FALL 2001

Research Horizons

A PUBLICATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY

Tissue Engineering Confronts the Transplantation Crisis

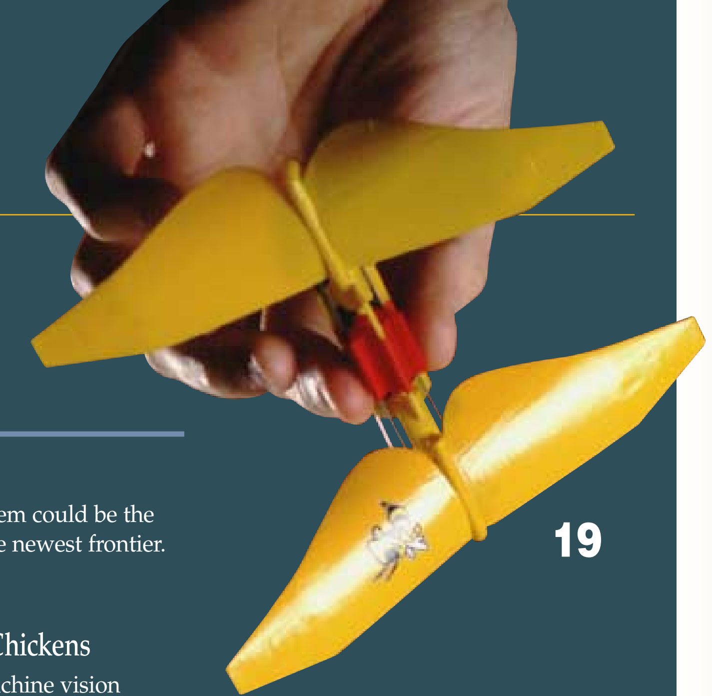
Georgia Institute of Technology

Preview

FALL 2001

COVER STORY

FEATURES



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Research Horizons
Volume 19 Number 1

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COVER: A shortage in donor organs has led to a transplantation crisis. Researchers at the Georgia Tech/Emory Center for the Engineering of Living Tissues are confronting the crisis with research to develop bioartificial tissues and organs. In one project, researchers are exploring the potential of human embryonic stem cells *(yellow image in lower left)* to engineer endothelial cells *(inset)* that line blood vessels. A patient's body would accept the resulting cells.
IMAGES COURTESY OF PHOTODISC INC., BRESAGEN INC. AND STEPHANIE KLADAKIS)

FAR LEFT: Atlanta artist Karen Ku's tissue-themed mural, "The Cell Wall," adorns the atrium of the Petit Institute of Bioengineering and Bioscience at Georgia Tech.
JONATHAN HILLYER PHOTO

Confronting the Transplantation *Crisis*

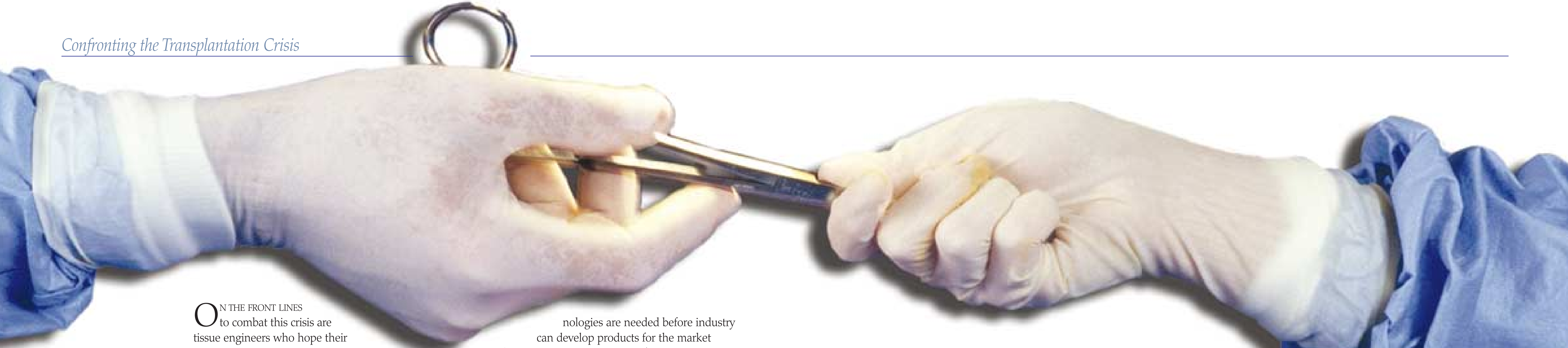
Engineered tissues and organs may one day end the waiting list for donor organs.

By Jane M. Sanders

If you need a kidney, get in line and prepare to wait — five years, in fact, in Georgia. David Bowman, an insulin-dependent diabetic in Atlanta, couldn't wait five years. Instead, he decided to go for a long shot — a kidney and pancreas transplant — that would give him a higher priority on the organ recipient waiting list. Bowman's decision paid off; he waited only eight months to get the organs.

Though a second pancreas transplant was later necessary, Bowman improved his condition from Type 1 to Type 2 diabetes, reducing the amount of insulin he needs. While he considers his transplant experience successful, Bowman is fully aware of the worldwide organ shortage. Now, he speaks to groups, encouraging them to sign up as organ donors.

Many people respond to the need, but the large demand for organs and the technology to store them have combined to create "a transplantation crisis." Thousands of patients die every year waiting for compatible organ donations.



Robert Nerem is director of the Georgia Tech/Emory Center for the Engineering of Living Tissues (GTEC). Research at the center officially began in 1998 with funding from the National Science Foundation and matching grants from Georgia Tech, Emory University and the Georgia Research Alliance.

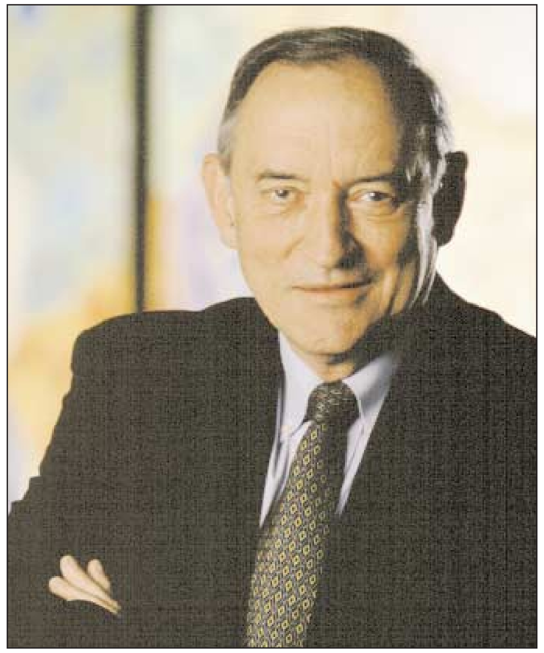


PHOTO BY GARY MEEK.

ON THE FRONT LINES to combat this crisis are tissue engineers who hope their research will one day provide living tissue and organ substitutes. The Georgia Tech/Emory Center for the Engineering of Living Tissues (GTEC) — begun in 1998 and funded by the National Science Foundation (NSF) and matching grants from the institutions and the Georgia Research Alliance — is on the leading edge of this effort.

"Tissue engineering is of great importance in confronting the transplantation crisis," says GTEC director Robert Nerem. "Patient need far exceeds donor availability — in fact, by a 10-to-1 ratio for the heart, liver, kidneys and pancreas. So we are moving toward technologies that address those vital needs, such as an artificial liver and heart components. Then the need for transplants will dramatically decrease."

Nerem defines the engineering of living tissues as "the development of biological substitutes for implantation into the body and/or the fostering of tissue regeneration and remodeling, with the purpose being to replace, repair, maintain or enhance function.."

GTEC researchers are developing enabling technologies to help tissue engineering achieve its full potential, Nerem explains. Their work includes basic and applied research, the development of intellectual property and technology transfer.

In defining its mission, GTEC and its biotechnology industry partners identified three areas where critical core technologies are needed before industry can develop products for the market (which is predicted to exceed $50 billion a year by 2020). Those are: cell technologies, such as methods for cell sourcing, control and function; construct technologies, which are methods for incorporating cells into structures that mimic native tissue in architecture and function, the manufacturing of these structures and the ability to make them available off the shelf; and integration of engineered tissues into living systems, which deals with implantation, and immune and other biological responses.

GTEC researchers are developing these technologies for three types of tissue — cardiovascular components, such as blood vessels and later, heart valve parts and myocardial patches; orthopedic tissues, primarily bone; and metabolic and secretory organs, such as the pancreas and later, the liver. The first three years of GTEC research — funded to date for $6.85 million from NSF — have yielded promising results. Still, the payoff for this investment — predicted to total $23.8 million by 2006 — and the potential relief for the transplantation crisis is at least 10 years in the future.

"There's never going to be a dramatic increase in the number of donor organs available," Nerem says. "The demand will still be there. Tissue engineering could provide a way to dramatically increase the supply. Yes, it's a long way off. But the impact will be enormous." **RH**

■ For more research information, contact Robert Nerem, Georgia Tech/Emory Center for the Engineering of Living Tissues, 315 Ferst Drive, Atlanta, GA 30332-0363. (Telephone: 404-894-2768) (E-mail: robert.nerem@ibb.gatech.edu). For information on organ donation, see the U.S. Department of Health and Human Services' organ donation Web site at **www.organdonor.gov** or call 301-443-7577 to request a donor card. In Georgia, you may contact LifeLink at 404-266-8884 or **www.lifelinkfound.org**.

Helping Hearts

Researchers are developing enabling technologies for cardiovascular substitutes.

By Jane M. Sanders

GTEC director Robert Nerem and doctoral students Jan Stegemann and Stephanie Kladakis have designed a model of a blood vessel wall (above left). They are testing the model to determine the optimal mechanical and biochemical conditions for the implant's appropriate response to normal physiological stimuli.

ARTIFICIAL BLOOD VESSEL IMAGE COURTESY OF JAN STEGEMANN.

WITHIN SEVEN HOURS ONE DAY THIS PAST SPRING, Jerry Klein went from a treadmill stress test to operating room table for heart bypass surgery. It was the most surreal day of his life, he recalls.

A 95 percent blockage in the "left main pump" of his heart stunned Klein, despite his family history of heart disease. In his early 50s, Klein has been an avid weight lifter and exercise enthusiast for 15 years.

"My training (in the gym) saved my life," he says. "I felt a burning sensation in my throat and upper left side of my chest when I worked out. I knew my body, and I knew something was wrong."

Klein — who has returned to work as a senior producer at CNN Sports Illustrated and resumed an exercise regimen — is a success story among the 600,000 patients who undergo heart bypass surgery in the United States every year. (Surgeons perform another 100,000 peripheral artery bypasses each year. And an estimated 25 million people in the U.S. and Europe have artery disease and may need surgery in the future.)

For now, surgeons must bypass diseased arteries with veins harvested from the patient, or, in the case of large vessels, a synthetic substitute made from Dacron or Goretex. Both options can present problems — a patient's veins are often of poor quality, and clots can quickly form in synthetics. Sometimes surgeons cannot use either option, and the patient's condition worsens over time.

Hope is on the horizon, though, because researchers in the Georgia Tech/Emory Center for the Engineering of Living Tissues (GTEC) are developing a blood vessel substitute — initially for small-diameter vessels. Soon, they plan to expand their research in tissue-engineered heart valves and add studies on

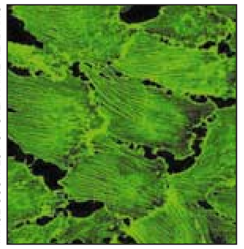


IMAGE COURTESY OF STEPHANIE KLADAKIS

This microscopic image of endothelial cells shows the effects of exposure to shear stress. GTEC researchers are conducting experiments.

RIGHT: Tissue engineering researchers are studying the use of donor cells with novel strategies for achieving immune acceptance. Chris Larsen, *left*, an Emory University transplant surgeon, believes co-stimulation blockade, a procedure he developed with surgical colleague Tom Pearson, may be part of the solution.

myocardial patches (which repair the middle muscular layer of the heart wall).

Specifically, GTEC researchers are developing enabling technologies for (1) controlling biological responses; (2) creating immune acceptance; (3) predicting clinical effectiveness; and (4) engineering biological scaffolds, which are three-dimensional structures in which cells can be seeded to create a construct (basically, an implant) that mimics native tissue function and structure. Meanwhile, researchers are also conducting studies to gain fundamental knowledge in cell biology, biomaterials, biomechanics, implant and transplant immunology, and genetic engineering.

IN THE LABORATORY OF Robert Nerem, GTEC director and head of cardiovascular substitutes studies, researchers are investigating cell sources for tissue-engineered blood vessels. Specifically, they are exploring the use of smooth muscle cells to seed a collagen gel implant coated with endothelial cells. (Endothelial cells line blood vessel walls.)

Nerem and doctoral students Jan Stegemann and Stephanie Kladakis have designed a model of a blood vessel wall. They are testing the model to determine the optimal mechanical and biochemical conditions for the implant's appropriate response to normal physiological stimuli.

Stegemann is engineering smooth muscle cells to suitably contract and interact with endothelial cells. Kladakis has worked with Nerem to quantify and enhance endothelial cell migration in the blood vessel wall model in the presence of simulated blood flow. Results from both students' experiments are promising, Nerem says.

In related studies, Steve Hanson, a professor in the Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech and Emory University, is characterizing the function of endothelial cells (which form the endothelium) and determining their potential use in tissue-engineered blood vessels.

"Researchers want to mimic nature and engineer living tissues that will exhibit the important biological functions of native blood vessels," Hanson explains. "The key issue in tissue-engineered vessels is the endothelium, which confers many of the properties needed to maintain blood flow."

The potential to use endothelial cells in tissue-engineered vessels is greater now due, in part, to recent research at the University of Minnesota. Scientists there developed a method for extracting endothelial cell precursors called angioblasts from whole blood using simple centrifugation techniques. The research showed a robust proliferation of these circulating endothelial cells in the lab, representing a new, easy and quick source of endothelial cells for use in tissue-engineered implants.

Hanson and his colleagues have replicated the University of Minnesota findings in the their laboratory using blood samples from baboons and humans. Now, they have begun animal experiments to compare the functions of circulating endothelial cells to endothelial cells derived from other tissues. Hanson, Nerem and their students are collaborating on research to determine the capacity of endothelial cells to migrate and proliferate on different substrate surfaces and to learn the cells' response to shear forces.

OTHER RESEARCHERS ARE GRAPPLING WITH THE immune response issues associated with the use of endothelial cells in tissue-engineered cardiovascular substitutes. "Endothelial cells are the show stoppers," Nerem explains. "They are very difficult to accept immunologically."

