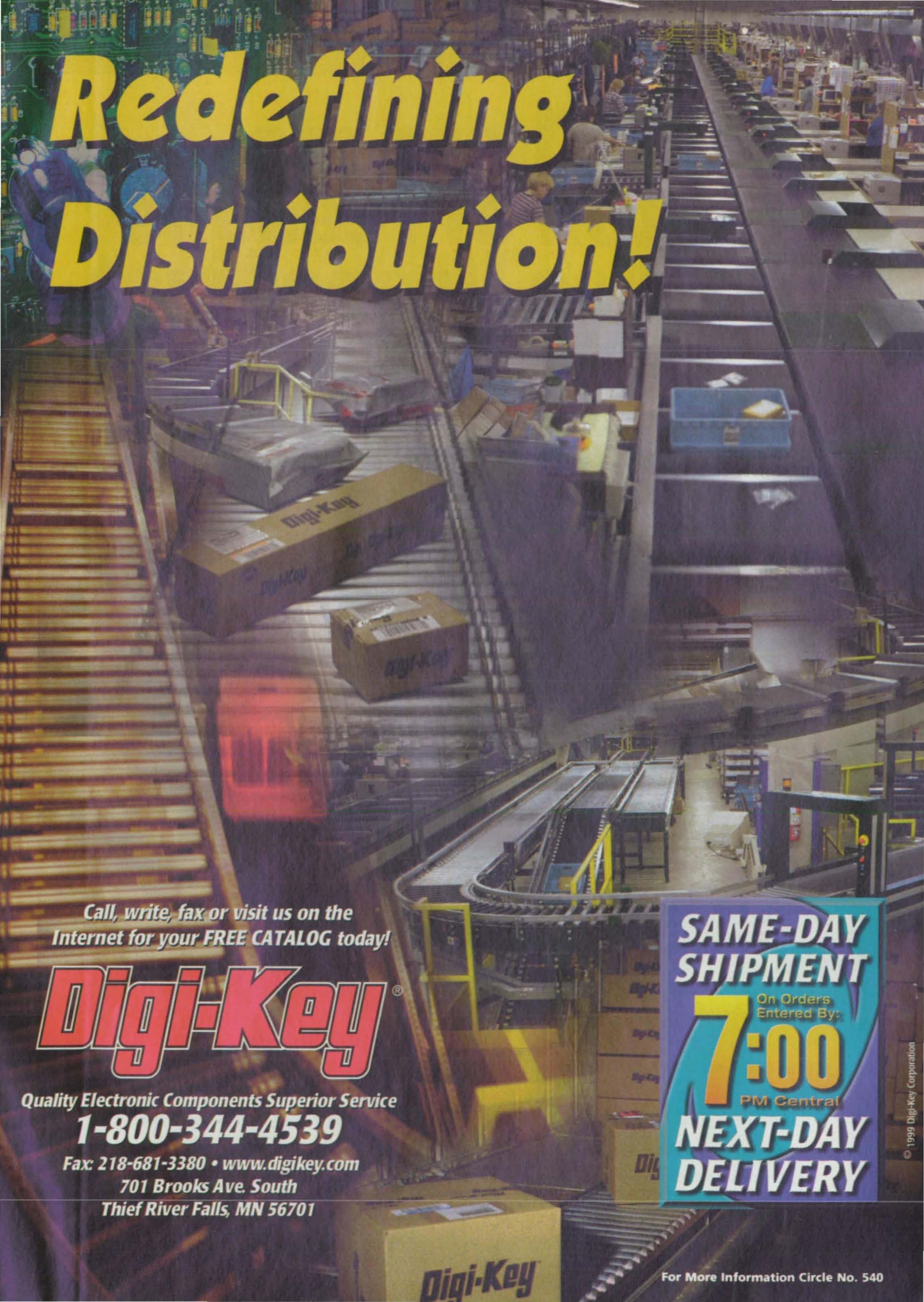
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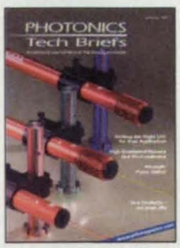

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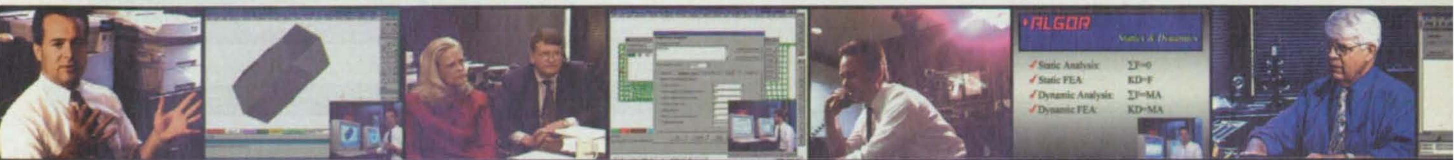

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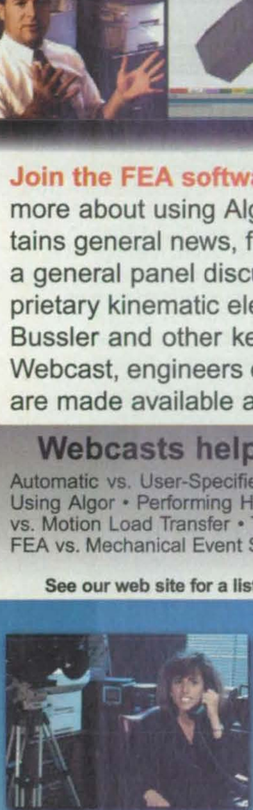

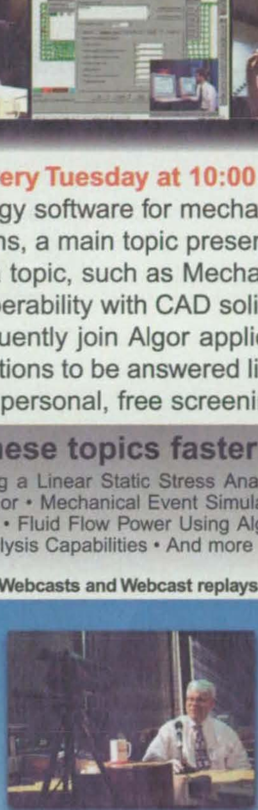

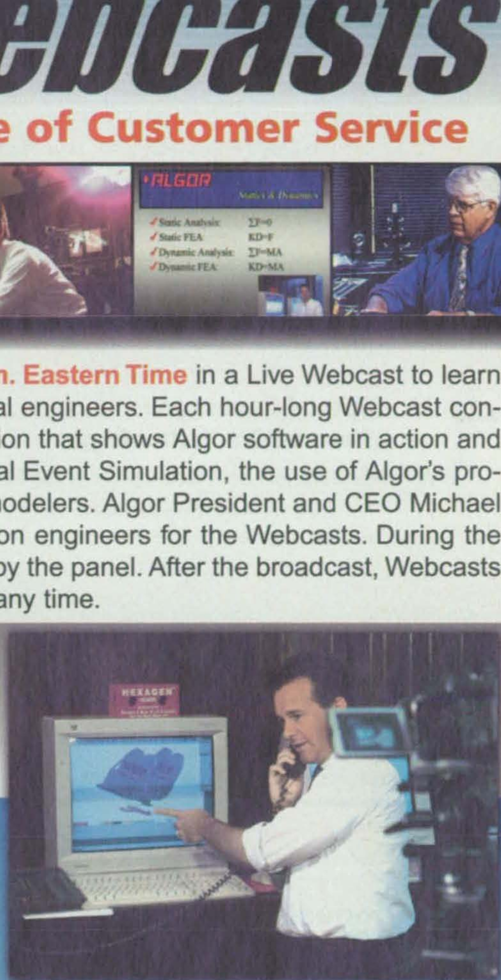

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Gage Applied Sciences introduces CompuScope 1602, a 16-bit A/D and Scope card for the PCI bus.

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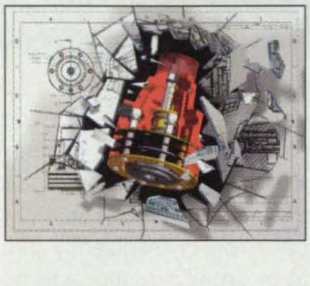
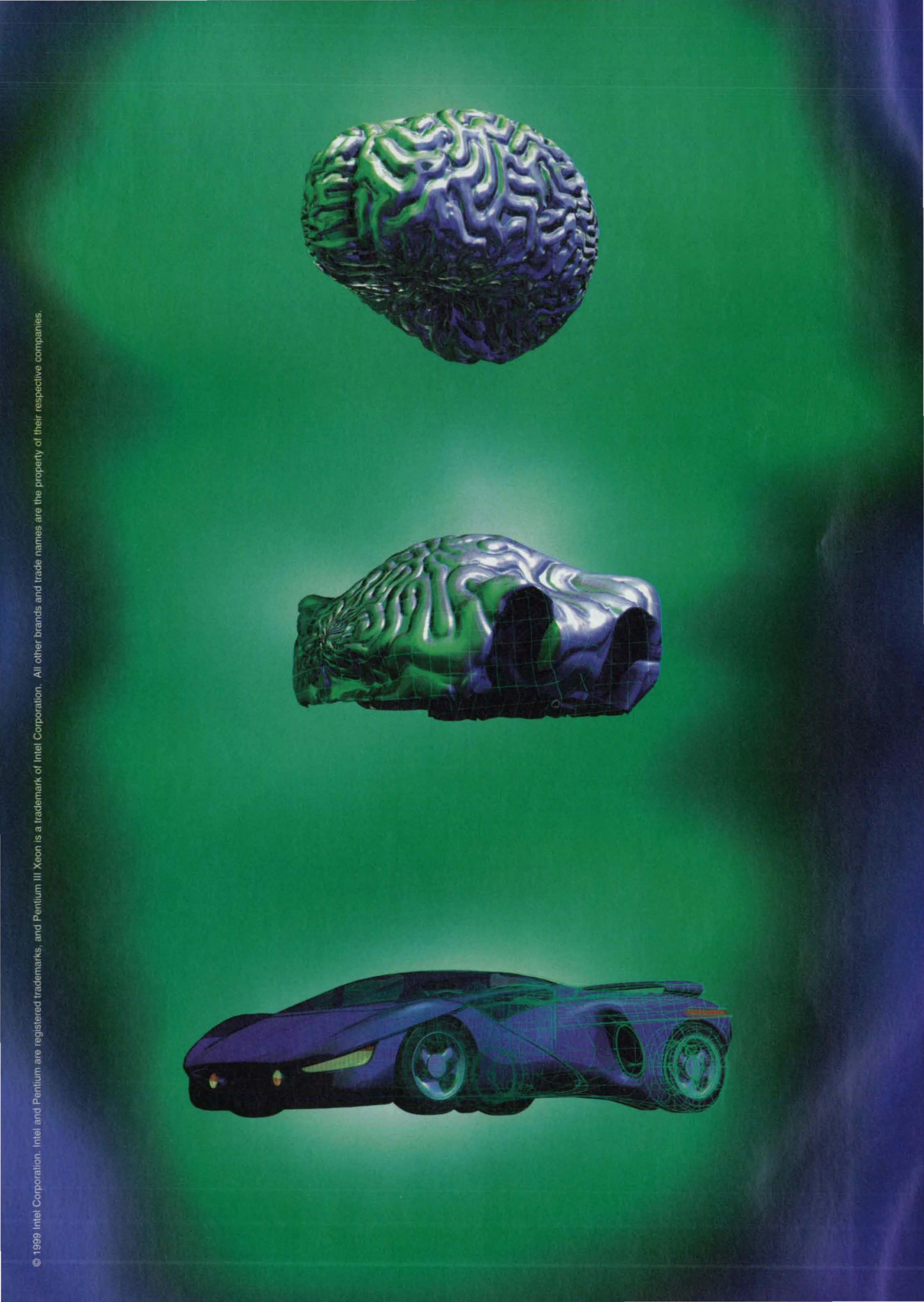


Badger Meter of Tulsa, OK, designed the valve positioner in this image with Solid Edge CAD software from Unigraphics Solutions, Huntsville, AL. The breakthrough of 3D design from 2D drawings is the concept behind Unigraphics' new Solid Edge Origin 3D software, which is designed to move 2D users to the 3D design world. For more information on Origin and other advances in the CAD/CAE/PDM area, see the Special Coverage beginning on page 26.

(Image courtesy of Unigraphics Solutions)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Published by .... Associated Business Publications
Publisher .... Joseph T. Pramberger
Chief Editor .... Linda L. Bell
Associate Publisher, *Photonics Tech Briefs* .... Linda Silver
Editor, Market Focus Editions .... Robert Clark
Internet Editor .... Suzanne Bilyeu
Production Manager .... Margery Koen
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BRIEFS & SUPPORTING LITERATURE: Written and produced for NASA by **Advanced Testing Technologies, Inc.,** Hauppauge, NY 11788
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Staff Writers/Editors .... Dr. Theron Cole, George Watson
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NASA Tech Briefs are provided by the National Aeronautics and Space Administration, Technology Transfer Division, Washington, DC:
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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.

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John H. Glenn Research Center at Lewis Field
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Marshall Space Flight Center
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Stennis Space Center
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NASA Program Offices

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

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

PRODUCT OF THE MONTH

Gage Applied Sciences, South Burlington, VT, has introduced the CompuScope 1602 single-slot 16-bit A/D and Scope card for the PCI bus that is capable of dual-channel, simultaneous conversion rates to 2.5 MS/s. The card features a 75-dB signal-to-noise ratio and auto-calibration feature. It operates in two modes: Memory Mode, with up to 8 million samples of acquisition memory; and Real Time Mode, in which it can stream data to host memory for up to 1 billion samples of acquisition memory. The card uses Bus Mastering, enabling data to be transferred from on-board memory to the PC's memory at rates to 100 MB/s. The CompuScope 1602 is supported by GageScope for Windows software, which enables users to operate the card like an oscilloscope without writing code. Users can view, manipulate, store, analyze, and print data, as well as convert it to an ASCII format for use in spreadsheets.

For More Information Circle No. 745

Insubordination vs. Safety

An expert in cognitive linguistics from the Georgia Institute of Technology (GIT) and a NASA Ames researcher are investigating the types and structure of communications between commercial airliner captains and first officers. The study found that first officers who need to correct their captain's mistake rely on "indirect" methods, rather than stating explicity what to do.

The NASA-funded study's findings could be important not only to airline safety, but to space missions that use multi-cultural crews. Dr. Judith Orasanu of NASA Ames Research Center in California explained that statements such as, "You are 15 knots too slow" are often sufficient to get the captain to correct his or her approach speed. However, said Orasanu, "ordering the captain to do so may be unwarranted by the situation and may actually interfere with the safe operation of the airplane by inducing annoyance at the socially inappropriate behavior of the co-pilot."

Dr. Ute Fischer of GIT's School of Literature, Communication, and Culture, said that communication problems contribute significantly in aircraft accidents and incidents. Examples include an Air Florida Boeing 737 that crashed into the Potomac River in 1982 because of excessive snow and ice on the plane. "By being indirect, speakers run the risk of not being heard," said Fischer.

NASA and GIT have received help from pilots in developing eight fictional flight scenarios, which were then posed to 576 airline captains and first officers to gauge how each would respond verbally to their colleagues. NASA funded the study because of its implications for teamwork among crews on the International Space Station.

For more information, contact Dr. Ute Fischer of GIT at 404-894-7627; e-mail: ute.fischer@lcc.gatech.edu.

Imaging System Complements Hubble

Developed at Southwest Research Institute (SwRI) in San Antonio, TX, with joint funding from NASA and SwRI, the Southwest Ultraviolet Imaging System (SWUIS) instrument package is an innovative telescope and a UV-sensitive, charged-coupled device (CCD) camera system that operates from inside the Space Shuttle cabin. The system is used to image planets and other solar system bodies in order to explore their atmospheres and surfaces in the UV spectral region.

The SWUIS has attributes that make it a valuable complement to the Hubble Space Telescope, including an unusually wide field of view that is up to 30 times that of Hubble's, and its ability to observe objects much closer to the Sun.

The system weighs just over 60 pounds, and made its first flight on STS-85 in 1997. On that mission, SWUIS obtained more than 400,000 images of comet Hale-Bopp at a time when the Hubble could not observe the comet because of glare from the Sun. The SWUIS flew again on STS-93 during which it imaged the clouds of Venus, searched for faint emissions in the jovian system, mapped Earth's moon at ultraviolet wavelengths for the first time, and conducted several other observations.

This computer-enhanced image obtained by SWUIS shows the comet Hale-Bopp in the visible and ultraviolet spectra. (Image courtesy of SwRI and NASA)

For more information, contact Dr. Alan Stern of SwRI's Space Studies Department in Boulder, CO, at 303-546-9670; or visit the web site at www.boulder.swri.edu/swuis/

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 would like to obtain any available information on service-life problems with bearings — roller, spherical — and bushings. Since aircraft and helicopter structural failures are many, this is an area of concern for aircraft safety, cost, and weight problems. Thanks for any information.

Eugene R. Speakman
Fullerton, CA
714-529-2012
erspeakman@aol.com

I am looking for a good source — book or technical paper — on step-by-step procedures to insure clean assembly of parts for an assembly with bearings. I have information on building a cleanroom, but I can find nothing on the small details of getting clean parts to the cleanroom. Thanks for any assistance.

Robert Crader
rcrader@trane.com

*(**Editor's Note:** We've received comments from many of you regarding the Editor's Note in our May Reader Forum concerning aerogel, the "solid smoke" material developed by NASA. We stated that aerogel, which is made of silica, alumina, carbon, and other materials, "weighs less than the same volume of air." Our readers brought to our attention that this statement is not accurate. Terrance Mason of NASA's Jet Propulsion Laboratory, explains further: "The density of the silica network that makes up the aerogel is that of bulk glass; i.e., 2 g/cc. The density of air is 0.001255 g/cc. Therefore, there can be no combination of silica and air that has a density less than air. The miniscule pores in aerogel could be filled with helium or hydrogen and thus be made 'lighter than air,' but that is short-lived. The gas will leak out to the point where it would be heavier than air and fall." Thanks to Terrance for his clarification, and to our readers for pointing out this error.)*

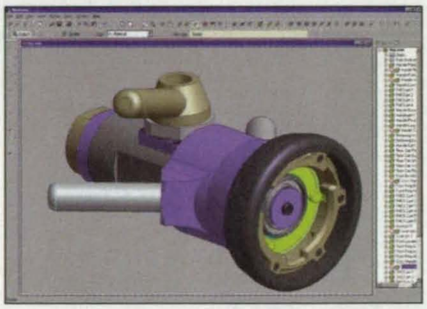
Post your letters to Reader Forum on-line at: www.nasatech.com or send to: Editor, *NASA Tech Briefs*, 317 Madison Ave., New York, NY 10017; Fax: 212-986-7864. Please include your name, company (if applicable), address, and phone number or e-mail address.

Autodesk Inventor: A New Look at MCAD

Steven S. Ross

Autodesk is taking fresh aim at MCAD, the mechanical design CAD market, with an entirely new software package, Autodesk Inventor. Unlike the popular AutoCAD Mechanical Desktop, Inventor is not based on AutoCAD itself. In fact, files created with the two packages are not completely compatible. Autodesk started development on Inventor in February 1996, two months before Mechanical Desktop first shipped.

The existing Mechanical Desktop is certainly a successful product. In fact, with a half-million copies sold, Autodesk claims market leadership in MCAD. But Autodesk has never claimed it is as robust as many of its competitors, especially for big assemblies of 300 to 3,000 components or more. Inventor, known to insiders by its code name "Rubicon" during its three-year development cycle, is aimed squarely at that market.



In this nozzle assembly, the components are interdependent and the cross handle is shown as an adaptive component. Inventor's Adaptive Assemblies functionality allows users to make changes anywhere in the model, not just in the order in which they created the constraint system.

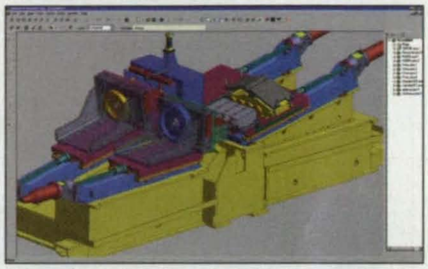
In a round of private press briefings and demonstrations earlier this summer, Autodesk emphasized three key features of Inventor:

- Ease of use. The interface is clean, there's an awesome sketch-into-entity facility (much better than the one in other Autodesk products), and a great help system that includes tutorial videos. Autodesk claims designers can get used to it in a day or come back to it infrequently and still be productive.
- The ability to design from the top down (starting with the design's overall function, and plugging in parts to fit), or the way most other packages work — designing from the bottom up, one part at a time. Designers can mix finished parts with schematic links, in 3D, to see how everything might work before designing the final version of the link part or parts.
- A new internal segmented database (it is a bit of an oversimplification, but a CAD program can be considered nothing more than clever interface to create database records, each record being a design entity) that arranges things so you load only the detail and functionality of each entity you need at the moment. Assemblies of 3,000 components load in a matter of seconds instead of many minutes. Other programs might appear to load views quickly, but this usually is done with lightweight images of parts and assemblies. These images do not contain all the information about the parts and may not reflect the latest version of the assembly.

There are other goodies as well:

- An integrated "engineering notebook" that can record the reasons you chose certain design solutions. The notebook can accept data files, specification tables from a vendor catalog, or images and even videos and sound.
- The ability to "associate" parts and subassemblies to one another without a one-way dependency. This sidesteps the annoyance of parametrically basing one part's dimensions on another that you've designed previously. In that case, modifying a later part does not have any effect on the earlier one; the modification destroys the parametric relationship. In Inventor, modifying the later part will indeed have an effect upon earlier ones.
- Collaboration tools. Multiple team members can each work on a part or subassembly. Inventor keeps track of who has what piece. Even those without Inventor can track the design process.
- Super-fast pans and zooms. Inventor is the first 3D mechanical design package to use the Fahrenheit 3D graphics technology being developed by Microsoft and SGI. This adds detail as the drawing scale changes, and also manages the on-screen drawing, avoiding time wasted drawing areas that can't be seen on the screen.

In general, files from AutoCAD Mechanical Desktop can be read directly into Inventor. Inventor is both an OLE server and client, so its 2D and 3D data can be embedded into Desktop files. But Inventor files cannot be read into Desktop while keeping their full intelligence. To put it another way, 2D data moves in both directions, but 3D data moves cleanly only from Desktop to Inventor. Desktop 4.0, early next year, will be better at that.



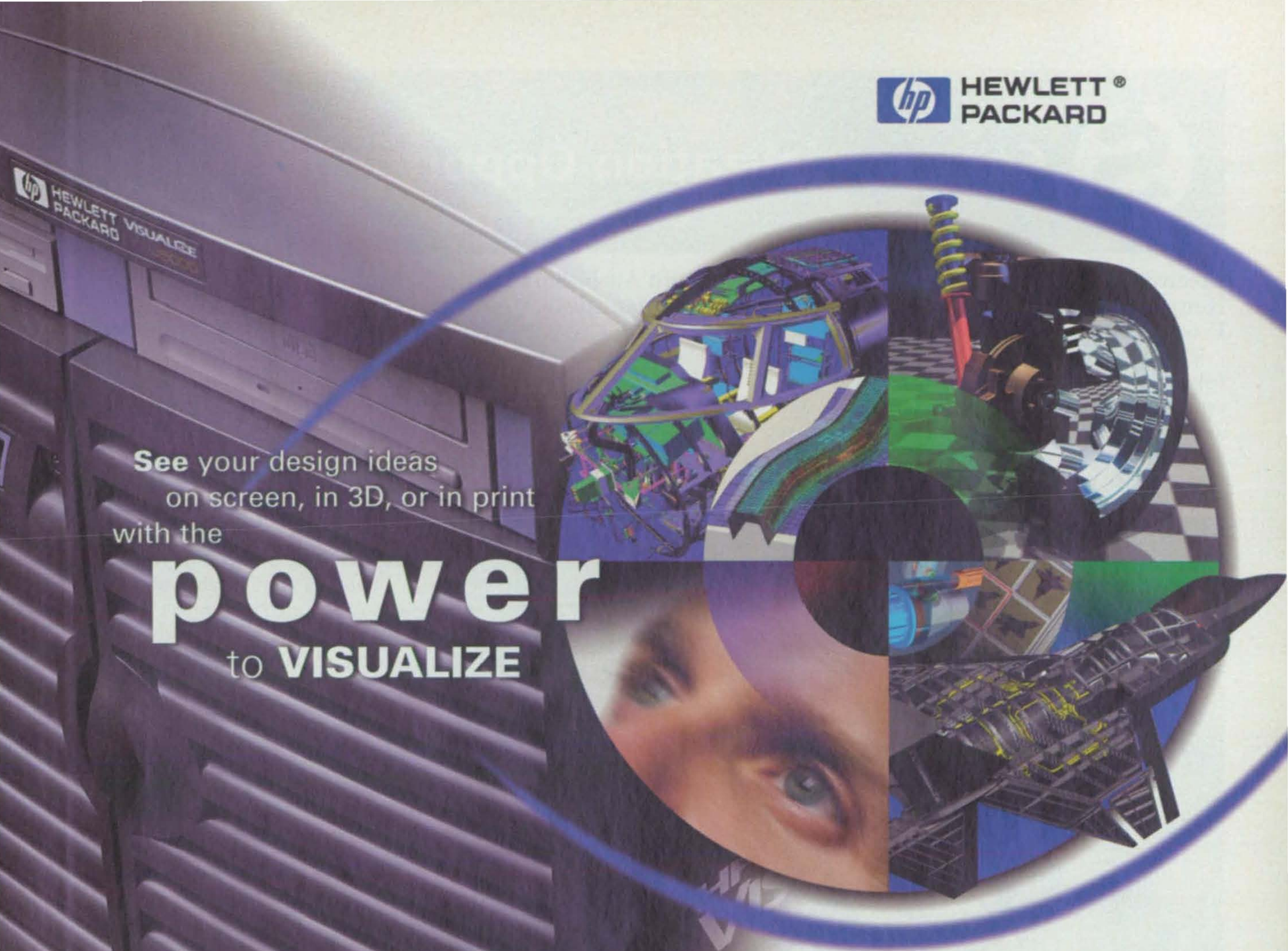
Shown here is a six-stage transfer machine for machining the cylinder heads for an automobile engine. Inventor allows users to work in the context of their entire design, however large the assembly is, without sacrificing power or performance. Inventor can effectively handle assemblies of 10,000+ components, and opens files two to ten times faster than other competitive best-performing solutions.

The first release of Inventor, due this month, will lack some polish. There are only limited tools for surface texture, for instance, and no easy way to show exploded assemblies without reading the Inventor file back into Desktop and handling the task there.

Autodesk claims to have spent $25 million developing Inventor. It has filed for 17 patents on new technology created along the way. The database technology itself is clearly a major advance in CAD — probably the biggest since object technology became truly useful a few years ago.

When you think Inventor, think SolidWorks on steroids. You simply have to play with it, especially if you are involved in large projects with thousands of parts. Also think about using it in conjunction with Mechanical Desktop — the products will co-exist for at least the next two or three years. And think about digging deep into your wallet. The price will be around $5,000.

Steven Ross is an associate professor of journalism at Columbia University. He has written several major design texts.



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For More Information Circle No. 541

THE **ULTIMATE** DESIGN MACHINE

Commercialization Opportunities

Electrodialysis To Remove Ammonium Ions From Wastewater

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(See page 48.)

Making Liquid Air in Small, Economical Quantities

A mixing apparatus combines liquid oxygen with liquid nitrogen to make liquid air in small, convenient quantities. Both gases are readily available in liquid form, and the process can produce batches as small as 100 liters.

(See page 50.)

Air-Purification System Utilizing Humidity Swings

This system would remove toxic gases from solid-waste incinerator exhaust and remove trace contaminants from breathable air. Conceived originally as part of a life-support system, the system can be adapted to the treatment of industrial and municipal exhaust streams.

(See page 56.)

Hybrisol Rocket Engines

This is a combination of a hybrid and a solid-propellant rocket engine. Estimates show that this design could be produced at half the cost of conventional rocket engines.

(See page 58.)

A Precise Closed-Loop Temperature-Control System

This system is designed to use a single thermal source to control the temperature of a closed-loop system. Precise temperature control is important to a number of industries, including photographic, pharmaceutical, food-processing, heating-ventilation-and-air-conditioning, and many others. Predicted temperature accuracy is ±0.5 °F (±0.3 °C).

(See page 60.)

Adaptable Drill Guide

This drill guide can be adapted to a curved or flat surface. The main function is to keep the axis of a drill perpendicular to the surface being drilled. The tool can also be used to guide a reamer and other tools and to control the depth of drilling.

(See page 61.)

Improved Array of X-Ray Microcalorimeters

This array of microcalorimeters is proposed for x-ray spectrometers for astrophysical research. The spectrometer will be used to measure the x-ray spectra of celestial objects at unprecedentedly high resolutions.

(See page 62.)

Miniature Ring-Orbitron Getter Ion Vacuum Pumps

Miniature pumps are proposed for supplying high vacuums to advanced scientific instruments expected in the next few years. Examples of such instruments are electron microscopes, ion mass spectrometers, and instruments based on electronic probes.

(See page 62)

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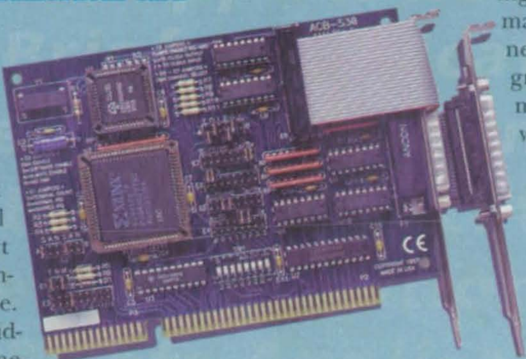

The Geodynamics Branch of NASA's Goddard Space Flight Center's Laboratory for Terrestrial Physics has been researching direct measurement advances and techniques for more than a decade. Recently, Goddard engineers decided to adapt an airborne laser altimeter for use on the Space Shuttle. The measurement laser and its corresponding computers had to be operated remotely.

The project required an RS-422 card with dual channels. NASA chose the high-speed Sync/Async card, which was worked into both the laser setup on the shuttle, and the control modules on the ground to facilitate communications on a microwave link. The communications function was even more important due to the fact that the shuttle's re-entry and landing could damage the hard drives and information collected. As much data as possible needed to be relayed to and stored on the ground. In addition, conditions in orbit meant that the high-speed data channel would be open only 20 minutes a day.

The card facilitated data transmission, including measurements of the heights of ground surfaces and vegetation canopies gathered from three million laser shots. The system was controlled remotely from the ground station using signals transmitted by the card. "The Sealevel card was chosen because it fit the specifications we needed, and also, because we trusted its reliability," said David Rabine, an aerospace engineer at NASA Goddard. "We plan to use it in several more projects and in devices that are going to be used in two more upcoming shuttle flights."

For More Information Circle No. 743

Software Helps Manage Changes for Space Station Team

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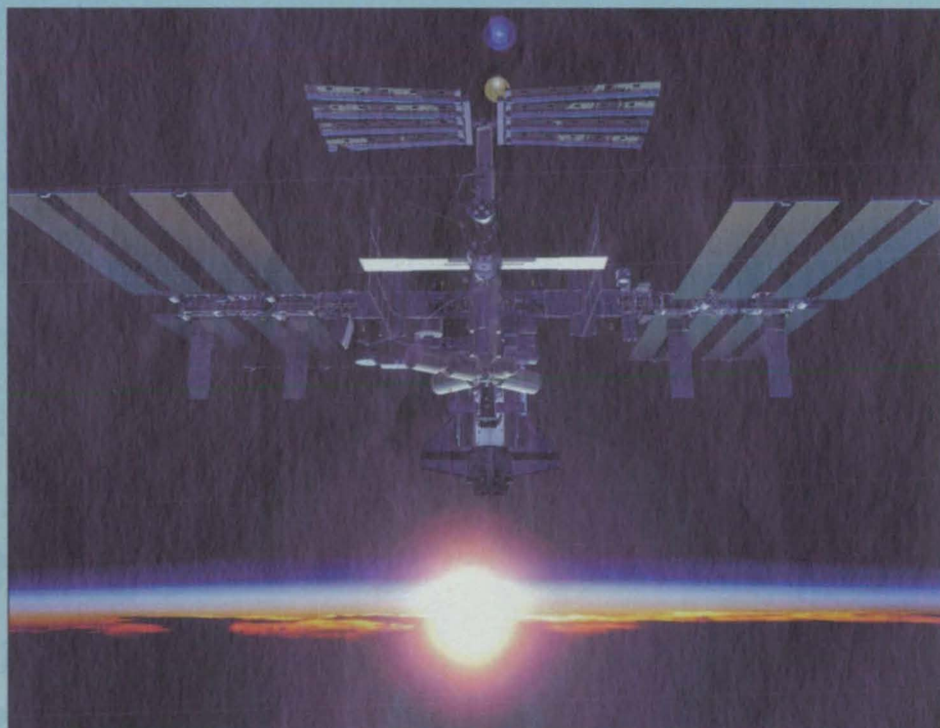

NASA's International Space Station (ISS) is the largest scientific cooperative program in history, drawing on the resources and scientific expertise of 16 nations. The Boeing Company, NASA's prime contractor, has assumed the task of manufacturing, testing, and delivering the U.S. modules of the ISS.

The building of Unity, the first U.S. module, began with Boeing utilizing the problem-tracking portion of the PVCS Dimensions software to track bugs and authorize changes to integrated products across the Space Station program. The process-based configuration management (CM) system is hosted on a Sun server; Boeing plans to expand its use on a Windows NT platform.

"The Boeing F-22 personnel in Seattle were achieving top quality levels and gaining a competitive edge via their successful implementation of PVCS Dimensions," according to Janna Larsen, Boeing's ISS software configuration manager. "We observed first-hand the major successes these highly complex development environments experienced via this advanced solution, and this was a major factor influencing our decision to purchase the system."

The program provided an active view of development efforts and allowed management of software changes in complex, heterogeneous environments via the seamless integration of change, version, and process management. The development teams can access the system in parallel and concurrently by a variety of means, including the Internet, PC clients, and the X Windows Interface. This is important, since the system supports the needs of many Boeing teams in building software collaboratively.

For More Information Circle No. 744

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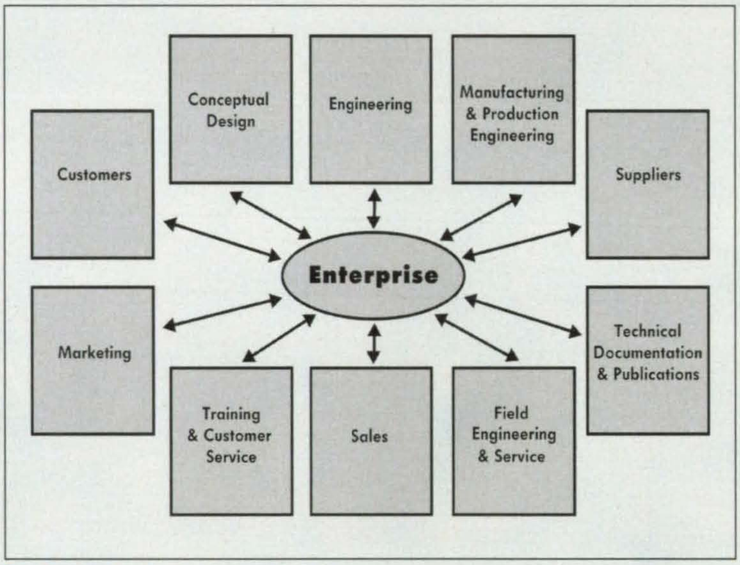
For More Information Circle No. 575

Cost Reduction and Profit Improvement Through Design Chain Integration

e-Engineering is the creation of a dynamic, integrated product development and realization process, one with the necessary agility and deftness to respond to the demands of an e-commerce world. e-Engineering stems from a recognition that for companies to reap maximum benefit from the large investments and considerable pain in implementing Enterprise Resource Planning (ERP), the product process that feeds into the supply chain must be optimized. This product process is the Design Chain, the interlinked contributors to the creation and realization of a product. The Design Chain is not only R&D, but customers, marketing, suppliers, and production.



The Design Chain

Design Chain costs can have a greater impact on earnings than any other area of the organization. In the typical enterprise, by the time a product reaches the supply chain, nearly 80% of product costs have been predetermined by the Design Chain. As attractive as earnings improvement is, the option to implement Design Chain integration rapidly will cease to be an elective choice. The emergence of the Internet will make it a competitive necessity.

e-Engineering requires three fundamentals: pervasive use of 3D for product data, gaining access to that product information, and the use of fit clients to leverage that data throughout the Design Chain. Companies that achieve Design Chain integration through e-Engineering not only improve product process efficiency, but also the bottom line.

3D: The Universal Language

The first fundamental of Design Chain integration through e-Engineering is the use of 3D data for product development. There are many links in the Design Chain, and without shared information, integration is impossible. Engineering data has to be understood by all contributors, and 2D engineering drawings do not facilitate communication of product features and attributes to those outside of engineering.