One possible approach is to implant a graft without an endothelium and engineer it to recruit the patient's own endothelial cells. Another method is to provide a transitional endothelial-like lining using an immune-acceptable cell. Yet another possibility is the use of embryonic stem cells to make endothelial cells, an investigation by University of Georgia researcher and GTEC collaborator Steve Stice.

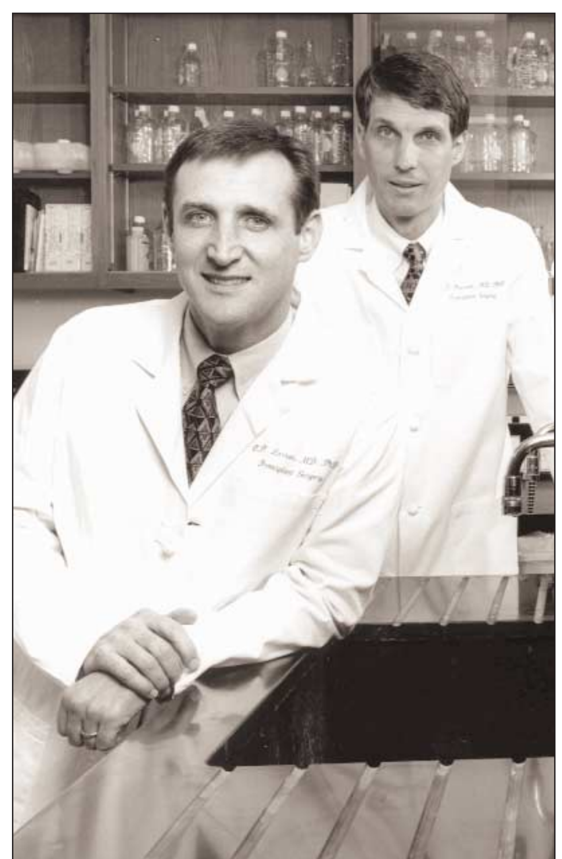
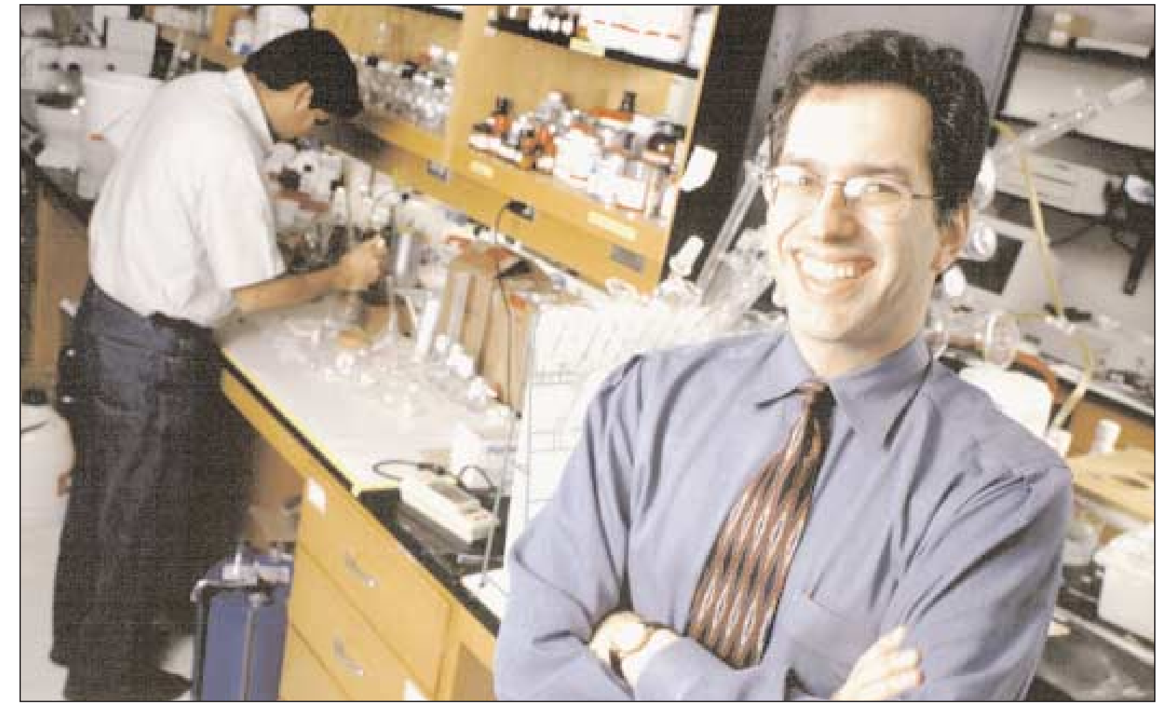


PHOTO COURTESY OF EMORY UNIVERSITY

PHOTO BY GARY MEEK



Elliot Chaikof, an associate professor of surgery at Emory and adjunct professor of biomedical and chemical engineering at Georgia Tech, is studying collagen, which ensures that tissues are strong, and elastin, which allows tissues to stretch and recoil. Using genetic engineering techniques, Chaikof and Vincent Conticello, an Emory chemistry professor, are developing an artificial biopolymer that mimics elastin. Combined with collagen and other materials, it could become a significant building block for artificial blood vessels similar in function to normal ones.

A fourth approach is the use of donor cells with novel strategies for achieving immune acceptance. Chris Larsen, an Emory University transplant surgeon and director of the Emory Transplant Center, believes co-stimulation blockade, a procedure he and his colleagues developed, may be part of the solution. They give patients an agent to selectively block an immune response to a transplanted organ. Doctors concurrently use a second strategy called hematopoietic chimerism (named after the mythical Greek animal called a chimera, which was composed of parts from various animals). With this approach, doctors perform a partial bone marrow transplant — meaning when they transplant an organ or tissue graft, they also introduce bone marrow from the same donor. The co-stimulation blockade should prevent an immune response to the marrow.

"This process re-educates the recipient's immune system so it doesn't reject tissue from a donor," Larsen explains. "The bone marrow-derived cells play a crucial role in defining what the immune system recognizes as self and not self."

Larsen's research results to date are promising. In rodents, researchers have recorded a 98 percent transplant success rate using co-stimulation blockage and hematopoietic chimerism. In primates, barriers still exist, though the results are yielding hope, Larsen adds.

GTEC RESEARCH ALSO ENCOMPASSES THE development of biomaterials that mimic the building blocks of normal blood vessels. Elliot Chaikof, an associate professor of surgery at Emory and adjunct professor of biomedical and chemical engineering at Georgia Tech, is studying collagen, which ensures that tissues are strong, and elastin, which allows tissues to stretch and recoil. Both building blocks provide an optimal mechanical environment for cells to function, he explains.

Using genetic engineering techniques, Chaikof and Vincent Conticello, an Emory chemistry professor, are developing an artificial biopolymer that mimics elastin. Combined with collagen and other materials, it could become a significant building block for artificial blood vessels similar in function to normal ones. It may also have application in tissue-engineered heart valves and cartilage.

"We want to fully characterize the mechanical properties of the polymer, optimize the design characteristics and integrate the structures with collagen so they closely mimic target properties of normal blood vessels," Chaikof explains. "We also want to characterize how well these structures function in animal models. So we're still a number of years away from clinical studies. But we are approaching organ design from a viewpoint of taking rational incremental steps forward."

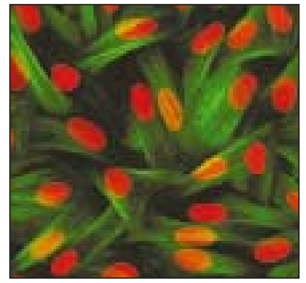
MEANWHILE, FUNDAMENTAL RESEARCH AT GTEC IS showing the role of mechanical forces in tissue engineering. Ray Vito, a professor in the Georgia Tech School of Mechanical Engineering, is using an organ culture system designed by his colleague David Ku, a Regents professor in the School of Mechanical Engineering and a professor of strategic management and engineering entrepreneurship in the College of

(Right) Graduate student Jan Stegemann is engineering smooth muscle cells to suitably contract and interact with endothelial cells. Results from his experiments are promising.

(Below) Ray Vito, a professor in the Georgia Tech School of Mechanical Engineering, and graduate student Yu Shin Kim, foreground, are using an organ culture system designed at Georgia Tech as a test bed for understanding the mechanical environment of cells. Ultimately, researchers will use information from these studies to establish a rational basis for tissue-engineered design.

Management, as a test bed for understanding the mechanical environment of cells. (The culture system keeps arteries and vascular graft implants alive in the lab for up to two weeks.) Ultimately, researchers will use information from these studies to establish a rational basis for tissue-engineered design.

IMAGE COURTESY OF JAN STEGEMANN



"What's going on mechanically has an influence in determining the function of cells present in a vessel or tissue-engineered implant,"Vito explains. "We've found some surprising things by looking at the heterogeneous microstructure of blood vessels. Mechanics could influence function."

Experiments in Nerem's lab correspond to Vito's findings. Researchers have found that the application of cyclic strain force to Nerem's bioartificial blood vessel model during tissue culturing in the lab improves its mechanical strength and structural organization. And Nerem and colleagues have shown that mechanical forces regulate vascular biology, specifically the role of smooth muscle cells in enhancing the properties of the arterial wall.

IN RESEARCH ON TISSUE-ENGINEERED HEART VALVES, GTEC assistant director Ajit Yoganathan and graduate student Yun Xing are investigating the mechanically diverse forces — specifically, physiological pressure and shear stress — that affect heart valve leaflet cells. (Heart valve leaflets are the flaps that cover the valve openings.)

The researchers are subjecting leaflets to a specially designed pulse-type pressure system. Other experiments will apply shear stress to leaflets. Researchers know from previous studies the estimated level of shear stress to mimic what occurs in the body.

Results of this research will provide insight into the function of native heart valves and yield a standard of comparison for future tissue-engineered heart valves.

Research is ongoing at the Massachusetts Institute of Technology and Harvard University to develop tissue-engineered heart valves. Yoganathan hopes to contribute to this work by using information on cell response to mechanical environments to predict an optimal design for bioreactors used to test tissue-engineered heart valves in the laboratory. **RH**

■ For more information, contact Robert Nerem, Georgia Tech/Emory Center for the Engineering of Living Tissues, 315 Ferst Drive, Atlanta, GA 30332-0363. (Telephone: 404-894-2768) (E-mail: robert.nerem@ibb.gatech.edu)

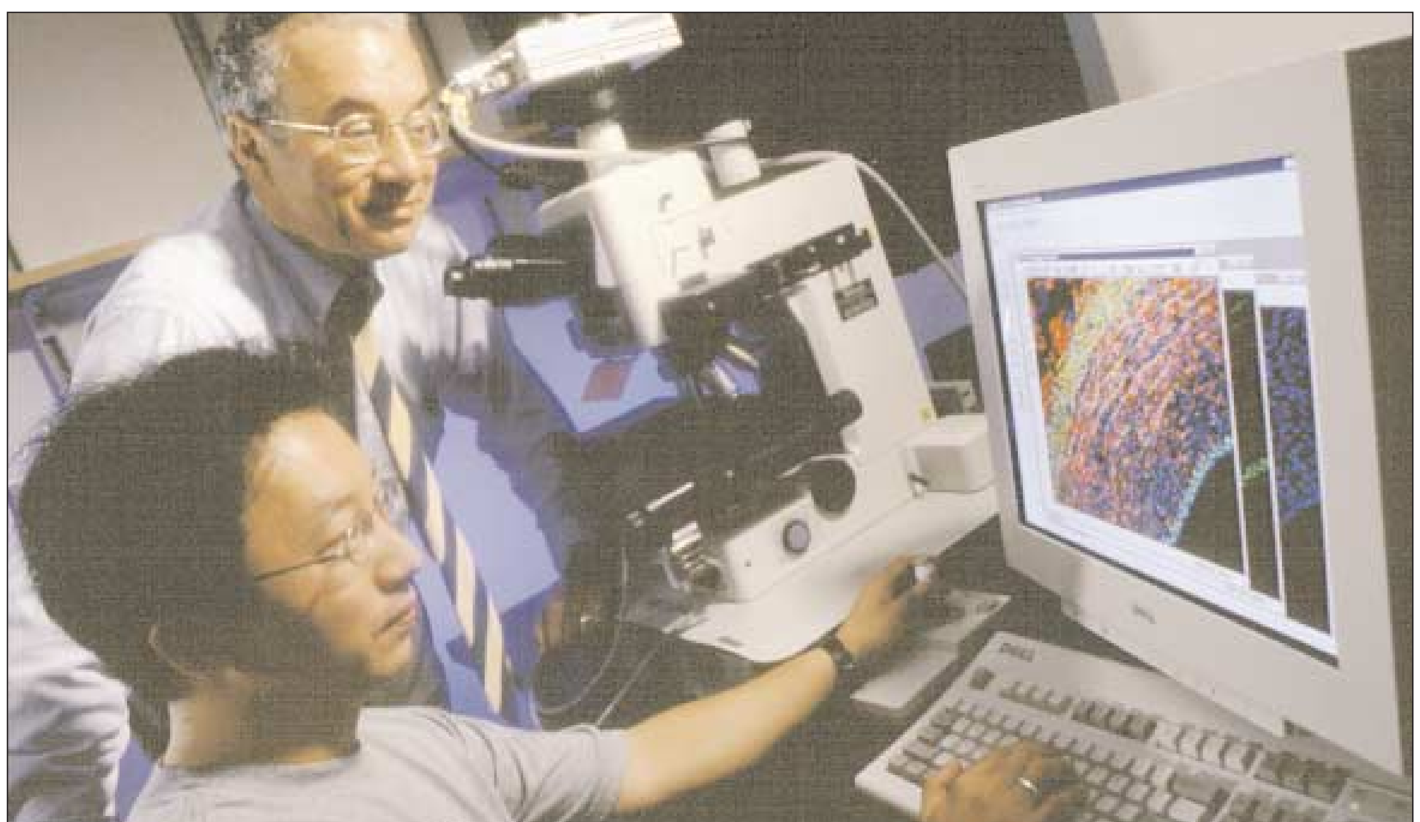


PHOTO BY GARY MEEK

Controversy Over Embryonic Stem Cells

Scientists get opportunity to investigate disease treatment applications for stem cell technology.

THE USE OF HUMAN EMBRYONIC STEM CELLS IN possible treatments and cures for disease is one of the most hotly debated issues in the United States right now. People are grappling with the issue from ethical, legal, moral, political, religious, scientific and social perspectives.

Embryos must be destroyed to harvest embryonic stem cells, which are young cells that have not yet differentiated to serve various functions, such as tissue production. Typically, these cells are derived from 5- to 7-day-old embryos that are discarded by in vitro fertilization clinics, which create multiple embryos in hopes of helping couples bear children. But there is also discussion about taking fetal stem cells from aborted fetal tissues, and about deriving embryonic stem cells from cloned embryos.

Stem cells can also be derived from adult tissue, but these cells can only serve functions related to the specific tissue from which they were taken. Embryonic stem cells, however, can be engineered to differentiate into many different types of cells related to any type of tissue. It is this ability that makes scientists believe embryonic stem cells may lead to treatments and cures for diseases, such as diabetes, Parkinson's and Alzheimer's.

The next year or so will reveal much more information about the actual potential of embryonic stem cells, says Steve Stice, a University of Georgia researcher, Georgia Research Alliance Eminent Scholar and collaborator at the Georgia Tech/Emory Center for the Engineering of Living Tissues (GTEC). Because President George Bush recently began allowing limited federal funding for research involving 60 embryonic stem cell lines, research will expand from the private sector into academia. Stem cells can be reproduced in the lab indefinitely to form cell lines.

"This is a great step forward," Stice says. "I think we will find out quickly what the capabilities of embryonic stem cells are…. And we have an advantage in Georgia because we have four embryonic stem cell lines at Bresagen (an Australian-based company with a laboratory in Athens, Ga.) I work with them, and we are interested in bringing these cell lines (derived from U.S. sources) into research at UGA and other institutions in Georgia, including Georgia Tech."

The 60 embryonic stem cells lines may not ultimately be enough to lead to successful treatments and may not be accepted for human trials because many of cell lines have been mixed with mouse cell lines. The mouse cells help support stem cell growth. Many labs are working on more acceptable alternatives. But Stice believes the 60 lines are enough for initial research that will reveal their potential.

PHOTO COURTESY OF UNIVERSITY OF GEORGIA

Steve Stice, a University of Georgia researcher and Georgia Research Alliance Eminent Scholar, is working with GTEC to provide non-human primate embryonic stem cells as a source of endothelial cells for primate experiments with bioartificial blood vessels. Endothelial cells line blood vessels and, because of immune responses they provoke, are difficult for patients to accept from donors.

"I think it's on the scientists' back now to show there are applications for this technology," Stice adds.

Robert Nerem, director of GTEC, is also hopeful about embryonic stem cell research, particularly for applications in cardiovascular tissue engineering. Stice is working with GTEC to provide non-human primate embryonic stem cells as a source of endothelial cells for primate experiments with bioartificial blood vessels. Endothelial cells line blood vessels and, because of immune responses they provoke, are difficult for patients to accept from donors. In addition to embryonic stem cell sources, GTEC researchers are exploring several approaches to engineering endothelial cells.

"I don't know if stem cells represent the most promise," Nerem says. "I'm not convinced they are the solution. But we have to understand the developmental process from embryonic stem cells up the line. We are not interested in using embryonic stem cells in products, but for development in biological research only."

— Jane M. Sanders

■ For more information, contact Steve Stice, University of Georgia, Animal Science Complex, Athens, Ga., 30602. (Telephone: 706-583-0071) (E-mail: sstice@arches.uga.edu); or Robert Nerem, Georgia Tech/Emory Center for the Engineering of Living Tissues, 315 Ferst Drive, Atlanta, GA 30332-0363. (Telephone: 404-894-2768) (E-mail: robert.nerem@ibb.gatech.edu)

Reducing the *Risks* and *Routines*

Tissue engineering holds promise for insulin-dependent diabetics.

By Jane M. Sanders

Physician Peter Thulé of Emory University and the Atlanta Veterans Administration Medical Center is developing a gene therapy to regulate insulin production. It could result in a tremendous improvement in the quality of life for diabetics, but this therapy and other similar ones are at least five to 10 years away from clinical practice.

PHOTO COURTESY OF EMORY UNIVERSITY

TOM HARTER WAS FINISHING HIS SOPHOMORE YEAR at the U.S. Naval Academy when symptoms of increased hunger, thirst, urination and weight loss sent him to the infirmary. A doctor there quickly diagnosed Type 1 diabetes, and Harter began a life of insulin dependency.

He has managed the disease well, painstakingly monitoring his diet and blood sugar and exercising regularly. Now 47, Harter has an insulin pump, giving him some freedom, but still requiring a rigid daily regimen, which has helped him avoid common diabetic complications, such as organ failure, heart disease and vision loss. The disease has not slowed the pace of this successful businessman's life. Still, Harter hopes for more.

"If there was a new therapy to treat diabetes, I'd be first in line for it," Harter says. "Caring for yourself is still an ongoing challenge every day.... You have to battle your blood sugar. If it goes too high, you're affecting all your organs. If it goes too low, you go into insulin shock.... So what I'm saying is, I think I've attacked diabetes very well, but it's still a hassle I'd love to get rid of."

Researchers in the Georgia Tech/Emory Center for the Engineering of Living Tissues (GTEC) want to give Harter and the four million other insulin-dependent diabetics in the United States a life free of diabetic regimens and disease complications that cost more than an estimated $20 billion annually. They are developing an implantable, tissue-engineered artificial pancreas, which will regulate insulin for more than a year before needing replacement in a minor surgical procedure. Researchers also plan to initiate studies toward development of an artificial liver — a temporary liver support device at first and later a long-term artificial organ.

"Our focus is enabling technology, not products," says research manager Athanassios Sambanis, an associate professor in the Georgia Tech School of Chemical Engineering. "We want to enable the manufacture of metabolic and secretory organs at a clinically relevant scale, and make them immune-acceptable and available off the shelf."

Researchers are well into their work on the pancreas, but intensive studies on the liver will not begin until 2002. "We are expanding into the liver area because the problem of liver failure is at the heart of the transplantation crisis," Sambanis explains. "Also, the temporary device and later the liver substitute are good test beds for core enabling technologies."

Despite promising results, it will be probably 10 to 20 years before these technologies result in routine procedures in humans, Sambanis cautions.

A CHALLENGE FOR GTEC RESEARCHERS IS THE TYPE OF cells to use for creating a tissue-engineered artificial pancreas. In diabetics, insulin-producing cells are not properly functioning or are dead. Donor cells from cadavers are not readily available; it would take 200,000 to 300,000 cadavers a year to generate enough islets, or clusters of insulin-producing cells, to treat 100,000 diabetics for one year. Pig islets have been studied as another possible cell source, but their immune acceptance in humans is a large obstacle.

So GTEC researchers are pursuing the use of allogeneic cells — that is, donor cells from the same species. Other labs are providing continuous pancreatic cell lines that are genetically engineered to grow in a culture. GTEC researchers led by surgeon Collin Weber at Emory University are implanting encapsulated continuous cell lines in diabetic mice and monitoring the restoration of a normal blood glucose level, as well as the animals' immune response. Weber is using novel immune suppression strategies to enhance acceptance.

"This solves the cell availability problem," Sambanis explains. "Researchers can make an unlimited quantity of these cells in the lab. But there's still the problem of immune acceptance. To enable this, we are encapsulating the cells in a semi-permeable membrane that allows nutrients in and insulin out, but excludes larger molecules, such as antibodies and cells, including lymphocytes. This provides immune protection. It's not complete, but it helps a lot."

Another promising approach is the use of autologous cells — that is, the patient's own cells. In the case of the diabetic, researchers led by physician Peter Thulé at Emory University and the Atlanta Veterans Administration Medical Center are targeting liver cells. Thulé combines promoters (the region of a gene that determines whether it is "turned on" or expressed) from two liver-specific genes to create a promoter that mediates insulin production in response to blood glucose levels. Liver cells harvested in a biopsy could theoretically be infected with a virus carrying a glucose-responsive insulin gene, and subsequently be re-injected into the donor. In a more direct gene therapy approach, physicians could deliver insulin to a patient via a simple intravenous injection of a virus.

Gene therapies to regulate insulin production could result in a tremendous improvement in the quality of life for diabetics, but they are five to 10 years away from clinical practice, Thulé estimates.

"When you have to stick your finger five times a day to determine what to eat and what activities you can do, day in and day out, that becomes so intrusive in your life," he adds. "If you could get the same result and not have to do anything, it would be great. So gene therapy could provide a huge lifestyle benefit,

Researchers in the Georgia Tech/Emory Center for the Engineering of Living Tissues are developing an implantable, tissue-engineered artificial pancreas, which will regulate insulin for more than a year before needing replacement in a minor surgical procedure. Graduate student Tony Tang is conducting experiments for the project.

PHOTO BY GARY MEEK

even if the health benefits were similar to current therapies."

Engineered cells from a patient's cell bank also could seed an artificial pancreas for implantation. Thulé and Sambanis are developing ways to encapsulate these cells, allowing more or less insulin output, as needed. The capsule isolates these genetically engineered cells in the area where they are implanted, making them easier to retrieve and reducing the risk of an immune system response, Thulé explains.

Ioannis Constantinidis, director of radiological sciences at Emory University, is developing a non-invasive method for determining the level of metabolic function in an implanted bioartifical pancreas. The technique, called nuclear magnetic resonance imaging, will also reveal whether the implant is integrating with surrounding tissue as it should.

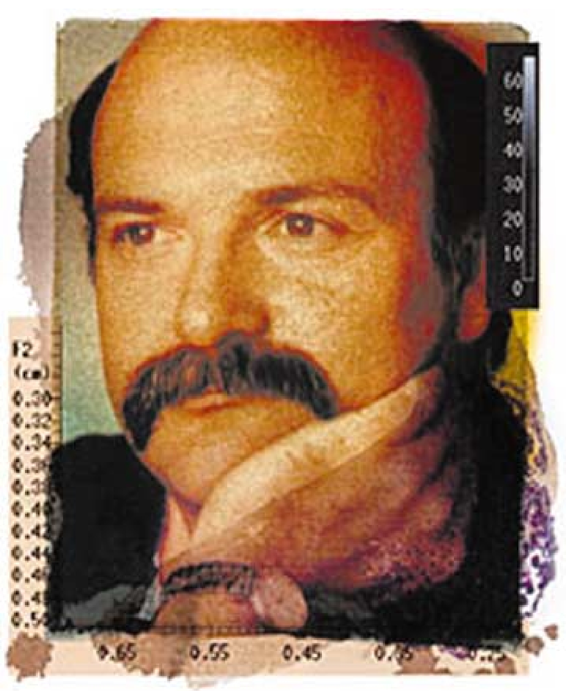


PHOTO COURTESY OF EMORY UNIVERSITY

MEANWHILE, JULIA BABENSEE, AN ASSISTANT PROFESSOR in the Wallace H. Coulter Department of Biomedical Engineering (BME), is conducting fundamental research on the immune responses caused by antigens presented by free and encapsulated cells. Her results will provide insight for better design of capsules to promote immune acceptance.

Joe LeDoux, also an assistant professor in BME, is developing retroviral delivery mechanisms for engineering non-pancreatic cells to secrete insulin in response to glucose.

In a related project, Sambanis hopes to improve the secretion dynamics of genetically engineered cells, further altering them to respond more rapidly to glucose levels. And he and his colleagues are also developing cell biomaterial hybrids that enable and enhance cell function.

Researchers are facing other challenges in the development of the bioartificial pancreas. These include designing the capsules so that they can accommodate a high number of properly functioning, insulin-secreting cells (this reduces the volume of the implant that is needed to achieve a physiologic effect); the low-temperature preservation of the capsules so they can be available off the shelf; and the avoidance of excessive fibrosis after implantation in the patient.

EVEN THOUGH THE ARTIFICIAL PANCREAS IS MORE THAN a decade from clinical practice, researchers want to be prepared to monitor the organ when it does become a reality. So Ioannis Constantinidis, director of radiological sciences at Emory University, is developing a non-invasive method for determining how well the implant is functioning metabolically and whether it's integrating with surrounding tissue as it should. Constantinidis uses nuclear magnetic resonance (NMR) spectroscopy and imaging, the same technology used for MRIs in humans, to monitor tissue-engineered implants — first the artificial pancreas and later cardiovascular implants and other tissue-engineered constructs.

"The long-term objective is to develop a prognostic test to tell patients how well the construct is functioning and to predict when they will need to come back to the doctor," Constantinidis explains.

In addition to lab studies in bioreactors, Constantinidis recently began studying the use of NMR in monitoring implants in the abdomens of mice over several months. He implants "beads" — cells engineered to produce insulin in response to glucose, trapped in a natural gel-like biomaterial, and surrounded by a semi-permeable membrane. For this prototype, the beads are contained in a silicone O-ring, making the implant easier to study with NMR.

"We need to understand what we're seeing with NMR," Constantinidis says. "How can we harness the information? We see certain changes — brighter parts and darker parts. Does the contrast indicate viability? Can we quantify and monitor these changes over time?"

Constantinidis hopes his findings will yield insight for optimizing the design of the bioartificial pancreas.

"I believe we will see bioartificial organs in my lifetime," Constantinidis says. "The imaging techniques that we use are already applied to patients' native tissues… so imaging will not be the limiting factor."

THOUGH DIABETES IS A CHRONIC AND SOMETIMES devastating disease, it is usually not immediately life threatening. That fact gives researchers an advantage, Sambanis says. They can design therapies that involve cell banking over a two-month period, while patients needing blood vessel replacements usually don't have the luxury of time, he adds.

"Any procedures we do must be safe and efficient in the long term," Sambanis emphasizes. "The artificial pancreas is not a cure, but it will be a significant improvement in the quality of life for diabetics. And it will significantly reduce long-term complications such as cataracts and cardiac disease." **RH**

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Tissue Engineering Education

Teaching students is a primary mission of GTEC.

GTEC students teach K-12 students about tissue engineering with an interactive demonstration showing an outline of the human form with the current state of replacement parts available (e.g., a metal hip, artificial skin). Students also get hands-on experience with an artificial knee and other props.

AMONG THE MISSIONS OF THE GEORGIA Tech/ Emory Center for the Engineering of Living Tissues (GTEC) is technology transfer. And the most important form of it is educating students, says GTEC director Robert Nerem.

GTEC faculty members teach tissue engineering to 79 graduate students and 44 undergraduates. Students are earning degrees in a variety of fields, including biomedical engineering, bioengineering, mechanical engineering and chemical engineering.

And students are learning from a wide variety of faculty experts, including biomedical engineers, chemical engineers, mechanical engineers, genetic engineers, cell biologists, molecular biologists and immunologists. GTEC even collaborates with faculty from Georgia Tech's schools of Management and Public Policy.

"We want students to be able to move from bench-top science to commercialization," Nerem says. "We plan to develop courses in public policy because we know tissue engineering is being shaped by legal and ethical issues, as well."

Students are vitally involved in GTEC research and often publish papers and give presentations at professional meetings. In addition, students founded and now operate a kindergarten through 12th grade (K-12) outreach and education program that was a finalist for the Governor's Technology Leadership Award for Public Service in 2000.

"Our main goal is to make sure students know tissue engineering exists as a career choice," says Jan Stegemann, one of the founders of the K-12 program, who expects to receive a doctoral degree in December. "Students often don't realize they can be involved in the healthcare industry without becoming a doctor."