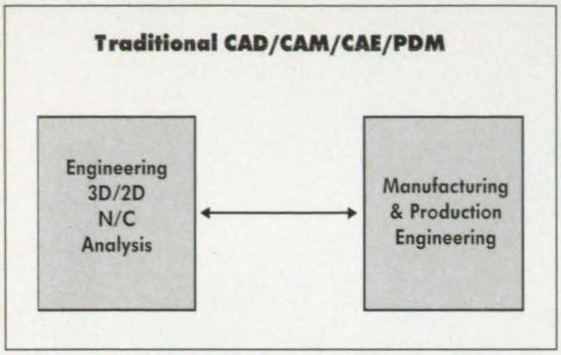
Two-dimensional representation of real-world objects is hard for many participants in the enterprise to understand. To emphasize this, put a human face to some of the various links in the Design Chain: customer, purchasing agent, salesperson, factory worker, dealer, manager, and field service technician. A seemingly simple part, such as an automotive wheel, might require a dozen or more 2D drawings to communicate all the necessary details, versus a single 3D file. Globalization makes 3D even more imperative. The ability to use animation and visualization technologies of 3D data can eliminate thousands of pages of text. Some companies literally have seven different languages spoken on the factory floor, and 3D is the universal language.

e-Engineering requires a core technology architecture that supports the entire flow of design — everything from concept through customer delivery. This new architecture, Design Flow, is the backbone of e-Engineering, providing the foundation for improving product processes while allowing for integration of the Design Chain into supply chain management and ERP. Design Flow is the first new 3D development architecture in more than a decade, and unlike existing CAD architecture, it can be used outside engineering and in the Design Chain.

Corporations that have deployed solid modeling into product development already have reaped enormous productivity gains of 3D. However, these traditional solid modeling technologies require a great deal of investment before those gains are realized. Just as companies are beginning to see light at the end of the tunnel, that light may be the proverbial oncoming train. That train is e-business, and it is quickly rendering traditional solid modeling obsolete.

Current Technology Falls Short

The traditional CAD/CAM/CAE/PDM systems are point solutions focused departmentally, not as enterprise tools. The complex proprietary data structures of these systems are barriers to communication, not enablers. Furthermore, engineers utilizing identical systems find it difficult to collaborate effectively. The reasons are two-fold. First, is the issue of feature and history data, or how each model was constructed. Commonly referred to as design intent, it is a fundamental requirement of these systems for building



Traditional CAD/CAM/CAE/PDM

geometry. Even the simplest parts are bound by the methodology used to construct them. As parts and assemblies become more complex, for one engineer to use data from another, he or she has to interpret the other's design intent. Most drivers of these CAD systems find it faster and easier to rebuild the entire model than to try and de-bug someone else's work.

Because the creation history and feature data are central to the architecture of traditional solid modeling, concurrent engineering utilizing these systems demands that everyone use the same system. Why don't these systems facilitate integration? They simply cannot be deployed effectively throughout the Design Chain. It takes from nine months to two years to become proficient in the use of these systems. The greatest cost is the loss in productivity while engineers gain proficiency.

The re-creation of data is not limited to engineering; at every link of the Design Chain, data is being re-created. Once the 3D model is created, it becomes the virtual product; however, it usually ends up in a data vault where it sits unutilized. Even though the model is sent to production engineering, because of the restrictive data structures, production engineers often are afraid to make changes to the 3D model, and instead resort to making changes in 2D.

Three-dimensional data is essential to the e-corporation. It is the fuel that drives virtual product development, and it provides usable and understandable information to every contributor in the Design Chain. Design Flow Architecture overcomes the inherent limitations of existing 3D design systems that are expensive to implement, require months or years to deliver productivity, are barriers to collaboration, and do not meet the needs of all contributors. By using 3D to communicate and link engineering, manufacturing, marketing, and customers, products can be built faster, cheaper, and smarter.

Information Access: Time is Money

Information access is the second fundamental requirement for e-Engineering. It is impossible to capitalize on engineering assets if no one can locate those assets. This inability to find and utilize existing engineering data leads to more of the previously mentioned re-creation inefficiencies.

Just as the Internet is revolutionizing information technologies in other segments, it will revolutionize the Design Chain. The power of the Internet is not derived from everyone sharing a central server, but from the power of linking millions of different servers. Envision the different links of the Design Chain as distinctive servers. Design Flow Architecture links diverse servers, creating a powerful tool for interactive information access and management.

The leaders in mainframe-based CAD fell behind with the introduction of UNIX workstations and PCs. As workstations became powerful enough to support solid modeling, yet another market leader emerged. Now, the Internet will spark the establishment of the next-generation market leader, and will have a more sweeping effect than any of the technology shifts that occurred before.

"Fit" Clients

The final fundamental necessary for e-Engineering is the concept of the "fit" client. Current engineering systems are dependent on what is referred to as the "fat" client — powerful workstations networked to a server with a workgroup focus. e-Engineering requires the new concept of fit clients. The client is tailored, or fit, to the functionality and interface requirements of the user.

Fit clients should not be considered the same as custom clients. With so many varied contributors to the Design Chain, e-Engineering requires tools that can be deployed universally to every contributor. A master set of interface tools provides for each user of a fit client to interact only with the toolbars and menus necessary for their application. Utilizing the Wintel platform, OLE integration with the suite of Microsoft® Office, and net Design Flow Architecture, it is easy and cost-effective for IT groups to build an integrated environment that links all contributors.

Return on Investment

What kind of return on investment can companies expect from e-Engineering? Cost savings throughout the enterprise result from increased efficiency, reduction in re-creation of information, and leveraging of data upstream and downstream from engineering. This will, of course, vary from one enterprise to another.

Here is a snapshot view of what an e-corporation using e-Engineering looks like, using a cell phone manufacturer as the example:

- After completing several conceptual designs, marketing puts them online in a "virtual" phone show in which customers give feedback online that is used by conceptual designers to improve the design.
- Engineering begins detail design, while concurrently, marketing uses the conceptual design to begin developing sales tools, point of purchase, and brochures.
- Production engineering uses the concept to begin understanding the manufacturing requirements, while purchasing uses it to line up suppliers of a new material for the case.
- Technical publications begin creating the necessary documentation. Design engineering sends a nearly finished design for input from suppliers.
- The supplier of the LCD panel makes a small change in the design to accommodate a less expensive part.
- The completed design is released to manufacturing, and a production engineer uses it for designing tooling.
- Manufacturability becomes an issue and a new design that is much cheaper to produce is up on the virtual phone show. With a positive customer reaction, the design is finalized.
- The OEM sales force is in the field showing it to customers on their laptops and taking orders.
- Animations are created to show how to assemble and service the phone.
- The new design is "plugged in" to all the marketing and technical publications in place of the original.
- As production begins, monitors at an offshore plant use the animations to demonstrate assembly to workers.
- The same animations are sent to field service centers around the country.
- Concurrently, the final design was plugged into all the activities of marketing and technical publication so that everything accompanying the new product goes out the door at the same time, and is an exact match to the production product.
- Early buyers of the phone provide feedback, which the conceptual designers use for new designs.

For more information on e-Engineering, contact the author of this article, Gary Stoll, Vice President, Engineering, of Visionary Design Systems, at 2790 Walsh Ave., Santa Clara, CA 95051; Tel: 408-969-8000; or visit the web site at: www.vds.com.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For More Information Circle No. 517

Program for Designing a Mechanical System

This program offers advantages of ease of use, accuracy, efficiency, and speed.

John H. Glenn Research Center, Cleveland, Ohio

Mechanical System Design/Analysis Tool (MSAT) is a user-friendly software system that facilitates and accelerates the processes of synthesizing and analyzing designs of mechanical systems. MSAT is particularly well suited for designing aircraft engines. MSAT can be used in the preliminary-design stage as well as in the detailed-design stage of a product-development process.

MSAT is a multicomponent, multidisciplinary program with a modular architecture that organizes design-analysis tasks around object-oriented representations of (1) components of the engine or other system that one seeks to design, (2) analysis programs, and (3) data-transfer links among the constructs listed in (1) and (2). The modular architecture enables the rapid generation of input data streams for trade-off studies of various configurations of the system to be designed. Once the user has set up a sequence of computations, the data-transfer links automatically transport output from one analysis/design program for use as input in the next analysis/design program in the sequence. The computations are managed via constraint propagation — that is, by reference to constraints provided by the user as part of the design definition.

MSAT provides a global perspective on system design. Building from subcomponents and components, the user sets detailed requirements for performances of components and of the system to be designed. The plug-and-play software framework of MSAT enables the user to add new analysis/design programs and/or components of the system to be designed and to perform trade-off studies rapidly; this capability helps to increase the quality of the ultimate design.

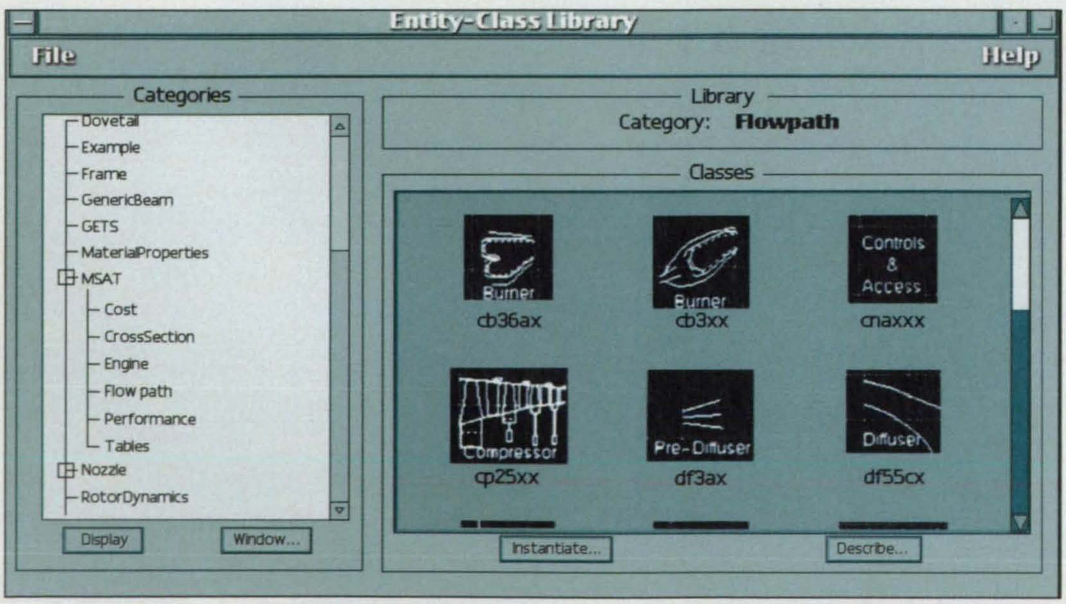
The plug-and-play feature of MSAT can also be utilized to make MSAT itself more versatile: New optimization and robust design software modules can be plugged in without extensive effort. As advanced computer programs are developed, the user can plug them in quickly, without having to delete older programs. This building-block application to the extension and improvement of MSAT is expected to reduce both the cost of further development of MSAT itself and cost of designing engineering systems by use of MSAT.

MSAT offers advantages of accuracy, efficiency, and speed. MSAT promotes accuracy by detecting errors in data entered by the user. A mathematical model of an engineering system can be built quickly and easily (see figure), and once the model has been built, the user does not have to rebuild the model for subsequent analysis. MSAT manages an optimization program and other analysis/design programs in performing multiple iterations without interaction with the user. In a typical case in which five iterations would be needed to arrive at a reasonable product design by conventional means, MSAT can perform the same analysis in one run, thereby saving about 80 percent in time and cost.

MSAT is expected to be integrated with NASA's Numerical Propulsion System Simulation (NPSS) computer program, which is used for coupling computer codes for the design and analysis of propulsion and propulsion/airframe systems.

MSAT has already been integrated with Monte Carlo, design-of-experiments, response-surfaces, and optimization software modules to provide a capability for robust preliminary design and uncertainty analysis. This capability can be exploited to determine whether a product is underdesigned (poses an excessive risk) or overdesigned (costs more than necessary).

This work was done by Charles Lawrence of **Glenn Research Center** *and HuaHua Lee, Mark Kolb, and Jack Madelone of General Electric Co. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Information Sciences category.*
LEW-16710



An **Icon-Based Library-Browser** subprogram in MSAT can be used in creating a mathematical model quickly and easily by performing pick-and-drop operations on the relevant icon(s). Here the icons represent components of an aircraft turbine engine.

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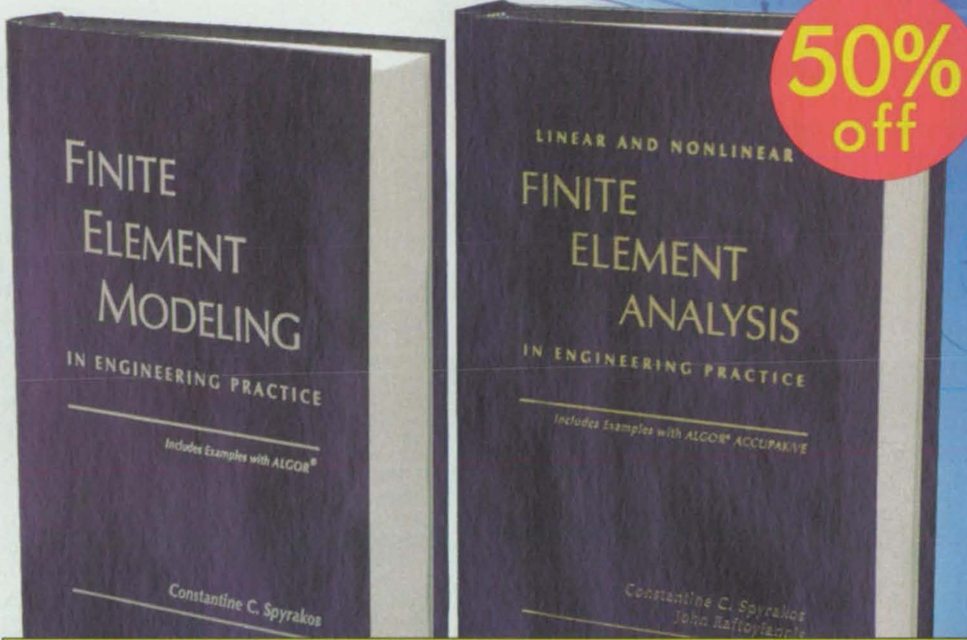

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About the Authors

Professor Constantine Spyrakos is a faculty member at the National Technical University of Athens (NTUA) and the College of Engineering at West Virginia University. He holds B.S. and M.S. degrees in Civil Engineering from NTUA, Greece. He also holds an M.S. in Engineering Mechanics and a Ph.D., with an emphasis on the utilization of FEA methods to solve dynamics problems, from the University of Minnesota.

Dr. John Raftoyiannis holds B.S. and M.S. degrees in Civil Engineering from NTUA. He also holds an M.S. in Civil Engineering and a Ph.D. in Mechanical Engineering from West Virginia University with an emphasis in stability, composite materials and computational mechanics. He was recently invited to join the Civil and Geological Engineering Department at the University of Manitoba in Canada.

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Program Predicts Uncertainties in Properties of CMCs

This program can help engineers design reliable, long-lived structural components.

John H. Glenn Research Center, Cleveland, Ohio

Probabilistic Ceramic Matrix Composite Analyzer (PCEMCAN) is a user-friendly computer program that predicts uncertainties in the mechanical and thermal properties of ceramic-matrix composite (CMC) materials. These materials are candidates for fabrication of structural components that will be required to withstand loads at high temperatures in advanced aircraft engines. PCEMCAN is intended to help researchers develop improved CMCs for aircraft-engine components and to help engineers assess reliability and assure long operational lifetimes for those components.

PCEMCAN is an integrated computer code that embodies a combination of:

- the formal probabilistic methodology of CEMCAN [reported in "CEMCAN — Ceramic Matrix Composites Analyzer" (LEW-16327), *NASA Tech Briefs*, Vol. 21, No. 5 (May 1997), page 32]; and
- the fast probability integration (FPI) technique [reported in "Probabilistic Analysis of Composite-Material Structures" (LEW-16092), *NASA Tech Briefs*, Vol. 21, No. 2 (February 1997), page 58].

Micromechanical and macromechanical theories as implemented in CEMCAN are used to predict the strengths and other properties of CMCs. Uncertainties in primitive variables are provided as input to PCEMCAN in the form of means, standard deviations, and types of probability distributions that characterize those uncertainties. The types of probability distributions available in PCEMCAN include normal, Weibull, and log-normal.

The probabilistic integration of random primitive variables is performed by use of the FPI technique. Fewer computational simulations are needed to determine the scatter in response variables (e.g., properties of plies and laminates) when using the FPI technique than when using the Monte Carlo technique. PCEMCAN expresses the scatter in the response variables in the form of cumulative probability distribution functions (CDFs), which are useful for probabilistic analyses of structures and assessments of degrees of reliability of components. PCEMCAN also quantifies the sensitivities of the response variables to the random primitive variables.

More specifically, for given scatter of properties of fibers, properties of matrix and interphase materials, fiber volume ratio, ply thickness, and other primitive variables, the response variables (properties of the composite material) for which CDFs can be computed include the modulus of elasticity, Poisson's ratio, coefficients of thermal expansion, thermal conductivity, and laminate failure strength. PCEMCAN also computes the means, medians, and standard deviations of response variables.

These results can be used in probabilistic structural analysis to compute the reliability of a component or to asses the life of the component for a desired reliability. Sensitivity information can be used to increase reliability and to improve manufacturing processes and quality control. Finally, the probabilistic approach of PCEMCAN is beneficial in reducing the number of experiments needed, reducing (relative to the deterministic approach) the degree of conservatism in the design of a component, and making material-development and design processes more cost-effective.

This work was done by Pappu L. N. Murthy of **Glenn Research Center**, *Ashwin R. Shah of Sest, Inc., and Subodh K. Mital of the University of Toledo. 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-16653.

Automation Language for Managing Operations

This software provides a facility for capturing expertise and procedure.

NASA's Jet Propulsion Laboratory, Pasadena, California

Automation Language for Managing Operations (ALMO) is a computer program that assists a human operator at a central control station in monitoring and controlling a complex equipment system that includes multiple subsystems connected in a digital communication network. Still undergoing development, ALMO is designed specifically for automating the operations of NASA's Deep Space Network (DSN). ALMO could be modified for use as control software in other applications that involve monitoring and control; examples include assembly lines, chemical-processing plants, and environmental management systems.

ALMO assists in the automation of operations by providing a facility for expressing procedure and operators' knowledge in the form of instructions executed by software. These instructions interact with the subsystems via a transport layer.

ALMO comprises two main components: the ALMO language and the ALMO engine/interpreter. The ALMO language is an interpreted programming language that is used to write blocks in the control software of the DSN. As used here, "block" denotes a software construct equivalent to a subroutine that performs a specific function. A block contains preconditions, one or more directive(s) to subsystems, and post-conditions. A block is executed either from a command line or from a graphical user interface for a subprogram associated with a temporal-dependency network (TDN), which is a directed graph of interconnected nodes that represents an end-to-end sequence of operations. The TDN subprogram is equivalent to a main program that calls a subroutine at the appropriate time.

ALMO contributes to automation in several ways:

- It provides visibility for information about subsystems.
- It affords an extensive facility for executing logistics involved in system operations.
- The ALMO language can be characterized as a scripting language that can represent most, if not all of a human operator's actions in operation of a subsystem. ALMO retrieves monitor data and event messages and enables a block to react to them. In this respect, ALMO reduces the operator's workload, enabling the operator to monitor and control multiple subsystems, and thereby reduces the cost of operation.
- ALMO provides means to detect anomalies via subsystem monitor data, event messages, and directive responses, and alerts the operator when it detects an anomaly.
- ALMO reinforces the concept of modular programming, in that blocks are written as modules. Modules can be reused for different subsystems and in different applications; the number of blocks that must be written for a given application is thus smaller than it would otherwise have to be; the cost of maintaining the software is also correspondingly lower.
- ALMO can be used as a means for knowledge engineering and acquisition of knowledge.

This work was done by Paul Pechkam and Patricia Santos 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 Information Sciences category.*
NPO-20587

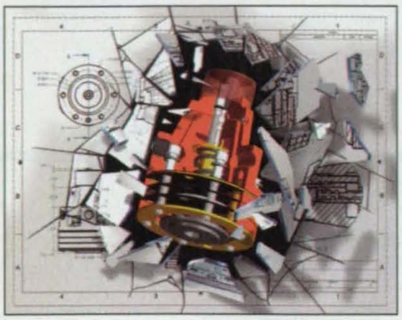
Program for Designing Multiple-Reflector Antenna Systems

NASA's Jet Propulsion Laboratory, Pasadena, California

Millimeter-Wave Optics Design Tool (MOD Tool) is a computer program for analyzing and designing multiple-reflector antenna systems that operate at microwave and millimeter wavelengths. MOD Tool is intended for use in conjunction with a computer-aided-design (CAD) program along with other specialized programs that focus, variously, on thermal, mechanical, and other aspects of design. MOD Tool is a distributed client/server application program that includes a data base of design information residing on a server computer, plus software components that perform physical-optics analyses on a variety of supercomputers. The client portion of MOD Tool includes graphical-user-interface software components that reside on a desktop computer. In addition to enabling an antenna designer to obtain computations for analysis and design of antennas, the client portion of MOD Tool serves as a data interface between (1) the antenna design and (2) the CAD and the structural and thermal designs. MOD Tool creates one standard data type for both physical optics and geometric optics and translation mechanisms for each. It can utilize parallel supercomputing to speed time-consuming physical-optics calculations. The graphical user interface relieves the antenna designer of many details, thereby simplifying the designer's task.

This program was written by Daniel Katz, Andrea Borgioli, Thomas Cwik, Chuigang Fu, William Imbriale, Vahraz Jamnejad, and Paul Springer of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Software category.*
NPO-20628

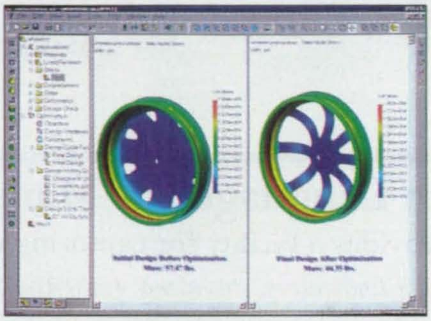
Special Coverage: CAD/CAE/PDM



Unigraphics Solutions, Huntsville, AL, has introduced Solid Edge Origin and Solid Edge Origin 3D **solid modeling software**. Solid Edge Origin is available free of charge to anyone desiring to test the productivity increases in Solid Edge. Capabilities include evaluation of basic 3D part creation, Solid Edge's drafting component, importing and exporting capabilities for 2D data, and the ability to import 2D drawings and convert them to 3D models.

At the company's web site, users can order the Solid Edge Origin CD for testing, or may purchase the Solid Edge Origin 3D program for $495. The latter program adds the capability to save 3D model drawings to disk, and provides production-ready basic part modeling and 2D drafting, enabling users to create drawings via 3D models.

For More Information Circle No. 736



COSMOS/Works™ 5.0 **design analysis and simulation software** from Structural Research & Analysis Corp., Los Angeles, CA, is embedded in SolidWorks 99 solid modeling software. COSMOS/Works analyzes assemblies with contacts and gaps, allowing designers to analyze press fits and bearing surfaces. The new version also offers fully iterative shape optimization.

A new transitional mesher, AccuStress™, provides stress accuracy results and user controls. It automatically detects small areas of geometry and places small elements at those positions, then transitions the mesh smoothly to the global size. Several manual controls allow users to apply the mesh size of their choice to edges, corners, faces, and individual components within assemblies.

For More Information Circle No. 737

SolidWorks Corp., Concord, MA, has introduced SolidWorks® 99 **3D mechanical design software** with more than 150 major enhancements and innovations in the areas of modeling, assembly design, detailing, visual communications, ease-of-use, data sharing, piping, and sheet metal. The Windows-native software generates complete, production-level engineering drawings that meet international standards.

Enhancements include SolidWorks Property Manager, a graphical user interface that enables editing of properties in drawings; AutoCAD® Command Line Emulator that recognizes frequently used AutoCAD commands; Real-Time Collision Detection that spots design problems with moving parts; and new translation tools that enable easy exchange of data with other CAD packages.

For More Information Circle No. 741

Autodesk, San Rafael, CA, offers Actrix™ Technical **diagramming software** that provides an automated drawing environment for creating schematics, electrical engineering diagrams, factory layouts, fluid power diagrams, and piping and instrumentation layouts. The program features interoperability with AutoCAD®, allowing users to import DWG files as backgrounds for space plans, layouts, and diagrams.

Features include the ability to drag and drop ActiveShapes™ objects from task-specific templates. The objects automatically snap, align, and rotate into position. A variety of objects can be drawn and edited; the objects can be completed using formatting and annotation features. Drawings may be organized by layers, and may be viewed with real-time pan and zoom capabilities.

For More Information Circle No. 738

Framework Technologies Corp., Burlington, MA, has introduced ActiveProject™ 5.0 **project management software** that allows project teams to design, publish, and manage collaborative Project Web Sites without knowledge of HTML or other web programming languages. Project members can use a standard web browser to find, review, discuss, track, and collaborate on information in real time.

Documents, CAD drawings, schedules, spreadsheets, photos, and other applications can be drag-and-drop published and maintained as part of a Project Web Site. The software integrates Microsoft's NetMeeting web conferencing technology, and contains web site templates for users to create project sites.

For More Information Circle No. 739

NuGraf® 2.2 **3D rendering and visualization software** from Okino Computer Graphics, Mississauga, ON, Canada, imports, simulates, photo-realistically renders, and translates all major 3D file formats. An intuitive graphical user interface allows objects to be selected, transformed, materials assigned, and camera and lights interactively moved to create a photo-realistic rendering.

Rendering features include fast shadow generation, automatic reflection mapping, analytic texture filtering, and color, bump, and transparency texture mapping. Data can be transferred from CAD packages such as Solid Edge, SolidWorks, AutoCAD, Pro/ENGINEER, and CADKEY as IGES, STL, or SAT files. Other features are a multi-threaded ray tracer and automatic 2D bitmap conversion.

For More Information Circle No. 740

MAP- and Laurent-AMP-Based Carrier Synchronization in GMSK

Preliminary computational simulations indicate excellent performance.

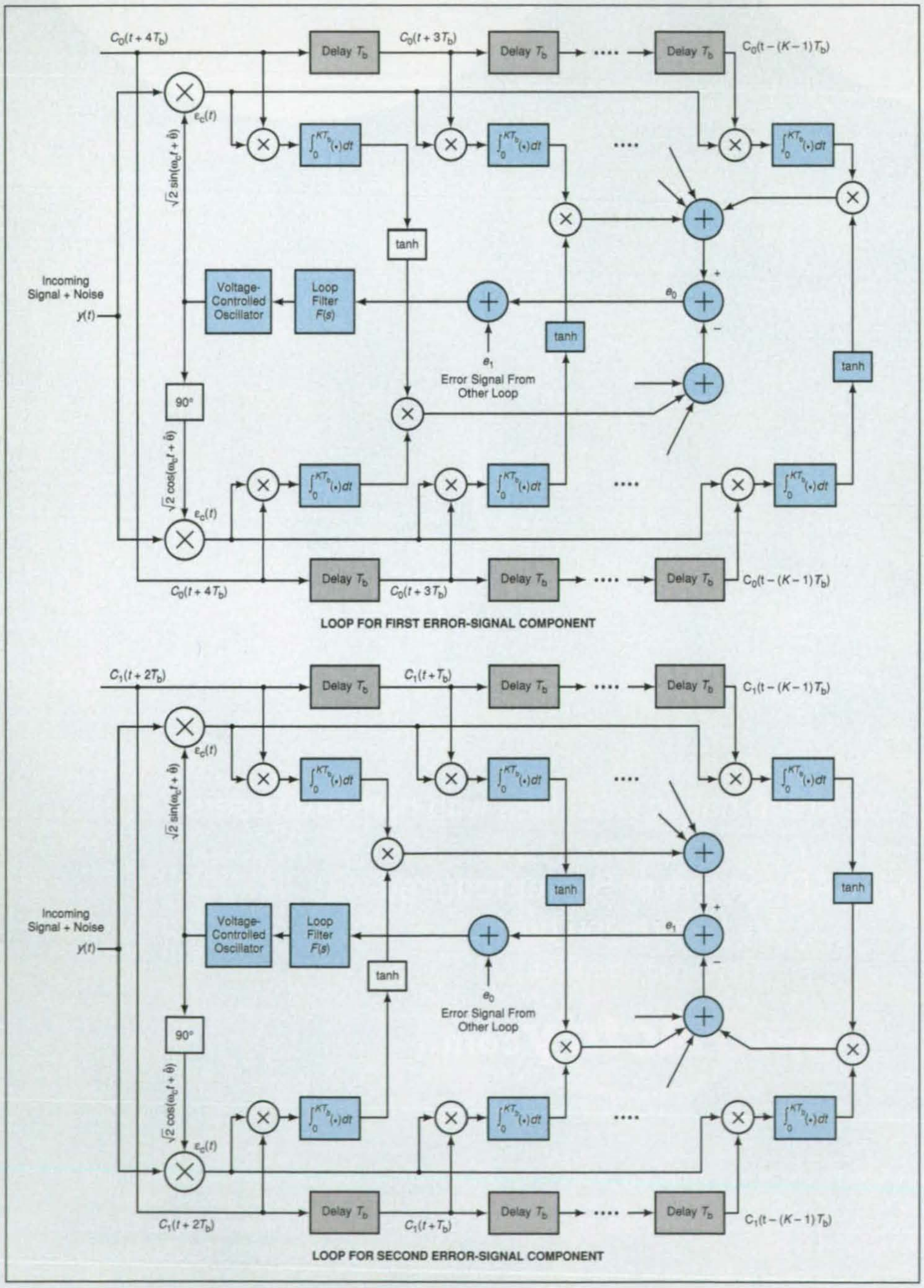
NASA's Jet Propulsion Laboratory, Pasadena, California

An improved method of closed-loop synchronization of a radio receiver with the phase of a carrier signal modulated by Gaussian minimum-shift keying (GMSK) has been proposed. Synchronization of the receiver with the phase of the carrier signal ("carrier synchronization" for short) is necessary for coherent detection of the data modulation. The method could improve the performances of digital wireless communication systems — particularly European cellular systems, wherein GMSK is the standard form of modulation but efficient means of carrier synchronization for coherent detection have thus far been lacking.

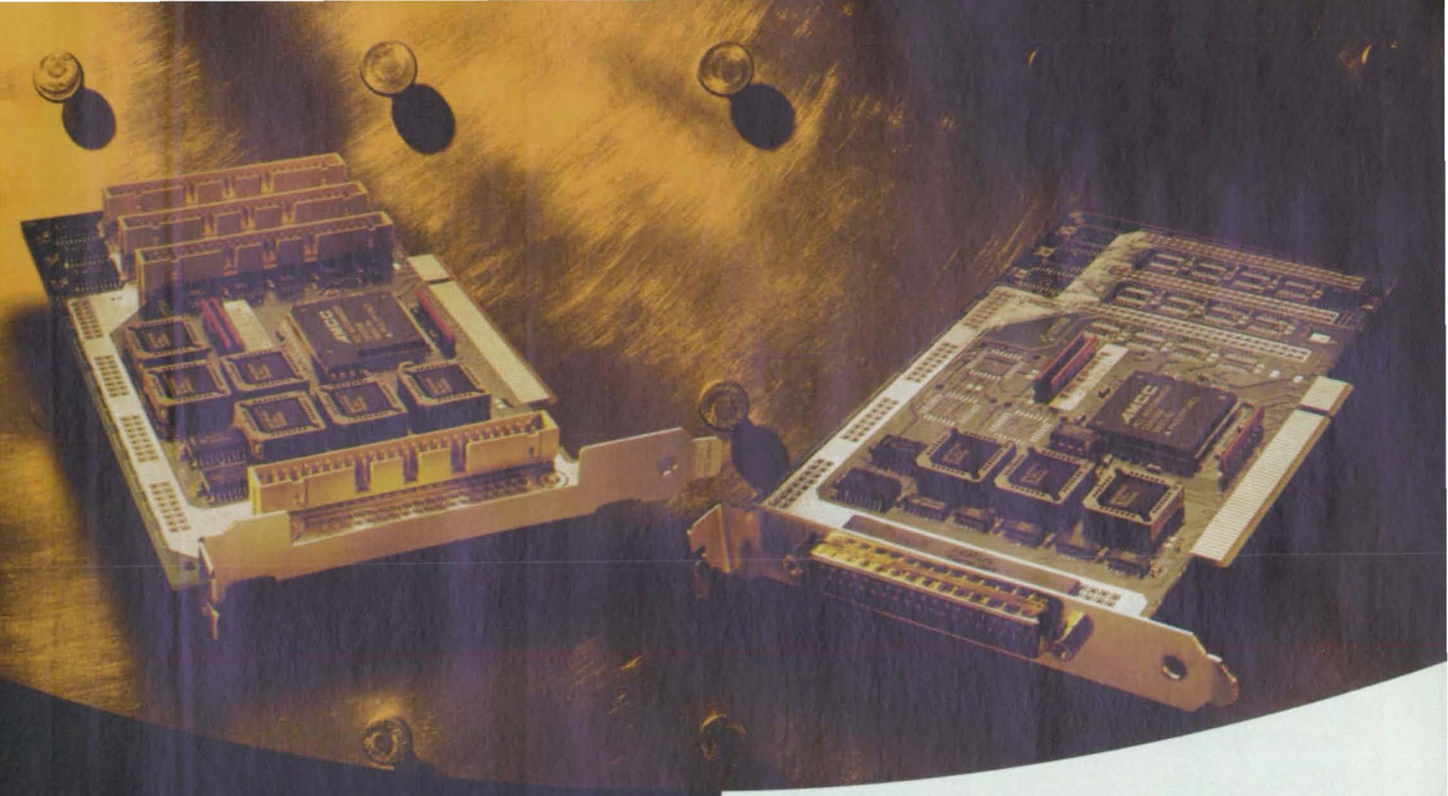
In GMSK, continuous-phase frequency-modulation pulses are used to convey digital data. The specific pulse shape is such that each pulse can last longer than one baud interval or bit period, T_b. The pulse duration is given by LT_b, where L is an integer that is typically chosen to equal 4. The overlapping of pulses when $L>1$ gives rise to additional inter-symbol interference (ISI) — beyond the ISI attributable to the memory associated with continuity of phase. In older GMSK carrier-synchronization methods, ISI is not taken into account; consequently, GMSK carrier-synchronization systems designed according to those methods perform suboptimally. In the proposed method, ISI is taken into account, making it possible to approach optimum performance.

The present method is based on a combination of (1) maximum *a posteriori* (MAP) estimation of digital modulation containing ISI and (2) the Laurent amplitude-modulation pulse (AMP) representation of continuous-phase modulation conveying digital data. In the Laurent AMP representation, a GMSK signal is described in terms of a superposition of 2^{L-1} amplitude-and-phase-modulated pulse streams, some containing pulses that extend beyond T_b. Thus, effects of ISI are included.

In the typical case of $L = 4$, the Laurent AMP representation contains 8 pulse trains. However, two of the pulse trains (for which the pulse durations are $5T_b$ and $3T_b$,



An **ISI-Compensated Closed Loop** for MAP estimation of the phase of a GMSK signal carrier would be constructed by superposing two loops, each corresponding to a component of a carrier-phase-error signal and to one of two pulse trains in an approximate AMP representation of the GMSK signal.



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• Bundled Software	DriverLINX® and TestPoint™ Drivers	DriverLINX® and TestPoint™ Drivers

For More Information Circle No. 572

respectively) contain most of the signal energy (the fraction of signal energy in the other six pulse trains is only 2.63×10^{-5}). Therefore, the signal can be approximated closely by the $5T_b$ and $3T_b$ pulse trains. This is advantageous because the design of a closed carrier-synchronization loop based on these two pulse trains only can be simpler than a design based on all eight pulse trains.

The loop design is derived from a combination of (1) the foregoing two-pulse-train representation and (2) an equation for an error signal as a function of the estimated carrier phase for the GMSK signal observed (along with noise) during a given number of baud intervals. The zero-error condition is an estimated carrier phase equal to the open-loop MAP phase estimate. One would close the loop by updating the phase estimate in the effort to null the error signal.

It turns out that the right side of the equation for the error signal as a function of the estimated carrier phase can be decomposed into two components, each corresponding to one of the two pulse streams in the approximate AMP representation. Thus, a closed-loop GMSK carrier synchronizer could be constructed as a superposition of two loops, each contributing one of the components of the error signal (see figure).

At the time of reporting the information for this article, the method had been tested in some computational simulations, with promising results; simulated carrier-phase synchronizers designed according to the proposed method exhibited excellent performance. Moreover, inasmuch as the second pulse stream contains significantly less energy than the first one does, it might be possible to reduce the complexity of the basic synchronizer design by use of a single-pulse-stream AMP representation of GMSK.

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

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

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Refer to NPO-20482, volume and number of this NASA Tech Briefs issue, *and the page number.*

Software for Real-Time Display of Data via the Internet

This program can be used easily on almost any computer connected to the Internet.

John F. Kennedy Space Center, Florida

The JGOAL collection of computer programs facilitates the real-time display, via the Internet, of multiple streams of data from the space shuttle and its ground support equipment at Kennedy Space Center. JGOAL is also readily adaptable to other applications that involve the real-time display of real or simulated data from other sources. JGOAL is so named because it is written in the Java programming language and because the data to be displayed are first processed for distribution over the Internet by a program called "PCGOAL," which runs on a server computer that receives the data streams from a common data buffer.

JGOAL was developed to overcome a limitation of PCGOAL that previously limited the availability of the data displays to a narrow class of clients: PCGOAL packages the data in such a way as to be suitable only for display on predefined screens of client computers that run the MS-DOS operating system and that are dedicated to displaying the data. JGOAL makes it possible to display the data on almost any computer connected to the Internet.

JGOAL is written in Java to take advantage of the compatibility of Java with all major modern computer hardware and operating systems, and with popular commercially available Web-browser software. This feature reduces the time and cost of development of Internet-compatible application programs, while maintaining security and portability. Java, which is an object-oriented language, supports application-program-development constructs that enable smooth mapping from requirements to implementation; this feature shortens development time further and minimizes the effort needed for maintenance.

The major costs of implementing most client/server computing systems occur at client sites. However, this is not the case in the system based on JGOAL. Because many client computers are now equipped with Web-browser software, there is no need to configure display systems and train users of JGOAL; there are no additional client-side costs for software, configuration, maintenance, or training.

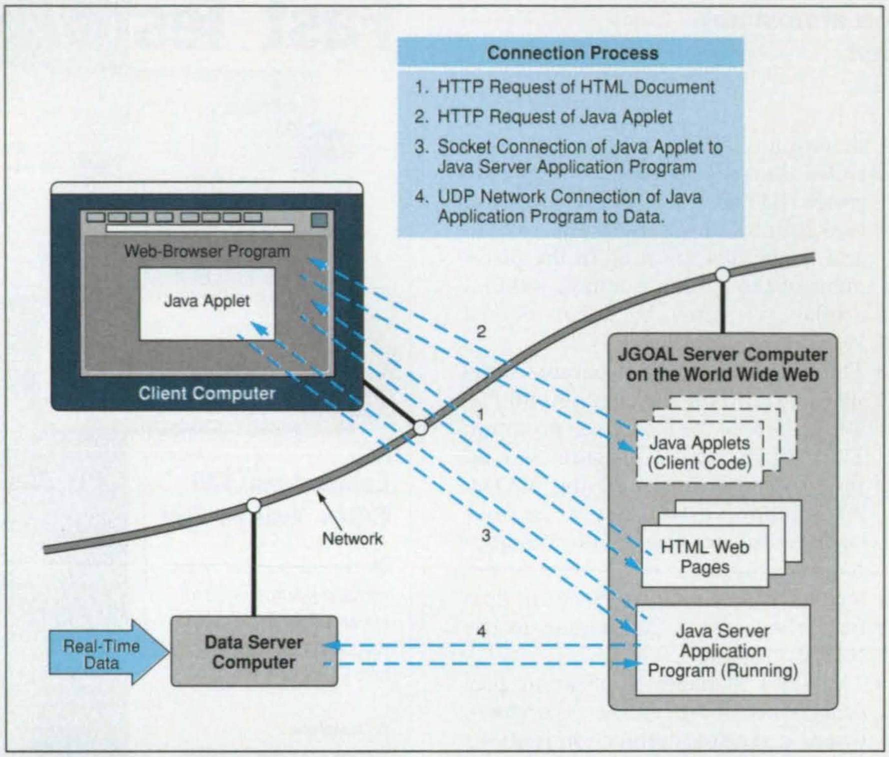
JGOAL (see figure) includes the following programs:

- The Display Translator is an application program that converts a display description (DSP) file used by PCGOAL into a Hypertext Markup Language (HTML) file and a graphical background image file. The HTML and image files are used in the placement of the data in question within a display generated by a commercial Web-browser program.
- The Display Applet program is designed to run on a client computer in a commercial Web-browser program. The Display Applet program sets up the graphical display of the JGOAL information, establishes a network connection to the Data Manager (server) application program described next, and processes the data from the network connection to the JGOAL display.
- The Data Manager application program runs on the server computer, where it receives connection requests from the Display Applet (client) program, requests data from the common data buffer (which is, essentially, another server that operates independently), and sends the requested data to the client computer.

At the time of reporting the information for this article, the development of an upgraded combination of JGOAL and PCGOAL called "JView" was under way. JView is intended to enable a user at a desktop computer running Web-browser software to connect to a data server computer, select a data stream, and activate plot-window displays. JView is expected, when fully developed, to support the entire Kennedy Space Center user community (estimated at 800 users).

The JView application program would comprise two main subsystems: one for the server and one for the clients. The JView server subsystem would be responsible for communicating with a variety of data sources, acting as an archive of information and executable computer code, delivering requested data to clients, and regulating access through user names and passwords. The JView client subsystem would comprise JView applets (Java programs that would run within Java-enabled web-browser programs). It may become necessary to make the client programs downloadable as Java application programs.

JView client programs would support users' requests to generate selected static background displays, plot desired data streams, and manage alarm, display, and plot options. Upon startup, a JView client program would establish a connection with a JView server and download the requested data stream along with initialization values and other pertinent auxiliary data. Once the client program was initialized and all current data were received, the client program would enter a "listen" mode, in which it would periodically receive data-change values from the server. The client could also request that the server computer gather historical data from another server computer. The client computer would periodically notify the server computer of its status and of any significant changes in its configuration.



A Client Computer Is Connected to a Data Server Computer in a four-step connection process.

This work was done by John M. Dockendorf, Charles H. Goodrich, Mark Long, and Steven R. Beltz formerly of I-NET, Inc.; Ryan Stansifer of Florida Institute of Technology; Kevin Gillett of Princeton University; and Will Riddle of Duke University for **Kennedy Space Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category.*

If your company is interested in the JView technology or need additional information, please contact the nonexclusive license holder Netlander, Inc., Stephanie Beever, Vice President, Florida/NASA Business Incubation Center, 1311 N. Hwy US 1, Suite 129-N, Titusville, FL 32796. Telephone: (407)383-5275, fax: (407)383-5273. KSC-11949

Analysis of Progressive Failure in Laminated Composites

The progression of damage from initial loading to final failure can be predicted.

Langley Research Center, Hampton, Virginia

A computational methodology for predicting the initiation and propagation of failures in laminated matrix/fiber composite-material structures has been developed. The methodology follows the progressive-failure approach, in which it is recognized that a laminated composite structure can develop local failures or exhibit such local damage as matrix cracks, fiber breakage, fiber/matrix debonds, and delaminations under normal operating conditions, and that such damage can contribute to the eventual failure of the structure. The ability to predict the initiation and growth of such damage is essential for predicting the performances of composite structures and developing reliable, safe designs that exploit the advantages offered by composite materials.

In this and other progressive-failure-analysis methodologies, a typical analysis involves a multistep iterative procedure in which the load on a mathematically modeled structure is increased in small steps. At each load step, a nonlinear analysis is performed until a converged solution (representing an equilibrium state) is obtained, assuming no changes in the mathematical submodels of the component materials of the structure. Then using the equilibrium state, the stresses within each lamina are determined from the nonlinear-analysis solution. These stresses are compared with allowable stresses for the affected materials and used to determine failure according to certain failure criteria.

If a failure criterion indicates failure of a lamina, then the mathematically modeled properties of the lamina are changed according to a mathematical submodel of degradation of the affected material properties. When this happens, the initial nonlinear solution no longer corresponds to an equilibrium state, and it becomes necessary to reestablish equilibrium, using the modified lamina properties for the failed lamina while maintaining the current load level. This iterative process of obtaining nonlinear equilibrium solutions each time a local material submodel is changed is continued until no additional lamina failures are detected. However, in this progressive failure methodology, small load step sizes were used instead of the iterative process of obtaining equilibrium solutions to minimize the effect of not establishing equilibrium at the same load level. The load step is then incremented and the foregoing analysis repeated until catastrophic failure of the structure is detected.

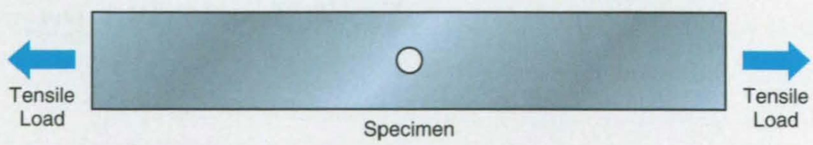
The present progressive-failure-analysis methodology includes the use of C^1 (slope-continuous) shell finite elements from classical lamination theory for calculation of in-plane stresses. The failure criteria used in this methodology include the maximum-strain criterion, Hashin's criterion (a stress-based criterion that predicts failures in tensile and compressive fiber and matrix modes), and Christensen's criterion (a strain-based criterion that distinguishes between fiber failures and fiber/matrix-interaction failures). The material-degradation model used in this methodology includes several options; the best option in each case depends on the choice of failure criterion and on the nature of the composite material (e.g., unidirectional composite vs. fabric composite).

The methodology is implemented by computer code that has been incorporated into the Computational Mechanics Testbed (COMET) program, which is a general-purpose finite-element-analysis program. As thus augmented, COMET can predict the damage and response of a laminated composite structures from initial loading to final failure.

The methodology and its various failure criteria and material-degradation submodels were compared and assessed by performing analyses of several laminated composite structures. The results from these computations were found to be well correlated with available test data (see figure), except in structures in which interlaminar stresses are suspected of being large enough to cause certain failure mechanisms (such as debonding or delaminations) that are not modeled in this methodology.

This work was done by David W. Sleight of **Langley Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Materials category.*

L-17660



Failure Criterion	First Ply Failure Load, lb.	Final Failure Load, lb.	Dominant Failure Mode
Hashin's Criterion	1,520	3,212	Matrix Tension
Christensen's Criterion	1,520	3,261	Fiber/Matrix Interaction
Experimental Results	Unavailable	3,523	Unavailable

The **Final Failure Load** of a tension-loaded 20-ply laminate plate as computed by two variants of the present methodology, is compared with the experimentally determined value.

Mixed-Carbon Anodes for Improved Li-Ion Cells

A small amount of carbon black increases retention of charge capacity.

NASA's Jet Propulsion Laboratory, Pasadena, California

Rechargeable lithium-ion electrochemical cells that contain anodes made from a mixture of graphite and carbon black have been found to perform better than do similar cells that contain anodes made of graphite alone. As explained in more detail below, the addition of carbon black improves performance by increasing effective electrical conductivity.

Typically, the anodes in state-of-the-art lithium-ion cells are made of amorphous carbon (coke) or graphite. Heretofore, these forms of carbon have been considered to have excellent electrical conductivity; therefore, until now, no attempt was made to incorporate carbon black or other conductive diluents into the anodes. Now, however, it has been observed that when a carbon black (more specifically, Shawanigan black) is incorporated into graphite electrodes, cycle-life performance is significantly improved.

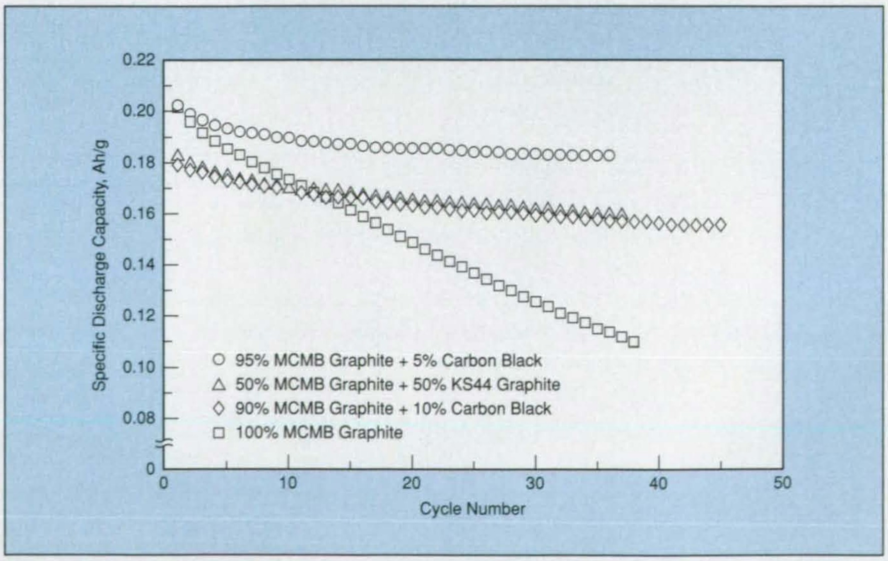
Four lithium-ion cells were fabricated for experiments to determine the effects of incorporating carbon black into graphite anodes. In each cell, the cathode was made of $LiCoO_2$ and the electrolyte was made of a 1.0 M solution of $LiPF_6$ in a solvent that consisted of equal volume parts of ethylene carbonate (EC), diethyl carbonate (DEC), and dimethyl carbonate (DMC). The anodes of the four cells had the following compositions:

1. A commercial graphite (10-28 MCMB);
2. A mixture of 95 weight percent 10-28 MCMB and 5 weight percent carbon black;
3. A mixture of 90 weight percent 10-28 MCMB and 10 weight percent carbon black; and
4. A mixture of 50 weight percent 10-28 MCMB and 50 weight percent of another commercial graphite (KS-44).

In cyclic charge/discharge measurements, all three cells containing mixed-carbon anodes (cells 2, 3, and 4) retained greater proportions of their initial discharge capacities than did the cell containing the single-carbon anode (cell 1). Moreover, at about 15 cycles, the absolute discharge capacity of the single-carbon cell fell significantly below that of all three mixed-carbon cells (see figure).

The tentative explanation for some of these experimental results is the following:

- The carbon black particles are significantly smaller than those of 10-28 MCMB. Therefore, in the 10-28 MCMB/carbon-black electrodes, the carbon black particles are conjectured to occupy the voids between the larger 10-28 MCMB particles. In so doing, the carbon black particles increase the effective electrical conductivity of the anode by contributing to overall electrical contact among the anode particles throughout the anode.
- The 10-28 MCMB and KS-44 graphites have different particle sizes; consequently, electrical contact and electri-



Specific Discharge Capacities of four cells were measured in cyclic charging at a current of 30 mA and discharging at a current of 60 mA.

cal conductivity in the mixed-graphite anode are increased in the same manner as in the 10-28 MCMB/carbon-black electrodes.

While carbon black contributes to electrical conductivity, it also irreversibly consumes some lithium and thereby contributes to a partial irreversible loss of capacity. Apparently, the 5-weight-percent carbon black content provided sufficient electrical contact for increased retention of capacity while contributing little irreversible loss during initial charging. The anode containing 10 weight percent of carbon black exhibited approximately the same retention of capacity, but the initial irreversible loss was considerably greater than in the anode containing 5 weight percent of carbon black. From these observations, one can conclude that 5 weight percent is the optimum amount of carbon black.

This work was done by Chen-Kuo Huang and Jeffrey Sakamoto 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 Materials category.*
NPO-20603

Electrodialysis To Remove Ammonium Ions From Wastewater

A simple treatment removes most of the ammonium content.

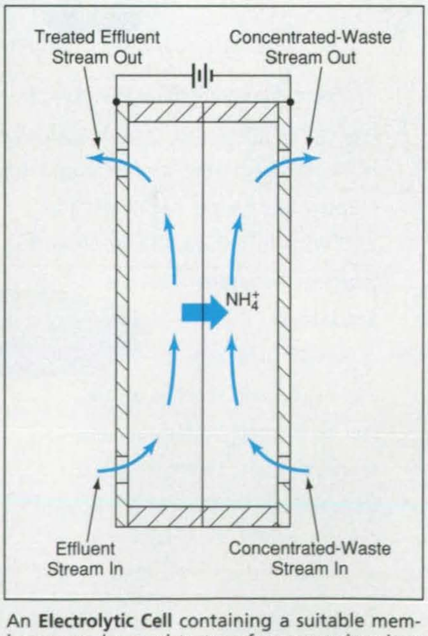
Lyndon B. Johnson Space Center, Houston, Texas

Electrodialysis has been shown to be an effective means for removing ammonium ions from wastewater without use of consumable chemicals and without adding other substances to the treated water. Provided that continuing efforts to develop efficient electrodialysis equipment prove successful, it should be possible to apply this treatment principle to wastewater streams to be recycled in life-support systems for spacecraft and other closed habitats. Effluents from some industrial processes that generate high concentration of ammonium ions may also be treatable by this principle.

In electrodialysis (see figure), an electric potential is applied across a membrane that is selectively permeable by the ions of interest — in this case, ammonium (NH_4^+). Typically, a membrane suitable for this purpose comprises a polymer matrix, within which ionophores are immobilized. Membranes based on perfluorosulfonic acid and membranes in which nonactin serves as the ionophore have been found to function efficiently as selective transporters of ammonium ions from effluent to concentrated-waste streams.

In an experiment, electrodialysis in an electrolytic cell containing such a membrane reduced the ammonium concentration of a simulated effluent stream from 290 to 2 parts per million. The rate of flow of the stream was 1.152 liters/day. The area of the membrane was 10 cm^2. With a potential of 10 V applied, the electric-current density in the cell was 2 mA/cm^2. With these parameters, the specific energy consumption amounted to 1.5×10^4 joules per liter of treated water. Because the minimum ammonium concentration was still above the maximum allowable (0.5 parts per million) for potability in a life-support system, further effort would be necessary to develop a practical electrodialysis unit for incorporation into such a system.

This work was done by Ella F. Spiegel of Eltron Research, Inc., for **Johnson Space Center.** *No further documentation is available.*
MSC-22818



An **Electrolytic Cell** containing a suitable membrane can be used to transfer ammonium ions from one stream to another.

September 1999

PHOTONICS Tech Briefs

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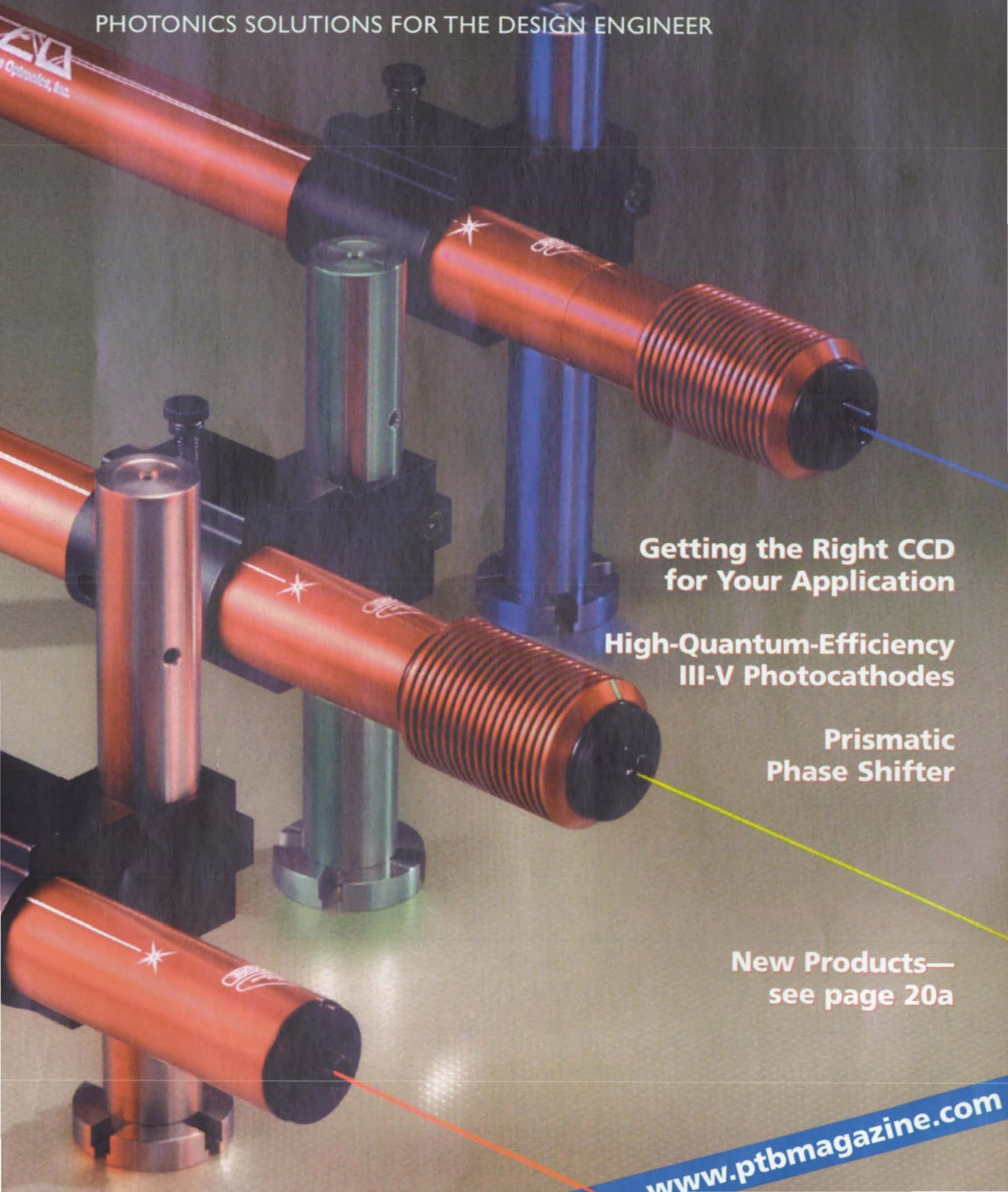

Getting the Right CCD for Your Application

High-Quantum-Efficiency III-V Photocathodes

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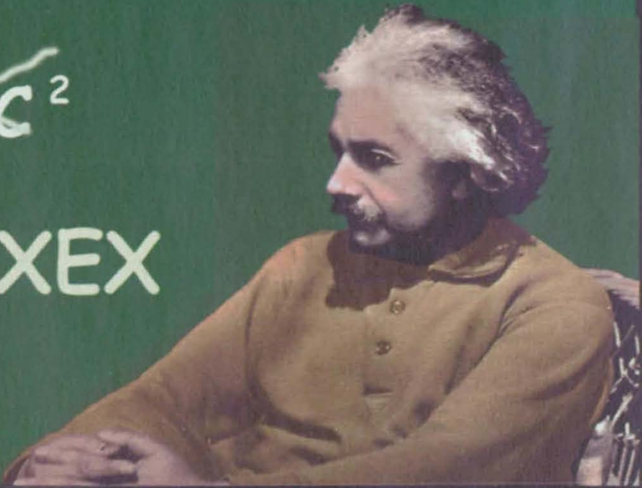

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Supplement to *NASA Tech Briefs'* September 1999 Issue
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Cover photo courtesy Cutting Edge Optronics Inc. See "New Products," page 20a.

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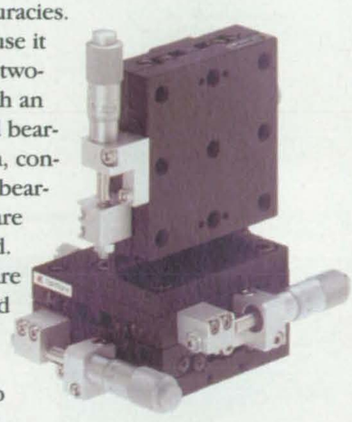

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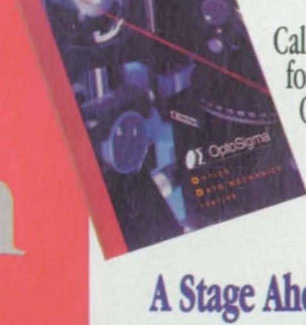

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Getting the Right CCD

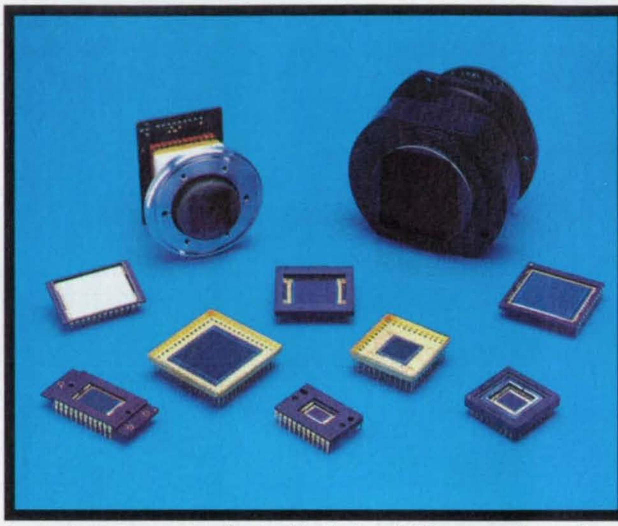
Though charge-coupled devices represent a mature technology, as with all things technical the user must understand the criteria to make the right choice.

Recent innovations in the processing and design of charge-coupled devices (CCDs) have allowed some price-performance barriers to be knocked down. A review of the technology and selection criteria for these scientific imagers is timely.

Selection of the right CCD requires a close look at electrical performance. Several parameters, such as those on the selection chart on page 12a, should be considered. Though this list is not exhaustive, it is representative of the variety of devices available. The values of some of these parameters have been measured under differing conditions: *e.g.*, RMS noise for the FT18 was measured at 25 frames per second read rate, while for the SI502 it was measured at 0.2 frames per second.

The process of reading the information from a CCD is subject to a limit on noise performance called readout noise. Because pixels are read sequentially, the reading of a new pixel requires clearing the charge from the one that precedes it. This reset operation never quite goes the same each time, so there is a small but still significant uncertainty. Generally CCDs designed to optimize noise performance will have noise floors on the order of 5 electrons (e-), while others designed with speed of readout in mind may have higher noise floors, from 15 to 35 e-. Applications requiring the utmost sensitivity would require these lower-noise devices. The drawback to them is that they must be read out relatively slowly, and this may make them unsuitable for applications requiring high temporal resolution.

High frame rates require high-speed readout, but speed can come with a heavy penalty: higher read noise. A tradeoff between speed and noise may be required in the selection process. CCDs designed for very low-noise operation are among the slowest offered. To circumvent this limitation some are available with multiple outputs, allowing readout of the image information through parallel identical read electronics. This multiplies more than just the read rate, however: the price tag for the system can get multiplied quickly. But it is possible to compromise a bit and still get good performance at a good price. For example, the Orbis 2 from SpectraSource can accommodate CCDs with 1, 2, or 4 outputs, allowing a device with fine noise performance to operate at effective read rates much higher than possible using a single-output design.



SpectraSource cameras offer a wide choice of CCD sensors for optimum performance in a variety of applications.

On the other hand, if speed is the overriding consideration, there is a good selection of relatively fast CCDs available. Devices from several manufacturers have 1000 × 1000 resolution and read rates high enough to support 25 or even 30 frames per second. At these rates mechanical shutters are impractical, since few available can even achieve these rates, and those that do have short lifetimes. For example, a shutter with a lifetime of 1 million operations will last only about nine hours at 30 frames per second.

Dark current is a source of signal inside the silicon of the CCD that is time- and temperature-dependent. Two factors should be considered. One of them is the dark current rate, usually measured in electrons per pixel per second, and the other is the shot noise inside the dark current signal (see Figure 1).

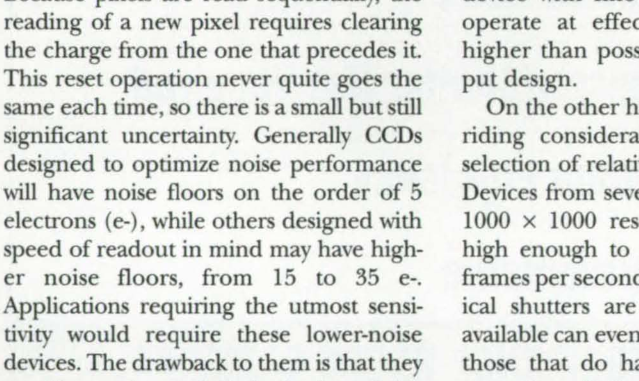


Figure 1. The shot noise component of dark current.

The dark current is sometimes incorrectly considered to be noise, but since the signal part is repeatable, it can be subtracted from image data. If not subtracted, it does add its own perhaps noisy-looking contribution to the image, but almost all of this disappears when a dark field subtraction is performed on the image. If integration time is long enough, it is possible for this signal alone to saturate pixels, so for low-flux applications this is an important parameter.

Within this signal there is noise in the form of shot noise (as there is in the photon signal we want to measure). The noise inside this signal is random and therefore does not repeat. So it cannot be subtracted away, rendering a perfect image. But its influence on image quality is not great, because the shot noise varies by the square root of the signal.

Figure 2 shows the performance of a SpectraSource Teleris 2 CCD camera equipped with the Kodak KAF0401E CCD. With a Peltier thermoelectric cooler, this system has excellent dark current performance, operating at a temperature that results in it having a dark-current rate of about 0.5 electron per second per pixel. The noise floor of this camera is plotted at a time-independent 13 electrons RMS, typical for these systems. Note that the signal shoots off the graph very quickly, but this would be subtracted from the image data anyway. The important thing to note is the point of the crossover between the shot noise in the dark signal and the read noise of the CCD. The length of time required for this to occur could be considered a figure of merit for the CCD camera, which tells us how long an integration time is possible before the shot noise dominates over the read noise

of the camera. The longer this takes, the better the camera. For the Teleris with a Kodak KAF0401E, this time is more than 300 seconds.

Another consideration is full-well capacity, a measure of the maximum signal that a pixel can hold. While the value for full well is highly dependent on a number of factors, the general rule of thumb is the bigger the pixel the bigger the full well. Applications requiring wide dynamic range or the best signal-to-noise ratio possible in high-illumination settings would tend to need CCDs with the highest possible full-well capacity.

Checking Design Features

CCD technologies have evolved into three main design types that address quantum efficiency (QE), the ratio of incident photons to detected photoelectrons. These are:

Front illuminated: the standard method of CCD fabrication. Photons enter the silicon by passing through the transparent overlying layers of the integrated-circuit elements from the front of the device. The advantages are low cost and good selection. The disadvantages are low quantum efficiency—at best 30 or 35 percent peak, and low blue and no near-ultraviolet (NUV) response.

Enhanced front illuminated: included are the Texas Instruments Virtual Phase and Kodak Blue Plus processes (see Figure 2). By enhancing the geometries and materials used in the normal front-process CCDs, some of the losses of front illumination can be reduced, thereby increasing the peak quantum efficiencies to as high as 75 percent, and extending response into the near-UV. This technology represents the best price-vs.-performance tradeoff for the types discussed here. Advantages are low cost, though not so low as standard front-illuminated, and improved quantum efficiency. A disadvantage is that selection is limited.

Back illuminated: By building the CCD as in the standard process, but turning the device over and allowing the incident radiation to enter from the rear side, the losses incurred in a front-illuminated CCD are greatly reduced. The advantage is high quantum efficiency — some manufacturers report it as high as 90 percent. The disadvantages are higher cost and poorer selection.

Some manufacturers offer special coatings to enhance spectral response of CCDs. The two common coating types are:

Antireflection coatings: AR coatings reduce losses at surfaces and in thin layers, thereby increasing quantum efficiency. These coatings can be "tuned" or optimized for certain wavelength ranges, enhancing the visible or NUV response as desired. For example, see the curves for the SITe CCDs in Figure 2.

Fluorescence: These coatings, commonly known as lumogen and used only with front-illuminated devices, enhance response only in the short-wavelength part of spectrum. They do this by taking radiation at a wavelength that the CCD is not sensitive to and converting it to a longer wavelength that the CCD is sensitive to. The response is extended into the shorter wavelengths, but the improvement amounts only to about 10-15 percent. For example, see the curves for the Kodak CCDs in Figure 2.

Some CCDs are made with features that reduce blooming. This is the reaction of a CCD to very bright illumination, where vertical spikes of white "bloom" from bright points in the image. Blooming occurs when a pixel or pixels are overfilled, beyond their full-well capacity, usually by several times. Antibloom reduces this effect considerably, sometimes to many thousands of times full-well signal, but with a price: loss of linearity in response, or a reduction in active area in a pixel, known as fill factor (see below).

There are several different methods of controlling the duration of exposure or integration time. These are:

Interline transfer: CCDs designed for video applications use this technology almost exclusively. The good thing about these devices is that they can be "shuttered" very quickly, in the microsecond time regime or faster. This makes them extremely powerful sensors for comparative measurements where two events are separated by only a tiny slice of time, or where very short exposures are required. The drawbacks to this technology are that it has less than 100-percent fill factor, reducing quantum efficiency and introducing potentially negative optical effects. Fill factors are generally about 70 percent, and QE can be down around 15-20 percent. Kodak and Sony supply several devices in this category.

Frame transfer: This type of CCD is a cross between an interline device and a full-frame device (see below). It has the interline CCD's ability to electronically shutter, but has the full-frame's fill factor and QE. The electronic shuttering is not as fast as the interline device's, since it requires a complete vertical clock cycle for every line the imager has in the Y direction. This means that a 512-×-512-pixel device needs 512 vertical clocks to completely shutter for a full image exposure. Since the shuttering is accomplished by transporting an image into a storage area, there is a possibility that significant signal will fall on the image while it is moving into the storage area, resulting in smear. Because the image and storage areas

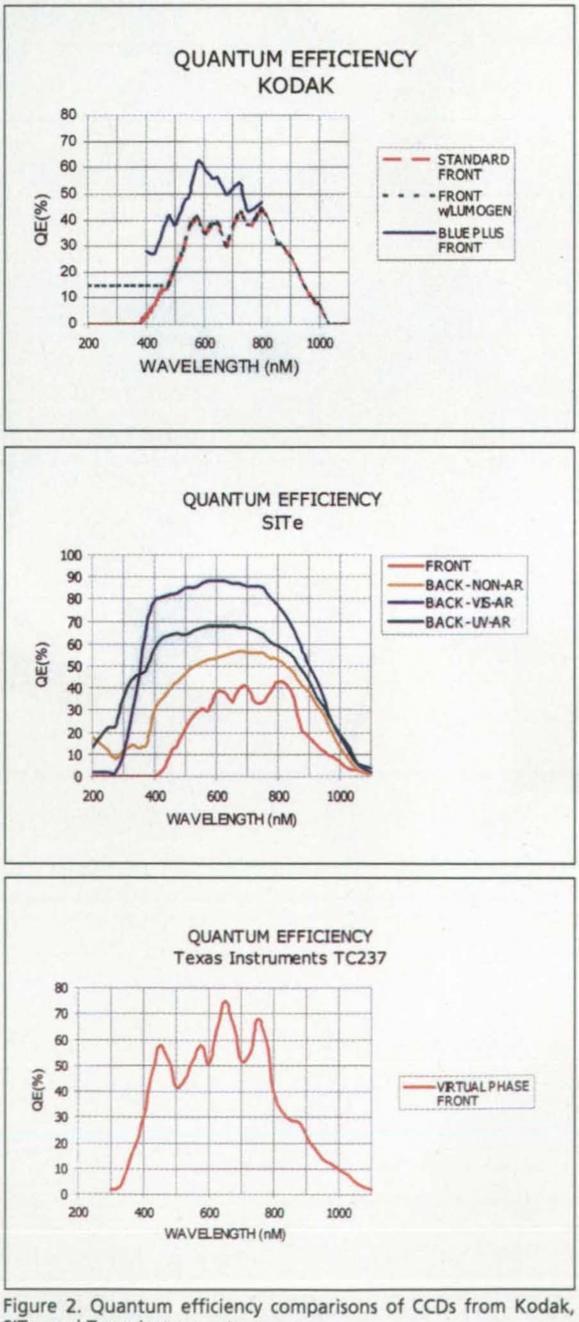


Figure 2. Quantum efficiency comparisons of CCDs from Kodak, SITe, and Texas Instruments.

are controlled separately, some interesting control methods can be used to achieve high frame rates along with low noise. Pipelining subarray images through the storage area can result in rates of 200 per second or higher, while holding the noise floor down to 10 e- RMS, making possible applications in adaptive optics or similar areas. Manufacturers that supply these types of devices are Texas Instruments, Thomson CSF, and Philips, among others.

Full-frame: This technology has no intrinsic shuttering features, which means that unless some means are used to block the incident flux, photons will fall on the image area during the entire readout period. This usually results in unacceptable levels of smear, and so necessitates the use of an electromechanical shutter. Since no features of the architecture are used for exposure control, these devices have high QE and fill factor. They are also less expensive than their frame-transfer equivalent, since there is no doubling of the number of pixels for the storage array. Many manufacturers offer full-frame CCDs, among them Kodak, Texas Instruments, Thomson CSF, Philips, EEV, EG&G, and others.

Optical Considerations

Among optical considerations is fill factor, the ratio of the actual collecting area of a pixel to its overall geometric area. Though at first it might seem that these would be equal, some technologies such as the interline transfer CCD reduce this ratio from unity. Typically, fill factors of 70 percent are about the best currently available with interline CCDs. Besides the loss of efficiency, reduced fill factor causes other deleterious effects: aliasing of spatial frequencies and reduction of contrast at high spatial frequencies are typical problems.

Antibloom features can also reduce fill factor. Typically, CCDs with antibloom will use a drain electrode that must be positioned next to each pixel to sweep off the excess charge created by high illumination levels. This drain blocks or reflects light, and hence lessens fill factor. Some specialized processes, such as that used by Texas Instruments, eliminate or greatly reduce these losses through the use of transparent materials for the overflow drain, so that not all CCDs with antibloom will suffer from reduced fill factor.

The answer to the question of what pixel size is right depends on several things unique to an application. The primary consideration is usually spatial resolution, but to select a pixel size several things need to be nailed down. In determining the required spatial resolution, the user should be mindful of the deleterious effects of too large a pixel (spatial resolution too low), such as aliasing, reduced modulation transfer function (MTF), etc. It is better to err on the small side.

If the focal length of the optics to be used can be adjusted as required, then selecting based on pixel size is easier. A 12-μm pixel used with a 100-mm focal length achieves the same spatial resolution as a 24-μm pixel and a 200-mm focal length, but at a lower cost, since bigger pixels usually implies higher prices.

If the optical configuration is fixed, however, then the pixel size must be adjusted to achieve the target resolution. This may or may not result in a practical solution. If, when all is considered, a 3-μm pixel is needed, there will be a very small list of potential devices to choose from. Conversely, if a 50-μm pixel is needed, there are few devices so big. But in this case, a technique known as binning can synthesize big pixels from small. The camera selected must support binned operation for this to be possible, so the camera specs should be checked.