About 30 graduate students participate in the outreach program as speakers and tour guides. Since the program began in 1998, students have visited about a dozen classrooms and hosted about 10 student visits to tissue engineering labs on campus. They have reached about 500 students through these efforts.

"It is our hope that these visits and demonstrations will impress upon the K-12 students the opportunities that are available to those who learn math and science," says Donna Brown, administrative director of GTEC. "K-12 teachers are also involved in these groups and are provided enrichment for themselves and their classrooms."

— Jane M. Sanders

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Restoring Hope to Orthopedic Patients

Tissue engineers devise technologies to enable bone repair and regeneration.

By Jane M. Sanders

PHOTO BY GARY MEEK

Assistant Professor Marc Levenston and graduate student Christopher Hunter have developed an *in vitro* model system to study integration between tissue-engineered cartilage and native tissue. Here, Hunter holds an engineered construct containing cells from cow knee cartilage.

KATHRYN WAS 54 WHEN SHE FRACTURED a vertebra in her spine while riding a stationary exercise bike. It was the first sign of osteoporosis, a disease that eventually robbed her of four inches in height and left her with severe back pain.

Osteoporosis causes a decrease in bone mass and density. The result is bones that are porous and fragile, and therefore prone to fracture. About 25 million American men and women, mostly post-menopausal women, have osteoporosis, and they suffer about 2 million fractures a year.

Today, doctors can prescribe medications and recommend lifestyle changes to slow bone loss, but there is no treatment to add significant bone mass or strength. However, tissue engineering and other advances in medical research may offer new hope within the next decade for patients with debilitating musculoskeletal diseases such as osteoporosis and osteoarthritis, as well as traumatic injuries to bone and soft tissues in joints.

Researchers in the Georgia Tech/Emory Center for the Engineering of Living Tissues (GTEC) are seeking solutions to regenerate functional bone, cartilage and fibrocartilage.

"At GTEC, we are doing fundamental studies and developing technologies that will enable companies to develop products for clinical use," says Robert Guldberg, a GTEC research director and assistant professor in the Georgia Tech School of Mechanical Engineering. "In orthopedic tissue engineering, we hope to see these technologies lead to improved therapies that will impact patient care within five to 10 years."

ONE PROMISING TECHNOLOGY IS A DELIVERY mechanism for a localized gene therapy using LMP-1, a gene that stimulates surrounding cells to make bone. A research team led by Scott Boden, an Emory University professor of orthopedic surgery, discovered LMP-1 in 1997 and soon learned its potential. Subsequently, a Memphis, Tenn., company, Medtronic Sofamor Danek, purchased the rights from Emory to use LMP-1 to improve the success rate of spine fusion surgeries.

Boden's team is now conducting fundamental research on how LMP-1 functions, and is meanwhile collaborating with Guldberg on preliminary studies in the development of a gene therapy delivery mechanism. Boden is exploring an *ex vivo* approach in which the patient's own blood cells can be mixed with a virus containing the LMP-1 gene. Surgeons would either directly inject the LMP-1 cells into a skeletally deficient site or deliver the genetically engineered cells within a porous biomaterial scaffold.

"It's too early to tell what sort of increase in bone density could be expected from LMP-1 gene therapy," Boden says. "But even a 10 percent increase would be very significant clinically."

Laboratory studies are under way. The results so far indicate a moderate, but consistent increase in trabecular bone (the porous region of bone, which is affected by osteoporosis) formation in non-human limbs injected with cells genetically engineered to overexpress LMP-1, Guldberg reports.

Guldberg's part in the project is to analyze tissue-engineered bone with high-resolution micro-computed tomography (micro-CT). "We can visualize changes in the 3D microarchitecture of the bone and quantify not only the amount of new bone formation, but how it is oriented and organized," Guldberg explains.

Preliminary studies should be completed within a year. After that, Guldberg plans to conduct mechanical tests on bone produced by the LMP-1 gene. Meanwhile, Boden is studying immune response issues stemming from the viral delivery of LMP-1. He wants to use the lowest, and therefore safest, dose of the virus that will effectively deliver the gene without triggering antibodies that will attack the virus, he explains.

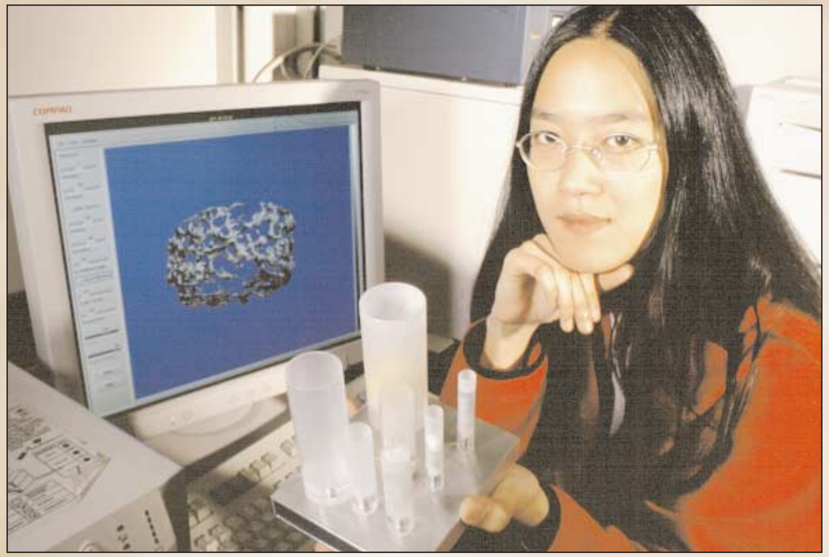
Eventually, LMP-1 gene therapy could treat unhealed fractures, age-related spine degeneration, and regional or systemic osteoporosis, Boden adds.

Another gene delivery technology under development at GTEC focuses on Runx2/Cbfa1, a bone cell master gene that stimulates bone production. In the Georgia Tech School of Mechanical Engineering, Assistant Professor Andres Garcia and graduate student Benjamin Byers are engineering various types of cells — including cells that do not typically make bone — to express Cbfa1 and make bone in culture.

"We're focusing on stimulating cells that usually do not make bone tissue to express this master gene in order to turn on other genes responsible for bone formation and eventually enhance bone production in culture," Garcia explains.

Eventually, researchers will combine Runx2/Cbfa1-producing cells with biological and synthetic scaffolds to creates mineralized templates. Surgeons could then use these implantable constructs to treat bone defects in patients.

PHOTO BY GARY MEEK

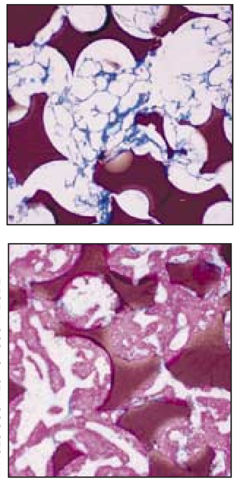


Graduate student Kimberly Huynh is working with Georgia Tech Assistant Professor Robert Guldberg to analyze tissue-engineered bone with high-resolution micro-computed tomography (micro-CT). Here, she holds a tray of specimen containers for the micro-CT imaging system. On the computer screen behind her is a 3D image of bone grown in an incubator in Guldberg's lab. Researchers can visualize changes in the 3D microarchitecture of the bone and quantify not only the amount of new bone formation, but also how it is oriented and organized.

For now, Garcia and Byers are experimenting with delivering this gene to clinically relevant target cells in the laboratory. So far, they have found that the extent of mineralization depends on the target cell. Experiments with bone marrow and other bone-forming cells have produced excellent enhancement of bone tissue production in culture, Garcia says. The next phase of the research involves the integration of these genetically engineered cells with scaffolds of adequate biological and mechanical properties.

OPTIMAL BIOLOGICAL SCAFFOLDS ARE A KEY component to the success of tissue-engineered constructs, or living implants. "And a major barrier is producing scaffolds with sufficient mechanical properties to withstand *in vivo* forces within a patient," Guldberg explains.

In a new manufacturing approach developed and patented by GTEC partner company BioAmide, graduate student Angela Lin is collaborating with corporate scientist Tom Barrows to coat a polymer onto small wires and then fuse them together. A pore-forming agent in the polymer is triggered when researchers submerse the polymer in hot oil. The high temperature decomposes the pore-forming agent in



IMAGES COURTESY OF SCOTT BODEN

GTEC laboratory studies indicate a moderate, but consistent increase in trabecular bone (the porous region of bone, which is affected by osteoporosis) formation in non-human limbs injected with cells genetically engineered to overexpress the LMP-1 gene discovered by a research team led by Scott Boden, an Emory University professor of orthopedic surgery.

something like a foaming process. The result is interconnected porosity that creates a scaffold with a lot of surface area where cells can attach and grow. Researchers remove the fine stainless steel wire in the scaffold and create even larger pores that run throughout the scaffold.

"Longitudinal pores in the scaffold are the highways, and micro-pores are the parking spots for cells once they arrive," Guldberg explains. "The highways also provide nutrient pathways to cells." The intent is to provide the cells with rapid access to the scaffold interior so the cells can quickly integrate with vascular tissue.

Guldberg and Lin are quantifying the architecture of these scaffolds and comparing their mechanical properties to their porosity. "The scaffolds have stiffness and strength comparable to trabecular bone. The next step is to evaluate the function of cells seeded onto the scaffolds," Guldberg says. "We have used confocal microscopy to verify cell viability within the scaffolds at one week and have just completed a study quantifying the formation of mineralized bone within the scaffolds after four weeks. One observation we have made is that more bone forms on the outside of the scaffolds than on the inside because of nutrient diffusion limitations."

To overcome this limitation, Guldberg, graduate student Blaise Porter and post-doctoral fellow Sarah Cartmell are developing a 3D tissue culture system that pushes nutrients through scaffolds at controlled rates. They are testing the effects of perfusion rate on gene expression and viability of cells at the center of the scaffolds. Guldberg has filed a provisional patent on the system, which in addition to perfusing constructs, has the ability to simultaneously apply cyclic forces intended to simulate the mechanical environment in the patient. This system will be used to screen cell and scaffold technologies and provide a test bed for improved construct designs.

MEANWHILE, MARC LEVENSTON, AN ASSISTANT professor of mechanical engineering at Georgia Tech, and graduate student Christopher Hunter are facing the challenge of integrating tissue-engineered cartilage with surrounding native tissues. Damaged cartilage does not heal well, in part, because it has no blood supply. Repaired cartilage is often mechanically inferior to normal tissue and may become painful or arthritic. Tissue-engineered cartilage, however, could provide hope for patients who have cartilage damaged because of overuse, sports injuries, rheumatoid arthritis or genetic factors.

In repairing damaged cartilage, tissue engineers face the challenge of finding ways to seamlessly integrate engineered cartilage with remaining normal tissue. Levenston and Hunter have developed an *in vitro* model system to study integration between tissue-engineered cartilage and native tissue. They cut a piece of cow knee cartilage into a doughnut shape. In the center, researchers place a piece of tissue-engineered cartilage created from the same animal's cells. Together, the components create a hybrid construct that Levenston and Hunter place in an incubator and then examine for signs of tissue integration. They also apply cyclic deformation to the construct, loosely simulating the mechanical environment associated with walking.

"In a general sense, we see that living tissue affects cells in the engineered tissue regardless of mechanical loading," Levenston says. "The engineered tissue is getting signals from cells in the living tissue, and the cells are proliferating at a slower pace. Normally, cells divide a lot. So the trend we're seeing is that the cells divide slower, but produce more tissue."

The researchers are comparing different types of constructs and measuring how much force it takes to push the tissue-engineered cartilage out. "This will test the interface and tell us how much integration we are getting," Levenston explains. "Then we can screen the interfaces in advance of animal model studies." It will likely be five to 10 years before tissue-engineered cartilage therapies become widely available for human clinical use. **RH**

Georgia Tech Assistant Professor Robert Guldberg, right, and graduate student Blaise Porter discuss their work on a 3D bone culture system that pushes nutrients through biological scaffolds at controlled rates. They are testing the effects of perfusion rate on gene expression and viability of cells at the center of the scaffolds. Guldberg has filed a provisional patent on the system.

PHOTO BY GARY MEEK

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NASA PHOTO

Flying On Mars

Nature's flight system could be the key to exploring the newest frontier.

By John Toon

ONE OF THE OLDEST FORMS OF FLIGHT — THE flapping wings of insects — may support a revolutionary new class of robotic flying machine uniquely suited for exploring a brave new world: the planet Mars.

The thin Mars atmosphere, composed mostly of carbon dioxide and lacking oxygen for combustion, provides an inhospitable environment for conventional aircraft and helicopters. Compounding the challenge are size constraints imposed by the spacecraft delivering air vehicles to Mars.

But the flapping wing "Entomopter," a patented mechanical insect capable of both flying and crawling, may be ideal for meeting the demanding requirements of Mars aerial exploration. With support from NASA's Institute for Advanced Concepts, a team of researchers that includes Georgia Institute of Technology engineers is conducting a comprehensive feasibility study designed to show whether a fleet of scaled-up Entomopters could one day help explore the Red Planet.

"Mars is a nasty place to fly a conventional air vehicle because almost everything there is working against you," says Anthony Colozza, who coordinates the Entomopter study as the principal investigator for the Ohio Aerospace Institute (OAI), the project facilitator. "The Entomopter concept is really a breath of fresh air because it makes the environment of Mars our friend."

He envisions exploration by a fleet of Entomopters landing and taking off, perhaps from a rover able to refuel and support them as it crawls across the Mars surface gathering scientific information. In that scenario, the Entomopters could study the surface from an altitude of less than 100 feet, sample the atmosphere, look for minerals and collect surface samples, while guiding the rover to the most interesting locations for study. Though limited in range to one or two kilometers on either side of the rover, the Entomopters could nevertheless cross canyons, large rocks and other features that would stop the rover.

"The trouble with the rovers is that they land in one spot and are very limited in the extent to which they can explore," says Robert Michelson, principal research engineer at the Georgia Tech Research Institute (GTRI) and lead developer of the Entomopter design. "It's frustrating to be looking through the camera of a rover and wonder what might be on the other side of the next ridge. If we could get a vehicle that could fly over that ridge, we could do surveys much more efficiently."

The Entomopter concept originated at GTRI with U.S. military interest in palm-sized "micro air vehicles" that could surreptitiously explore underground bunkers and other structures. For that mission, a 50-gram Entomopter with a 15-centimeter wingspan could fly through ventilation ducts and using insect-like legs, crawl through narrow passageways or half-open doors. Development of that version continues in parallel with the Mars version.