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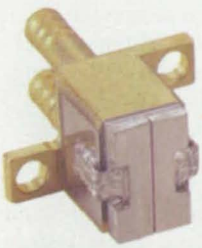

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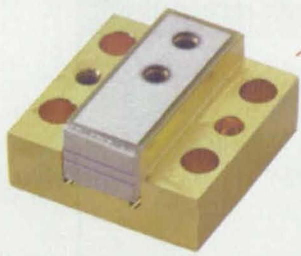

Shown with 40 Watt laser bar.

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Shown with 20 Watt laser bar.

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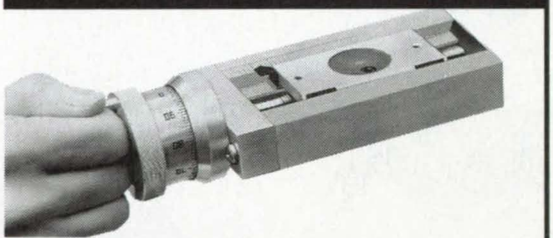
Table 1. CCD Comparison Chart

CCD	FORMAT	PIXEL SIZE (sq.)	ARRAY SIZE (mm)	DYNAMIC RANGE	RMS NOISE	DARK CURRENT
KAF0261	512 × 512	20 × 20	10.2 × 10.2	15-16 bits	<15 e-	<0.5e-/p/s
KAF0401	768 × 512	9 × 9	6.9 × 4.6	13-14 bits	<15 e-	<0.15e-/p/s
KAF1001	1024 × 1024	24 × 24	24.6 × 24.6	15-16 bits	<15 e-	<1.5 e-/p/s
KAF1302	1280 × 1024	16 × 16	20.5 × 16.4	13-14 bits	<15 e-	<1.0 e-/p/s
KAF 1401	1317 × 1035	6.8 × 6.8	8.98 × 7.04	11-12 bits	<15 e-	<0.5 e-/p/s
KAF 1602	1526 × 1024	9 × 9	13.8 × 9.2	13-14 bits	<15 e-	<0.15 e-/p/s
KAF 4202	2032 × 2044	9 × 9	18.4 × 18.4	12-13 bits	<15 e-	<0.5 e-/p/s
KAF6303	3072 × 2048	9 × 9	27.6 × 18.5	12-13 bits	<15 e-	<0.5 e-/p/s
KAF 16801	4096 × 4096	9 × 9	36.8 × 36.8	12-13 bits	<15 e-	<0.5 e-/p/s
SI502	512 × 512	24 × 24	12.3 × 12.3	15-16 bits	<10 e-	<2 e-/p/s
SI003	1024 × 1024	24 × 24	24.6 × 24.6	15-16 bits	<10 e-	<2 e-/p/s
70X0-0908	532 × 256	24 × 24	12.3 × 6.2	14-15 bits	<10 e-	<2 e-/p/s
70X-1008	1024 × 256	24 × 24	24.6 × 6.2	14-15 bits	<10 e-	<2 e-/p/s
THX7899	2048 × 2048	14 × 14	28.7 × 28.7	15-16 bits	<10 e-	<2 e-/p/s
TC281	1000 × 1000	8 × 8	8 × 8	10-11 bits	<25 e-	<1.5 e-/p/s
TC237	680 × 500	7.4 × 7.4	5.0 × 3.7	12-13 bits	<25 e-	<1.5 e-/p/s
TC255	336 × 244	10 × 10	3.4 × 2.5	11-12 bits	<25 e-	<1.5 e-/p/s
TC211	204 × 165	13.75 × 16	5.0 × 3.7	12-13 bits	<25 e-	<1.5 e-/p/s
FT18	1024 × 1024	7.5 × 7.5	7.7 × 7.7	11-12 bits	<20 e-	<1.5 e-/p/s

One the required spatial resolution has been determined, the array size can be calculated. This is pretty straightforward: it is simply the ratio of the linear dimension of the image area and the pixel size. For example, if the pixel size is 10 μm, and an area of 5 mm × 5 mm must be imaged, then a 512-×-512-pixel array would be fine. Budget may determine the choice of array size, since big pixels can have big price tags. The biggest CCDs can be as large as 4000 × 4000 pixels.



A Variety of Applications

SpectraSource Instruments (SSI) has supplied thousands of camera to researchers, scientists, and engineers for diverse application environments around the world. Below are listed some general application areas, along with recommended camera and CCD configurations.

Radiography: Medical and industrial radiographic applications will have differing requirements that affect the selection process. In this digital form of x-ray imaging, for some systems lens-coupling the camera to the phosphor output will be adequate, but in other applications fiber optic coupling is needed to insure the highest coupling efficiency. SSI supplies either using many different CCDs on either the Teleris or Orbis platforms.

Biomedical: Frequently the application in biomedical imaging involves low flux conditions, as in green fluorescent protein or fluorescent in-situ hybridization fluorescence imaging, so low noise and low dark current are of importance. Also, these applications are often microscope-based imaging, so in these areas a smaller pixel size can be an advantage.

Spectroscopy: Often as in Raman applications, high quantum efficiency and low dark current are of primary concern, since flux rates can be extremely low. In this case, back-illuminated CCDs or those with newer enhanced front-illuminated technologies like Kodak's Blue Plus and Texas Instruments' Virtual Phase CCDs would be the sensors of choice, because of their high quantum efficiencies. Special CCDs optimized for spectroscopy, such as rectangular arrays, are available in back-illuminated configurations. Supercooled dewar systems using LN_2 can be configured for the CCD of choice, insuring extremely low noise levels even in the long-duration integrations commonly required in this field.

Astronomy: This can be a challenging arena, both in the selection process as well as in the performance of the camera system. For deep sky work, LN_2 systems with low noise and high quantum efficiency are the systems of choice, while in planetary imaging a simpler, less expensive Peltier thermoelectrically cooled system could be used.

For more information contact Stephen B. McArthur, president of SpectraSource Instruments, 31324 Via Colinas, Ste. 114, Westlake Village, CA 91362; (818) 707-2655; fax: (818) 707-9035; E-mail: spectrasrc@earthlink.com; www.spectrasource.com.

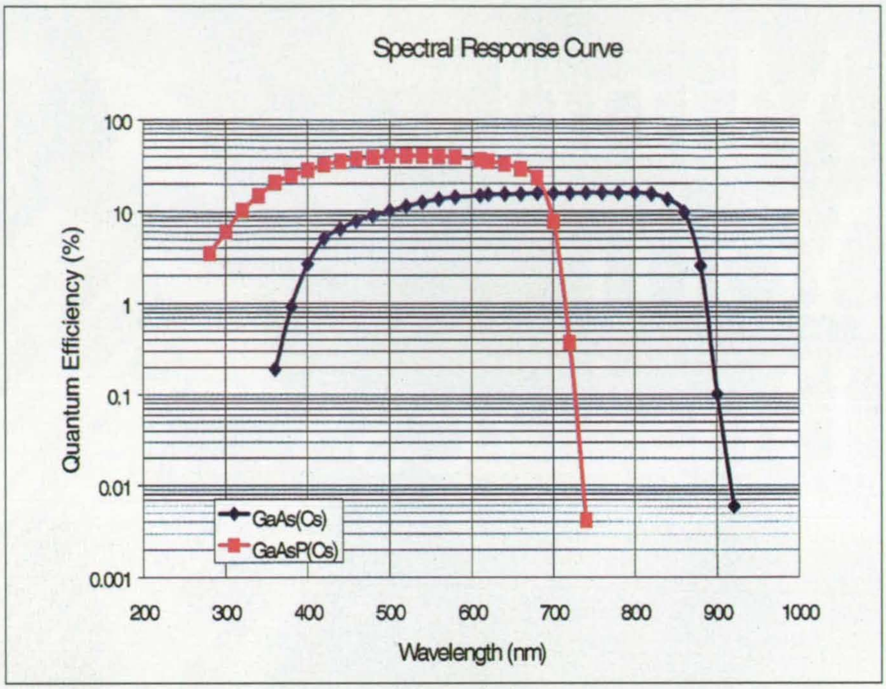
High-Quantum-Efficiency Photocathode for Photomultiplier Tubes

III-V semiconductor photocathodes offer high quantum efficiency and low dark noise for applications requiring the detection of very weak light signals.

Hamamatsu Photonics, Electron Tube Center, Hamamatsu, Japan

Photomultiplier tubes (PMTs) have long been recognized as the detector of choice for very weak light detection. The high gain of the PMT, in excess of 10×10^6, makes it a useful detector for applications such as LIDAR, bioluminescence, fluorescence, and chemiluminescence. However, a requirement for higher sensitivity has always existed within the detector community. Now Hamamatsu scientists have incorporated III-V semiconductor photocathodes of GaAsP(Cs) and GaAs(Cs) offering high quantum efficiency and low dark noise for applications requiring the detection of very weak light signals with high signal-to-noise ratios.

Conventional PMTs typically have quantum efficiencies (the ratio of detected electrons to incident photons expressed as a percentage) in the vicinity of 20 percent in the visible light range to a few percent in the red and near-infrared. GaAsP(Cs) and GaAs(Cs) semitransparent photocath-



Spectral Response Curves for III-V compound photocathodes.

odes have been used in other devices, such as image intensifiers, and the Electron Tube Center felt that incorporating them into PMTs would represent a significant improvement in the performance. Photomultiplier tubes employing these cathodes have quantum efficiencies in the visible of up to 50 percent and over 15 percent in the near infrared.

Photocathodes work by the process called the photoelectric effect, described by Einstein in the early part of the century:

$$E = \frac{hc}{\lambda} - E_b$$

where E = energy imparted to the electron, h = Planck's constant, c = the speed of light, λ = wavelength of light, and E_b = binding energy of the electron to the atom.

When a photon enters the photocathode material and the energy (hc/λ) of the photon exceeds the binding energy of the electron, the latter will be excited from the valence band to the conduction band of the photocathode. The electron must then be emitted from the photocathode into the vacuum of the PMT. In conventional photocathodes, the process of emission is hampered by a characteristic known as electron affinity (E_A), which represents an energy barrier to the vacuum level. Therefore, to excite an electron into the vacuum, the incident photon must have an energy of $E_b + E_A$. The advantage of III-V photocathodes over conventional cathodes is that it is possible to produce materials with negative electron affinity, when they are properly activated with cesium. With negative electron affinity materials, the barrier to the vacuum is completely removed. In fact, the negative electron affinity actually improves the probability that the electron will escape to the vacuum.

In the past, III-V compound cathodes were available for PMTs only in a reflective mode, when the electron is emitted from the same side of the cathode on which light is incident. This configuration makes electron collection difficult, resulting in reflective-mode PMTs that are large and bulky. The latest III-V compound cathodes use transmission-mode photocathodes. In this configuration, the electron is emitted from the side opposite to the light input, allowing the production of a very compact PMT. This compactness makes for very small cooled photon-counting PMT modules. *Continued*

In photon counting, a photon enters the tube and is converted to an electron that is amplified by the tube's gain. The result is a pulse with a specific amplitude. All pulses coming from the tube with this amplitude are counted as photons. The photocathode can also, however, emit "dark pulses" because of thermionic emission from the photocathode. The number of dark pulses depends on the E_b of the photocathode. The GaAsP(Cs) has about 5,000 per second, while the GaAs(Cs) has about 15,000 per second at room temperature. Therefore, for most applications, cooling is required to reduce these dark pulses. The dark counts are then reduced to 80 per second for GaAsP(Cs) and 100 for GaAs(Cs) at 0 °C.

The limiting factor in using these PMTs in all current applications is the maximum allowable photocathode current of 2 picoamps. To get long operating life from the tubes, it is prudent to use them only for photon counting or very weak analog signal detection.

Future improvements will include increasing the sensitivity, further reducing the dark pulses, and increasing the maximum photocathode current. The Hamamatsu Electron Tube Center is constantly working to raise photomultiplier technology. The incorporation of III-V compound photocathodes into very compact PMTs is a significant step forward.

This work was done at the **Hamamatsu Photonics Electron Tube Center.** *For further information, contact Hamamatsu at 800-524-0504 or visit usa.hamamatsu.com. The author of this brief is Earl Hergert, Hamamatsu engineer.*

Hybrid Imaging Technology

Devices are made from CCD and CMOS components, which can be independently optimized.

NASA's Jet Propulsion Laboratory, Pasadena, California

"Hybrid imaging technology" (HIT) is the name of a discipline in which the advancement of electronic image sensors is pursued via hybridization of charge-coupled-device (CCD) and complementary metal oxide/semiconductor (CMOS) circuitry. The guiding principle of HIT is to combine CCD and CMOS components into units that afford capabilities that neither CCD nor CMOS circuitry can provide by itself. HIT can be applied to advantage in almost any situation in which there are requirements for very high imaging quality and low power dissipation. Applications can include portable video and portable digital still cameras, remote surveillance cameras, and low-power cameras in spaceborne and terrestrial scientific instrumentation.

HIT merges the exceptional quantum efficiencies, fill factors, broad spectral responses, and very low noise levels of CCDs with the low power levels, system-integration capabilities, and low costs of CMOS-based active-pixel sensor (APS) circuits to create the next generation of high-performance image sensors. Some of the related research outside HIT has included attempts to merge CCD and CMOS components at the device-fabrication-process level. Although these attempts have yielded working image sensors, the devices have exhibited poor image quality and high noise because of lack of optimization of CMOS processes. In turn, the lack of optimization has been due to a basic incompatibility between CCD and CMOS processes as they relate to processing temperatures and to required oxide thicknesses for CMOS transistors.

An essential element of the HIT approach is that no attempt is made to unite CCD and CMOS devices at the device-fabrication-process level; instead, the CCD and CMOS components of a given device are fabricated in separate CCD and CMOS processes and then joined mechanically and electrically (hybridized) by bump bonding. This element of HIT makes it possible to avoid costly process development. This approach also makes it possible to optimize the CCD and the CMOS parts independently, in such a way as to maximize the overall performance of the resulting image sensor in a highly miniaturized format.

Another advantage of HIT is that it enables the reuse of CCD imaging devices and CMOS readout circuitry without need for costly refabrication. A supply of unhybridized components can be maintained so that combinations of components can be selected to satisfy requirements in specific applications.

The imager integrated-circuit chip of an HIT image sensor is essentially a CCD chip, except that the on-chip amplifier usually found in such a device has been replaced by either a floating diffusion or a floating gate output node. The companion CMOS chip must contain a charge-to-voltage conversion amplifier similar to an operational amplifier configured as a charge integrator. Depending on the application, the CMOS chip could also contain additional circuitry to perform such functions as correlated double sampling and analog-to-digital conversion. Matching bump-bond pads are formed on the CCD imager and CMOS chips during their respective fabrication processes. Indium bumps are deposited on the pads, and the chips are joined by standard bump-bonding techniques.

This work was done by Mark V. Wadsworth 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-20542 *Continued*

High-Speed Image Detectors With Subelectron Noise Floors

Hybrid devices exploit the best of CCDs and CMOS circuits.

NASA's Jet Propulsion Laboratory, Pasadena, California

Parallel ultra-low-noise hybrid detectors (PHUDs) are developmental image-detector devices for use in low-power, scientific-grade video cameras. The hybrid nature of a PHUD lies in the incorporation of both charge-coupled-device (CCD) image-detection circuitry and complementary metal oxide/semiconductor (CMOS) parallel readout circuitry. PHUDs promise to revolutionize optical spectrometers and related instruments by providing low-noise, single-photon detection capabilities at conveniently high video data rates.

Until now, subelectron-noise, single-photon-detection capabilities have been achieved by multisampling, nondestructive readout from CCDs. The major disadvantage of this approach is slowness, because of a need to sample each data packet 10 to 100 times in serial fashion; readout rates have been of the order of 5×10^4 pixels per second, resulting in readout times of tens of seconds per frame for typical images of 800×800 pixels. In principle, multisampling could be speeded by performing it in parallel instead of serial fashion, but attempts to implement parallel sampling have resulted in excessive power consumption (>1 W per CCD) and consequent excessive heating that degrades device performance.

In contrast, PHUDs are designed to achieve low noise (<1 electron root mean square), and readout rates of the order of 10^6 pixels per second while consuming less than 50 mW per device. The key design concept of PHUDs is exploitation of the best features of both CCDs and of CMOS imaging devices:

- CCD Features — High quantum efficiency, broad spectral response, low readout noise, high resolution, and large format.
- CMOS Features — Low power consumption, capability for on-chip implementation of such additional functions as digitization and multiplexing, and compatibility with external CMOS circuitry.

The design of a PHUD involves not only hybridization of CCD and CMOS components but also departures from conventional designs of these components. The conventional high-speed serial register is removed from the CCD, a charge-conversion structure is incorporated at the output end of each column in the CCD, and a high-speed CMOS multiplexer for output of voltage-domain signals is added. The signal charge is sensed by a floating polysilicon gate or other suitable nondestructive sensing node located within the CCD at the output end of each column. Charge conversion occurs simultaneously for all columns of pixels. The charge packet in each pixel in a given row and column is measured N>1 times on the sensing node of the column, and each measurement is stored in the CMOS chip by means of an averaging circuit; the resulting readout noise is approximately $N^{-1/2}$ times what it would otherwise be. Because this multiple sampling occurs simultaneously for all pixels along a row, the overall frame rate is not appreciably diminished.

Column-to-column variations in signal offsets and gains in a PHUD can readily be corrected in the course of routine digital processing of readouts. Calibration data for use in computing the corrections are averages and variances of readouts from uniform images.

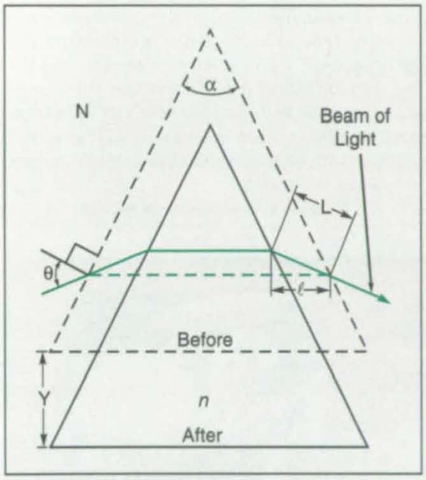
This work was done by Mark V. Wadsworth of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Electronic Components and Systems category. NPO-20576*

Prismatic Phase Shifter

Small phase changes can be obtained with relatively coarse mechanical adjustments.

Langley Research Center, Hampton, Virginia

The prismatic phase shifter is a novel device that can be used to control the phase of a coherent beam of light. Phase shifting is becoming an integral function of most modern interferometric systems. Phase shifting can be accomplished by use of any of a variety of older devices including moving mirrors, rotating quarter-wave plates, moving gratings, and Bragg cells, all of which have disadvantages. Surface losses and/or changes in polarization are induced by these various devices. In the case of a moving mirror, subwavelength translation can be difficult. Some of the other older devices produce lateral shifts of the beam.



Phase Shift Is Introduced into the beam of light when the prism is moved along its plane of symmetry.

The prismatic phase shifter introduces an easily controlled change of phase to a beam of light without the disadvantages of the older devices. This device consists of a prism mounted on a translation stage. The prism is placed in the beam oriented at the angle of minimum deviation. The orientation of the stage is chosen so that translation causes the prism to move along its plane of symmetry.

The figure shows the prism before (dashed) and after (solid) translation. Because of the symmetry of the configuration, the beam is not deviated or translated, and a phase shift is introduced to the beam. For decreasing apex angle, increased translation is needed to obtain a given phase shift. This effect is termed "optical leverage" and makes it possible to obtain small phase changes with relatively coarse mechanical adjustments.

The change in effective optical-path distance, ΔOPD, is given by

$$\Delta OPD = 2\ (n\ell\ -\ NL)$$

where n and N are the indices of refraction of the prism and the surrounding medium, respectively; ℓ is half the difference between the old and new distances along the optical path inside the prism; and L is half the difference between the new and old distances along the optical path outside the prism. By the law of sines,

$$\frac{L}{\sin \alpha/2} = \frac{Y}{\cos \theta}$$

where Y is the translation distance, α is the apex angle of the prism, and θ is the angle of incidence for minimum deviation. This angle is given by

$$\theta = \arcsin \left[\frac{n^2 - n}{n - N} \sin \alpha/2 \right]$$

Furthermore, ℓ is given by

$$\ell = \frac{Y \sin (\alpha/2) \cos (\theta - \alpha/2)}{\cos \theta}$$

Therefore, ΔOPD is given by

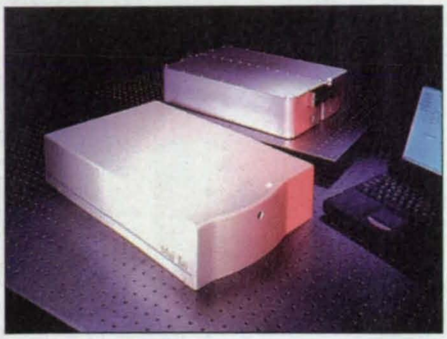
$$\Delta OPD = \frac{2Y \sin (\alpha/2)}{\cos \theta} \left[N - n \cos \left(\theta - \alpha/2 \right) \right]$$

When this device is operated at Brewster's angle, it imposes no surface losses. The only requirement the prism material must satisfy is that it be transparent at the wavelength of interest and be of reasonable optical quality. Because translation of the prism to produce change of phase does not cause deviation or translation of the beam, the device can be used in a system in which strict alignment must be maintained.

This work was done by Brooks A. Childers of **Langley Research Center.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category. LAR-14637*

NEW PRODUCTS

PRODUCT OF THE MONTH



Tunable One-Box Ti:sapphire Laser

Spectra-Physics, Mountain View, CA, says that its Mai Tai™ laser is the first and only tunable Ti:sapphire femtosecond laser source in one box. The laser, which combines the Millennia® diode-pumped laser with Tsunami® Ti:sapphire technology, has an output power of more than 700 mW and a pulsewidth of <100 fs at 800 nm. The laser has a standard tuning range of 750-850 nm, over 100 nm; it can be easily customized for specific applications. The laser head, constructed as a monolithic box, is 59 × 35 × 12 cm (23 × 14 × 5 in.).

For More Information Circle No. 750

High-Quantum-Efficiency PMT

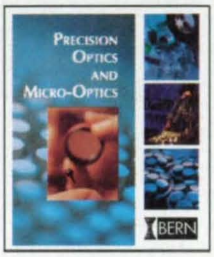
Hamamatsu Corp., Bridgewater, NJ, says that its R7639 solar-blind photomultiplier tube (PMT) features a quantum efficiency of 40 percent at 155 nm, making it an excellent choice for such applications as emission spectroscopy and VUV spectrophotometers. A nine-stage side-on PMT with a solar-blind photocathode, it is highly resistant to intense ambient light levels. Its spectral response range is 115-230 nm, with peak response at 155 nm. Gain is 1×10^7. Time response characteristics include an anode pulse rise time of 2.2 ns, electron transit time of 22 ns, and transient time spread of 1.2 ns. The PMT comes in a 28-mm package and weighs 45 g.

For More Information Circle No. 751

355-nm Ultraviolet Laser

Cutting Edge Optronics, St. Charles, MO, says that its ultraviolet Stiletto laser can generate more than 750 mW of 355-nm output at 15 kHz via external sum-frequency mixing. The laser has typical pulsewidths of 25 ns at 1 kHz and 50 ns at 10 kHz. The 355-nm version is the newest based on the Nd:YAG fundamental of 1064 nm; conversion to 532 and 355 nm is achieved by an extension containing the nonlinear crystals and dichroic filters that is screwed onto the output of the laser head. The systems operate from 1-50 kHz, with conversion efficiency to the harmonics highest at 8-10 kHz.

For More Information Circle No. 752



Micro-Optics as Small as 0.11 mm

Bern Optics Inc., Easthampton, MA, announces the expansion of its line of micro-optics, with sizes as small as 0.114 mm in diameter (windows), 0.19 (lenses), and 0.5 mm (achromats and prisms). Micro lenses can be made from virtually any glass type. Radius, center thickness, and diameter can be held to 10-micron tolerances. Bern says innovative manufacturing techniques ensure a tilt-free and concentric lens every time. Custom reflective and antireflective coatings are available, from single-layer to more complex multilayer depositions.

For More Information Circle No. 753

QCW Laser Diode Driver

Coherent Inc.'s Semiconductor Group, Santa Clara, CA, says that its new high-current quasi-continuous-wave (QCW) laser diode driver was designed to drive diode bars and stacks at high average powers. A complete turnkey system, the air-cooled driver delivers a peak output current up to 250 A with a compliance voltage of up to 80 V and an average power to 2.4 kW. The user can adjust pulse length and period, current, duty cycle, and compliance voltage via a front-panel RS-232 interface or external TTL gate. It is equipped with built-in overload, laser-diode current, and voltage protection.

For More Information Circle No. 754

For More Information Circle No. 471

Vol. 23, No. 9 September 1999 This form expires: February 29, 2000

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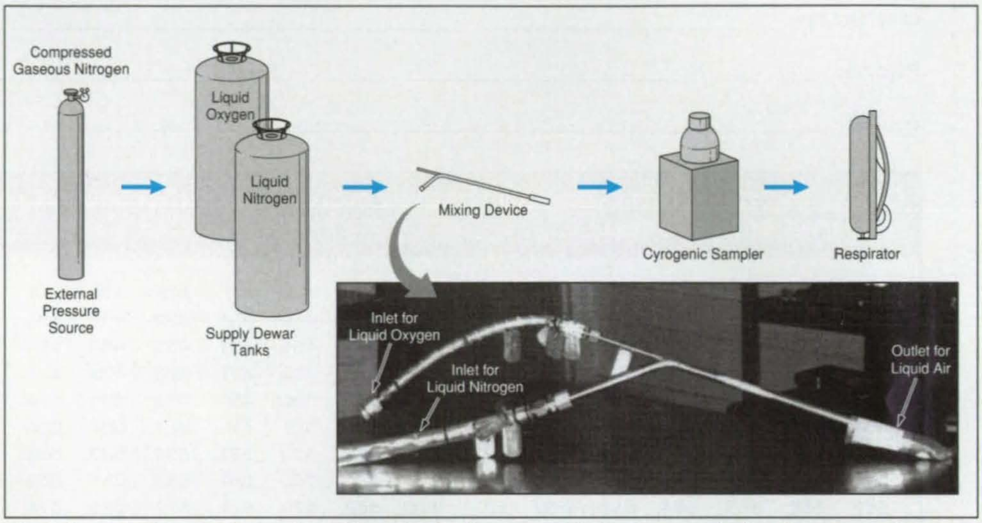
Mechanics

Making Liquid Air in Small, Economical Quantities

Liquid oxygen and liquid nitrogen are mixed on demand.

John F. Kennedy Space Center, Florida

A mixing apparatus combines liquid oxygen and liquid nitrogen to make liquid air in small, convenient quantities. Heretofore, equipment used to make liquid air by mixing was incapable of making batches smaller than 600 gallons (2,300 L). The present mixing apparatus produces liquid air on demand in batches as small as 100 liters; a batch of this size is suitable for filling self-contained breathing apparatuses like those worn by firefighters and others working in hostile environments.



The **Y-Shaped Mixing Device** combines flows of liquid oxygen and nitrogen to make liquid air to supply breathing air for respirators.

It is impractical to liquefy air directly from the atmosphere because nitrogen boils at a temperature lower than that of oxygen and thus tends to evaporate faster from the liquid mixture, leaving the mixture richer in oxygen. It is therefore more practical to make liquid air by mixing the constituent oxygen and nitrogen liquids, which are readily available. Also because of the tendency toward oxygen enrichment, it is more economical to make liquid air on demand than it is to store it in large quantities that sometimes must be dumped because they become too rich in oxygen.

In the present apparatus, a tube carrying a flow of liquid oxygen converges with a tube carrying a flow of liquid nitrogen in a Y-shaped mixing device (see figure). Within this device, the tube carrying the liquid oxygen is immersed in the flow of liquid nitrogen (which is the colder of the two constituent liquids) so that the flow of liquid air receives additional cooling on its way to the collection vessel.

Prior to mixing, the constituent liquids are stored in dewar tanks, which are pressurized by gaseous nitrogen from the liquid nitrogen supply for transfer and mixing. For safety, the pressure is limited to about 60 psi (414 kPa). The use of the same pressure for transfer of both constituent liquids helps to minimize the number of operational variables that could affect the mixing ratio. Liquid air is produced in the mixing device and collected in a receiving dewar which can then be sampled using a cryogenic sampler and used to fill respirators with no additional analysis. Sampling can also be done using the respirator as a sampler. In either method, a portable oxygen analyzer is used to determine the oxygen content.

This work was done by Robert B. Martin formerly of EG&G Florida, Inc., for **Kennedy Space Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category.*

This invention has been patented by NASA (U.S. Patent No. 5,678,536). 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. Refer to KSC-11774.

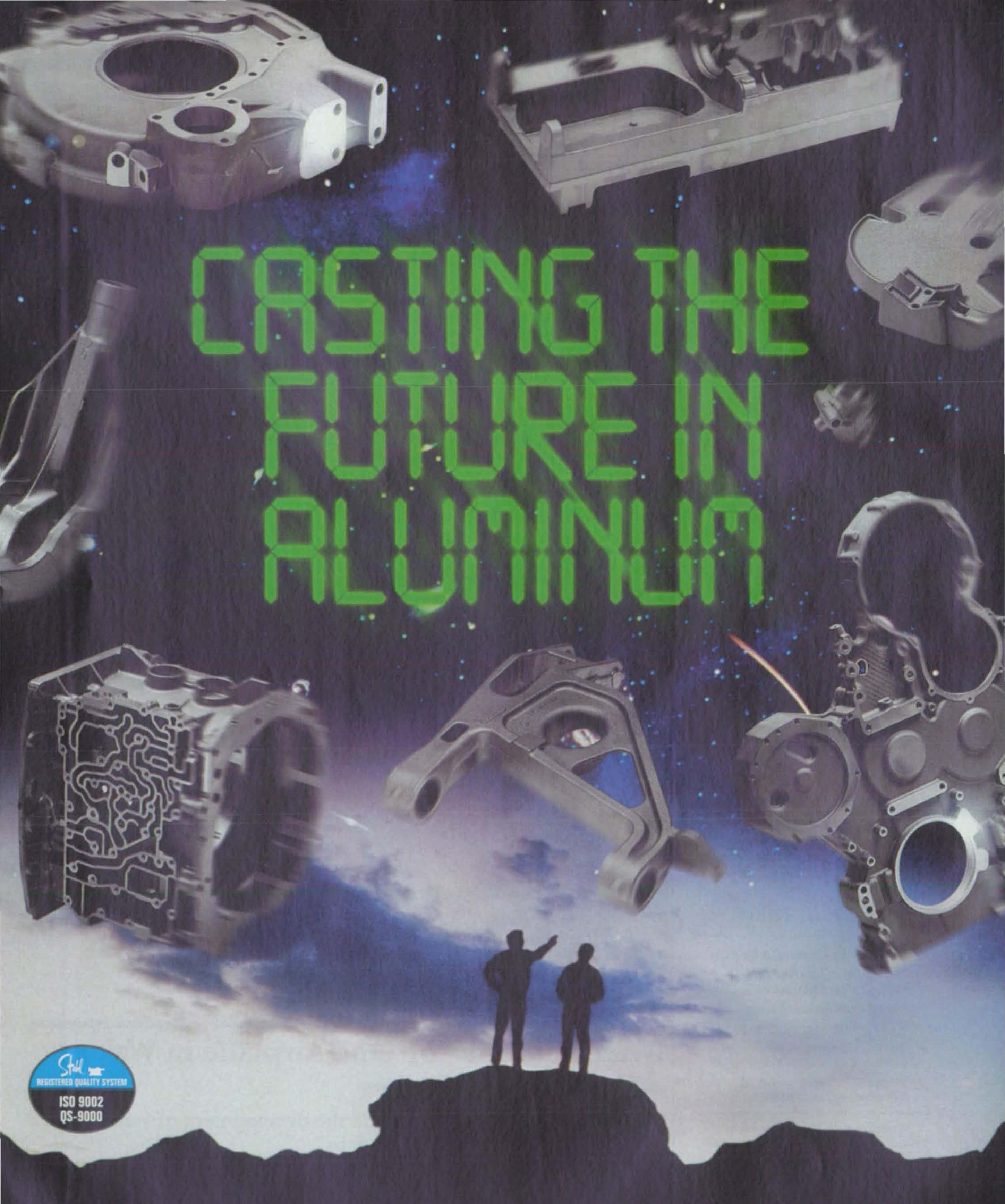
Deflection of Stretched Circular Membrane Under Pressure

Previously reported equations are generalized to account for a stretch preload.

Goddard Space Flight Center, Greenbelt, Maryland

Equations have been derived to describe the deflection of a circular membrane under both in-plane and transverse loads. More specifically, the equations describe the radial (in-plane) and perpendicular-to-the-plane deflections for the case of a circular membrane that has been stretched at its periphery with a uniform preload to keep it taut, then clamped rigidly at its periphery, and then subjected to differential pressure.

Equations for deflection of a rigidly clamped circular membrane with differential pressure but without pre-stretching were presented in "Deflection of Circular Membrane Under Differential Pressure" (GSC-13783), *NASA Tech Briefs*, Vol. 22, No. 5 (May 1998), page 78. The present equations are generalized versions of the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previously reported equations. As before, the derivation follows a strain-energy/virtual deflection approach, which is common in stress-and-strain problems of this kind. The departure from the previously reported equations involves the incorporation of additional terms to account for the change in strain energy associated with work done by the preload.

The displacements of the membrane under load are described by the equations

$$w = w_0\left[1-(r/a)^2\right]^2 \quad (1)$$

and

$$u = r(a-r)(c_1 + c_2 r) + \frac{p(1-\nu)}{2\pi aEh}r, \quad (2)$$

where r is the radial coordinate, a is the radius of the clamping edge, w is the transverse displacement (that is, the deflection perpendicular to the nominal membrane plane) at radius r, w_0 is the maximum transverse displacement, u is the radial displacement at radius r, c_1 and c_2 are constants, p is the preload force, ν is Poisson's ratio of the membrane material, E is the Young's modulus of the membrane material, and h is the thickness of the membrane. The term $p(1-\nu)r/2\pi aEh$ in equation 2 describes the component of radial displacement attributable to the preload.

The radial and transverse strains are given, respectively, by

$$\varepsilon_r = \frac{du}{dr} + \frac{1}{2}\left[\frac{dw}{dr}\right]^2 \quad (3)$$

and

$$\varepsilon_t = \frac{u}{r} \quad (4)$$

The strain energy associated with stretching of the membrane is given by

$$V = \frac{\pi Eh}{1-\nu^2}\int_0^a \left(\varepsilon_r^2 + \varepsilon_t^2 + 2\nu\varepsilon_r\varepsilon_t\right)r\,dr \quad (5)$$

To calculate the deflection of the membrane, one must solve the foregoing equations to find c_1, c_2, and w_0. First, one substitutes the right sides of equations (1) through (4) for the corresponding terms in equation 5. Using the resulting form of equation (5), one finds c_1 and c_2 by imposing the requirements that

$$\frac{\partial V}{\partial c_1} = 0 \quad (6)$$

and

$$\frac{\partial V}{\partial c_2} = 0 \quad (7)$$

Next, one imposes the requirement that the change in work done by the differential pressure acting through a virtual displacement equal the change in strain energy associated with the virtual displacement. If the virtual displacement is chosen to be $\delta w \propto \delta w_0$, then this requirement is expressed by the equation

$$\frac{\partial V}{\partial w_0}\delta w_0 = 2\pi q \delta w_0 \int_0^a \left[1-\left(\frac{r}{a}\right)^2\right]^2 r\,dr \quad (8)$$

where q is the differential pressure on the membrane. Eventually, one obtains the following equations:

$$\pi Ehw_0^3 + 2a\alpha^3 pw_0 - \pi a^4\alpha^3 q = 0 \quad (9)$$

where

$$\alpha^3 = \frac{6615\left(\nu^2-1\right)}{2\left(2791\nu^2 - 4250\nu - 7505\right)} \quad (10)$$

Equation 9 can readily be solved to obtain the maximum deflection, w_0, at the center of the membrane.

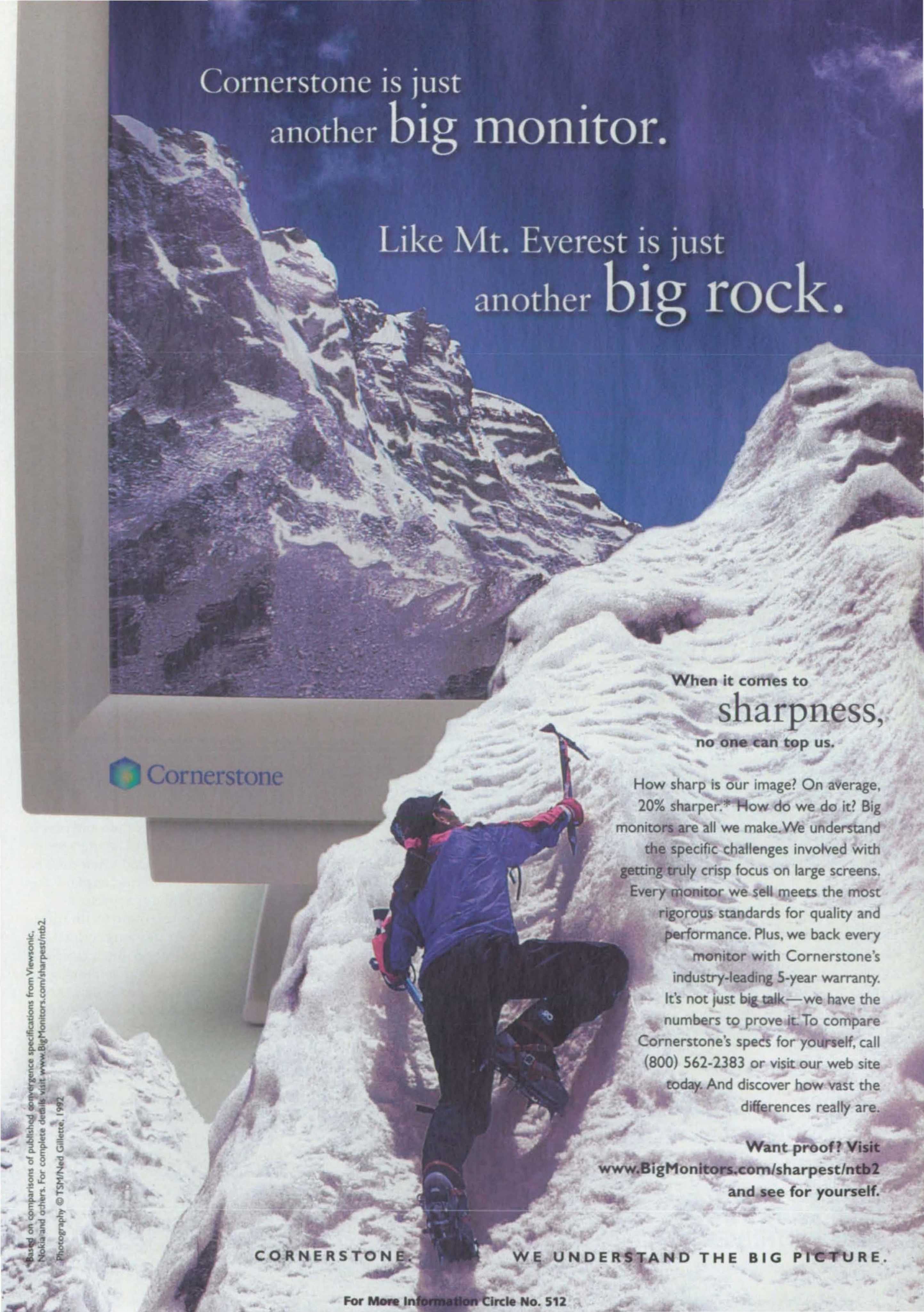
This work was done by Alfonso Hermida of **Goddard Space Flight Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category.*
GSC-14223

Accelerations of One Airplane in Wake Vortices of Another

Results of a study could guide the development of valid simplified mathematical models.

Langley Research Center, Hampton, Virginia

Accelerations of one airplane encountering a vortex or pair of vortices in the wake of another airplane were computed in a parametric study. The approach taken in the study was to systematically investigate the effects of progressively more nearly complete descriptions of the interaction of an airplane with a wake-vortex system, in order to compare the theoretical effects of some of the major simplifying assumptions that are commonly made in formulating mathematical models to represent this interaction. Despite their theoretical nature, this study and other related studies have practical significance: For example, mathematical models of airplane/vortex interaction are needed for pilot-training flight simula-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tors. The models must represent the dominant vortex-encounter effects, yet must be simple enough to be adaptable to a variety of airplanes and simulators.

In this study, the axis of the vortices was parallel to the *x* axis of a Cartesian coordinate system fixed with respect to the Earth. The *y* and *z* axes were the lateral horizontal and vertical axes, respectively. In the case of a pair of vortices, the origin of the coordinate system was located between the vortices. Using a previously developed mathematical model of wake vortices, the *y* and *z* components of the vortex velocity at a given *y,z* location were taken to be (1) proportional to the weight and inversely proportional to the velocity and wing span of the wake-generating airplane and (2) proportional to functions of *y* and *z* that decrease with distance from the vortex cores and that include the radii and the *y* and *z* positions of the vortex cores as parameters.

In addition to the vortex coordinate system described above, there was a coordinate system fixed to the airplane body axes and five aerodynamic-surface axis systems, to model the right and left wing panels, the right and left horizontal tail panels, and the vertical tail panel. The body-axis system could be located at an arbitrary position and orientation relative to the vortex axis system. The orientation was specified by the standard airplane yaw, pitch, and roll Euler angles. The five aerodynamic-surface axis systems were placed at arbitrary positions and orientations relative to the airplane body-axis system. The equations for the wing and tail surfaces were written in general terms for planar aerodynamic surfaces with sweep, taper, and dihedral. No fuselage was modeled, and the aerodynamic surfaces were treated as originating at the center line of the airplane.

Each surface was broken up into *N* spanwise incremental areas. The angle of attack and sideslip at the three-quarter-chord point of each incremental area was calculated independently of those of its neighbors. The vortex and encountering-airplane velocities were transformed into the aerodynamic-surface axis systems and used to compute aerodynamic forces, which were assumed to act at the quarter-chord point of each incremental area. The aerodynamic forces were then transformed back into the body axis system and used to compute the accelerations of the encountering airplane.

As an example case, the vortex flow field modeled in the study had the nominal characteristics of the wake of a Boeing 767 airplane, while the encountering airplane had the nominal characteristics of a Boeing 757 airplane. The majority of cases considered in this study involved roll-dominant encounters, in which the longitudinal axis of the encountering airplane was nearly parallel to the vortex *x* axis. The first case considered was that of a drag-less rectangular wing in the flow field of a single vortex. Then in a sequence of increasingly complex cases, the study progressed to the case of a complete airplane with (1) aerodynamic surfaces characterized by taper, sweep, and dihedral; (2) aerodynamic behavior that included stalling; and (3) the vortex pair in ground effect. The effects of the pitch, roll, and yaw attitudes of the airplane on the calculated accelerations were also investigated.

The numerical results of the calculations were plotted as contours of constant acceleration in a 300-by-300-ft (91-by-91-m) area centered on vortex pairs. The following conclusions were drawn from the results:

- The effects of the single vortex field extended to larger distances from the vortex core than did the effects of a counter-rotating vortex pair. However, near the cores, the effects of the vortex pair were greater and covered a larger area. In addition, the acceleration contours for the vortex pair were more complicated with more sign reversals. Thus, it appears that a vortex pair poses a potential hazard greater than that of a single vortex.
- The dominant accelerations were in roll and the *z* body axis, although significant yawing, pitching, and lateral accelerations were calculated when the vertical and horizontal tail surfaces were added to the mathematical model. Longitudinal acceleration was not a major factor.
- A nonzero lift coefficient, drag, wing dihedral, and localized stalling had negligible effects on the accelerations relative the effects of taper ratio and sweep.
- Significant distortion of all the acceleration contours occurred when the attitude of the encountering airplane was changed by 20° about any axis.
- In the case of an encounter with vortex perpendicular to the longitudinal airplane axis, the *z* and pitch accelerations were generally comparable to those for a parallel encounter, except for small areas of much larger accelerations around the vortex cores. However, the rolling, yawing, and lateral accelerations were zero because of the symmetry of the airplane.
- The effect of a ground plane at 150 ft (45.7 m) below the vortex system was minimal except when the encountering airplane was near the ground.

This work was done by Eric C. Stewart of **Langley Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category.*

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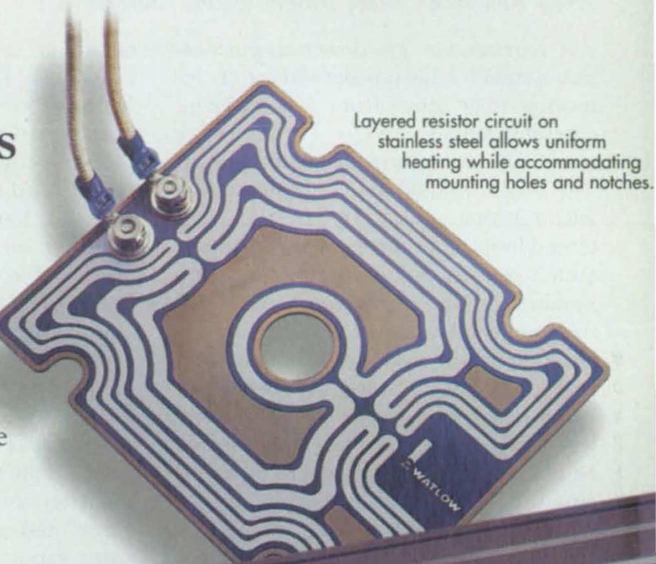

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Air-Purification System Utilizing Humidity Swings

This system could operate at relatively low power.

Ames Research Center, Moffett Field, California

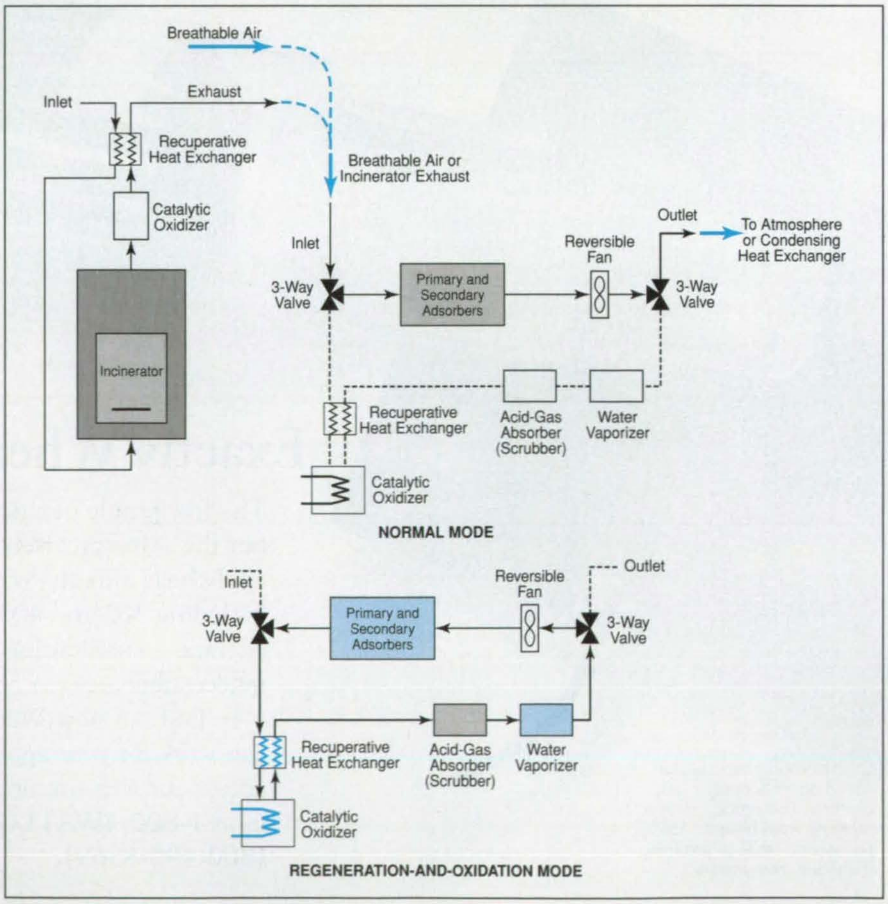
A regenerable, low-power air-purification system has been proposed for (1) removing toxic gases from solid-waste-incinerator exhaust and/or (2) removing trace contaminants from breathable air. The system would include a primary gas adsorber that would be regenerated in a closed-loop humidity-swing desorption cycle to ensure the destruction of contaminants before the gas stream under treatment was vented to breathable air. In comparison with a traditional thermal desorption cycle, the humidity-swing desorption cycle would consume less power. The system was conceived to be part of a life-support system in an enclosed habitat (*e.g.*, a spacecraft or submarine); it could also be adapted to treatment of industrial and municipal incinerator exhaust streams.

The basic system concept is an outgrowth of research in which it was found that water vapor in air may suffice to displace many strongly adsorbed chemical species from a carbon-based adsorber. If humid air were circulated in reverse through a closed loop containing a saturated adsorbent column and a catalytic oxidizer, then the adsorbed contaminants should become desorbed at relatively high concentrations and be destroyed efficiently in the oxidizer. This treatment would be effected without need for high temperatures, and contaminants would be retained in the loop until destroyed.

The adsorbent column in the proposed system would contain a broad-spectrum adsorbent — possibly, though not necessarily, activated carbon, some or all of which could be platinized to provide for removal of CO and H (in addition to other gases) at ambient temperature. The catalytic oxidizer could be based on any of a number of suitable catalysts — for example, one comprised of a noble metal on alumina.

One proposed system and its modes of operation are depicted schematically in the figure. During operation in the normal mode — that is, during processing of incoming exhaust or contaminated air — all contaminants except methane and ammonia would be retained or destroyed on the platinized adsorbent in the primary adsorber. Methane could be removed in a secondary adsorber containing a hydrophobic adsorbent. Ammonia would be removed elsewhere by a condensing heat exchanger. Normal operation would be terminated when the concentration of a particular contaminant gas would rise above an allowable level.

The system would then go into a regeneration-and-oxidation mode. First, the catalytic oxidizer would be heated to its operating temperature. Three-way valves would then be turned to form the closed loop that would include a water vaporizer, the adsorbers, the catalytic oxidizer, and an acid-gas absorber. The water vapor introduced into the loop would cause the desorption of contaminant gases from the secondary and primary adsorbers. The temperature in the loop would also rise gradually, causing further desorption of contaminants less susceptible to purging by water vapor. The contaminant gases would be destroyed in the catalytic oxidizer, and any acidic oxidation products (*e.g.*, HCl and HF) would be removed by a scrubber containing a suitable absorbent (*e.g.*, lithium carbonate). The scrubber would not be regenerable, but it would have a long life and would seldom, if ever, have to be replaced. Upon completion of the regeneration-and-oxidation cycle, the treated air would be vented or else sent to the condensing heat exchanger for further processing.



The **Proposed Air-Purification System** would operate in the normal mode to process incoming exhaust gas or contaminated air, and would then be switched into the regeneration-and-oxidation mode to regenerate the adsorbers and complete treatment.

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SPECTRAL DYNAMICS

This work was done by John E. Finn and Cory K. Finn of **Ames Research Center**, *M. Douglas LeVan of Vanderbilt University, and W. Scot Appel of the University of Virginia. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery/Automation category.*

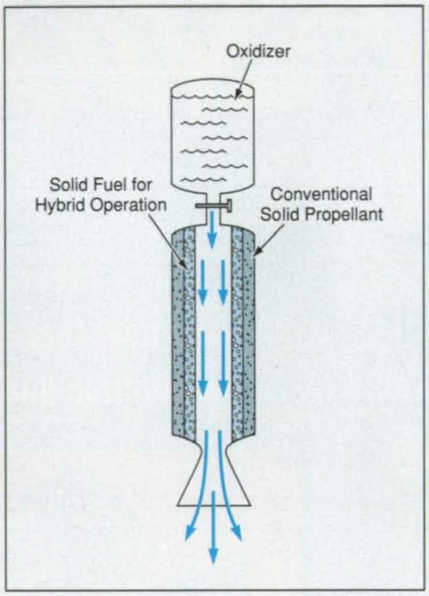
Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center; (650) 604-5104. Refer to ARC-14262.

Hybrisol Rocket Engines

These engines offer potential safety and cost advantages over solid-fuel engines.

NASA's Jet Propulsion Laboratory, Pasadena, California

"Hybrisol" denotes a proposed rocket engine that would contain hybrid and solid-propellant parts within a single combustion chamber. ["Hybrid" as used here denotes a type of rocket engine in which a solid fuel is burned by use of a liquid or gaseous oxidizer and the flow of the oxidizer can be throttled to control the engine. Unlike conventional solid rocket propellants, a solid fuel for a hybrid rocket engine can be made relatively inert in the absence of the oxidizer and therefore presents little hazard of explosion or inadvertent ignition.] Inside a hybrisol rocket engine, there would be two concentric tubular energy-storage layers: an outer layer of conventional solid rocket propellant and an inner layer of solid hybrid fuel (see figure).



A **Hybrisol Rocket Engine** is a combination of a hybrid and a solid-propellant rocket engine. As the hybrid fuel nears burnout, its burning ignites the solid propellant.

In operation, the solid hybrid fuel would be consumed first. As the hybrid fuel approached burnout, the burning would ignite the outer layer of solid propellant. The hybrisol concept would thus confer the following advantages:

- The use of the burning of the hybrid fuel to ignite the solid propellant would increase reliability. It would also enable a reduction in overall rocket mass because there would be no need to carry a device to ignite the solid propellant.
- The rocket would operate initially in the hybrid mode, which would afford the inherent safety of that mode plus the controllability that is typically needed during the early phase of ascent. The later burning of solid propellant would provide the high thrust typically needed in the thinner upper atmosphere.
- During ascent, mass could be reduced sharply by jettison of the empty oxidizer tank immediately after burnout of the hybrid fuel.

Detailed calculations have shown that a hybrisol design could be executed at about half the cost of its nearest competitor. In addition to the advantages mentioned above, during the hybrid phase of operation, the hybrisol concept offers the advantage of lower (in comparison with other rocket-engine concepts) pollution from its exhaust and lower temperatures. The lower temperatures make it easier to solve heat-transfer and heat-related material problems.

Potential applications for hybrisol rocket engines range beyond the spacecraft launching market to such terrestrial applications as sounding rockets for science, distress markers, and rockets for triggering small avalanches to prevent larger ones. To the degree to which there is a toy and/or amateur rocket market, the hybrisol rockets could be attractive as safer alternatives to conventional solid-propellant rockets.

This work was done by Kumar Ramohalli 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-20387*

A Precise Closed-Loop Temperature-Control System

Flow from one thermal source at a time is varied to actively control temperature.

Lyndon B. Johnson Space Center, Houston, Texas

A control system that includes a single thermal source has been designed to afford precise control of the temperature of a fluid flowing in a closed-loop system. Similar control systems could make it possible to increase production levels and to reduce risks in industrial situations in which temperatures must be strictly maintained — especially situations that involve aggressive or hazardous materials that exhibit safety-related, temperature-dependent properties. For example, in the photographic and other chemical industries, control of temperature is vital for manufacturing products and for safety of manufacturing processes; for another example, the ability to control temperature is a major concern for manufacturers of heating and cooling equipment. Overall, precise temperature-control systems like the present one can serve as valuable tools that will insure both production and safety in affected industries, in the armed services, and in the U.S. space program.

The operation of this system includes monitoring of the flow(s) of thermal (heating and/or cooling) fluid(s). Control of mass flows of thermal fluids is basic to heat-exchange systems. In traditional heating and cooling systems, constant-thermal-fluid-flow sources (*e.g.*, pumps) and on/off valves are used to maintain temperatures at acceptable levels; this practice is expensive and is fraught with production irregularities and safety risks.

In other temperature-control systems, hot and cold fluids are constantly mixed to keep temperatures within optimum bands. In the present system, a variable flow from a single thermal source (a circulation heater or a circulation chiller, depending on whether heating or cooling is needed at the time) is used to effect precise control of the temperature of a fluid circulating in a closed-loop system. Although the system is rated to maintain the temperature within ±1 °F (≈0.6 °C) of the set point, the designer's specification predicts a range of ±0.5 °F (≈0.3 °C).

The system has been installed in a space-station simulator in St. Louis, Missouri. The specification for the simulator requires that temperature be maintained within ±0.5 °F (≈0.3 °C). Because the temperature tolerance for this simulator is almost as restrictive as are the temperature tolerances in other industries (including the photographic and chemical industries, heating-equipment manufacturers, and branches of the U.S. armed services), this system could also be put to good use in those industries.

This work was done by Thomas J. Poteat of McDonnell Douglas for **Johnson Space Center.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery/Automation category.*
MSC-22774

For More Information Circle No. 422

Manufacturing/Fabrication

Adaptable Drill Guide

This tool is easy to use and gives accurate, repeatable results.

Ames Research Center, Moffett Field, California

The tool shown in the figure is a drill guide that can adapt to a curved or flat surface. The main function of the adaptable drill guide is to keep the axis of a drill perpendicular to the surface at the location of the hole to be drilled. The tool can also be used to guide a reamer into a drilled hole, to control the depth of drilling or reaming, and to guide tools other than drills and reamers. With simple changes in dimensions, the basic design of the tool can readily be adapted to drill bits and reamers of various diameters.

A vacuum pump and connecting hose are needed to operate the tool. The tool includes suction-cup feet; it is attached to the surface of a workpiece by applying vacuum to the suction cups. In this way, it can even be attached to a lubricated surface without need to remove the lubricant.

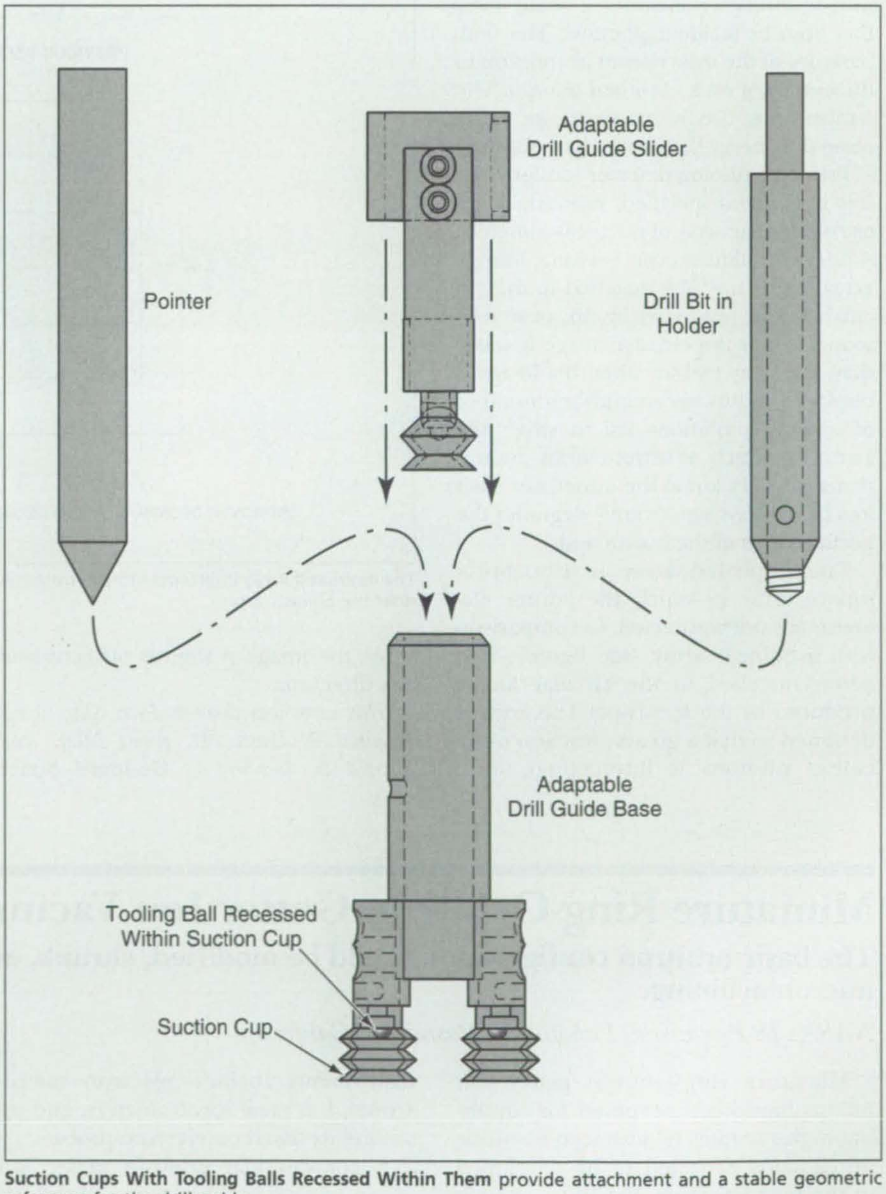
Other aspects of the design and use of the tool are best described in terms of the following typical sequence of operations:

1. A pointer is inserted in the drill guide, extending past the suction cups.
2. The drill guide is maneuvered to place the pointer at a desired marked location (*e.g.*, the center of a hole to be drilled) on the workpiece.
3. With the pointer pressed gently on the surface at the desired location, the drill guide is moved to bring the suction cups into gentle contact with the surface.
4. Vacuum is applied, causing the suction cups to pull the drill guide toward the workpiece surface until tooling balls mounted inside the suction cups make contact with the surface, providing a stable drill-guide base.
5. The pointer is removed from the drill guide.
6. A drill, reamer or other tool bit, mounted in a modified holder attached to a conventional hand tool, if necessary, is inserted in the drill guide.

Prior to the development of this tool, it was necessary to either rely on a skilled technician or else use a complex, computer-controlled five-axis milling machine to make a hole perpendicular to an arbitrary surface at an arbitrary location. In the case of a skilled technician, the degree of accuracy and repeatability of the hole is open to question. In contrast, this tool makes it possible to locate and orient drilled holes accurately and repeatably, without need for expensive machinery like a five-axis milling machine.

This work was done by Earl T. Daley and Lawrence W. Whiteside of **Ames Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Manufacturing/Fabrication category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center; (650) 604-5104. Refer to ARC-14259.



Suction Cups With Tooling Balls Recessed Within Them provide attachment and a stable geometric reference for the drill guide.

Physical Sciences

Improved Array of X-Ray Microcalorimeters

Modification of array geometry increases the number of photons intercepted.

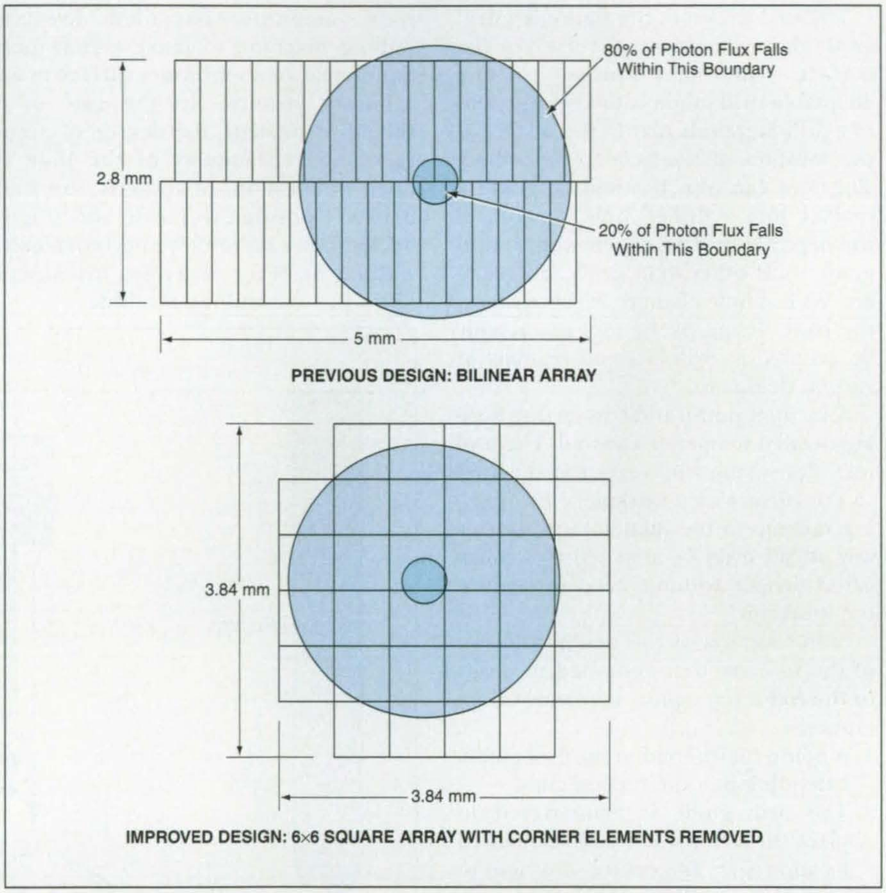
Goddard Space Flight Center, Greenbelt, Maryland

An improved array of microcalorimeters has been devised for use as photon detectors in an x-ray spectrometer for astrophysical research. The spectrometer will be used to measure the spectra of celestial objects in the "soft" x-ray range (photon energies from 200 eV to 10 keV), to a resolution much higher than has been possible until now.

Microcalorimetry is an established technique for measuring x-ray energies. Each microcalorimeter includes a small mass that absorbs incident photons. The temperature of the mass rises in proportion to the energy of each absorbed photon. The temperature rise is measured to determine the energy flux of incident photons.

Previous photon-detector designs for this instrument specified, variously, a linear or bilinear array of microcalorimeters. A linear or bilinear array is a long, narrow array that is not well matched to the circular image produced by an x-ray telescope: When the circular image is wider than the array and/or when the image is displaced widthwise, a significant number of incoming photons fail to strike the array. Inasmuch as astronomical photon fluxes are very low at the outset, any such loss of photons significantly degrades the performance of the instrument.

The improved array is a six-by-six square array in which the corner elements are not connected. In comparison with a bilinear array (see figure), it is better matched to the circular image produced by the telescope: The array is designed so that a greater fraction of incident photons is intercepted, even when the image is slightly off center in any direction.



The **Improved Array Intercepts More Photons** (even when the circular image is slightly off center) than does the bilinear array.

This work was done by Peter Shu, Sanghamitra B. Dutta, D. Brent Mott, and Harold D. Isenberg of **Goddard Space Flight Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

GSC-13808

Miniature Ring-Orbitron Getter Ion Vacuum Pumps

The basic orbitron configuration would be modified, shrunk, and implemented by micromachining.

NASA's Jet Propulsion Laboratory, Pasadena, California

Miniature ring-orbitron getter ion pumps have been proposed for supplying high vacuums to advanced scientific instruments expected to be developed in the next few years. Examples of such instruments include electron microscopes, ion mass spectrometers, and instruments based on electron probes.

A conventional orbitron getter ion pump (shown in the top part of the figure) includes a positively biased rod electrode on the axis of a cylindrical cavity with typical dimensions of tens of centimeters. Electrons are injected into the cavity, where they collide with and

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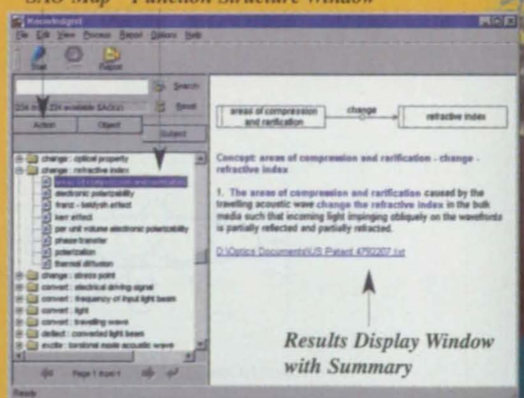

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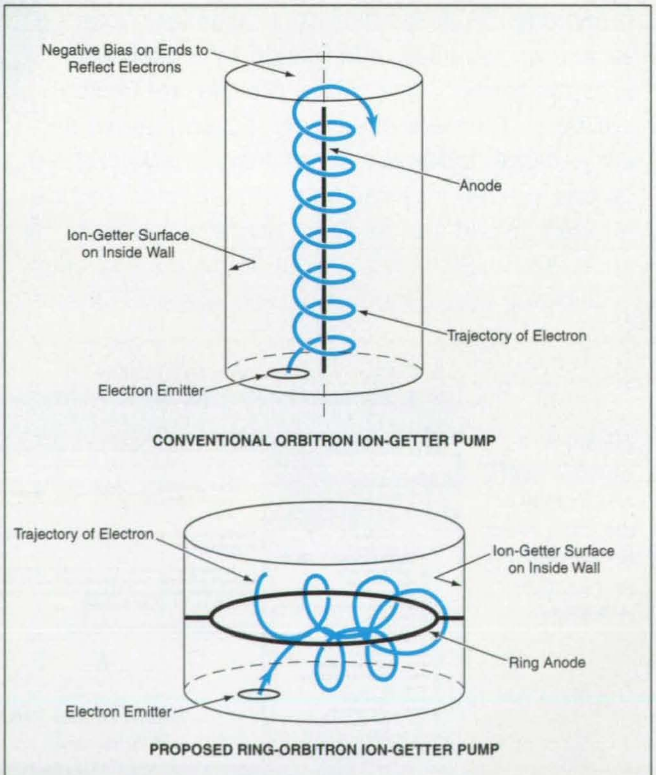
thereby ionize residual gas molecules. The resulting ions are accelerated toward, and become buried in, an ion-getter material on cavity surfaces. Because of the positively biased rod, the injected electrons get caught in orbits around the rod. The orbiting confines the electrons in a region away from the walls, thus increasing the electron path lengths and the probability that the electrons collide with the gas molecules, leading to increased efficiency of pumping.

In a conventional large orbitron getter ion pump, a negative bias is applied to the flat end walls of the cylindrical cavity to deflect the approaching electrons back into the cavity. However, the required relatively large voltage becomes increasingly impractical as the size of the pump is reduced. Thus, miniaturization must entail elimination of negative bias on the end walls; this makes it necessary to find another way to confine electrons in the cavity.

The proposed ring orbitron configuration would provide the needed confinement. The rod electrode of the conventional orbitron would be replaced with a wire ring electrode, as shown in the bottom part of the figure. As in the case of the rod electrode, positive bias on the ring electrode would create a potential well, causing the electrons to spiral around the ring, and the electrons would be injected slightly off-ring to give them enough angular momentum to go into the orbits.

Unlike a conventional orbitron, a ring orbitron would be scalable to subcentimeter dimensions. In the fabrication of miniature orbitron pumps, bulk and surface micromachining and lithography could be used to define ring electrodes, ring-supporting posts, and electron emitters. Cavities could be fabricated from stacks of micromachined wafers.

This work was done by Jaroslava Z. Wilcox, Thomas George, and Jason Feldman 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-20436*



The **Positive Electrode in the Proposed Orbitron Pump** would be a ring around the axis, instead of an axial rod as in the conventional orbitron. In the proposed orbitron, unlike in the conventional orbitron, there would be no need for negative bias on the end walls to reflect escaping electrons back into the cylindrical cavity.

Digitally Tunable Color Filters and Beam Scanners

Total internal reflection would be switched on and off spatial segments.

NASA's Jet Propulsion Laboratory, Pasadena, California

Color-filtering and beam-scanning devices based on electro-optical switching of internal-reflection states have been proposed for use in display and measurement applications. Associated digital circuits would apply electronic control signals to spatial segments of these devices to obtain discontinuous spatial and/or spectral displacements of reflected and/or transmitted light beams. If this description seems a little too general, it is because the basic device concept is rather general; it could be implemented in numerous different optical and electronic configurations.

The proposed devices would take the places of the galvanometer-driven mirrors, rotating prisms, color-filter wheels, and other optomechanical devices that have been used in some beam-scanning and -filtering apparatuses until now. Unlike the optomechanical devices, the proposed devices would contain no moving parts. Relative to the optomechanical devices, the proposed devices would offer advantages of high speed and light weight.

Figure 1 illustrates a color-filter device of the type proposed, with a simple design chosen for explaining the basic principle of operation. A ferroelectric liquid crystal or other suitable electro-optical material would be sandwiched between two long Dove prisms. A continuous thin film of indium tin oxide on the sandwich contact surface of the left prism would serve as an electrode for applying an electric field to the electro-optical material. A thin film of indium tin oxide would also be applied to the sandwich contact surface of the right prism, but this film would be divided into segments to form electrodes corresponding to discrete color/beam-scanning pixels. Each electrode segment would be coated with an interference or other suitable optical filter to define the color of the pixel.

The device would be positioned and oriented so that white light entering through the lower end of the left prism would strike the sandwich contact surface at an angle slightly greater than the minimum angle for total internal reflection in the absence of applied voltage. Therefore, in the absence of applied voltage, the white light would bounce along inside the left prism through a number of total internal reflections; none of the

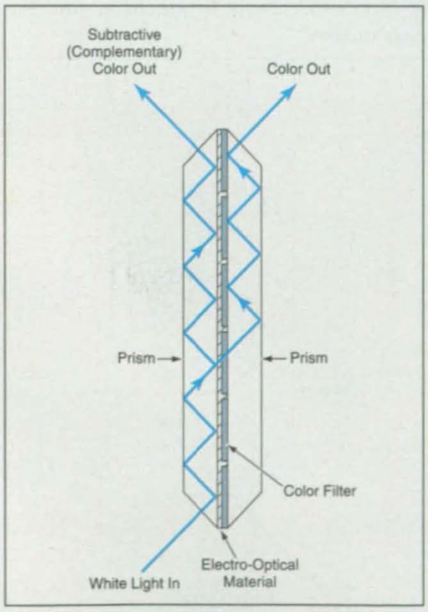


Figure 1. A **Unique Output Color** could be selected by applying voltage to an electrode coterminous with one of the color filters. The electric field would increase the index of refraction of the electro-optical material by an amount sufficient to stop total internal reflection at the selected filter, thereby making light pass from the left prism, through the filter, to the right prism.

light would be coupled to the right prism and the light would be reflected out, still white, at the top of the left prism.

If a sufficient voltage were applied between the single large electrode on the sandwich contact surface of the left prism and one of the pixel electrodes on the sandwich contact surface of the right prism, then the index of refraction of the electro-optical material in that pixel would increase sufficiently to raise the minimum angle of incidence for total internal reflection above the actual angle of incidence. In that case, the incident light would strike the color filter in the affected pixel, so that light of one color would pass through the filter into the right prism, while the complementary color would be reflected back into the left prism. The end result would be that light of the color passed by the filter would travel along the right prism by total internal reflection and would leave the right prism at its top end, while light of the complementary color would behave similarly in the left prism and would leave that prism at its top end. If the pixels contained filters of different colors, then one could select a unique output color by applying voltage to the pixel of that color.