Another World, Another Environment

FLYING ON MARS INVOLVES overcoming a series of obstacles, Michelson and Colozza agree. Among them:

❍ The Mars atmosphere is 95 percent carbon dioxide, with slightly more than a tenth of 1 percent oxygen. That rules out oxygen-breathing motors and forces flying machines to rely on chemical or electrical propulsion.

❍ The Mars atmosphere is very thin, similar to the Earth's atmosphere at 100,000 feet. "Nothing flies at that altitude with any regularity," Michelson says. "You must fly very fast and are on the ragged edge of control."

❍ Because the Mars atmosphere is so thin, a conventional aircraft would have to fly at least 250 miles an hour to generate enough lift to stay aloft. At that speed, landing or taking off from the rocky terrain would be impossible, limiting a conventional aircraft to a single flight. A wide turning radius would also make it difficult to come back for a closer look at an object of interest.

❍ Temperatures swing wildly from 20 degrees Celsius to minus 140 degrees Celsius, creating materials and fuel challenges.

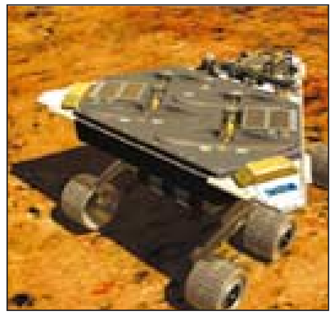
PHOTO BY GARY MEEK

Robert Michelson, principal research engineer with the Georgia Tech Research Institute, holds a stereolithographic model of the Entomopter designed for use on Earth. For terrestrial use, the device would have a gross weight of 50 grams and a payload of about 10 grams. A version of the Entomopter designed for use on Mars would be much larger.

IMAGES COURTESY OF NASA

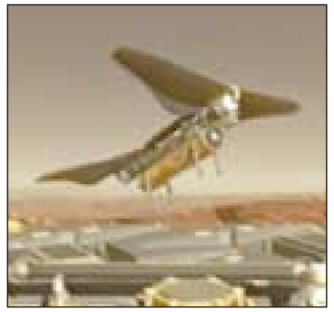
Schematic views show the Entomopter from different angles, displaying the unique wing structure, reciprocating chemical muscle and fuel storage cartridge.

This panoramic view of the Mars surface was taken by the Mars Pathfinder, developed and operated by the Jet Propulsion Laboratory for NASA.










ABOVE: A sequence of renderings shows how an Entomopter could be used to explore Mars, taking off, landing to retrieve samples, then returning to and landing on a Mars rover moving across the surface. The rover would serve as a refueling station for the Entomopters as they explore the planet from the air.

❍ Because the speed of sound is 20 percent lower in carbon dioxide, propellers or rotors can't spin as fast as they could on Earth without creating destructive shock waves. That limits the lifting power of rotorcraft, or forces them to use less efficient multiple rotor systems.

Learning from Insects

IN THE PAST DECADE, SCIENTISTS HAVE begun to understand how insects use their flapping wings to generate lift. It's a complicated phenomenon believed to involve the formation of wing vortices that multiply the lifting power. Flapping wings also give insects the unique ability to land and take off, quickly change directions and hover. Unlike aircraft, which must move the entire vehicle rapidly to generate lift, insects can move only their wings rapidly — while the body flies slowly. That could be as useful for exploring Mars as it is for spotting nectar in flowers.

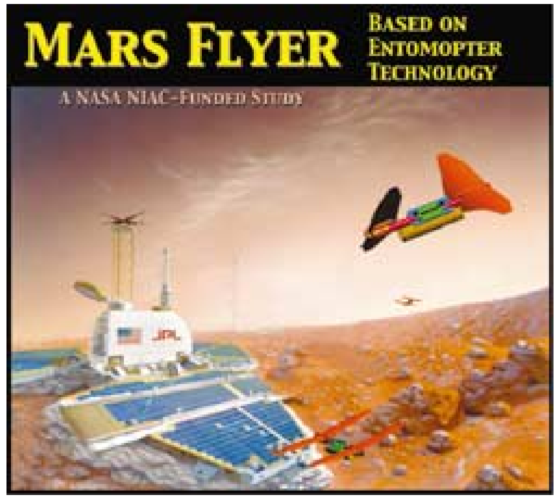
One scientist who has contributed to the understanding of insect flight is Charles Ellington, a professor at the University of Cambridge in England. Ellington met Michelson four years ago during a conference on micro air vehicles, and he has since become part of the team developing the terrestrial version of the Entomopter.

To control their direction, insects use a complex system to vary the beating of each wing and alter how they encounter the air. Rather than replicate that system, Michelson and GTRI collaborator Robert Englar are adapting an active flow-control technique originally developed for fixed-wing aircraft. On aircraft, the system uses compressed air released by valves to control direction and augment lift over the wings. On the Entomopter, waste gases produced by its power source — a reciprocating chemical muscle — would substitute for the compressed air in multiplying lift and providing control.

"This allows us to have a much simpler wing-beating mechanism," Michelson explains. "It makes the Entomopter manufacturable and helps keep the costs down."

The term Entomopter combines the concept of an insect (ento) with segmented wings (mopter). The multi-modal design concept — combining wings for flight, legs for ground locomotion and a chemical muscle for power — received patent protection in July 2000.

"They are intelligent, autonomous aerial robots that do more than just fly," he adds.



An Artificial Chemical Muscle

OPERATING ON A VARIETY OF FUELS, THE CHEMICAL muscle needs no oxygen to produce the motion required for flapping wings. Michelson and his team have advanced the muscle — for which they are seeking a patent — through three different prototypes and can now generate motion at 70 cycles a second with enough power to fly.

"It's a simple device that can generate the fairly high levels of power that are essential to flight," he says. "Our liquid fuel has a higher energy density than a battery. We can extract enough of that energy to be able to create the force necessary to flap the wings, fly and still have some energy left over for other applications."

Like real muscles, Michelson's chemical muscle generates wastes — heat and gases. On the Entomopter, the heat could be used to create electricity through a thermoelectric process. Beyond augmenting lift and providing control, the gases can also operate an acoustic ranging system to help the machine navigate and avoid obstacles.

Since electrical energy is essential for the machines' autonomous navigation system, science package, radio transmitter and control systems, the team is also exploring the use of flexible solar panels on the wings. A safe tritium-powered generator could keep critical electrical systems alive between flights or during times the Entomopter may have to "hibernate" during a Mars dust storm.

Though the Mars environment provides mostly challenges to overcome, it does offer one important advantage. Gravity there is only one-third that on Earth, meaning the Entomopter's size can be scaled up without incurring the same weight penalty it would on Earth. Michelson believes the larger size, perhaps a meter across, would enable it to carry a sufficient payload without sacrificing the attractive aerodynamics.

The Next Step

FOLLOWING AN INITIAL PHASE I review completed in November 2000, Georgia Tech researchers, Colozza and scientists from the Ohio Aerospace Institute have now launched a 12-month Phase II study. The goals are to develop data to support the concept and to recommend the best choices for options such as fuel, electrical generation sources, size and range.

The Mars Entomopter builds on five years of previous work supported by GTRI, the Defense Advanced Research Projects Agency (DARPA) and the U.S. Air Force's Revolutionary Technology Program. Over that time, development of the chemical muscle has advanced dramatically, the aerodynamics of the circulation control system have been studied, an acoustic ranging system has been tested in GTRI's aeroacoustics facilities, manufacturing processes have been developed to build the wing structures directly from computer models, and a tissue-and-wood model has made hundreds of brief flights.

"We have demonstrated a lot of the pieces of it," says Michelson, "but what we need now is one big program to pull it all together."

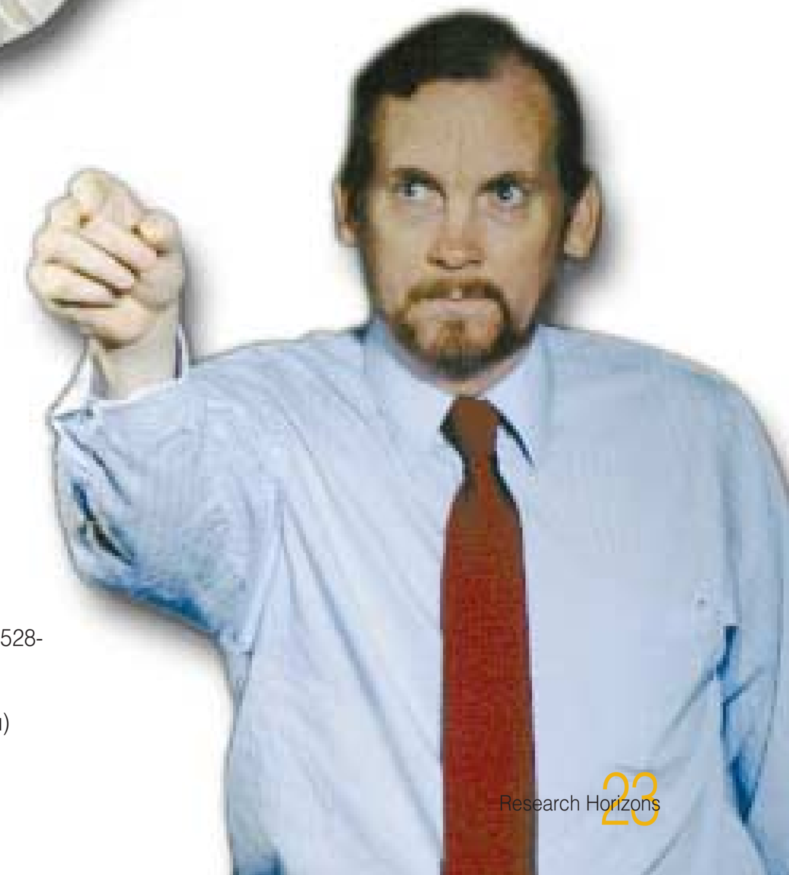
The complex wing aerodynamics now pose the greatest challenge to the future of the Entomopter.

"One of the major challenges that faces us is working out the wing aerodynamics," Michelson explains. "That is a major issue. Steady aerodynamics over fixed wings is well understood, and even the active flow control of wings already has a good body of knowledge. But we are talking about pneumatic control of unsteady airflow over a flapping wing. No work has been done on that."

The problems of autonomous navigation and flight also loom large, though significant progress has been made over the past decade — much of it through the aerial robotics competition Michelson created for the Association for Unmanned Vehicle Systems, International.

If the feasibility study turns out as positive as Michelson hopes, the next step will be to convince one of NASA's research centers to pick up the project and invest the resources needed to develop the technology.

If all goes well, Entomopters could be flying on Mars within a decade, giving scientists a unique new capability. "Combining Entomopters with a rover would give us a very nice integrated solution," Colozza adds. "They will give us a unique capability not available any other way." **RH**

A simplified wood and tissue model of the Entomopter powered by a rubber band demonstrates the ability of a flapping wing device to fly. Here, Robert Michelson releases the model for flight.

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PHOTO © EYEWIRE INC., 2001

The average American eats 81 pounds of chicken a year — the highest per-capita consumption of any major meat.

Counting Their Chickens

Researchers use machine vision technology to find poultry defects before processing.

By Gary Goettling

> “We’re looking at applications that span the whole gamut of the processing operation.”
>
> — Wayne Daley

GEORGIA INSTITUTE OF TECHNOLOGY RESEARCHERS believe they’re on the edge of a breakthrough, but they don’t want to count their chickens before they’re...processed.

At Gold Kist’s poultry processing plant in Carrollton, Ga., a machine vision system developed at the Georgia Tech Research Institute (GTRI) is undergoing field-testing. If it results in the success researchers expect, it could open the door for automating many visual-inspection tasks in the industry.

The technology is called a systemic screener. Installed near the front end of the chicken-processing line, cameras look for defects such as improperly bled birds and those afflicted by systemic diseases, such as septicemia and toxemia. Unique software and algorithms provide the intelligence for translating visual data from the system’s cameras into the appropriate mechanical commands for dispensation of each chicken. Those that pass the screening proceed to the next step, while unfit chickens are quickly and automatically removed from the processing line.

“It’s a vision-based, closed-loop inspection and removal system — one of the first of its kind,” says Craig Wyvill, chief of the Food Processing Technology Division in the Electro-Optics, Environment and Materials Laboratory of GTRI.

By removing unacceptable birds early in the operation, the systemic screener allows subsequent areas of the plant to have “higher utilization of the processing line,” he notes.

While poultry processing is already highly automated, it still depends heavily on manual processes, many of which are visually based. Thus the field trial at Gold Kist is part of a broader effort.

“We’re looking at applications that span the whole gamut of the processing operation,” says Wayne Daley, senior research engineer at GTRI and head of the development team. “From beginning to end, live bird to the shrink-wrapped package, there are places where visual input is required to properly process the product. We’re looking at where we can apply machine vision technology, what would be required, and how we can modify our system to run tests and see how it functions.”

Wyvill adds: “Even though many processes have been automated, the industry still has to leave people on line to do visual screening and to take actions accordingly. If we can automate the vision functions throughout, we think we can greatly enhance the opportunity to fully automate the operation.”

Even many of the inspections required by law under the authority of the U.S. Department of Agriculture (USDA) may be conducted with machine vision, Daley notes. In fact, Daley and his GTRI team started work in the area back in the mid-1980s. At the time, the Agriculture Department was sponsoring a project to augment its on-line inspectors with computer technologies. A key focus of the project was to generate a consistent, objective and definable performance standard.

When the project ended, so did the government’s interest, or so it seemed.

GTRI’s researchers redirected their efforts in the following years to developing a vision-based quality analysis system. Post-chill grading was the target area.

“Wayne and his crew developed a very good grading system that worked well in its ability to hold up under harsh plant conditions,” Wyvill says. “The software they developed is state-of-the-art in terms of what is called ‘soft’ computing, which means it uses concepts like neural nets and other features to allow it to learn from its experiences and adapt.”

The initial system was fairly expensive, but advances in camera and computing technology have brought the cost down considerably, Wyvill notes. The screening system has been configured to work with USB cameras, similar to the home-computer models available for a few hundred dollars.

With the recent introduction of the Hazard Analysis and Critical Control Point Inspection Models Project (HIMP), the door has been reopened to visit the USDA inspection area. The research team has seized this opportunity to transition its grading system into a systemic screening system.

Wyvill believes commercialization of both concepts is near. “Once we get one of these systems in a plant on a commercial basis,” he explains, “I’m confident we’re going to see many more of these types of systems flooding out to other areas of the plant.”

GTRI is already at work examining other potential applications of machine vision in poultry processing.

“For example, we envision using computer vision to determine the orientation and positioning of live products to help load them onto the shackles,” Daley says.

Another important visual screening that could be handled by computers entails identifying cosmetic defects such as tears, bruises or missing limbs, and using that information to accurately route the product to the appropriate product-handling station.