Figure 2 illustrates a simple non-color-discriminating beam-scanning device. This device would be similar to the device of Figure 1, except that there would be no color filters and instead of one long prism on the right side, there would be multiple small prisms — one prism for each pixel. As in the example of Figure 1, in the absence of applied voltage, light would travel along the left prism by total internal reflection and would emerge from the top of the left prism. In this case, however, the left prism would be configured so that the light emerging from the top would be traveling rightward instead of leftward. If a sufficient voltage were applied to one of the pixel electrodes, then the light would pass through to the right side and would emerge through the upper right face of the pixel for that prism. Thus, one could discontinuously scan (digitally switch) a beam of light among discrete parallel paths by applying voltage sequentially to different pixel electrodes.

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

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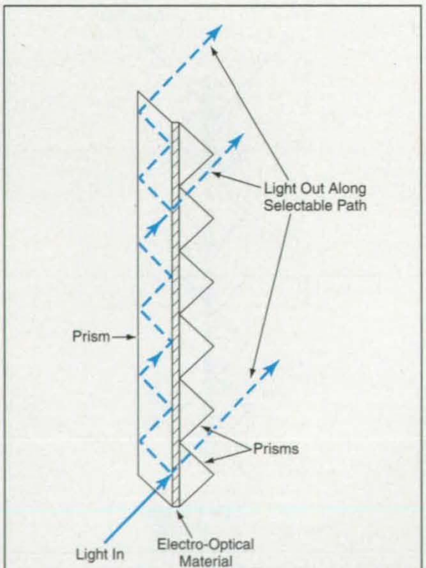


Figure 2. A **Unique Output Path** could be selected by applying voltage to an electrode coterminous with one of the small prisms on the right side. Except for the prism configuration and the lack of filters, this device would function similarly to that of Figure 1.

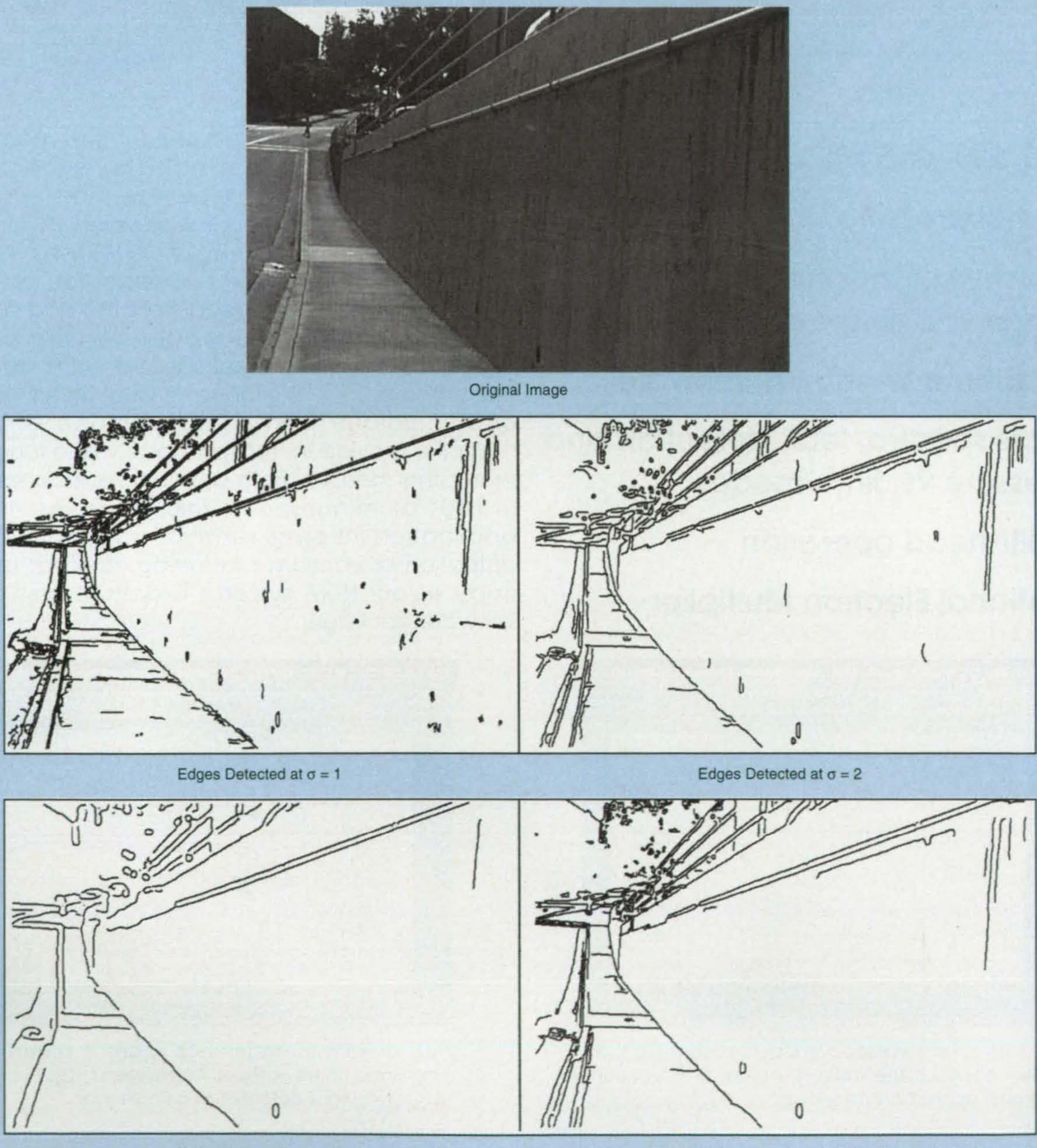
Information Sciences

Image Smoothing and Edge Detection Guided by Stereoscopy

Edges can be detected with comparable performance at various distances.

NASA's Jet Propulsion Laboratory, Pasadena, California

A method of smoothing and edge detection in digitized images involves the use of a Gaussian smoothing filter that is adaptive in the sense that the filter scale varies with the estimated distance between each scene point and the camera. The estimate of distance is obtained via stereoscopy. The method was conceived for a developmental image-processing system that would recognize unexploded ordnance on a military test range. The method can also be used to



Edges Were Detected by applying a gradient-based edge-detection algorithm to a Gaussian-filtered version of the original image. The edge-detection performance depends on the filter scale, σ.

enhance performance in other edge-detection applications.

Older methods of smoothing and edge detection involve, variously, the use of a single scale or a set of scales, without knowledge of which scale is appropriate for each location in an image. In other words, the scale is not related to the sizes of objects in the image, even though the apparent sizes of objects vary widely with distance. As a result, the use of a single scale or an inappropriate set of scales for all image points can result in spurious edge detection or in failure to detect edges of interest.

In the present method, the scale at each point in an image is adjusted to account for the variation of apparent size with distance and is thus related to the real-world size of the object depicted at that point. The scale (σ) at pixel coordinates x,y is given by $\sigma(x,y) = K/R(x,y)$, where K is a predetermined constant and $R(x,y)$ is the distance computed at x,y from the disparity between the two images of a stereoscopic pair. The algorithm that computes $R(x,y)$ incorporates the calibration of the stereoscopic camera rig and includes a correction for radial lens distortion. The disparity between the left and right images for each pixel is obtained by minimizing the sum-of-squared-difference (SSD) measure of windows around the pixel in the Laplacian of the image. The coordinates of each pixel are then computed by triangulation. In the case of pixels for which $R(x,y)$ cannot be computed (*e.g.*, where image texture is too low), $R(x,y)$ values are propagated from neighboring pixels by use of a technique that approximates nearest-neighbor search.

The variable scale Gaussian smoothing filter is applied in a window of $2W+1$ by $2W+1$ pixels centered at the pixel x,y. Ideally, the output of the filter would be given by

$$S(x,y) = \sum_{i=-W}^{W} \sum_{j=-W}^{W} I(x+i,y+j) \frac{1}{\sigma(x,y)\sqrt{2\pi}} e^{-\frac{(i^2+j^2)}{2\sigma(x,y)^2}},$$

where $I(x,y)$ is the brightness of the image at x,y. It turns out to be inefficient to perform this computation exactly, using $\sigma = \sigma(x,y)$ for each pixel. For greater efficiency, the filter output is approximated by first convolving the entire image with a discrete set of Gaussian filters with scales related by factors of 2, then performing a parabolic interpolation to the appropriate scale for each pixel.

Edges are detected by an algorithm that computes gradients in the filtered image. For the purpose of edge detection, gradients must be comparable. However, gradients representing otherwise identical edges are stronger in regions smoothed at smaller values of σ. Therefore, to make gradients comparable, the magnitude of the gradient each pixel x,y is normalized by multiplying it by $\sigma(x,y)$.

The figure shows an original 750-by-500-pixel image along with examples of edge detection, without and with stereo-guided scale selection. At $\sigma=1$, edges close to the camera are rough and a number of extraneous edges are detected. As the scale jumps from $\sigma=1$ to $\sigma=2$ and $\sigma=4$, details of most distant objects (the trees and the far end of the railing) are lost. In the case of stereo-guided scale selection, edge-detection performance is high at both close and distant points in the scene.

This work was done by Clark F. Olson 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 Information Sciences category.*

NPO-20475

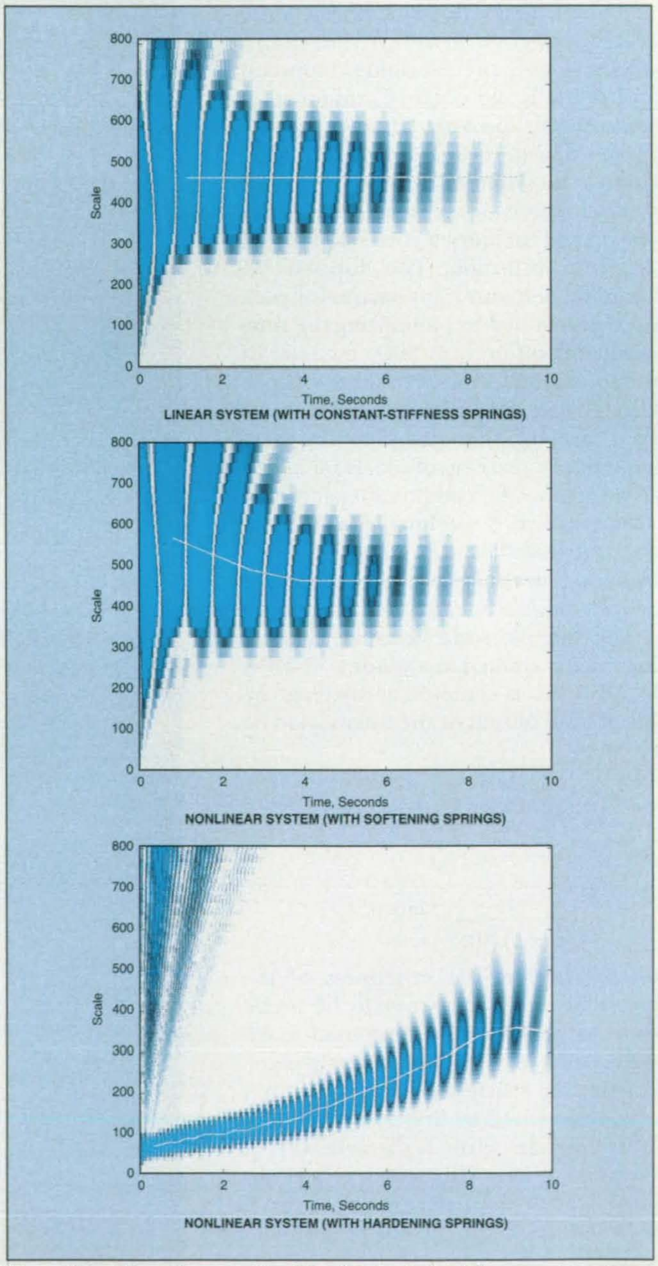
Characterizing Nonlinear Dynamics by Use of Wavelet Analysis

Wavelets can be used to determine the degree and type of nonlinearity.

Dryden Flight Research Center, Edwards, California

A method to detect and to characterize the type of nonlinear dynamics in an aeroelastic system involves the utilization of information from wavelet processing of measurement data. This method is intended to assist in identifying unmodeled dynamics of aircraft during flight testing.

Some background information is prerequisite to an explanation of this development. The term "wavelet" as used here denotes a signal that is nonzero for a short time. The relevant wavelet in the present case is the Morlet wavelet, which is essentially a windowed sinusoidal signal of finite length. The



These **Maps Were Generated by Wavelet Analysis** of linear and nonlinear pitch responses of an aeroelastic system in a test bed with three different types of springs.

Morlet wavelet is a function of parameters, called "scale" and "position," that affect, respectively, the period of the sinusoidal component and the time when the nonzero component is centered. Wavelet processing involves computation of the magnitudes of correlation between a measured signal and wavelets of different scales and positions. The wavelets with the highest correlation magnitudes represent dominant features in the measurement data.

Wavelet analysis inherently extracts time-varying features of a signal because of the short duration of the nonzero portion of the wavelet. The wavelets at a position in time determine only the features of the signal near that position. Thus, the changes in wavelets that correlate highly with the signal at different times indicate the changes in features of the signal as time progresses.

In the present method, responses from several configurations of an aeroelastic test bed are analyzed to determine the nature of the nonlinear dynamics that affect an aeroelastic system. The various configurations include various springs associated with pitch movement of a wing assembly. The forces generated by these springs can vary linearly with pitch angle or can vary nonlinearly, as in the cases of hardening or softening springs. Pitch angles are measured during free decay of oscillations of the system in response to an initial pitch placement.

The figure presents maps that result from wavelet processing of pitch responses for different system configurations. These maps can be regarded as three-dimensional in the sense that they depict magnitudes of correlation as functions of wavelet scales and positions: The color at each point in a map indicates the magnitude of correlation; specifically, white represents low correlation, the color changes gradually to darker levels of gray as the correlation increases, and the color becomes blue for particularly high correlation.

The dominant features of each map are extracted by identifying correlation peaks. Because these peaks are sometimes difficult to identify visually from the colored two-dimensional representations of the three-dimensional maps, a curve is drawn in each map to indicate the scale associated with the dominant feature at each position in time.

The dominant features extracted from the wavelet maps clearly indicate the presence of a nonlinearity in the aeroelastic dynamics. The curve is level and shows no change in scale for the dominant feature of the response from a linear system, but the curves vary, showing changes in scale for the dominant features of the responses from the nonlinear systems. This result is expected because (a) the response from a linear system should be a decaying sinusoid that has a constant frequency, while (b) the response from a nonlinear system should be a decaying sinusoid with a changing frequency. Thus, it is straightforward to detect the presence of nonlinearity from the variation in scale shown by the curve through the correlation peaks in a map.

The type of nonlinearity can be characterized by the type of change in the curve. The response from a hardening spring features a decreasing frequency, so its map should show an increasing scale. Conversely, the response from a softening spring features an increasing frequency, so its map should show a decreasing scale. The curves indicate these behaviors, demonstrating that wavelet analysis provides means for both detection and characterization of nonlinear dynamics.

This work was done by Rick Lind and Martin Brenner of **Dryden Flight Research Center** *and Kyle Snyder of the University of Tennessee Space Institute. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Information Sciences category.* *DRC-98-42*

Books & Reports

Conservatism in Deterministic Structural Analysis

A paper discusses the excessive conservatism that has long been suspected to exist, because of the use of conventional (deterministic) safety factors, in the analysis and design of quasi-static structures. The origin of this conservatism is identified as a violation of statistical error-propagation laws that occurs when statistical data on loads and stresses are reduced to deterministic values and then combined through several computational processes. These findings are suggested to indicate a need to replace deterministic methods with probabilistic methods to prevent violations of error-propagation laws. It is also suggested that, as an alternative to adoption of fully probabilistic methods, it may be more expedient to partially convert deterministic methods to probabilistic ones to retain familiarity, confidence, and correlation with experience.

This work was done by V. Verderaime of **Marshall Space Flight Center**. *To obtain a copy of the report, "Inherent Conservatism in Deterministic Quasi-Structural Analysis," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category.*

MFS-27333

Evaporation of Isolated and Collections of Fluid Drops Under Supercritical Conditions

A report presents a computational study of heat and mass transfer for isolated and interacting drops of one fluid (liquid O_2) immersed in another fluid (H_2) in finite, quiescent surroundings under supercritical conditions. The mathematical models used in this study were described in three previous articles in *NASA Tech Briefs*; namely, "Model of a Drop of O_2 Surrounded by H_2 at High Pressure" (NPO-20220), "The Lewis Number Under Supercritical Conditions" (NPO-20256), and "Model of Interacting O_2 Drops Surrounded by H_2 at High Pressure" (NPO-20257), Vol. 23, No. 3 (March 1999), page 70.

This work was done by Josette Bellan and Kenneth Harstad of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "Heat and Mass Transfer for Isolated and Interacting Fluid Drops Under Supercritical Conditions," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

NPO-20404

Gimbaled Injectors for Testing Spacecraft Thrusters

A report proposes an assembly of gimbaled valve/nozzle subassemblies for use in injecting either a propellant fluid (*e.g.*, monomethyl hydrazine) or a propellant-simulating fluid (*e.g.*, water) into the combustion chamber of a spacecraft thruster during hot-fire or cold testing, respectively. The proposal is a response to the problem of how to find the angle of impingement of injected fluid that results in the best thruster performance.

This work was done by Marlin Klatte of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "Gimbal Injector," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Machinery/Automation 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, NASA Resident Office–JPL; (818) 354-5179. Refer to NPO-20520.

Experiments on Vibration and Noise in Fuselages

A paper summarizes a continuing program of vibro-acoustic testing of two aircraft fuselage structures: (1) a 12-ft (3.7-m)-long generic aluminum testbed cylinder that contains stiffening rings and stringers and (2) the 40-ft (12.2-m)-long fuselage of a 10-passenger turboprop airplane, made of honeycomb core and graphite/epoxy face sheets. Each structure is mounted on compliant supports that permit approximately free vibration and is instrumented with more than 200 accelerometers, which are positioned according to predictions of the first 100 vibrational modes. Subsequent acoustic tests will focus on measurement of interior noise fields created by exterior mechanical and acoustic sources.

This work was done by Richard S. Pappa and Ralph D. Buehrle of **Langley Research Center** *and Jocelyn I. Pritchard of the Vehicle Technology Directorate of the U. S. Army Research Laboratory. To obtain a copy of the paper, "Vibro-Acoustics Modal Testing at NASA Langley Research Center," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Mechanics category.*

L-17851

Lithium-Based Primary Cells for Low-Temperature Operation

A report describes an experimental study of the low-temperature electrical characteristics of commercial Li/MnO_2, Li/CF_x, Li/SO_2, Li/$SOCl_2$, and Li/BCX primary electrochemical cells. These high-energy-density cells are under consideration for use as lightweight, compact electric-power sources for scientific instruments in terrestrial polar regions and on Mars, where they could be called upon to operate at temperatures as low as –85 °C. The experiments, performed at temperatures down to –100 °C, included steady-state current-vs.-voltage measurements during discharges with various increments of load resistance from 10^5 down to 10 Ω, complete discharge tests, and ac-impedance measurements.

This work was done by Frank Deligiannis, Harvey Frank, Evan Davies, and Ratnakumar Bugga of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Batteries for Ultra-low-Temperature Applications," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical Sciences category.*

NPO-20352

Development of Flight Software for Small Explorer Spacecraft

A report describes a continuing program of development of flight software for the attitude-control system (ACS) and the command-and-data-handling (C&DH) system of a prototype standard spacecraft of the Small Explorer (SMEX)-Lite class. Both the C&DH and ACS parts of the software are designed to run on a single reduced-instruction-set computer (RISC) with a peripheral com-

September 1999

Rapid Product Development

How 3D Scanning Technology Impacts Product Development

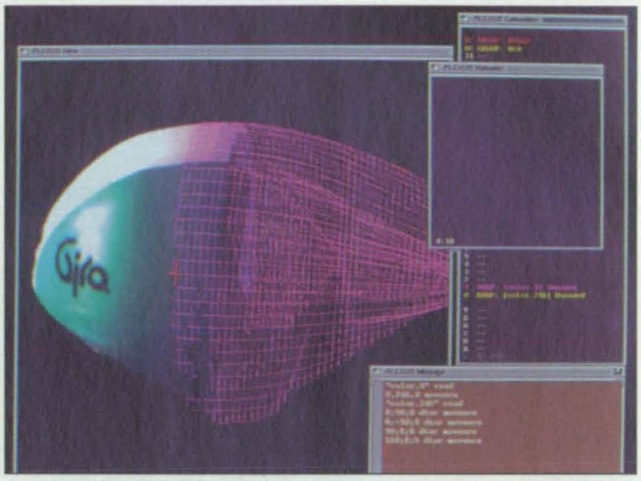
In order to meet the challenges of today's rapidly changing business landscape, companies are taking a close look at their methods, adopting new techniques, and looking for ways to make production more efficient and cost effective. Among the recent technological advances, there is a growing interest in the availability of fast, affordable optical range laser scanning. Manufacturing companies in particular are looking to the scanning industry as a potential tool for increasing productivity and resolving issues concerning the need to create a 3D digital file for an object where none had existed before.

Scanning a 3D image and sending the scan to prototyping or CAD software programs saves not only hours of painstaking work, but thousands of dollars as well. Reproducing an object by physically drafting it into the computer is difficult, and the result often does not match the original. Although reverse engineering is a method that companies have used for some time, a truly cost- and labor-effective method to go about it has not existed until now. Laser scanning also opens the door for many firms that initially prefer to sculpt objects in traditional mediums to retain the tactile and visual advantages that CAD systems lack.

More than three-quarters of the Fortune 100 companies depend on visual computing to help them design their products. Embracing this new technology allows firms both large and small to meet the computing challenges that are pivotal to their competitive strength. Laser scanning can provide a measurable difference for improved quality and accelerated time to market, while reducing costs for new products.

Laser scanning is accomplished by using a laser device that collects range data. The most common method for acquiring range data is active optical triangulation. Range data is produced by placing a depth value on a regular sampling lattice from the surface of an object. Then, by connecting triangular elements with the nearest neighbors, a range image is created.

Generally, a 1D or 2D sensor is swept linearly across the object or circularly around it. As this is usually not enough information to reconstruct the entire object being scanned, multiple passes must be made from different orientations. Specially written algorithms are required to merge multiple range images into a single description of the surface. Although this technology has been in use for over 20 years, the recent development of stable imaging sensors such as CCDs and lateral effect photodiodes has increased its speed and accuracy dramatically.



In laser scanning, a laser device collects range data by active optical triangulation. Range data is produced by placing a depth value on a regular sampling lattice from the surface of an object. Then, by connecting triangular elements with the nearest neighbors, a range image is created.

There are several different types of scanners that accomplish this. Their primary differences are in the structure of the illuminant (typically point, stripe, multi-point, or multi-stripe), dimensionality of the sensor (linear array of CCD grid), and the scanning method (move the object or move the scanner hardware).

One of the most obvious benefits to 3D scanning is the tremendous increase in speed with which a prototype can be reproduced. Traditional methods call for the object to be measured and redrawn in a CAD program. This is extremely time-consuming, and organic shapes are almost impossible to model using this method. Objects such as an ergonomically designed handle or new toy design can be sculpted easily and then scanned to insure the intended result. Laser scanning is at its best when dealing with shapes of this sort.

Benefits of 3D Scanning

Often, the time to market can make or break a new product. It is much easier to predict the future when the future is a few weeks away, rather than a few months away. In some cases, the resulting time savings can allow a manufacturing project to start later. This means that companies have time to work with clients longer in the conceptual process. Details can be explored fully, and customer requirements clearly understood before committing to the production stage. The entire scanning and post-editing process can happen in as little as four to five hours. This kind of time saving also means that companies have the ability to respond rapidly to changes in the marketplace. And because laser scanning technology is relatively quick, it generally is much cheaper than other types of scanning.

A couple of scanning hardware manufacturers have now developed scanners that accurately digitize the human body. Companies that need to produce ergonomically designed products such as safety helmets, orthopedic braces, or prosthetic devices can use this technology as a fast and safe method for collecting surface information of the human body.

Yet another advantage for the manufacturing community is that, in many instances, G-code can be created for CNC milling right from scan data, or from an STL file without taking the extra step of producing a NURBS surface model. This means that a prototype can be made and approved, scanned, and a mold made of any proportion quickly and easily; all of this happening in a matter of days. Scan data can be translated to nearly any file format — DXF, OBJ, 3Dstudio Max, IGES, ASCII, STL, HRC, Inventor, and others.

Product verification is another example of the benefits of scanning. After a product has been produced, it can be scanned and the resulting data compared to the CAD drawing. Deviations from the specs can then be accurately determined. Another routine use for scanning is periodic inspection of multiple parts to analyze how closely the product adheres to the original. This allows for greatly improved quality control, and helps to detect flaws in the manufacturing process.


Product verification is an example of the benefits of scanning. After a product has been produced, it can be scanned and the resulting data compared to the CAD drawing. Deviations from the specs can then be accurately determined.

Another benefit that is not so obvious, but can have a far-reaching effect on a company, is that once the object is in the computer, complex ideas can be conveyed accurately and easily. In today's world, manufacturing processes are carried out by multiple parties, often from different locations around the globe. The client and the design process can be in one place, while the manufacturing occurs in another. The synergistic effect of having several people collaborating on the development of an idea substantially broadens the scope of the design and manufacturing process. Once a prototype has been scanned, the engineering, analysis, quality control, and various other functions that used to take place consecutively, can take place concurrently before committing to manufacturing. All parties involved with the project can work from the same digital file. The result is a shortened development cycle, improved product performance, and greater flexibility — positive ramifications at every level.

Variables to Consider

When looking at this technology for use in the manufacturing industry, it is important to know how the surface information is gathered, and its advantages and limitations. There are many variables that affect the laser and subsequently affect the quality of the information. Reflectivity of the surface, color of the object, undercuts, narrow opening, and sharp edges all can pose challenges. Other things to consider are placement of the object in relation to the scanner, and operator experience. These challenges are reduced greatly with the right equipment and an experienced operator.

Operator experience is a critical factor with optical laser scanning. The operator must follow certain guidelines and be able to predict how the laser will react. The individual scans must be viewed carefully before merging, so that any unacceptable data will be thrown away. And the operator must have a clear understanding of how lasers work. Competing lighting in the room, the distance the object is from the scanner, and the color of the object all can affect the laser. The technician needs to be able to clearly distinguish acceptable from unacceptable data, and needs to be able to accurately analyze the point cloud — the native product of scanners.

In the case of reverse engineering, it is important to establish what it is you want to do with the data, and just as important, what is, or is not, important in terms of accuracy. Accuracy is the million-dollar question in the manufacturing community. What the accuracy of the scan will be is asked of the scanning industry as frequently as what file outputs are possible. It is important to understand the range of accuracy for the particular scanning hardware being used, and then to take into consideration the factors already mentioned. Both file translations and certain types of files have a margin of error. In applications such as STL, where the product will have finishing work done after being produced, this may not be an issue. And in most cases of CNC milling, the drill bit is larger than the deviation.

Many companies want to use optical laser scanning for inspection purposes. In these instances, a software package designed especially for interpreting the point cloud is needed. It is then imperative to gather the cleanest, most accurate data possible. Sometimes the manufacturer does not want the data altered in any way, so it is critical to choose scanning hardware or a service bureau that can produce proven results.

If the desired result is to get a PRT file format for use in CAD programs, then a surface must be created over the point cloud. There are many programs and methods that make this possible. The point cloud data can be sliced in order to generate B-splines, and a surface lofted from there, or a surface may be generated right over the point cloud.

Other considerations with this type of scanning are the cost and the time it takes to complete a project. This method is relatively fast compared to other types of scanning. Because three to four parts can be scanned and processed in a day, the cost tends to be lower. Because the object is never touched physically, it is not harmed in any way, and as there are no radiation rays, this is the preferred method for collecting surface data of the human body.

How can a company determine whether or not optical laser scanning is right for their project? First, determine for what you will be using the data. Second, look objectively at the object and decide whether it lends itself to scanning. An thirdly, consider the cost and timeline desired.

The laser scanning industry has come a long way in recent years. There are many options currently available that can be scheduled into a planned project with relatively predictable and cost-effective results. These recent improvements have opened the door to even the average user, who may never before considered using automated 3D model creation from real objects in product production.

This article was written by Lisa Federici of Scansite and was reprinted, with permission, from the proceedings of the Rapid Prototyping and Manufacturing '99 conference, held April 20-22 in Rosemont, IL. For more information, contact the author at Scansite, #1 Madrone Ave., PO Box 695, Woodacre, CA 94973-0695; Tel: 415-488-9500; Fax: 415-488-1647; www.scansite.com.

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Rapid Prototyping System Creates NASA Spacecraft Part

An SLS-generated DuraForm "science cup" holds instruments that measure magnetic fields within the Northern Lights.

How do you fit a half-dozen science instruments into a space no bigger than a hockey puck? Engineers at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, CA, were faced with this puzzle as they designed the Free Flying Magnetometer (FFM). Four of these palm-top spacecraft would be used in NASA's Enstrophy Project, a mission investigating the Aurora Borealis. JPL engineers set out to create a "science cup" to carry several instruments aboard each FFM. They needed to create this complex part quickly, requiring a material sturdy enough to withstand launch vibrations and the extremes of Earth's upper atmosphere. Because the instruments would be monitoring the aurora's magnetic fields, the science cup could not create any magnetic or electrical interference.

"Typically, we machine parts like these out of aluminum, steel, or titanium," said Kobie Boykins, a member of the technical staff at JPL's Mechanical Engineering Section. "Unfortunately, this design had thin walls and tiny, complex features that ruled out both metals and machining. It would have been exorbitantly expensive to create the part that way."

JPL's engineers were able to surmount several design obstacles by using the Sinterstation 2500 system from DTM Corp. of Austin, TX. Using the selective laser sintering (SLS) process, they were able to produce a satisfactory science cup from DuraForm, a plastic SLS material also supplied by DTM.

Boykins and his NASA colleagues had considered other options for creating the part, including stereolithography (SLA). They chose SLS, in part, because NASA already had a DTM Sinterstation system in-house. Engineers were also drawn to the strength of the DuraForm material. "The published numbers for DuraForm were better than those of the SLA materials," said Boykins. "We were also concerned about parts changing form, since there was a time lapse from the time the parts would be produced to actual assembly and take-off."

The engineers also felt the DuraForm part would have a better chance of holding the required part tolerances of ±0.125mm. When NASA tested the DuraForm SLS parts produced on the Sinterstation system, engineers' strength calculations proved correct. The parts were strong enough for the application, and tests showed that a #0-80 UNF threaded insert could hold approximately 89 Newtons of force. "From what we could tell," said Boykins, "these pieces held up well to all kinds of abuse, handling, and machining. We also didn't notice any dimensional changes."

The Sinterstation Process

The DTM Sinterstation method used by the JPL team creates solid, 3D objects — layer by layer — from plastic, metal, or ceramic powders that are "sintered" or fused using CO_2 laser energy. The steps of the process are as follows:

- Step 1: The user inputs 3D STL CAD data.
- Step 2: A thin layer of powder is spread across the part-build area via a roller mechanism. CO_2 laser energy is used to selectively "draw" the object on the powder layer. The laser energy heats the powder to a temperature above its softening or melting point, sintering the particles into a solid mass. Laser power is modulated so that only the powder described by the object's geometry is fused. This entire process is repeated until the object is complete.
- Step 3: The object is removed from the part-build chamber, and any loose powder is brushed or blown away. The object may be undergo further treatment, such as sanding or annealing, before final use.

NASA's Final Results

Using the SLS method to produce the science cups saved NASA time and money. Boykins estimated that it would have cost from \$3,000 to \$5,000 to fabricate the parts using machining and other traditional methods and materials. The SLS DuraForm parts cost about \$300. This method also made it easier to fine-tune the part design. "What's nice about the SLS parts is we could make

small changes very rapidly, with machining or sanding, or by simply changing the computer file and generating another set of SLS parts," said Boykins, who produced four SLS parts and more than 30 manual modifications to these parts.

On February 11, NASA sent four FFMs, each equipped with a DuraForm science cup, into space. Each held more than six instruments, including laser beacons, sun sensors, a magnetometer, batteries, a transmitter, and an antenna. All instruments, except the batteries, were glued into the science cups using a space-grade epoxy. The elements formed an assembly that slid into a graphite epoxy shell that was screwed together, forming a protective case. The tiny spacecraft were ejected from a rocket and fell back to Earth, measuring minute variations in the aurora's magnetic fields. Scientists at NASA and the University of New Hampshire (UNH) say that these fluctuations may be the cause of the mysterious light show.

"Our scientists and principal investigators at JPL and UNH are very happy with the results," said Boykins. "They are excited about the SLS technology and how we can use it to produce small, self-contained spacecraft. The opportunities are immense and could include missions to other planetary bodies."

For more information, contact DTM Corp. at 1611 Headway Circle, Building 2, Austin, TX 78754; Tel: 512-339-2922; Fax: 512-339-0634; or visit the web site at www.dtm-corp.com.

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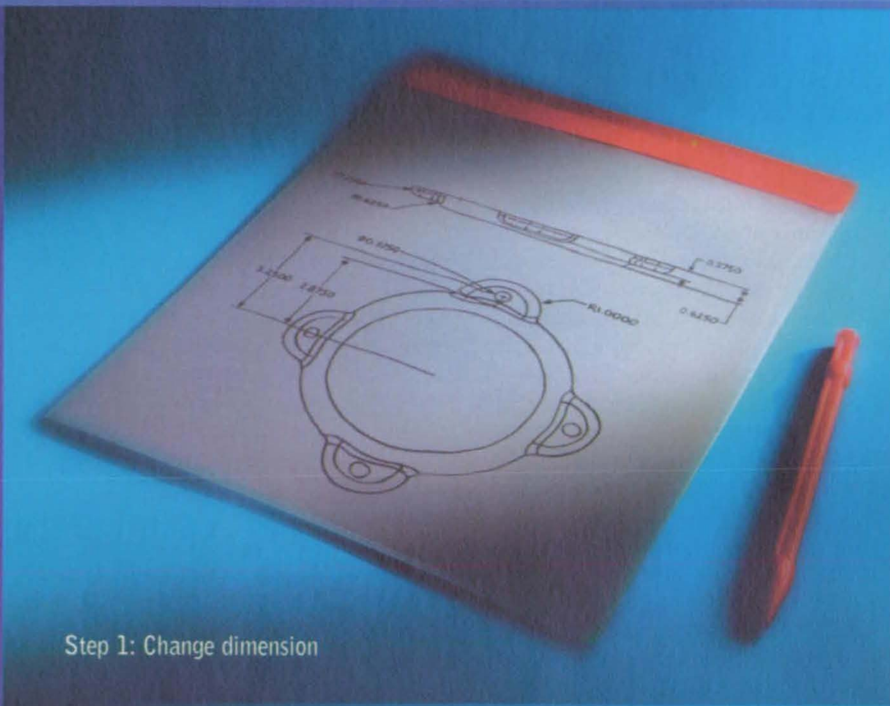
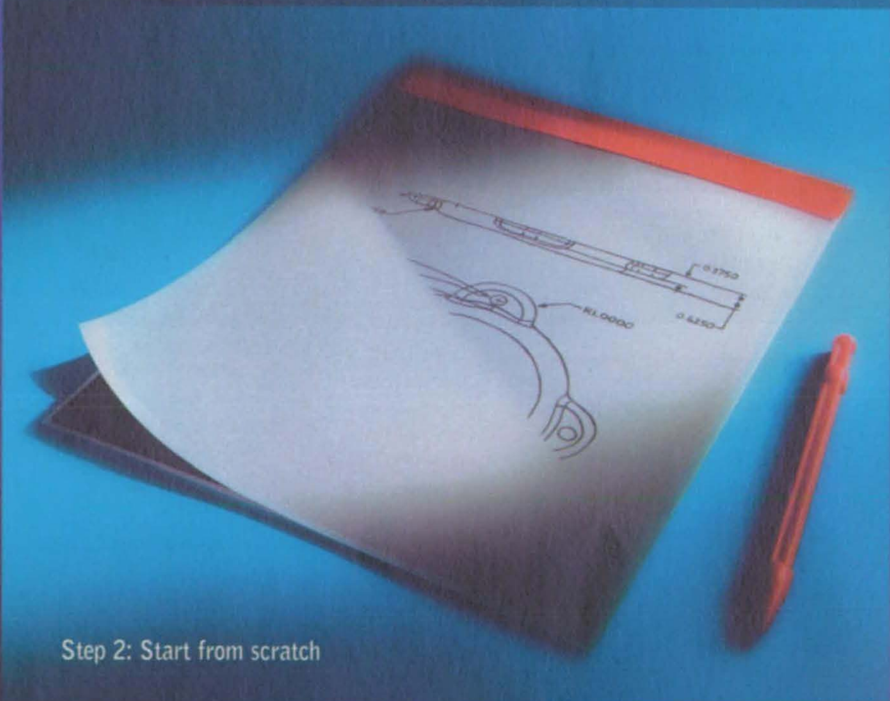
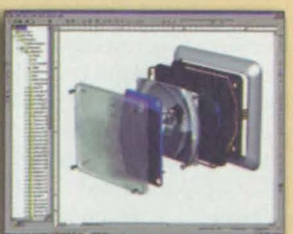


Step 1: Change dimension



Step 2: Start from scratch

Granted, almost every road from concept to finished design has its unexpected bumps, detours and dead ends. But that's no reason to head back to square one when you make a mistake or need to change direction. Especially after having invested hours designing a model. Unfortunately, with Mechanical Desktop®, that's exactly what you have to do. Not so with SolidWorks®. With SolidWorks you can explore options and change features to your heart's content. Without losing anything–time, money, or your sanity. All of which you risk losing with Mechanical Desktop. Still, it would be unfair to say that Mechanical Desktop makes all changes hard. After all, many former Mechanical Desktop users have told us it made switching to SolidWorks very easy indeed.



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Making "Art to Part" a Reality

New software from Rockwell Automation and others allows designers to more fully exercise their machine and part designs in a virtual world, before metal is cut and expensive resources are consumed.

Rockwell Automation Control Systems, Mayfield Heights, Ohio

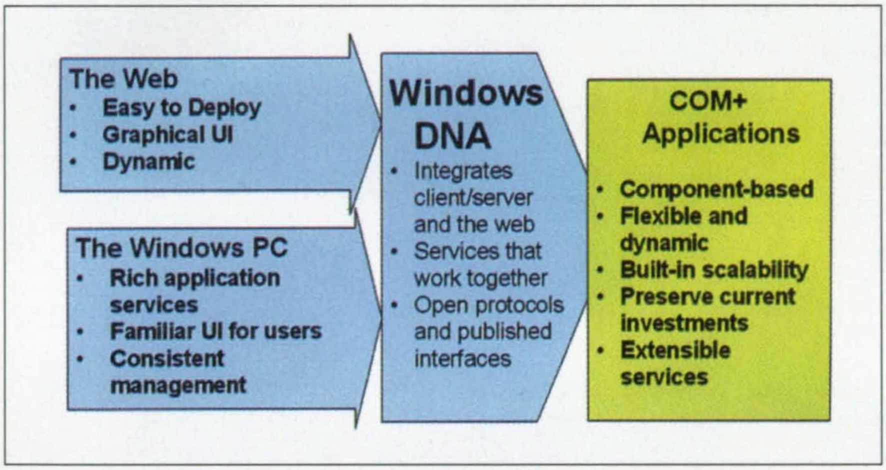
One of the most striking examples of an innovative approach to shortening the time from part design to production is occurring at DaimlerChrysler, and some of the other automotive manufacturers, in their body production systems. They are taking advantage of some of the newest software technology available from computer-aided design (CAD) vendors and other software suppliers such as Rockwell Automation Control Systems, of Mayfield Heights, OH, through its Rockwell Software brand, to integrate different plant-floor processes into a single simulation environment.

Often referred to us as digital factory, digital manufacturing, virtual machine design, or virtual factory, virtual manufacturing provides a way for engineers to develop, evaluate, refine, and simulate the use of a complex system entirely on a computer before any time and money are spent on the actual system itself. In essence, virtual manufacturing is the process of design and verification of manufacturing systems, incorporating the intended product before it is built. Thus communication channels can be opened between the production floor and the designers to allow for continuous product improvement. Three primary technologies are making this concept more realistic and affordable: CAD systems, 3D visualization, and hardware-neutral operating systems.

Mechanical CAD systems are dropping in price and becoming more accessible to lower-volume companies, while 3D visualization programs help design engineers understand changes that can be made early in the product design process to make the plant floor run more smoothly.

As 3D software entered the general market in the late 1980s, it became possible to describe part geometries in such a way that large cavities with sweeping curves could be accurately cut from the electronic representation of the part's surface. The automotive companies benefited by introducing cars with stamped fenders and other body parts that revolutionized styling.

The introduction of 3D solid modeling software, first on big UNIX machines and more recently on desktop PC workstations, has created the capability to make intricate cavities in molds. Electronic surfaces now have walls and thicknesses that can easily be manipulated as part of a single object. Part geometries can be translated into machining of molds that, when the two halves are mated, can precisely mirror the visualization of the part on the screen of the designer. Companies like Moldflow™ provide the injection-molding industry with a suite of software tools that help connect the design process to the plant floor.



Component Object Model (COM) enhances the user's capabilities.

What was only available to high-end users before is now being provided through standard products in an "off-the-shelf" computer market. Specifically, Component Object Model (COM), implemented in the Microsoft operating system environment, has provided application interoperability that greatly enhances the user's set of capabilities (see figure). A system built up using COM technology now allows not only a transfer mechanism between two systems, but a truly interactive session with two systems from two different vendors, where data is mutually accessible and there is a common user interface. Moldflow's product that works with SolidWorks is a good example.

Perhaps the most compelling feature of object modeling is the idea that a behavior—that is, instructions to tell the object to "do something" under certain conditions—can be encapsulated in the object in addition to static parameters or attributes. This allows the designer to build a model that can have static and dynamic characteristics embedded in its representation (that is, the object). The virtual part can now interact with other objects in the system in a fourth dimension—time. This collection of objects, suitably defined, can now simulate the performance of the part in the real world.

Systems such as Dynamic Designer, another plug-in to SolidWorks from Mechanical Dynamics, provide force and load simulation within the CAD environment. The SolidWorks COM interface allows Dynamic Designer to interact with the CAD 3D model directly. To a given part, the user can add characteristics like weight, material properties, and other attributes so that he can now run a simulation of its behavior in the real world.

The advances in the software industry have led many companies to make improvements in their own design processes. In the last four years, companies like Deneb and Tecnomatix have developed off-line programming for robots that allow full simulation in a virtual environment, including the translation of the part through space. Now the user can interact with a virtual robotic workcell and verify that his robot program did what he had intended. Typically, the components in the workcell (including the part or part components) already exist in some mechanical CAD environment and are available to these tools. However, to truly debug the robot program in a virtual world, the rest of the environment needs to interact dynamically with the motion of the robot. Clamps need to open and close; parts need to move in; humans need to start and stop processes. Today, these components are programmed in the virtual world through a combination of proprietary modeling languages and graphical interfaces. In the real world, these nonrobotic components are typically controlled with a programmable logic controller (PLC).

Other applications like material handling have similar software technologies. AutoSimulations provides throughput and decision modeling capability with their AutoMod product, which features 3D animated graphics with interactive modeling and expert system-based material handling with statistical output reports and graphs. The product runs on both UNIX and PC systems.

PLCs execute relay ladder logic programs that are input/output-specific and are usually written as the last step before startup. The mechanical designer at the machinery builder generates a timing chart, which diagramatically displays the sequence of the mechanical components of the machine, for the control engineer. And the designer, in turn, works from a process chart and floor plan that the end-user's process engineer has provided based on his unique knowledge of how to build the product.

DaimlerChrysler sponsored a demonstration of these two items at the IAM show a year ago. CATIA V5, in beta release at the time, was used to plan the workcell that was set up in the company's booth. A processing-planning tool, developed as an add-in to the CATIA architecture, was used to specify the behavior sequences of the nonrobotic components such as clamps and fixtures. The sequence also identified the interlocks with the robots in the workcell.

Because the object model was built up from the physical resources of the workcell, all items in the sequence were referenced by their names as objects in the CATIA system. Rockwell Automation, using newly developed Rockwell Software technology, was able to read in the timing diagram and convert it to PLC code. Finally, Deneb used the PLC code, executing in a soft controller, to drive the virtual workcell contained in their IGRIP product.

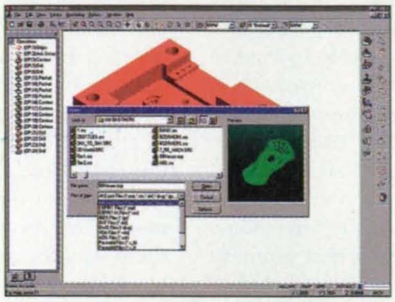
Rockwell Software Enterprise Controls™, currently still under development by Rockwell Automation, is intended to provide new capability to the machine and controls design customer. It will take the output of a mechanical design task—the development of the object model and its associated behavior (sometimes expressed as a timing chart)—and bring it into the controls development environment. Rather than convert the timing chart immediately to ladder logic, the system will allow the controls engineer to elaborate on the original intention of the upstream designer. The engineer can add mode behavior (manual, automatic, etc.), emergency responses, interlocks and safeties, exceptions such as bypass, and other control-specific information. The engineer can also link data reporting to the machine state information—production counts, utilization, rejects, and other management information.

As a next step in the code development process, the specific devices that are available to do the necessary tasks can be selected. Embedded in the device descriptions is the I/O behavior of that device. Only the last step is concerned with I/O. The controls engineer then can create all the names and device-specific detail. Part of the use of object-oriented design permits the encapsulation of device behavior; these entities are called control assemblies. Also contained in a control assembly is information that can be used for generating wiring diagrams, diagnostics, and HMI. Finally, the system can generate code for several different controllers, based on some unique compiler technology embedded in Enterprise Controls.

For more information on Rockwell Software Enterprise Controls, contact the author of this brief, director Jim Coburn, at **Rockwell Automation Control Systems**, *1 Allen Bradley Drive, Mayfield Heights, OH 44124; (440) 646-7977; fax (440) 603-9031. This brief is adapted from a paper of the same title in the 1999 Proceedings of the National Manufacturing Week Conference.* *Copyright © 1999 Reed Exhibition Companies.*

NEW PRODUCTS

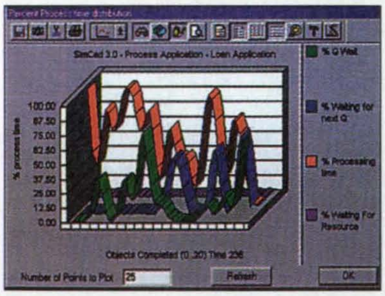
CNC Software



DP Technology, Camarillo, CA, has introduced ESPRIT 99 CAM software for all types of CNC programming. The software features a Windows-compatible interface, support for seven languages, and enhanced support for mill and lathe operations. The new automatic milling feature allows users to immediately generate an area profile for rest material. The program creates machinable features for uncut material and determines the tools needed for the finishing operation. Users can automate the creation of machinable features from a solid model. The software includes over 800 postprocessors and the ability to connect to any machine on a shop floor. **Circle No. 761**

Injection Molding Material

ClearTex™ single-component synthetic latex from Zeller International, Winter Park, FL, is a clear, stretchy rubber material that is non-allergenic, dries fast at room tempreature, is available in a variety of colors, and can be used to produce tear-resistant parts. It can be used for coating, casting, film-forming, injection molding, and extrusion of parts such as gaskets, seals, O-rings, handles, and grips. The waterproof material can be used for dielectric/conformal encapsulation coatings and liquid tapes. It is compatible with urethanes, fiberglas, metal, glass, ceramic, and polymer fortified gypsum, and is available in liquid or bead forms. **Circle No. 763**



Simulation & Modeling Software

SimCad Series 3.1 process simulation and modeling software from CreateASoft, Naperville, IL, enables users to recreate current operating environments, identify problem areas, and simulate real-time solutions. It can be used in any business process, from manufacturing to business services. The software incorporates animation, real-time feedback, and what-if scenarios to streamline process modeling flows. Enhancements include improved model-building, support for resource monitoring, real-time graphing and reporting, and time distribution. **Circle No. 765**

Prototyping Services

Planex USA, Fort Worth, TX, offers ProtoDuction™ services, including near-production-quality injection molded prototypes. The company uses a proprietary E-System process for producing epoxy composite tools. It offers a choice of production materials, low cost, and 200 to 1,000 parts off of each tool. Other services include short shots for mold flow evaluation, functional snap fits, production tolerances, insert molding, and aluminum tooling. **Circle No. 767**

Parts Printer

The Genisys Xs 3D parts printer from Stratasys, Eden Prairie, MN, allows users to build parts up to 12 x 8 x 8 inches. The system operates in a footprint of 36.5 x 32 inches, and can be set on a desk top. It prints in a polyester material; prints can be sanded, drilled, or painted. The system features a built-in clock that tracks cumulative build hours. When the system needs routine service, a user alert is displayed on the LCD panel. The printer uses the Linux O/S operating system and runs on an industrial-grade embedded controller within the machine. It is compatible with intranets and can be networked. All networked users can view the entire print queue to check the status of their parts. **Circle No. 762**

2D CAD Software

ViaGrafix Corp., Pryor, OK, has introduced ViaCAD, a 2D, entry-level CA system for engineering and drawing. Designed for the non-CAD professional, the software allows users to draw a line or other object, and displays the length of the line with the cursor in real time, along with the horizontal and vertical dimensions. The Autodimension command automatically adds dimensions for all selected items in a drawing. The four types of dimensions supported are linear, angular, radius/diameter, and coordinate. A library of 3,000 symbols is standard, and Internet compatibility is provided with JPEG and VRML file support. Other file formats supported for drawing import and export include AutoCAD's DWG and DXF. **Circle No. 764**

Prototyping Kits

Designer's Kits for engineers provide sample quantities of magnetic components made by J.W. Miller Magnetics, Gardena, CA. The samples are for use by engineers in design and prototyping projects. Two kits are available: one for PMH Series high current EMI beads, and one for PMC Series EMI suppression beads. Each kit offers ten pieces each of 12 popular size/impedance combinations. Applications include switching power supplies, computers and peripherals, telecommunications equipment, and audio equipment. They are designed to reduce high-frequency noise interference and are available tape-and-reel packaged in standard EIA chip sizes with solder-coated terminals for wave and reflow soldering. **Circle No. 766**

Infiltration Material

DTM Corp., Austin, TX, offers a polymer infiltration material that allows users to create functional, flexible prototypes such as tubing, hoses, and gaskets from DSM Desotech's Somos® 201 material. Somos 201 is a thermoplastic elastomer powder. Laser-sintered Somos 201 parts infiltrated with the new polymer material are watertight, have enhanced surface finish, and have high burst strength, wear resistance, and tear resistance. Parts can be made in any color. **Circle No. 768** ponent interface (PCI) bus architecture. The software consists of VxWorks tasks written in C++. Various components of the software have either been developed anew or redesigned from heritage code written for prior spacecraft missions.

This work was done by Stephan R. Hammers of the Hammers Co. for **Goddard Space Flight Center**. *To obtain a copy of the report, "SMEX-Lite ACS and C&DH Flight Software," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Information Sciences category.*
GSC-14214

Using Rayleigh Scattering To Measure Spacecraft Attitude

Two reports describe a Rayleigh-scattering attitude sensor (RSAS) — an optoelectronic instrument for determining the orientation of a spacecraft. An RSAS comprises a telescope/video-camera/image-digitizer combination that is mounted on the spacecraft and that captures images of the limb of the Earth in 355-nm-wavelength sunlight that has been Rayleigh-scattered from the atmosphere. (At 355 nm, the atmosphere scatters strongly but does not absorb significantly.) A computational model of the 355-nm radiance of the atmosphere as a function of altitude, lighting conditions, and viewing angle is then used to extract, from the image data, an estimate of the angle between the line of sight of the RSAS and the nadir.

This work was done by Pawan K. Bhartia and Ernest Hilsenrath of **Goddard Space Flight Center**. *To obtain copies of the reports, "Rayleigh Scattering Sensor for Spacecraft Attitude Sensing (RSAS)" and "Design Development, and Test-Flight of the Rayleigh Scattering Attitude Sensor," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Physical 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-13858.

Diagnosing Gas-Turbine-Like Combustion by Use of PLIF

A report describes experiments in which planar laser-induced fluorescence (PLIF) of hydroxyl radicals was used to study the structures of flames in burner test rigs (a flame-tube combustor and a sector combustor) under conditions like those in combustors of aviation gas-turbine engines. The PLIF images from the sector-combustor experiments generally confirmed that the combustor functioned as designed. The PLIF images from the flame-tube experiments revealed previously unknown nonuniformities in flame structures; these images provided guidance for selection of an optimum number of fuel-injection points and for modifications of the fuel-injector design to improve combustion characteristics.

This work was done by Yolanda R. Hicks and Robert C. Anderson of **Glenn Research Center** *and Randy J. Locke of NYMA, Inc. To obtain a copy of the report, "Multi-Dimensional Measurements of Combustion Species in Flame Tube and Sector Gas Turbine Combustors," 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: Tech Brief Patent Status, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16565.

Driving Plastics Use in Auto Design

Plastics join together to eliminate painting of automotive body panels.

Automotive production has long been a major area for innovative plastics applications. In recent years, increasing demands for lightweight construction have been the key reason for the growing amount of plastic used. Numerous interior components are made of plastics, and now, plastics are making inroads into the exterior car body parts, which largely have been the domain of steel.

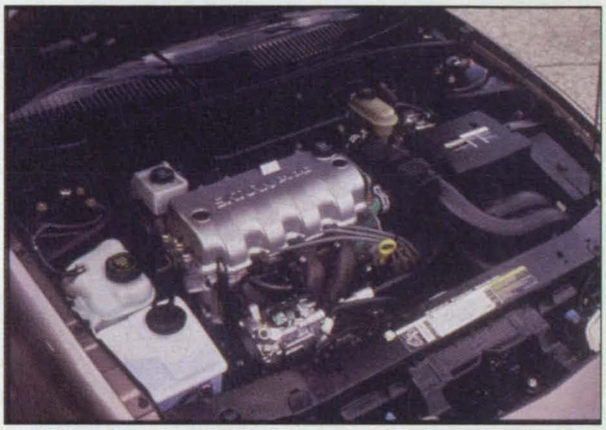


Photo 1: Heater/air conditioner vents now are made with plastics.

Photo 2: Automotive mirror housings also are commonly made of plastics.

For exterior parts, plastics offer the potential for an average weight savings of 50 percent. In addition, plastics provide greater design freedom, with the very significant benefit of parts consolidation. Thanks to the low tool costs in small- and medium-sized series, components made of plastics are comparable to sheet steel in terms of cost. Compared to parts made of other lightweight materials, plastics yield cost advantages in larger unit quantities. New types of vehicles, the diversity of models, and the desire for individual design all promote the increased use of plastics.

Many of the first exterior automotive plastics applications are painted. This is done for design reasons, so the plastic parts are the same color as the metal body. It also provides resistance to the effects of weathering — in general, plastics are affected by exposure to sunlight.

However, in the early 1990s, some exterior plastic components began to be made of Luran® S ASA (from BASF), a material that has excellent resistance to ultraviolet radiation and does not require painting. Today, many automobile manufacturers are using the plastic for heater/air conditioner vents, spoilers, headlight housings, mirror housings, cowl vent grills, and filler panels (See Photos 1 and 2).

A Strong Case for Plastics

A greater use for such materials that is growing steadily is large body panels such as rear hatch panels (See Photo 3). Extensive product and application development work is underway to develop lightweight composite plastic materials for making large body panels that do not require painting. Coextruded films, consisting of acrylic/ASA or acrylic/ASA-polycarbonate, can be applied to other plastic substrates to provide a pleasing aesthetic design and excellent UV resistance. Metallic, glitter, bronze, pearl, and tortoise-shell effects can be achieved with the film.

The coextruded films can be combined with many different types of plastic substrates such as:

- An outer shell thermoformed from coextruded film and an ABS support layer injection molded from behind the shell. The injection molded ABS backing provides an efficient means for reinforcing the shell and adding bosses and ribs for additional stiffness and mechanical fastening. Recycled ABS or other thermoplastics also can be used to lower materials cost.
- An outer shell thermoformed from coextruded film, behind which an ABS support is injection molded, then a glass fiber reinforced (GFR) polyurethane (PU) foam is sprayed, and the foam is covered with another shell formed from the coextruded film.
- An outer shell thermoformed from coextruded sheet, backed with a sprayed fiber reinforced foam. Spraying of a GFRPU foam system behind the outer shell allows the foam to bond to the inner surface of the shell and, thus, improve the structure's rigidity. The fibers are mixed with the PU ingredients before the mixture is sprayed. This ensures thorough fiber distribution in the foam. Glass fiber is the main reinforcement now used, but other fibers, including graphite, are possible. The fibers are used chopped and as fabrics, including three-dimensional structures.
- Laminating a synthetic fiber fabric to the GFRPU foam eliminates a separate manfuacturing step. The fabric is attached to the surface of the upper

Photo 3: An even greater use of plastics in automobiles is large parts such as rear hatch panels.

Photo 4: The new Smart Cars from Mercedes incorporate a plastic one-piece roof and roof liner.

Photo 5: The Paradigm™ prototype car makes extensive use of acrylic coated plastic body panels.

mold half and bonds to the foam when it expands in the closed mold. This technique is used to produce the one-piece roof and roof liner for the new Smart Cars made by Mercedes (See Photo 4).

One of the first vehicles to make extensive use of acrylic coated Luran S ASA body panels will be the Paradigm®, a new, low-emissions, high-mileage, mid-sized car (See Photo 5). Automotive Design & Composites Ltd. of San Antonio, TX, developed, designed, engineered, and built the Paradigm prototype. The Paradigm will go into production in December at a Huatong Motors plant in China. A second Paradigm plant is planned for San Antonio.

The Paradigm's body is made of reinforced thermoplastic composite panels. The high-gloss, pre-colored body panels are produced using three plastic processing techniques: sheet extrusion, thermoforming, and fiber reinforced molding. The process starts with co-extruding a three-layer sheet: a thin top layer of acrylic, providing gloss, scratch resistance, and surface hardness; a second thin layer of Luran S ASA for toughness, UV resistance, and color; and a third layer of Terluran® ABS, providing impact strength and stiffness.

Next, the co-extruded PMMA/ASA/ABS sheet is thermoformed and trimmed to the shape of the desired panel. In addition, a single-layer panel of Terluran ABS is formed to the same shape as the multilayer panel.

In the next step, the formed PMMA/ASA/ABS shell is placed in a holding fixture. A multi-layer fiber cloth, consisting of unidirectional fiberglass fabrics stitch-bonded together, is placed on the outer skin. Then, the formed ABS panel is placed on top of the dry fabric. The two thermoplastic panels are sealed at their perimeter. A vacuum evacuates the air from between the two sheets and pulls a thermoset resin into the fiberglass fabric. The part cures at room temperature, but curing time can be accelerated by placing the part in an oven. One or both skins can be removed from the composite piece, depending on the requirements of the customer. The cycle time is as low as eight minutes on large parts. The fiber reinforced molding process is a proprietary development of AD&C.

This article was contributed by BASF Corporation. For more information, contact BASF at 3000 Continental Drive North, Mount Olive, NJ 07828-1234; Tel: 973-426-2600; Fax: 973-426-2610; or visit the web site at: www.basf.com.

Optimization of Vehicle Interior Noise Treatment

A new approach combines test data, FEA, and boundary element methods for vehicle interior acoustic optimization.

Automated Analysis Corp., Ann Arbor, MI

Automotive interior noise has become a critical consideration for manufacturers. Many studies have shown that interior noise in a vehicle has a major impact on the customer's perception of operation, performance, and quality. However, to reach desired interior sound levels, many manufacturers have needed to add sound absorption, damping, and barrier materials to the vehicle. These additions lead to higher weight and costs.

Automated Analysis Corp. offers a new capability for optimizing vehicle interior noise treatments. The new approach combines test data, finite element analysis (FEA), and boundary element methods (BEMs) to produce the best available process for vehicle interior acoustic optimization.

Ideally, one would minimize noise generation at the source, whether it is the engine exhaust, tire-road contact (road noise), wind noise, or any of a hundred other sources. Often, treatments along the path of sound energy transmission are used to reduce noise. These may take the form of vibration isolation, sound barriers, sound absorption materials, or damping materials.

The new approach — Panel Acoustic Contribution Analysis or PACA — employs Automated Analysis Corp.'s COMET software combined with FEA and/or measured results. COMET uses the boundary element analysis process to build very precise relationships between the surface velocity of panels and noise at any interior point. These sensitivities allow the precise calculation of the contribution from a given panel.

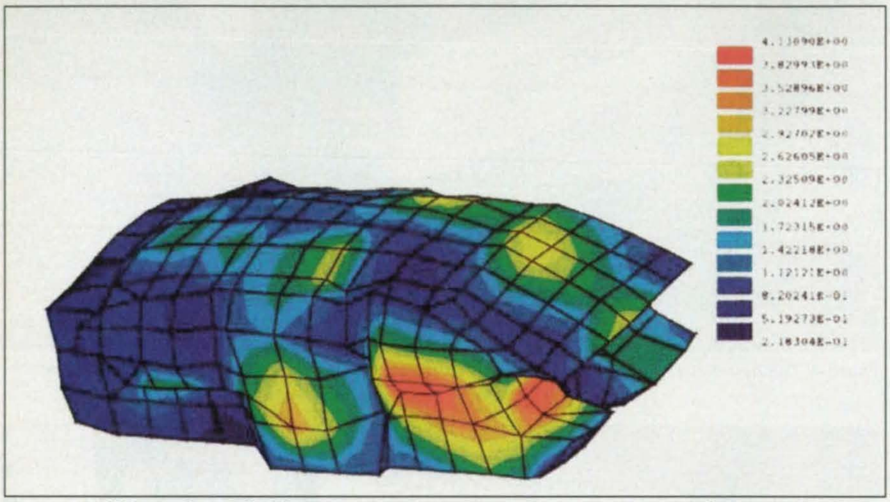


Figure 1: **Vehicle Surface Velocities**

Since COMET models the precise relationship between sound waves arriving at the point of interest, it is possible to determine which waves contribute positively to the total sound level, which have no contribution, and which contribute negatively or reduce the sound. By tracing these contributions back to the panel from which they originated, COMET allows the optimization of the noise treatment.

Where there is a negative contribution, one may reduce the noise treatment by removing barriers or damping treatments. The noise from those panels is actually reducing the noise level at the point of interest, and if possible, this effect should be increased. A significant side benefit of defining such panels is that vehicle weight reduction is possible by removing the sound treatments that are counterproductive.

Perhaps the best way to illustrate the usefulness of PACA is to run through an example. This instance begins with interior surface velocities that are obtained from a combination of measurements and FEA analysis. As is often the case with automotive vehicles, FEA analysis can be used to provide reliable predictions of results to only 200 to 250 Hz. Above these frequencies, the computational requirements get to be larger than what is practical. In this case, experimental measurements were made to determine surface velocities to 600 Hz.

COMET then was used to perform the PACA analysis with the driver's ear as the

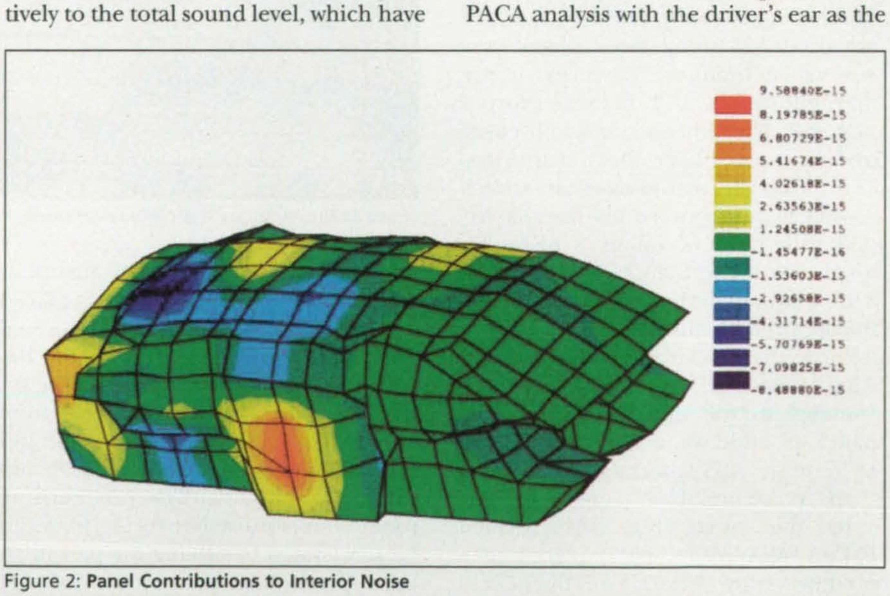


Figure 2: **Panel Contributions to Interior Noise**

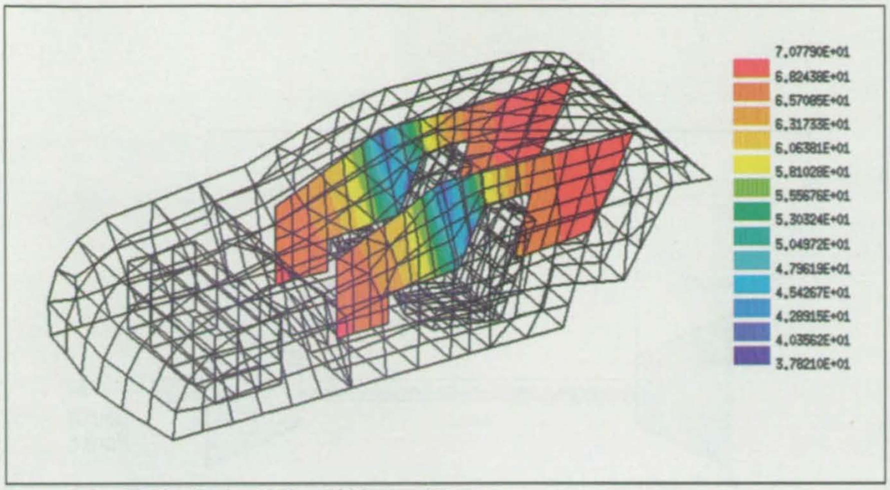


Figure 3: Sound Distribution in the Vehicle Interior

point of interest in the interior. Using a vertical line of icons, COMET takes the user from the entry of data through to the final analysis. Along the way, data and model checks are performed when appropriate, and the user is prompted for all information required. If the user desires, the computer interior noise with improved treatments can be played back using wave files to actually hear the results of recommended changes.

In this particular case, there are large surface velocities in the front passenger corner of the interior cabin (Figure 1). This is shown by the red-yellow color concentration in the lower right corner. Using traditional methods, this is an area that would receive additional acoustic treatments in an effort to lower the interior noise.

The PACA analysis for the same vehicle at the same frequency shows that the contributions from panels look quite different (Figure 2). This contribution calculation of sensitivity is expressed in a range from positive values to negative values representing positive to negative contributions to the noise at the driver's ear. In this case, the change from yellow to green represents the transition from positive to negative. The high velocities in the front passenger corner actually contribute negatively to the interior noise at the point of interest. The best approach would be to not alter or reduce the noise treatment in this area to reduce the noise level at the point of concern.

Midway along the length of the vehicle on the passenger side, as shown in Figure 1, there is another area of high surface velocity. In this case, the sensitivity shown in Figure 2 is positive, meaning that the high surface velocities are a significant contributor to interior noise. Improved noise treatment is necessary in this area to improve interior noise at the driver's ear.

One important concern in such optimization programs is that the optimum obtained be robust enough to handle actual vehicle and occupant variations. Using COMET, it is possible to examine the distribution of sound pressure along the length or width of the vehicle. This sort of analysis can show how sharp variations occur and whether the optimum reach for treatment is robust enough for variations in passenger seating or other factors (Figure 3).

Clearly, the PACA approach to vehicle interior treatment optimization has some academic value, but one may ask how it works with real-world problems. This approach has been used on several vehicle development programs. In one case, an automobile manufacturer was introducing a new sport-utility vehicle and had implemented a large amount of noise control treatment to meet ambitious noise performance goals. The goal was to achieve interior noise levels as good as a "best in class" luxury vehicle. Unfortunately, along the way, too much weight was added to the vehicle.

The development program had reached a stage at which the vehicle weight targets were exceeded and the noise objective was not quite achieved. In an attempt to reduce vehicle mass and continue to work toward the noise performance goal, PACA was employed on a trial basis. The result was a reduction of 2 dB in interior noise, with a weight reduction of 10 pounds. The vehicle was able to meet the ambitious noise performance target at a lower weight than what was thought possible.

This work was performed by James K. Thompson, Ph.D, PE, for **Automated Analysis Corp.**, *Ann Arbor, MI. For more information, call 313-973-1000; Fax: 313-973-1190; www.autoa.com.*

Software for Analyzing Performance of a Gas Turbine Engine

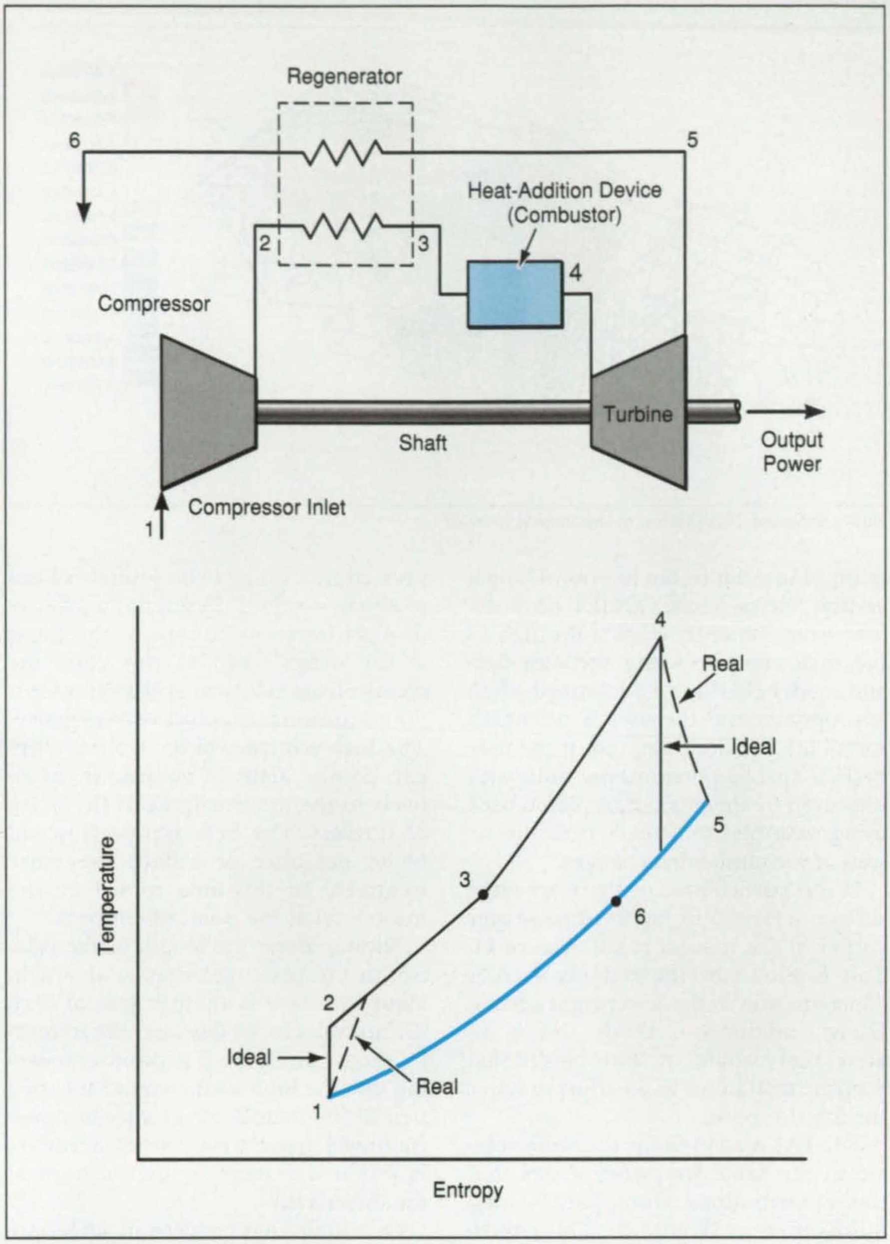
The user can rapidly evaluate alternative preliminary designs.

John H. Glenn Research Center, Cleveland, Ohio

A computer program provides capabilities for numerical simulation and analysis of the thermodynamic performance of aircraft or automotive gas turbine engines. The program was developed to utilize the turboshaft-engine experience base accumulated in aerospace disciplines for designing automotive engines. Potential applications range from (1) small hybrid automotive power systems (power systems that include energy-storage subsystems) with power levels of about 25 kW to (2) heavy truck and earth-moving-machinery powerplants with megawatt power levels.

Given such inputs from the user as turbine and compressor inlet temperatures and performance characteristics of subsystems, the program calculates such powerplant thermal-performance characteristics as thermal efficiencies, specific fuel-consumption rates, cycle state points, and rates of flow of working fluids. The program also calculates data on fuel economy for a specified vehicle weight and an assumed driving cycle.

The program is based on a mathematical model of an open Brayton thermodynamic cycle (see figure). It was derived from a closed-Brayton-cycle program, "BRMAPS," developed previously for outer-space power systems energized by nuclear or concentrated solar heat sources. Written in a scientific programming language called "VSAPL," the program includes several interconnected subprograms that calculate the thermodynamic-performance quantities and that use empirical mass models to calculate the masses of essential subsys-



An **Open Brayton Cycle** is the theoretical basis for analysis of the performance of a gas turbine engine.

tems and components. The code also computes the mass of the overall system, comprising the aforementioned components and subsystems plus interconnecting ducts and structures.

A key feature of the program is an iterative steepest-descent optimization routine that, for a given cycle temperature ratio (turbine-inlet-temperature/compressor-inlet temperature), rapidly converges to the optimum pressure ratios for maximum thermodynamic efficiency, minimum radiator area, and minimum overall system mass. Of course, performance figures can also be calculated for pressure ratios specified by the user, but by providing optimum values, the program enhances system analysis procedures drastically.

In its state of development at this writing, the program can be used to compare performances of alternative designs of automotive gas turbine engines and of hybrid systems that include gas turbine engines, under steady-state operating conditions. By use of this program, one can rapidly ascertain the payoff in fuel economy as a function of improvements in components or higher turbine inlet temperatures (made possible by use of advanced materials). Thus, the program can help to guide engine development along a most efficient and productive path. Subsequent versions of the program are expected to incorporate refinements of empirical models of component weights, plus models for volumes and costs.