In later processing stages such as cut-up, deboning, breading and marinating, machine vision software can help make machinery more intelligent. Whereas most assembly-line applications of machine vision involve single objects of consistent size and shape, chicken parts vary considerably in those characteristics.

“For this automation to work properly, the machines need to be able to adjust for product variability,” Daley explains. “You need detailed visual information that tells you about the specific part you’re working on.”

Carrying that point further, GTRI researchers are also working on ways to combine computer vision with X-ray imaging to improve the accuracy and thoroughness of product screening processes after deboning.

GTRI’s work with poultry is attracting attention from other segments of the food industry, as well. Representatives from the citrus and bakery industries are already working with Tech on machine vision techniques for high-speed imaging of products for quality evaluation and control of processes, Wyvill says.

“We think there’s a huge potential for computer imaging as an automatic quality evaluation and control system through the whole food industry,” he adds. RH

PHOTO COURTESY OF WAYNE DALEY

Engineers at the Georgia Tech Research Institute have developed a machine vision system that could open the door for automating many visual-inspection tasks in the poultry processing industry. The system is being field-tested by Gold Kist in Carrollton, Ga.

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Weird Chemistry

Researchers study unique radiation-driven reactions in extreme cold and high vacuum of Jupiter's moons.

By John Toon

BY HIS OWN ADMISSION, THOMAS ORLANDO DEALS with "weird chemistry." In fact, the Georgia Institute of Technology researcher studies chemical processes that are literally out of this world — reactions occurring on the moons of Jupiter, driven by extreme radiation at ultra-cold temperatures.

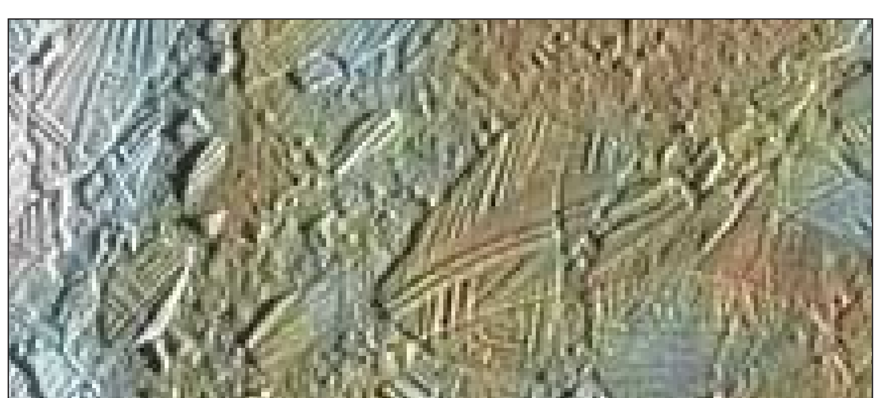
Based on laboratory simulations, work by Orlando and other researchers is helping planetary scientists understand data reported by a NASA spacecraft flying past the Galilean satellites Europa, Ganymede and Callisto. The studies provide new insight into the unique chemical reactions that take place on extremely cold, icy surfaces under high vacuum, driven by high-energy electrons and ions rather than normal thermal processes.

The moons, which are gravitationally locked to Jupiter, co-rotate with Jupiter and lie within Jupiter's intense magnetosphere. Here, they are constantly bombarded by radiation with the trailing sides receiving a greater radiation dose than the leading sides.

"When the magnetospheric particles (ions and electrons) are smashing into the surface of the moons, strange things happen, even though the surface is about as cold as cold can be. Radicals are produced, ionization occurs and reactive species produce materials that wouldn't normally be produced," explains Orlando, a professor in Georgia Tech's School of Chemistry and Biochemistry. "The bottom line is that weird chemistry goes on when there is too much energy."

Orlando discussed aspects of this "weird chemistry" at a meeting of the American Chemical Society this past August. His presentation was part of a chemical education section on the importance of radiation and high-energy chemistry in both the laboratory and the real world — which includes the outer reaches of our solar system.

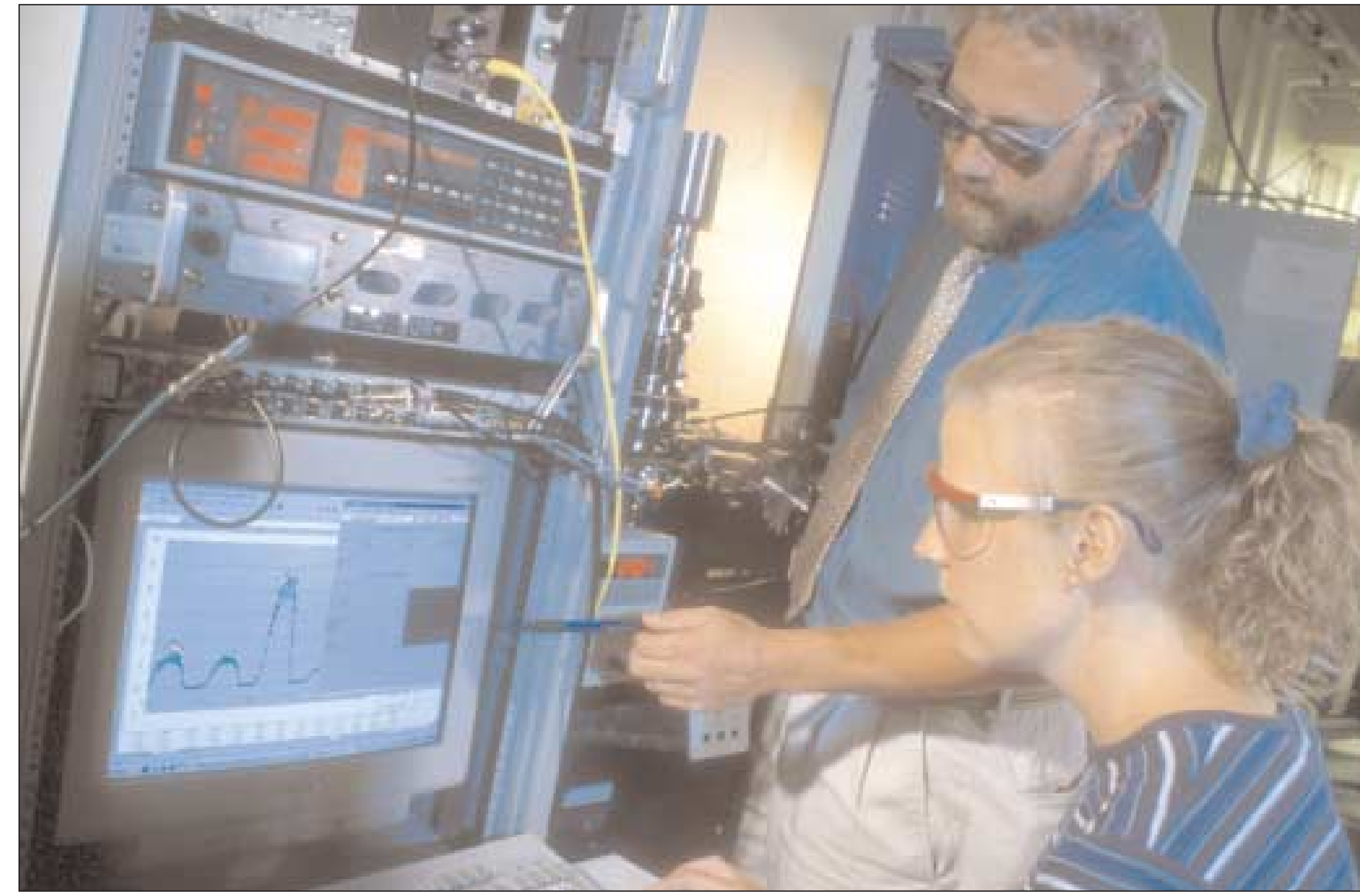
Near-infrared data sent from the Galileo spacecraft in 1997 indicated the presence of frozen brine on the surface of Europa. The University of Hawaii's Tom McCord and colleagues discussed the data in a 1998 *Science* article. Many planetary scientists believed the brine could have originated in a subsurface ocean beneath Europa's frozen crust. Brought to the surface by cryo-volcanic action, the brine would have been flash-frozen in the extreme cold (below 130 degrees Kelvin, or minus 145 degrees Celsius) and ultra-high vacuum (less than 10^{-10} Torr).



RIGHT: View of a small region of the icy crust of Jupiter's moon Europa showing the interplay of surface color with ice structures. The white and blue colors outline areas that have been blanketed by a fine dust of ice particles ejected by the formation of the large crater Pwyll. The image was taken in 1997 by NASA's Galileo spacecraft.

IMAGE COURTESY OF NASA

PHOTO BY GARY MEEK



Professor Thomas Orlando and doctoral student Janine Herring study data from ultra-high vacuum laboratory measurements. Orlando's research focuses on unique chemical reactions driven by radiation — such as those occurring on the icy surfaces of Jupiter's moons.

To test that hypothesis, a team of scientists led by Orlando (formerly of Pacific Northwest National Laboratory) and McCord duplicated the freezing of brine under similar conditions of temperature and vacuum, then cycled the samples through the thermal changes that occur on the surface of Europa. Near-infrared analysis of the resulting samples showed characteristics similar to what the spacecraft reported, supporting the brine theory.

"We made some pretty good connections to what the planetary scientists had seen on the surface of these moons," Orlando says. "We thought about flash freezing from the chemical physics standpoint because if you freeze the brine fast enough, you can 'lock' the waters of hydration into their local positions. These water molecules should have a different optical signature than the rest of the water molecules in ice."

Spacecraft have also measured oxygen molecules (O_2) as part of a tenuous atmosphere on the moons. To understand how oxygen could be produced and liberated from extremely cold ice on the moons, Orlando's research team at Pacific Northwest National Laboratory (PNNL) bombarded ice samples with an electron beam much like those used in the microelectronics industry. The result was an unexpected reaction that involved the production of a stable precursor molecule that would not form under conditions seen by most chemists.

Simulations may also help scientists construct a timeline for tracking the evolution and transformation of the moons' surfaces. Because the high-energy radiation is constantly changing the ice, understanding the rate at which those processes occur might allow researchers to date them — particularly if changes can be measured from one space mission to the next.

Beyond the Galilean satellites, Orlando's interest extends to Mars, comets, asteroids and even the dust found in space. "Radiation-induced processes are generally the rule in outer space," he says. "They're not limited to just one system. We are just simulating what cosmic rays do. Cosmic rays produce electrons, so we study the chemistry these electrons initiate."

A chemical physicist, Orlando began studying chemical reactions driven by radiation while a researcher at PNNL. There, the interest was in the effects of radiation on production of hydrogen and oxygen from nuclear waste. Transitioning that knowledge to planetary science shows the value of interdisciplinary studies, Orlando says.

"We're working in an interesting area where chemical physics, surface science and radiation chemistry can help planetary scientists address the issues raised by the really superb mission data," he notes. "The planetary science community is getting data so good that we can take a molecular view of what's happening."

At Georgia Tech, Orlando has established a laboratory to continue the study of radiation effects on icy surfaces. Using equipment that can produce ultra-high vacuum and temperatures down to 15 degrees Kelvin, he plans to study the production of hydrogen molecules, and to better understand how small changes in the processing conditions affect the characteristics of the very cold ice — and what can be derived from it.

"The surface morphology and the surface temperature greatly affect the products you make," he says. "At one temperature, you might make a lot of O_2. At another temperature, you may just sputter off water molecules and get water into the gas phase. The general radiation processing of low-temperature water is still not completely characterized."

Also on the agenda: photochemistry studies of iron oxides on Mars, sulfuric acid interaction with radiation — and possible nanotechnology and medical applications using controlled electron-beam technology.

NASA and the U.S. Department of Energy sponsor the Jupiter moons research. The research team conducting the brine studies included McCord, Gary Hansen and Lisa Van Keulen of the University of Hawaii, and Glenn Teeter, Matthew Sieger and William Simpson of the Pacific Northwest National Laboratory. A paper on brine work was published in Volume 106 of the *Journal of Geophysical Research*. A paper on the oxygen production was published in Volume 394 of *Nature*. RH

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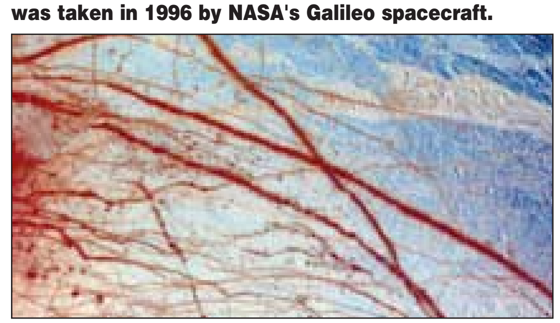
Family portrait shows Jupiter's moons Io, Europa, Ganymede and Callisto. The upper part shows the edge of Jupiter with its Great Red Spot. Europa, the smallest of Jupiter's moons, is about the size of Earth's moon.

BELOW: False color image shows features on the Jupiter moon Europa. Blue indicates ice; brown and reddish hues show contaminants in the ice. The image was taken in 1996 by NASA's Galileo spacecraft.



IMAGES COURTESY OF NASA

Seeing 3D in Real Time

Visualization system could improve severe weather forecasting.

By Jane M. Sanders

Researchers led by the Georgia Institute of Technology are developing a real-time, three-dimensional visualization system to help severe weather scientists improve the timeliness and accuracy of forecasting the formation, path and possible effects of storms.