This work was done by Albert J. Juhasz of **John H. Glenn Research Center.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the Software category.* *LEW-16709*

Special Coverage: Automotive Technology

Redlake Imaging, Morgan Hill, CA, has introduced the *Motion-Scope®* V series solid-state, high-speed, onboard **vehicle video systems** that mount directly to any vehicle. The systems feature 12-volt operation and a remote eight-key control pad. Applications include automotive suspension, tire and drive train research, engine testing, and automotive safety studies.

The systems can record 50 to 8,000 images per second, depending on the model. The systems also can record until triggered to capture both controlled and uncontrolled events. Options include camera-to-controller cable lengths up to 50 feet, a low-light camera, and a Hi-G camera.

For More Information Circle No. 730

The Series 22M **automotive transmitters** from Keller America, Hampton, VA, are designed for automotive air conditioning systems in the pressure range of 0 to 500 psi, with overpressure capability of 1500 psi. The units have an operating temperature of -40 to 135°C, and feature a ratiometric output from a 5-volt supply.

The transmitters are available in a brass housing and feature accuracy of 4% to 1%. They are built using a proprietary hydrogen brazing technology that enables fabrication of O-ring-free metal housings.

For More Information Circle No. 731

DVP, Rockville, MD, offers the OmniMeter™ handheld **data collection device** for use in automotive engine diagnostics. The open-architecture, programmable PDA-like device was designed specifically for the implementation of handheld data collection and instrumentation, and features a modular hardware and software architecture. The 195 x 120 x 42mm RISC-based computer is designed around a 190-MHz StrongArm SA-1100 processor.

Peripheral support includes a dual-slot PCMCIA connector, compact flash support, IrDA ports, RS-232 serial port, touchscreen, and keys. Space remains for the addition of custom data acquisition cards and peripherals. Other features include an on-board, multi-voltage power supply; handheld case with stylus and stand; and an HVGA monochrome display.

For More Information Circle No. 732

Watlow Gordon, St. Louis, MO, offers **temperature sensing products**, and insulated wire and cable products for applications including automotive. Various sensors are available, depending on the process being measured, the temperature range, the desired response time, accuracy, and the operating environment.

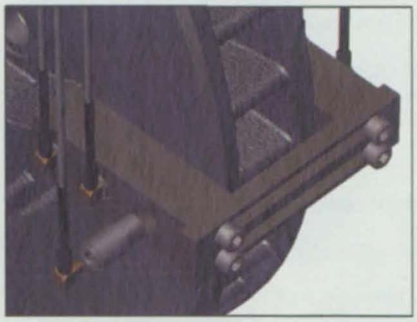
Available products include tube and wire, mineral-insulated, base metal, and noble metal thermocouples; handheld probes; mineral-insulated, metal-sheathed cable; two-wire transmitters; selector switches; connector systems; thermowells and protecting tubes; and Serv-Rite® wire and cable.

For More Information Circle No. 735

The Model 507 **precision current pulse generator** from Berkeley Nucleonics Corp., San Rafael, CA, is used to design and test automobile airbags and fuses. The generator offers digitally controlled current pulses with currents from 0 to 10.0 amps, and pulse widths from 0.1 to 100 ms.

Current control and time-domain resolution allows for characterization of electronic systems. TTL Sync outputs are suitable for video capture or other related test parameters. The Model 507 is available with 2, 4, and 8 channels.

For More Information Circle No. 734



Capacitec, Ayer, MA, has introduced a new line of **disc brake wear analysis sensors** that are capable of taking high-temperature (to 500°C) dynamic brake system measurements both in the lab using dynamometers, and on-vehicle.

The sensors measure displacement variables on a brake rotor in motion. As a result, data can be collected and analyzed to show several characteristics, including rotor run-out, thickness variations, coning, wobble, and thermal expansion.

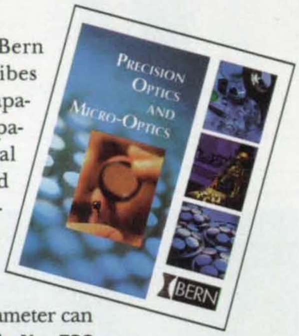
For More Information Circle No. 733

New LITERATURE

Plastics Products

A 51-page catalog from BASF Corp., Mount Olive, NJ, describes the BASF Group's complete line of plastics products. These include styrene copolymers, styrene polymers, engineering materials, foam materials, vinyl chloride polymers and modifiers, fiber composites, polyurethanes, and polyethylenes. Product applications range from automotive, appliances, and construction materials, to food packaging and toys. **Circle No. 725**

Optics and Micro-Optics



A four-page brochure from Bern Optics, Easthampton, MA, describes optics and micro-optics fabrication capabilities. It encompasses expanded capabilities in optical and mechanical design, coating, parts sourcing, and assembly. The company has developed techniques for fabricating micro-optics as small as 0.19 mm in dimension—about the size of a grain of salt. Radius, center thickness, and diameter can be held to 10 micron tolerances. **Circle No. 728**

Elastomer Products

Four information sheets are available from Kent Elastomer Products, Kent, OH, each focusing on a specific elastomer product type. The four categories are Natural Rubber Latex Tubing; Thermoplastic Elastomer (TPE) Tubing; Polyvinyl Chloride (PVC) Tubing; and Natural Rubber Latex and Neoprene Dip-Molded Products. Each product sheet is accompanied by tubing samples, sizing information, and material characteristics. **Circle No. 723**

Flexible Shaft Couplings

An 8-page brochure from KTR Corp., Michigan City, IN, describes the Rotex® GS line of flexible shaft couplings. These lubrication-free couplings are suited to food, paper, plastic, fabric, and other process line applications where lubrication failure can cause serious problems. The couplings are available for both low- and high-torque applications; materials include aluminum and steel. **Circle No. 720**

Tachometers and Sensors

Monarch Instrument, Amherst, NH, has published a Tachometer, Stroboscope, and Sensor catalog. Products include contact/non-contact, pistol-grip, and multifunction portable tachometers, as well as panel/benchtop models. Sensor types include self-powered, optical, laser, infrared, proximity, and magnetic. Portable and machine-vision stroboscopes for diagnostic inspection feature continuous cool operation and input/output triggers. **Circle No. 724**

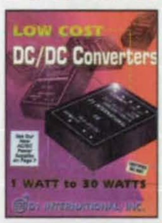
Molded Silicone Cables

A product-information kit from Cicoil Corp., Valencia, CA, describes flat, flexible cables designed for interconnection operations involving temperature and environmental extremes, vibration and shock, and repetitive motion. Applications include process automation, aerospace, robotic, and medical. The company offers more than 85,000 termination options. **Circle No. 726**

Sensor Magnets

Kane Magnetics International, Kane, PA, offers literature on its K-Sen series of sensor magnets. The company manufactures a variety of ferrite magnets using sintered, extruded, and injection-molded processes. Sensor magnets are used in airbag crash detectors, ABS brake systems, and other non-contact switching applications. The company also provides design assistance, 2D and 3D magnetics modeling, mold-flow analysis, and testing. **Circle No. 721**

DC to DC Converters



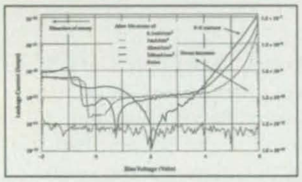
D1 International, Huntington, NY, has introduced a brochure listing more than 490 low-cost DC/DC converters. These products range from 1 to 30 Watts and are available in single- and multiple-voltage outputs. All units have input/output filtering, and they are designed for regulated low ripple and low noise. The company also offers AC-DC 10/15/20W open frame power supplies. **Circle No. 722**

New on DISK

Inspection Software

CGI, Minneapolis, MN, offers Spec.Check™ software that measures points, lines, arcs, circles, and roundness analyses through proprietary algorithms. It creates a dimensional template for the first part; this template is then used to dimension subsequent parts automatically. Each 2D cross-sectional measurement is put into standard SPC (Statistical Process Control) or PPAP (Production Part Approval Process) format. Three methods of part registration are available: manual, best-fit, and feature-based. Other features include color-coded pass/fail print reports and automatic 3D views. **Circle No. 710**

Toolkit Qualifies Semiconductors



The Wafer Level Reliability (WLR) Toolkit from Keithley Instruments, Cleveland, OH, is designed to provide semiconductor fabs with a foundation for implementing a WLR monitoring program. The toolkit can be used with Keithley's Automated Parametric Test (APT) systems to perform JEDEC standard tests. The test library offers isothermal electromigration, time-dependent dielectric breakdown, hot carrier injection, and mobile ion tests. The software is compatible with all Keithley parametric testers, including the S600, S900NT, and S400 UNIX-based APT systems. **Circle No. 711**

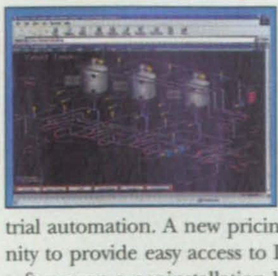
2D to 3D Conversion

Auto-Z 2.0 from EMT Software, Bellingham, WA, is the latest version of Auto-Z for AutoCAD R2000 and R14, as well as MDT versions 3.0 and 4.0. Using existing 2D multi-view drawings as a reference, Auto-Z builds an AutoCAD solid model. In some cases, Auto-Z builds a complete 3D model with no user input. In other cases, the program generates 30 to 99 percent of the 3D model, allowing the user to complete it in an AutoCAD 2D environment. Users can edit solid models by changing geometry in the 2D drawing. The software is network-ready. **Circle No. 712**

Data Visualization for Linux

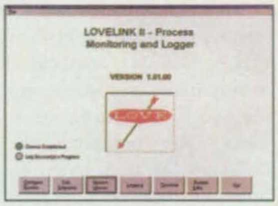
The Numerical Algorithms Group (NAG), Downers Grove, IL, has announced IRIS Explorer Release 4.0 visual programming system for data visualization for the Linux platform. It is designed for creating customized applications for displaying and analyzing complex data interactively. RedHat 5.1 serves as the distribution of the operating system, together with the leading-edge compiler for the port. The program enables collaboration on data analysis. **Circle No. 713**

Automation Package



National Instruments, Austin, TX, has introduced Lookout 4.0 automation software that features advanced multi-server, multi-client networking; integrated, interactive Web support; OPC server and client capabilities; and seamless connectivity with the company's BridgeVIEW™ — LabVIEW™ for industrial automation. A new pricing structure gives developers the opportunity to provide easy access to Lookout client systems without paying for software on a per-installation basis. To access info and screens from the server machines remotely, run-time client software provides users with full, interactive access to the Lookout system. **Circle No. 715**

Data Acquisition and Logging

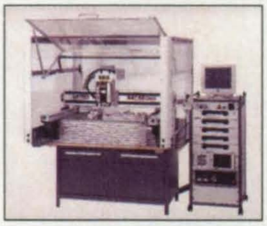


LoveLink™ II data acquisition and logging software from Love Controls Division, Dwyer Instruments, Michigan City, IN, features connection of up to 40 controls on a single computer port; data logging at individually adjustable rates, and user-friendly operator interface. It supports the Love Control Series of 1/4, 1/8, 1/16, and 1/32 DIN microprocessor-based temperature/process controls. It runs on Windows 95/98 and Windows NT Workstation 4.0. An RS-232 or RS-485 converter is available for communication with temperature controls. **Circle No. 717**

Welding Software

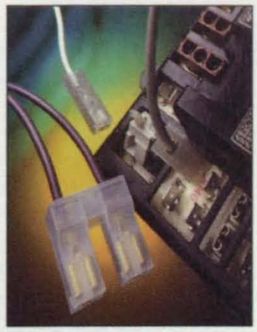
AWS Welding from Computer Engineering, Blue Springs, MO, is designed for writing accurate AWS welding-procedure specifications in compliance with AWS Structural Welding Code. The software creates Welding Procedure Specifications (WPSs) for AWS Section D1.3 and D9.1; prequalified WPSs for D1.1, D1.3, and D9.1; and Procedure Qualifications Records (PQRs) for D1.3 and D9.1. It also provides a welder-management program, and creates and maintains AWS-compliant Welder Performance Qualification Records (WPQRs), welder-continuity logs, and inspection logs. The program can generate lists of all welders qualified for a specific WPS. **Circle No. 714**

Milling and Engraving



Datron Dynamics, Mississauga, ON, Canada, has introduced a milling and engraving system specifically for electronics-industry applications such as front panels, enclosures, rapid prototyping, and machining of sub-assembly parts. The compact 3D system is designed for high-speed machining in aluminum, composites, and other non-ferrous materials. Features include a 60,000-rpm spindle, automatic tool-change unit, and a "Z" probe to measure and map irregular surfaces. Open architecture software design accommodates various file formats from third-party CAD/CAM packages. **Circle No. 700**

Fastening Receptacles



The FASTON™ positive lock receptacle from AMP, Harrisburg, PA, is designed to provide easy assembly and reliable connection. Design features include a reduced insertion force and a locking dimple. When secured, the lock audibly snaps into the hole in the mating tab, thereby helping the installer ensure a mated connection. The devices can be assembled using custom semi-automatic or entirely automatic machines. Two styles of tab-width dimensions are available: The 250 series accepts 22-10 AWG; the 187 series accepts 24-16 AWG. **Circle No. 701**

Long-Life Accumulators

Senior Flexonics Metal Bellows Division, Sharon, MA, offers HIPRES® accumulators that last for 10 years. The accumulators are designed to operate for more than 125,000 bottoming cycles, with system pressures up to 8000 psi. The proprietary welded bellows design hermetically seals gas charge. The all-welded construction has no seals to leak or wear out. The accumulators are designed to be located anywhere on an aircraft; need no charging lines or valves, and do not require an access door. **Circle No. 708**

Servo and Stepper Drives

Gemini digital servo and stepper drives from Parker Hannifin, Compumotor Division, Rohnert Park, CA, are available in nine power levels and two control levels. Features include simplified tuning and digital notch filters in the digital servo drives, along with ABS damping and encoder-less stall detect in the digital stepper drives. Gemini servo drives are designed for input power ranges of 120 or 240 VAC 1-phase and 240 VAC 3-phase for up to 5800 watts of continuous output power. Gemini stepper drives are designed for input power ranges of 120 VAC 1-phase and 240 VAC 1-phase for up to 1350 watts of continuous output power. **Circle No. 707**

Closed-Cell Sponge

Lauren Manufacturing, New Philadelphia, OH, offers a super-soft, EPDM black closed-cell sponge compound designed for applications requiring low closure force in the automotive, marine, transportation, heavy equipment, and weather-stripping industries. It features a density of 12 ±3 pcf, a compression deflection rating of 2-5 psi, compression set of 10%, and is rated as an ASTM 2A1. The sponge can be laminated with pressure-sensitive adhesive systems for seal attachment. It also is formulated for good ozone, UV, and weatherability characteristics. **Circle No. 705**

Thermocouple Wire

Omega Engineering, Stamford, CT, offers a complete line of thermocouple wire for a variety of applications. Thermocouple-grade and extension-grade wire is available from stock, pre-spooled in the following sizes: 24, 50, 100, 200, 500, and 1000 feet. Wire type is identifiable through ANSI standard color coding. The highest temperature-rated ceramic-insulation wire is designed for -17 to 1204°C; PFA-coated Teflon®-insulated wire has a range from -267 to 260°C. Twisted, shielded wire is provided with an integral drain wire to protect against extraneous electrical noise. **Circle No. 706**

New on the MARKET

Polyethylene Film

DuPont Polyester Films, Wilmington, DE, offers a glossy-black grade of its Kaladex® PEN film designed to deliver both aesthetic and functional advantages in flexible circuit substrates and other applications. The film is a biaxially oriented polyethylene naphthalate film. The black grade offers the same performance and mechanical properties as the clear version. Its high stiffness in thin sections allows reduction of mass for enhanced high-frequency response. It is designed to offer high mechanical strength, low thermal shrinkage, high dielectric strength, and chemical resistance. **Circle No. 703**

Clean Planetary Gearheads

Thomson Micron, Ronkonkoma, NY, has introduced cleanroom- and vacuum-compliant UltraTRUE™ True Planetary™ gearheads that are designed to deliver quiet, high-torque operations and feature all-metal construction with no plastic seals or internal components. Applications include equipment for wafer polishing, CMP (chemical mechanical planarization), chemical or plasma deposition, and wafer cleaning. The gearheads are available in either in-line or right-angle construction. The five frame sizes range from 1:1 to 100:1. They offer rated torque up to 31,000 in-lbs and a 92% efficiency. They can be mounted to a stepper or servo motor with the self-aligning Redimount™ mounting system. **Circle No. 709**

Rugged Enclosure

Dranetz-BMI, Edison, NJ, has introduced the LPC4300 enclosure for its Power Platform 4300 power-quality monitor. The enclosure is rated for harsh NEMA 4-X environments and includes sealed, weather-proof, molded cables for connection to the electric power system. Other features include a lockable case and provision for a security cable. The Power Platform 4300 is designed to monitor electric power lines for sags, swells, impulses, peak demand, harmonics, true RMS voltage/current, and power factor. **Circle No. 702**

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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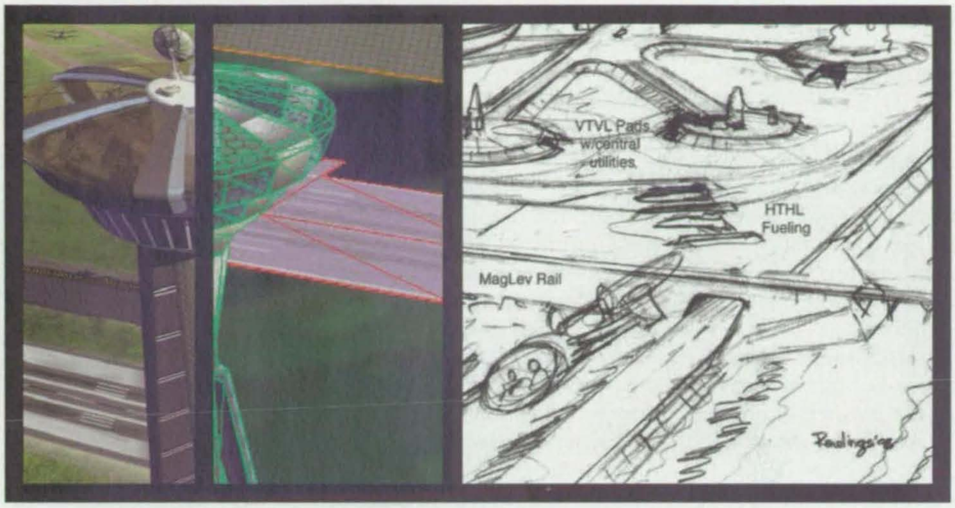


Vision Spaceport: Space Development in the New Millennium

NASA's Kennedy Space Center is leading a major initiative to identify the technologies that will enable revolutionary "spaceports" of the future. The Vision Spaceport program partners NASA and industry to develop the infrastructure to support the next generation of space planes. The initiative will be one of the featured tracks in the first-ever NASA Business Forum, focused on emerging commercial opportunities in aerospace and aviation. The forum is part of the NASA-sponsored Technology 2009 national technology transfer conference at the Fontainebleau Hilton in Miami on November 1-3. (For more information on the workshop, visit www.techeast.net.)

Leading up to this event, *NASA Tech Briefs* presents a special two-part article describing the major areas in which NASA is looking to partner with industry on technology development into the new millennium. This month's Part I features the technological and economic challenges of realizing Vision Spaceport, as well as models of industry participation. The October issue will conclude with space-based manufacturing capabilities and advanced propulsion and engine technologies.

It will be surprising to many to discover that today's airplanes and space vehicles have a lot in common. Both have engines using fuels and oxidizers to defy Earth's gravity. Some space vehicles, such as the Space Shuttle, have wings to return to Earth like an airplane. Airports and spaceports, too, share a number of features. Both have hangars, service shops, control centers, even runways.

A major difference between the two is flight rate. The process of readying a modern-day space vehicle is costly and time-consuming, primarily due to the complexity of the vehicles and ground operations required to prepare them for flight. One way to achieve higher flight rate and lower payload delivery cost is to create new, cost-effective space transportation that addresses both flight and ground systems in one unified design. This approach is aimed at providing a major reduction of vehicle-to-ground interdependence.

Enter Vision Spaceport, the first joint-sponsored research agreement between NASA Kennedy Space Center (KSC), industry, and academia. Each member of the partnership lends invaluable expertise to stimulate the creation of integrated space vehicles and spaceports.

Kennedy Space Center, as the Center of Excellence for Launch & Payload Processing Systems, in its role as the US Spaceport Technology Center, provides a gathering place for many of those people with expertise in launch site operations. That expertise is being shared by the Vision Spaceport partnership in casting a sharp eye on developing the technologies needed to support the increased flight rates envisioned for tomorrow's spaceports.

Great Technology Challenges

Prominent technology needs impact both flight vehicles and ground systems. Inflight systems, reusable cryogenic tanks, simplified turbomachinery and engines, tighter integration of sub-systems, and robust thermal protection systems are envisioned as areas for intense research and development. These items, though vehicle associated, are known to contribute to operations work load, and impact both cost and cycle time (launch rate).

In ground systems, a lean, integrated infrastructure is required everywhere, from propellant servicing, to command, control, and monitoring of spaceport activities. Efficient spaceport infrastructures envisioned for the future can encourage the growth of space transportation as an industry, while antiquated systems present numerous barriers to establishing record launch-rate capabilities. As new flight systems and technologies come on-line, their maturity and reliability will increase hand-in-hand, enabling still further growth of spaceport operations as hubs of economic activity.

One of the greatest challenges is to encourage designers of flight vehicle concepts — and the responding spaceport systems operators — to develop their designs together in a synergistic manner. Neither, alone, can develop the most operationally effective systems.

Economic and Policy Challenges

The task of developing fully functional spaceports for the next generation of launch vehicles also has technical, economic, and policy challenges. Technology challenges include

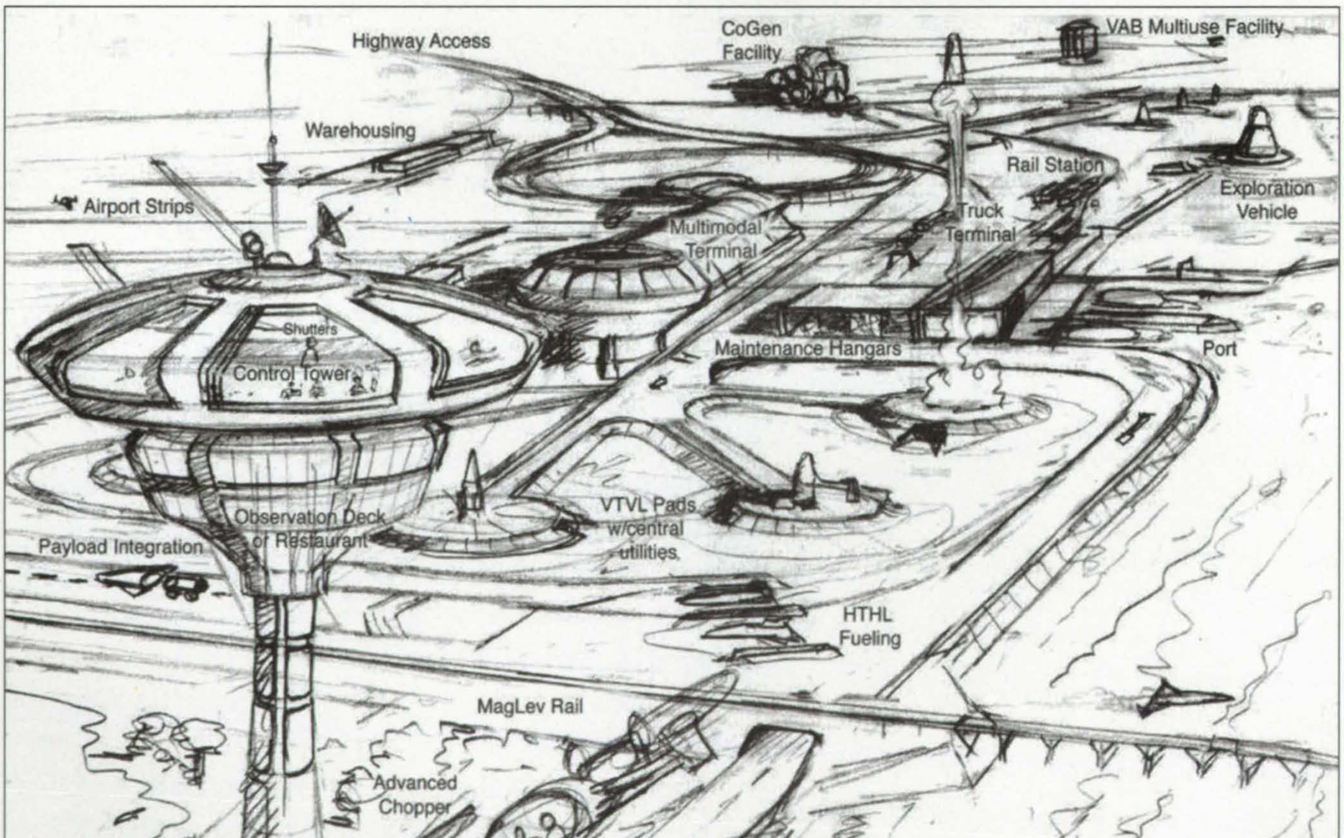
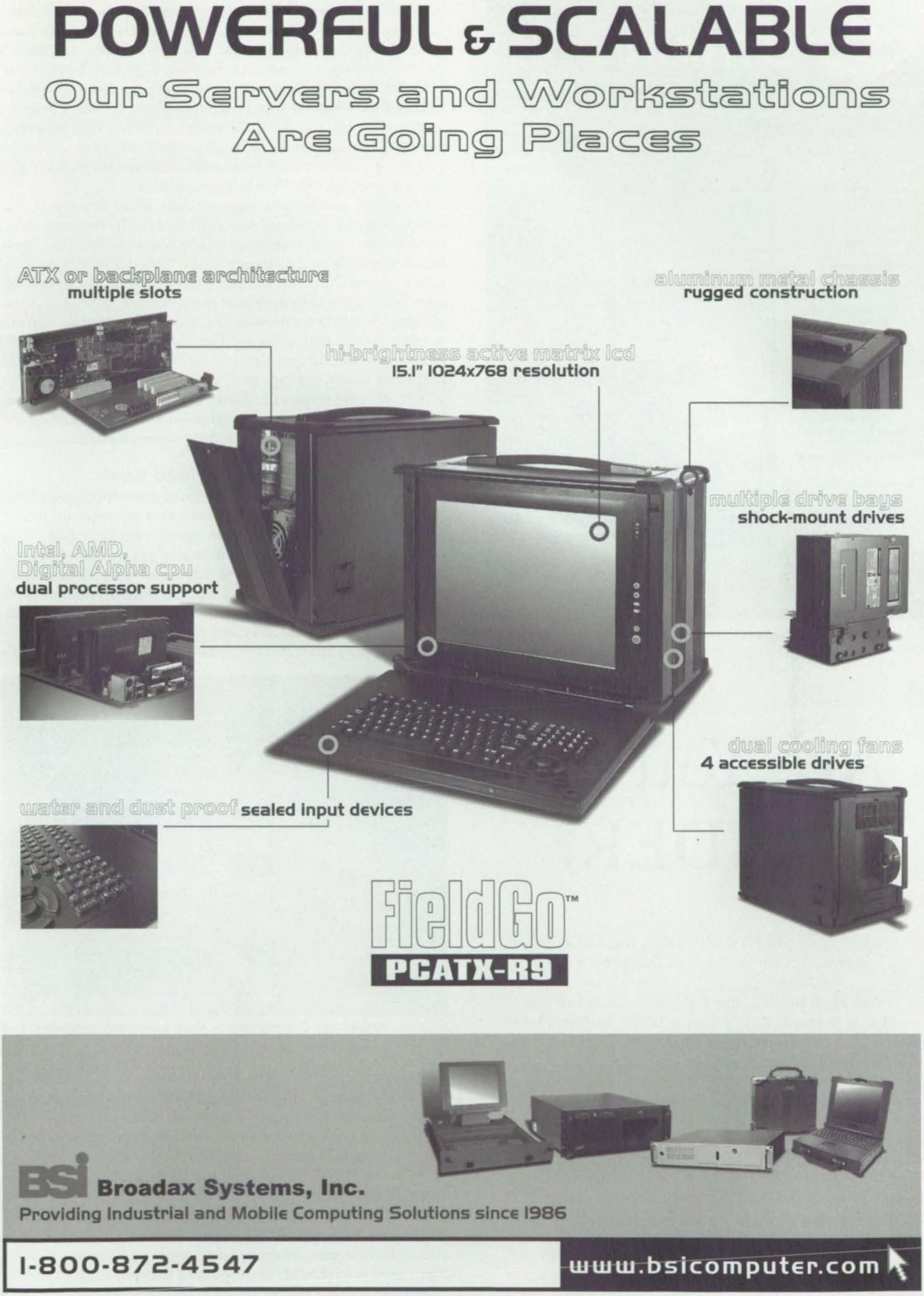


Figure 1: The Spaceport vision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integrating a host of 21st century systems, from operators, through electronic networks, to end items such as sensors and valves. Economic challenges include how to boot-strap financing the development of such systems, especially in the near term, while contemporary flight rates are not likely to quickly amortize such investments. Policy challenges include questions such as who will pay for such investments. Are user fees on a pay-as-you-go approach — such as with airports — useful guides for spaceport developments? What are the roles of private industry, and which befall government?

Integrated ground and flight systems, when developed, will lead to a global proliferation of spaceports. In the near term, because space vehicle reliabilities are not yet aircraft-like, public safety will drive developers to the national ranges as mandated spaceports. Even though proposed single-stage-to-orbit systems have no components to drop enroute to orbit, the single stage requires maturity and reliability far beyond current systems before flights over populated areas are envisioned. When these hurdles are cleared, the "spaceport as airport" will become a reality, perhaps seeing space planes departing from a host of new terminals. States such as Alaska, California, Florida, New Mexico, and Virginia already are investing resources to be ready and able to meet these challenges.

Routine Space Flight: Payload Cost

Economic studies have indicated that cost reductions of two orders of magnitude from today's markets are required before fully elastic markets develop in space transportation. This means getting "cost" down to about $100 per delivered payload pound, with "price" perhaps only twice as high. For comparison, this means getting the cost of a trip down to about that of a round-the-world ticket (with amenities) on the Concorde. Studies show that small, efficient space fleets of about 14 vehicles, with high utilization factors (launch rate), conceivably

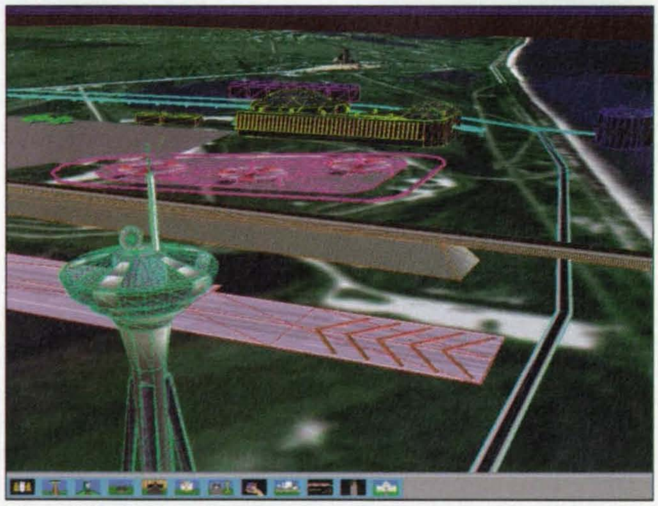

Figure 2: Technology Development — Paving the road to fulfillment of the vision

may enable such ventures as public space transportation, or large-scale energy enterprises such as the construction of Space Solar Power energy transmission stations in the sky. Fascinating challenges await the space transport industry. Many difficult questions must be examined and answered.

Vision Spaceport Partners

To lift the project off the ground, Kennedy Space Center gathered a circle of industry and academia partners to examine launch site operations and their cost-driving factors. Their goal is to identify technologies that will support the effective, affordable space transportation essential to opening space for commercial enterprise.

The partners have formed a consortium of launch site analysts and engineers, known as the Spaceport Synergy Team. The members are:

- NASA John F. Kennedy Space Center
- NASA Ames Research Center
- The Boeing Company
- Command and Control Technologies
- Lockheed Martin
- Quantum Technologies Services, Inc.
- Science Applications International Corporation
- The University of Central Florida

The KSC partnership also is working closely with Marshall Space Flight Center, Johnson Space Center, Langley Research Center, and industry partner vehicle designers to assure the model provides the best available operational assessment for future vehicle concepts.

Together, they are developing a cost and performance modeling tool for integrated vehicle and spaceport concepts. This innovative, computer-based model, when complete, will use information from the world's launch systems to estimate the cost and throughput performance of near-future designs. The model thereby can be used to assist designers of future Space Transportation Systems in focusing on achieving affordable operating cost.

The prototype "core" model has been completed and currently is undergoing extensive validation and calibration using historical data in cooperation with the other NASA centers. A validated Version 1.0 beta model is expected to be available for use late this year.

Figure 3: Vision Realized — When the application of vision and technology coincide

Based on the launch vehicle designer's input, the model is being developed to provide system design information in various categories, including, but not limited to, estimates of:

- Identity of required spaceport facilities
- Facility and support equipment acquisition cost
- Work force size
- Operations cost summary
- Vehicle and spacecraft processing time
- System flight rate

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Scope of the Model

Scope of the model covers three major areas of spaceport functionality:

Launch System Operations. This will include modules for:

- Payload preflight processing
- Launch operations
- Flight control
- Vehicle landing and recovery

The second major functional area is *Optional Facilities*, including accommodation for:

- Vehicle assembly and integration, if needed
- Vehicle servicing for return to flight
- Expendable elements, if any

The third functional area addressed by the model is *Support Infrastructure Facilities*, such as:

- Transportation system management and planning
- Concept-unique logistics
- Spaceport operations support
- Vehicle depot maintenance support

The model, serving as a decision-supporting tool, will enable designers to assess the new launch system concept and evaluate its cost-effectiveness.

The first step in using the model is to access the data input tabs. This is where designers define their flight system. Essential characteristics of the vehicle are input, as well as cargo-carrying capabilities, identity of subsystems, and other pertinent data. This step is key because vehicle characteristics influence the spaceport architecture, contributing to overall cost of the system and the resulting flight rate.

Figure 4: The three-dimensional Virtual Spaceport artist's concept

After flight vehicle design data are input, the model will generate simple data sheets showing required spaceport facilities, vehicle and spaceport operational costs, processing cycle times, and numerous other cost-affecting parameters. In a simple tabular format, the designer easily can see how different vehicle designs impact launch site infrastructure, and the associated costs and cycle times.

Graphical Output: The Virtual Spaceport

Another more intuitive output of the model will be a "virtual spaceport" — a real-time, three-dimensional sample rendering of facilities required by the system concept. The Virtual Spaceport uses three-dimensional launch site infrastructure models positioned on a two-dimensional ground reference. This will make the output data easier to interpret, and thus accessible to a broader audience.

Some launch site facilities commonly associated with present-day spaceports may not be essential for future concepts. For instance, a horizontal take-off space-vehicle may not require vertical processing infrastructure. Other types of spacecraft might rely on a magnetic-levitation rail for take-off. An airport-style control tower might be used in place of a bunker-like launch control center. The artist's concept in Figure 4 shows how future-generation processing and launch control equipment dramatically may reduce the required work force and accommodate increased flight rates.

The three-dimensional Virtual Spaceport will allow the user to fly through the model and examine the infrastructure from different perspectives. Many areas of the 3D model are being hyperlinked to data sheets for the particular facility in question.

Benefits of the Project

Kennedy Space Center, through its goal to become a Spaceport Technology Center, is a leading developer of spaceport technologies. The tools being developed there will provide an insight into spaceport designs of the future. As KSC moves into the future with greater emphasis on research and development, it is strengthening plans to be both a provider of spaceport technology, and a spaceport-of-choice for many customers of the future.

As the payload delivery and operations costs continue to go down, more and more commercial cargo will be launched into Earth orbit and beyond. NASA's vision is of a day when human space flight becomes routine and affordable for anyone. The new technologies to support this vision already are being developed. Vision Spaceport is about our future.

The Vision Spaceport partnership welcomes participation of organizations with a vision for achieving affordable space access. The partnership particularly seeks collaboration and expertise in key areas such as space operations performance benchmarking, technology roadmapping, cost modeling, facility visualization, and related fields. Spaceport operators also are particularly welcome to contribute their unique perspective on reducing spaceport operations costs.

Potential participants should recognize that they are expected to contribute funding or in-kind resources to the partnership. All products become property of the Vision Spaceport Project and are available publicly to all interested organizations within limitations of applicable export control regulations.

Those interested further may contact Carey McCleskey, Government Co-chair; e-mail: carey.mccleskey-1@kmail.ksc.nasa.gov, or Ray Byrd, Industry Co-chair; e-mail: byrdr@pgocM5.ksc.nasa.gov. For further information, visit the Vision Spaceport website at: www.visionspaceport.org.

A 10-minute video describing the Project and the modeling effort is available to qualified space industry applicants.

This article was written by Raymond J. Byrd, Industry Co-Chair, Vision Spaceport Project, and was co-written by Sergei Kossenko, Dynacs Digital Media Lab, Kennedy Space Center. Byrd has worked at Kennedy Space Center most of the past 34 years since becoming an S-1C mechanical systems engineer on the Saturn-Apollo program in 1965. His longtime experience in launch site activities is representative of the people and expertise now gathered in the Spaceport Synergy Team, with the goal of stimulating development of affordable space transportation. Sergei Kossenko is an award-winning producer of digital media products at the Kennedy Space Center. Artwork is by Pat Rawlings, SAIC Houston, Copyright 1999 Vision Spaceport Project.


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