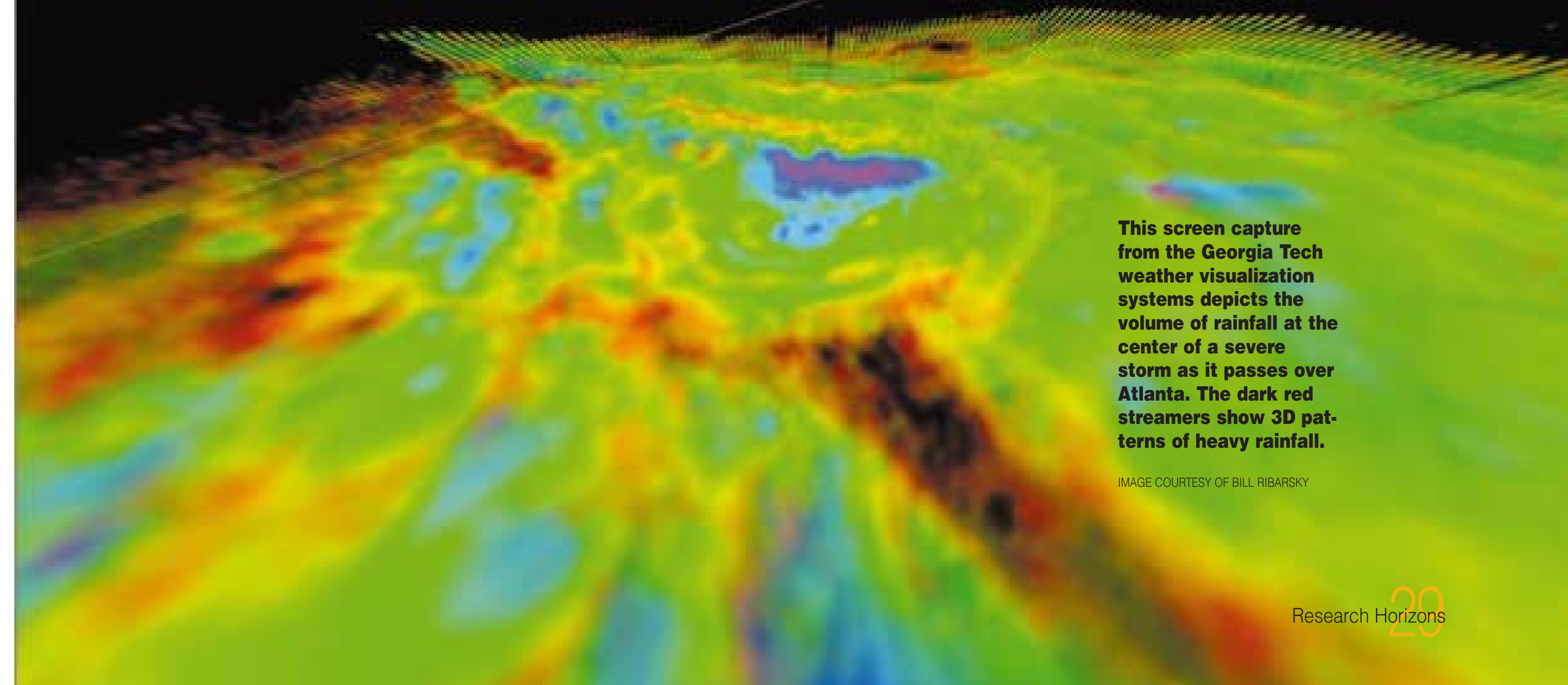
The system will allow weather researchers to use personal computers, as well as large-screen projections, to view, interrogate and analyze large observational data sets, including information from radar stations, severe weather detection software, high-resolution weather models, geographic information systems, satellites and aerial photography. These sources will not only provide weather information, but also data on terrain, building locations and even human activities, such as rush-hour traffic. All of this data will be merged in a platform called the Virtual Geographic Information System (VGIS) previously developed by the project's lead researchers.

Weather researchers will use the visualization system to improve storm detection software used by forecasters. And the National Weather Service may eventually use the system to help decide whether to issue watches and warnings, explains Nick Faust, one of the lead researchers and a principal research scientist at the Georgia Tech Research Institute (GTRI).

"This system will improve weather forecasting in a number of ways," says the other lead researcher, Bill Ribarsky of the Georgia Tech College of Computing. "Ultimately, forecasters will be able to make decisions faster and more precisely. For example, they might see a storm here and make a precise prediction that it's going to affect this community in this way. Forecasters will be able to make more accurate predictions because they will have more information — such as predicting a storm's path based on terrain information and information on human activities. If you have a storm at rush hour, there will be a different effect than if it occurs at night."

The visualization system and associated high-resolution weather models may help forecasters accurately predict general areas of severe weather up to six hours in advance, Ribarsky says. That much lead time could help emergency services personnel know how to respond — for example, whether, when and specifically what areas to evacuate in the case of flooding. Ultimately, predictions integrated with the visualization system could save lives, reduce injuries and save billions of dollars in lost products, equipment and time, Ribarsky adds.

The visualization system is a collaborative project funded by a National Science Foundation grant to



This screen capture from the Georgia Tech weather visualization systems depicts the volume of rainfall at the center of a severe storm as it passes over Atlanta. The dark red streamers show 3D patterns of heavy rainfall.

IMAGE COURTESY OF BILL RIBARSKY

GARY MEEK PHOTO

Researchers Bill Ribarsky, left, and Zachary Wartell run a 3D visualization system and view it on a large-screen projection platform called the Virtual Workbench. The PC-based system will ultimately work in real time. Severe weather forecasting may be improved by the 3D visualization system under development by researchers in the Georgia Tech College of Computing and Georgia Tech Research Institute.

Georgia Tech and the University of Oklahoma's Cooperative Institute for Mesoscale Meteorological Studies. Initial prototyping work was accomplished under funding from the Georgia Emergency Management Agency and the Georgia Tech Severe Storms Research Center (SSRC). The National Severe Storms Laboratory (NSSL) in Norman, Okla., is testing and evaluating the system, and also inserting the system's decision-support tools into NSSL severe weather detection software.

"This system will provide a rich trove of information for analysts and researchers," Ribarsky says. Researchers will not only be able to visualize information in a new way, they will also be able to merge and analyze multiple data sets to study similarities in storm structures in severe weather events. For example, they may merge historical touchdown data from all tornadoes in a certain geographical area to help visually answer the climatological question about whether Georgia has a "tornado alley."

Also, researchers may be able to better understand the impacts of human activities on severe weather. "We know some of the effects of human activities on weather," Ribarsky says. "But perhaps there are some we don't know. So this opens a new research realm."

For example, researchers could use the visualization system integrated with flood extent modeling to allow software predictions of the extent of a flood from a river overflowing its banks into a local area. "Up to now, all we've been able to get is a flood height (that is, when a river will crest)," Ribarsky explains. "But that doesn't tell you anything about what might be flooded. We will be able to predict the extent of the flood — what parts of the community may be affected, like whether a power plant or chemical plant might be flooded — and convey the information to the public in an easily understood, graphical manner. There are now better ways of estimating the amount of rainfall in a catchment basin. Merging all of these data with the terrain visualization could eventually lead to timely prediction of potential flood damage."

The flood-extent prediction capability of the visualization system is building on collaborative work between Faust and the Atlanta office of the U.S. Geological Survey (USGS). Faust worked with USGS researchers to integrate the USGS flood model for the Flint River near Albany, Ga., into Georgia Tech's VGIS platform. The area surrounding the Flint experienced severe flooding in 1994 and 1998. The collaborative effort helped USGS personnel produce a close estimate of the number of people to evacuate in 1998.

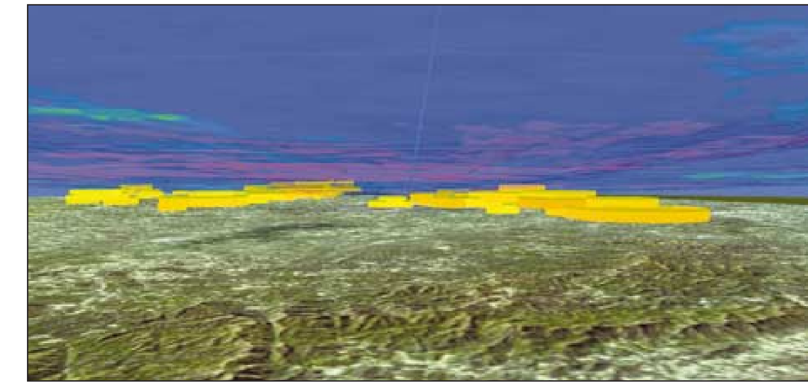
"What we're working on now is a tool that will help officials respond more quickly to severe weather," Faust says. "This visualization system will be very time-sensitive."

An initial version of the visualization system is already receiving north Georgia radar data via the Severe Storms Research Center at Georgia Tech, which gets its feed from the National Weather Service in Peachtree City, Ga. The data is processed by an NSSL severe weather software program that indicates storm signatures, and then automatically transferred to the visualization system for display. Though the visualization system is focusing on north Georgia for now, its structure is scalable — meaning it can be used for local, regional or even national forecasting if data and computing power are available, Ribarsky explains.

Researchers are working now to integrate other data into the system. The next step is integration of a high-resolution weather model, which can forecast conditions for areas as small as one to four square kilometers. Researchers expect to complete the project within two years.

"Once we have it all there, we will be able to show for the first time these dynamic volumes of information in this visualization system, basically as the data are received," Ribarsky says. "This has not been done in 3D before in a time-dependent format."

IMAGE COURTESY OF ZACHARY WARTELL



The Georgia Tech weather visualization system displays mesocyclone severe weather cells passing over the north Georgia mountains. Mesocyclone cells are features derived from Doppler radar data, which show the position, motion and extent of severe storms.

Faust adds that the ability to look at storms in three dimensions in real time will give researchers new insight into the 3D nature of storm development, and that information will result in better severe weather detection software.

In a related research project, Ribarsky and his colleagues are creating a wireless mobile computing system for the new weather visualization system and other applications. In the weather application, doctoral degree student David Krum envisions consumers accessing a personal weather forecast, or "nano forecast," via their personal digital assistant (PDA) or cellular phone. The forecast could be delivered as text and/or a simple graphic.

"The 'nano forecast' is a forecast just for you...." Ribarsky explains. "David Krum is developing techniques to define a user's area of interest (as small as one to four square kilometers). Then the user can get a forecast for when a weather event is going to reach them and from what direction."

Other applications for this wireless "situational visualization" system include finding things like an entrance ramp for a wheelchair-bound person. Emergency personnel could use the system and its dynamic streaming data to find specific locations, or the system could be extended to provide drivers with instant personalized traffic reports.

Researchers realize the commercial potential of the situational visualization system, and some companies have already expressed an interest in the technology, Ribarsky adds.

Working with Ribarsky and Faust on these projects are visiting researcher Chris Shaw, GTRI engineer Tony Wasilewski, and doctoral degree students Krum, Mitch Parry, Zachary Wartell and Richard Zhou. RH

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Jacqueline Johnson, a regional office engineer with Georgia Tech's EDI, uses a game to illustrate supply chain management concepts. Johnson emphasizes development of relationships within an entire supply chain.

Putting a Price on Supply Chain Problems

Study links supply chain glitches with falling stock prices.

By T.J. Becker

When a company announces a supply chain malfunction such as production or shipment delays, its stock price tumbles nearly 9 percent and losses can be as great as 20 percent over six months, according to a study by Vinod Singhal, an associate professor of operations management at the Georgia Institute of Technology, and Kevin Hendricks, associate professor of operations management at the University of Western Ontario.

"Supply chain management (SCM) is on everyone's mind. But any data about its payoff has been anecdotal or based on case studies," Singhal says. And that makes it tough to get buy-in from managers. An expensive and time-consuming process, SCM can require anything from new software to new infrastructure.

"If I'm a manager, I want to know what's the real value of SCM," Singhal explains. "Why should I invest millions of dollars to improve the effectiveness of my supply chain?"

Because information about a company's supply chain performance is typically off-limits to researchers, Singhal and Hendricks found another way to benchmark the value of SCM. They searched for articles in *The Wall Street Journal* and Dow Jones News Service from 1989 to 1998, looking for news of supply chain problems. Finding examples for 861 public companies, Singhal and Hendricks then analyzed how those glitches affected stock prices, using three different models to adjust for normal stock market movements.

When a supply chain malfunction is announced, stock prices plunge an average of 8.62 percent, and shareholder wealth decreases by $120 million or more per company.

"Everyone intuitively knows that having problems with your supply chain will affect performance, but people have been hard-pressed to know exactly what that impact is," says Soumen Ghosh, a professor of operations management at Georgia Tech. "Vinod's and Kevin's study is one of the first that quantifies the detrimental impact."

Even the researchers were surprised by the results. "I didn't expect it to be this dramatic," says Singhal, who anticipated decreases would be in the 2 to 3 percent range.

Yet fallout was even more far-reaching than the 8.62 percent loss. In the 90-day period before a supply-chain problem was reported in the press, stock prices eroded 9 percent, which researchers attribute to news of the glitch leaking out to investors before the formal announcement.

What's more, when Singhal and Hendricks examined stock performance 90 days after the announcement, prices continued to slip. For the entire 180-day period, supply chain glitches caused a 20 percent drop in stock value.

"If the market overreacted to the news, then stock should have regained some of its value," Singhal says. "So this is a fundamental loss. It tells you that the market takes a very dim view of supply chain problems."

In another surprise, it didn't matter who or what caused the problem, stock prices still dropped. The six most common causes of supply chain glitches include: parts shortages, changes requested by customers, new product ramp/rollouts, production problems, development problems and quality problems. Researchers expected investors to be more punitive if the malfunction was caused by internal company problems. But stock plunged 8.29 percent when internal problems caused the glitch, compared with an 11.97 percent decrease when a supplier caused the problem and an 8.48 percent drop when customers caused the problem.

"Even if it's not your fault, you're still going to pay," Singhal observes.

And fickle customers are a fact of life. "If you can't respond to their demands, they'll find someone that will," he adds. "Similarly, suppliers will not always perform to your expectations."

Even if companies have perfect internal operations, they can't relax; it's crucial to collaborate with supply chain partners and share information. "You can't go it alone," he says.

Supply chain glitches hit some companies harder than others. High-growth firms saw their stock drop 10.81 percent on the day a supply chain problem was reported in the media, compared to a 5.89 percent decrease for low-growth firms. Small firms lost 9.85 percent in stock value, while large firms slipped 7.68 percent.

High-growth firms are vulnerable because they typically have short product lifecycles, high margins and require short delivery times. Smaller companies are more at risk because the glitch is likely to affect a greater fraction of their sales. Also, they may not have the resources to put technology in place that could speed recovery.

With all the hype about SCM, the researchers expected to see recent supply chain problems take the greatest toll on firms. But when Singhal and Hendricks compared glitches that occurred after December 1995 with previous snafus, there was little difference. "The market has always placed a premium on a well-functioning supply chain," Singhal says.

"In some sense, we're presenting the darker side by showing what happens if you don't take action or your efforts aren't effective," he adds. Yet building responsive supply chains requires substantial time and money. Top management must be involved, and one of the best ways to grab their attention is to show how SCM impacts the bottom line — for better or worse.

"By showing them the negative consequences, you can make a case," Singhal explains.

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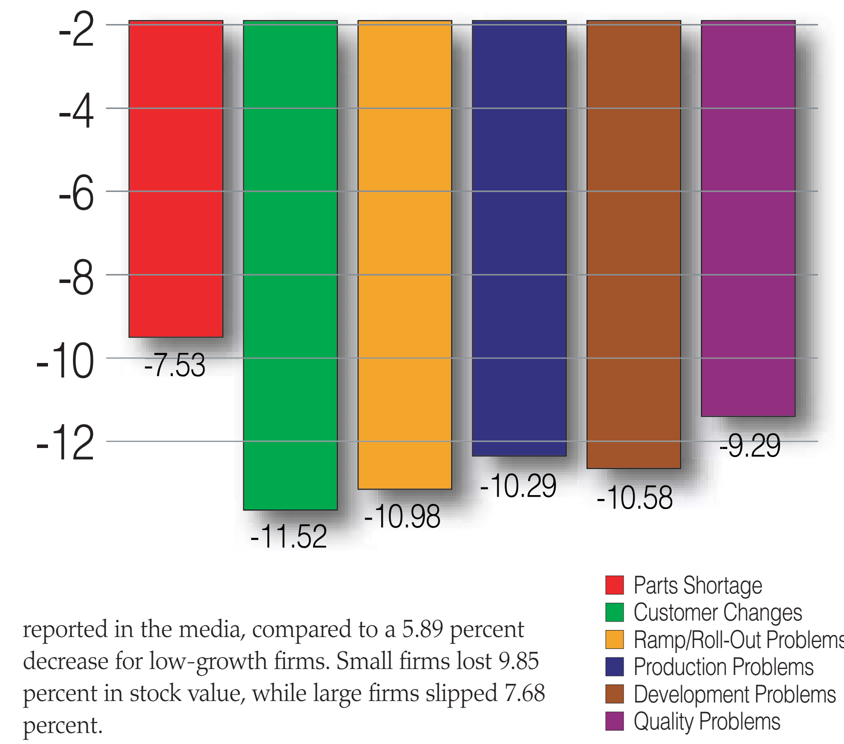
T.J. Becker is a Florida-based freelance writer.

Average Shareholder Return



This chart represents the average market-adjusted shareholder return by the six most-cited reasons for supply chain glitches. Results are the stock market reaction on the day information about supply chain problems was announced.

Jennifer Trapp-Lingenfelter, EDI's region manager for west Georgia, examines a circuit board with Chris Lewis, president and CEO of Spectral Response, an electronics manufacturer in Duluth, Ga. Trapp-Lingenfelter says supply chain management requires support from top management.

The Weakest Link

Supply chain management is only as strong as its weakest link.

NETWORKING SERVICES GIANT CISCO Systems recently posted a 30 percent decline in sales, announced plans to slash 8,500 jobs and wrote off $2.5 billion in excess inventory.

Company executives insist Cisco was blindsided by the economic slowdown and declining demand. Others, according to *Fortune* magazine, say Cisco had a problem managing its supply chain.

Dell Computer, on the other hand, has fared well in the recent technology meltdown. Why? Dick L. Hunter, Dell's vice president overseeing supply chain management, told *Business Week* the difference is "Dell's super-efficient supply chain."

Simply put, a supply chain is the network of companies that work together to design, produce, deliver and service products. In the past, companies emphasized manufacturing and quality improvements within their four walls. Their energies now extend beyond those walls to manage the entire supply chain.

What, then, constitutes good supply chain management? There are three basic links in a supply chain—the company, its suppliers and customers, says Jacqueline Johnson, a regional office engineer for the Georgia Institute of Technology's Economic Development Institute (EDI).

"As you manage the supply chain, it is imperative that you try to manage both ends, as well as yourself," Johnson says. "Because as the old adage goes, the chain is only as strong as its weakest link." Johnson also emphasizes the importance of developing relationships within the supply chain, monitoring performance, and collaboration on mutual benefits and improvement.

Jennifer Trapp-Lingenfelter, EDI's region manager for west Georgia, explains what constitutes poor supply chain management. "One of the downfalls is when companies think supply chain management is just letting suppliers hold their inventory," she says. "Well, you haven't done anything in your supply chain, all you've done is push the load back onto the little guy."

Johnson and Trapp-Lingenfelter offer several suggestions for companies wishing to implement good supply chain management. The first step is to identify and prioritize the links in the supply chain. "You can't be successful by dealing with all the links in your supply chain at one time," Johnson insists. "You need to make sure there's an alignment with your company's strategies and initiatives because there will be much more energy and resources to support it."

It is also important to be able to meet market demand by working in a partnership with suppliers. "You need to be flexible enough so you're not holding all that inventory," Trapp-Lingenfelter says. "If a change in demand does occur, you won't be caught in a sticky situation."

One way to develop these partnerships is by sharing information and resources, Johnson explains. "Bring customers and suppliers onto your site, go to their site to gain and learn from each other," she adds. "Use those partnerships to enhance your overall process."

Building partnerships with suppliers and customers hinges on good communication. "I believe that at some point you need to make an investment into your communications technology to have a good supply chain," Johnson says. "The information age is critical, and it's going to be hard for some of these smaller companies to bite off on it. But I think you can take baby steps and have an evolution toward real-time information by using what's in your hands."

Good supply chain management also moves beyond thinking in terms of cost-per-unit and begins to develop long-term goals. "Everyone's looking for the silver bullet and that automatic thinking of dollars, dollars, dollars," Trapp-Lingenfelter says.

Johnson agrees, noting that relationships are not always going to be based upon cost-per-unit. "What is their technology strategy? What kind of communications system do they have in place? What are their quality records like? Are they good corporate citizens?" she asks. "If you're picking your suppliers solely based on cost-per-unit, then you're missing out on everything else they may be able to offer."

Trapp-Lingenfelter insists that good supply chain management cannot be implemented without the support of top management. "CEOs should be talking to CEOs," she says. "One of the biggest downfalls you have is mid-level managers trying to make strategic decisions where they can only go so far within that company."

—Nancy Fullbright Millett

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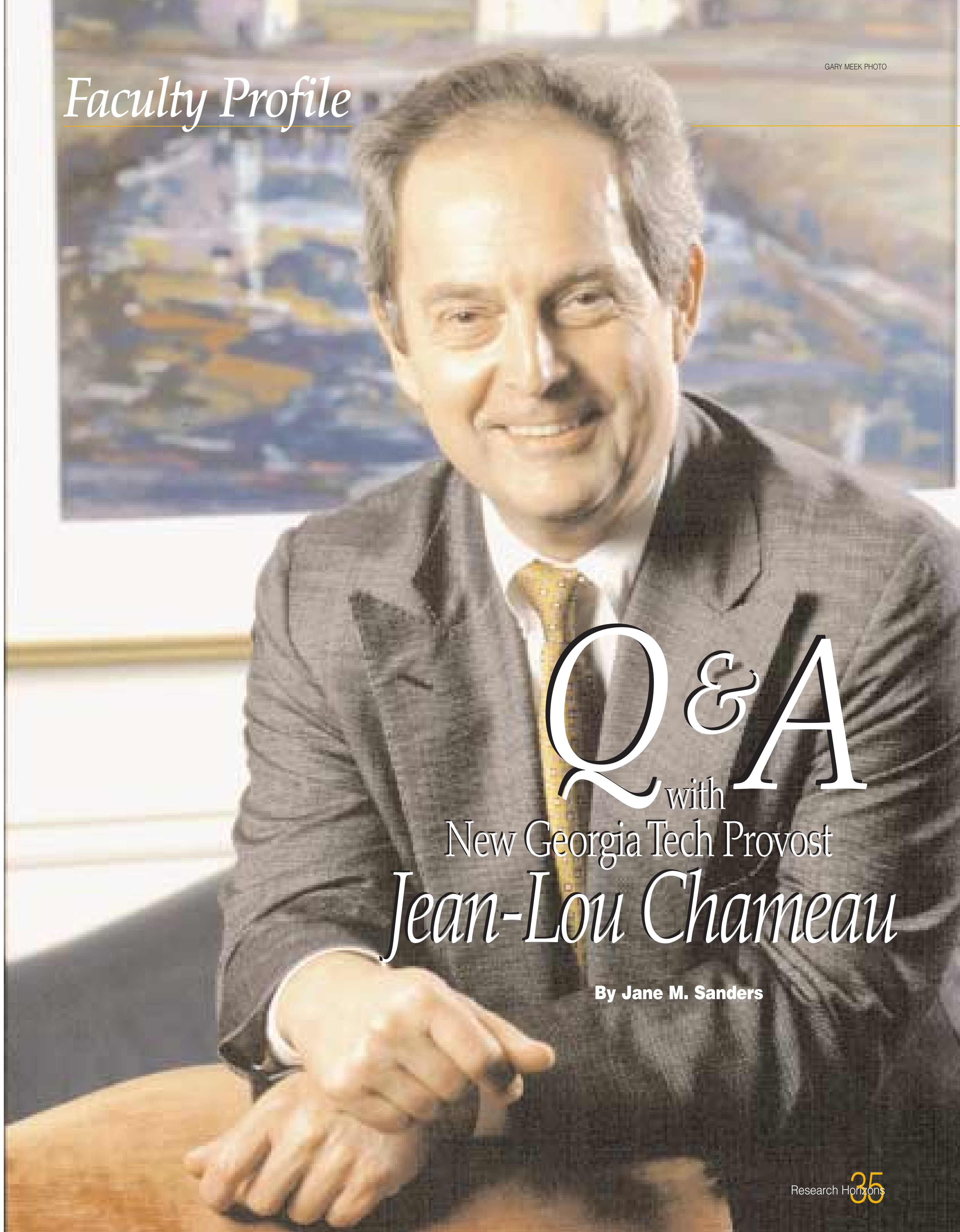
A Checklist for Implementing Good Supply Chain Management

✔ Identify and prioritize the links in your chain.
✔ Manage all three basic links in your supply chain — your company, your suppliers and your customers.
✔ Make sure the links in your supply chain align with your company's strategic goals and initiatives.
✔ Be flexible enough to meet market demand.
✔ Foster relationships by sharing information and resources. Be direct with your suppliers and your customers as to how you can benefit from each other.
✔ Develop long-term thinking — have a goal.
✔ Be proactive, not reactive.
✔ Invest in your communications technology.
✔ Move beyond thinking in terms of cost-per-unit.
✔ Involve top management.



GARY MEEK PHOTO

Faculty Profile

Q&A with New Georgia Tech Provost Jean-Lou Chameau

By Jane M. Sanders

Jean-Lou Chameau became provost of the Georgia Institute of Technology on June 1, 2001. The former dean of the Georgia Tech College of Engineering has a long and distinguished career in both academia and private industry. He is recognized for his focus on student success, support of faculty collaboration and entrepreneurship, interest in sustainable technology, his commitment to diversity, his global perspective and his devotion to Georgia Tech. Chameau, a native of France, completed his graduate education in civil engineering at Stanford University. Before coming to Georgia Tech in 1991, he was a professor at Purdue University. Also, from 1994-95, he was president of the civil engineering firm Golder Associates, Inc.

PHOTO BY GARY MEEK

Chameau is recognized for his focus on student success, support of faculty collaboration and entrepreneurship, interest in sustainable technology, his commitment to diversity, his global perspective and his devotion to Georgia Tech.

Q: In terms of technology transfer, what are the benefits to society of university research and expertise?

The first thing we bring is educated people. The most important product of this university is high-quality graduates who contribute to the community and the nation. This is our most important form of technology transfer.

We also provide technology transfer in the form of a knowledge base and research findings that can lead to opportunities for corporations to develop new products or new ideas…. And we're directly involved in the commercialization of new ideas by forming new companies and licensing technologies. This has a direct effect on the local economy when that takes place.

Q: What is the value of involving undergraduate students in research at Georgia Tech?

There are many reasons. First, if students come to what's called a research university, we should make sure they can take advantage of it. It's important for undergraduate students to have the opportunity to work with leading-edge researchers.

We've had some of this in the past 10 to 15 years. A significant number of our undergraduates have been involved in research, but it's not as many as we would like. There is a desire here to have a majority of our undergraduate students have the opportunity to interact with researchers. It should be a part of the experience of attending a research university.

Another reason is that research develops creativity skills that might not be developed otherwise. These skills can be useful in the future whether the students work in a technical or non-technical field.

Also, we get high-quality students here, and we need to challenge them. Otherwise, they get bored. Research can challenge them.

At Georgia Tech, we have a number of ongoing initiatives. It has been a priority in a number of the units on campus to get undergraduate students more involved in research…. Many schools require senior projects that are often research-oriented…. Also, faculty members are getting support through their grants for undergraduate involvement in research. The National Science Foundation has had such an initiative for a number of years. And now, the president of Georgia Tech has reinforced these activities by providing some seed funding to various research projects to allow undergraduate involvement.

Q: How would you describe Georgia Tech's relationship with industry? Is it primarily defined by sponsored research?

We have developed fairly comprehensive relationships with industry. There are many facets to these relationships.

We want corporations to recruit many students here. In fact, corporations often get involved with Georgia Tech and other universities because they want an advantage in recruiting our students. We also try to get opportunities for our students in the co-op program (alternating semesters of class and work) to work for some of these corporations.

And we try to get these corporations involved in research activities on our campus, some of which are fairly limited all the way to some major research initiatives or research centers. For large corporations like Georgia Power, GE, Ford, Intel and others, we try to provide interaction with researchers in many different areas. And we want to give our faculty and staff the opportunities to work within these corporations and vice versa.

So we emphasize lots of interaction with industry…. The motivation is to be a research university that has strong connections to the corporate world such that our education and research programs are strong, and that they have applications to industry and the real world.

Q: You also have a strong commitment to achieving diversity at Georgia Tech. What plans are being made to increase diversity here, and why is it a priority?

We have a good record in this area. We have taken some positive steps to achieve diversity, not only recently, but over the past 30 years. We also try to provide an environment that supports diversity.

I view diversity in a broad way. We want individuals on our campus who represent different viewpoints and bring different approaches and skills to solving problems.

Diversity is an important goal for Georgia Tech, and we are making progress in promoting an environment that is supportive of students and faculty. There is still a lot of work to be done…. But we rank number one in graduating ethnic minorities in engineering disciplines. We're proud of that, but we want to do more.

I also want to increase international awareness. We have a significant number of foreign students here, and we are giving opportunities to our U.S. students to go overseas to study abroad.

Q: How has your experience working in the private sector affected your perspective on university research, particularly that done for industry?

I have learned that you don't know what management means, what administration means, how to meet a budget and the bottom line unless you do it yourself. So my experience in the private sector has been extremely useful to me in my work in academia. It taught me to be effective with the resources we have

Georgia Tech ranks number one in the United States in graduating ethnic minorities in engineering disciplines. Chameau is proud of that ranking, but wants to do more to promote diversity at the institution.

PHOTO BY STANLEY LEARY

and to optimize those resources. It was good for me in terms of learning to manage and administer major parts of a large organization such as a university.

Q: How has your French heritage influenced your perspective in academia in the United States?

I have had a chance in my career to interact with people from many different backgrounds and countries. I was raised to know two or three different cultures. Nowadays, we live in a global environment. Whatever occupation you are in, there are issues that go beyond your little world. If you work for a corporation, you may be working for someone overseas and vice versa. Given this environment, it is an advantage to people now to have a good understanding of different cultures — how we work differently, but achieve the same goals…. So it's an advantage if you are a young person entering into real life to appreciate different cultures and take advantage of their strengths.

In fact, we have a goal here at Georgia Tech. We would like to have the majority of our students have some sort of international experience. In the long term, it will serve them well.

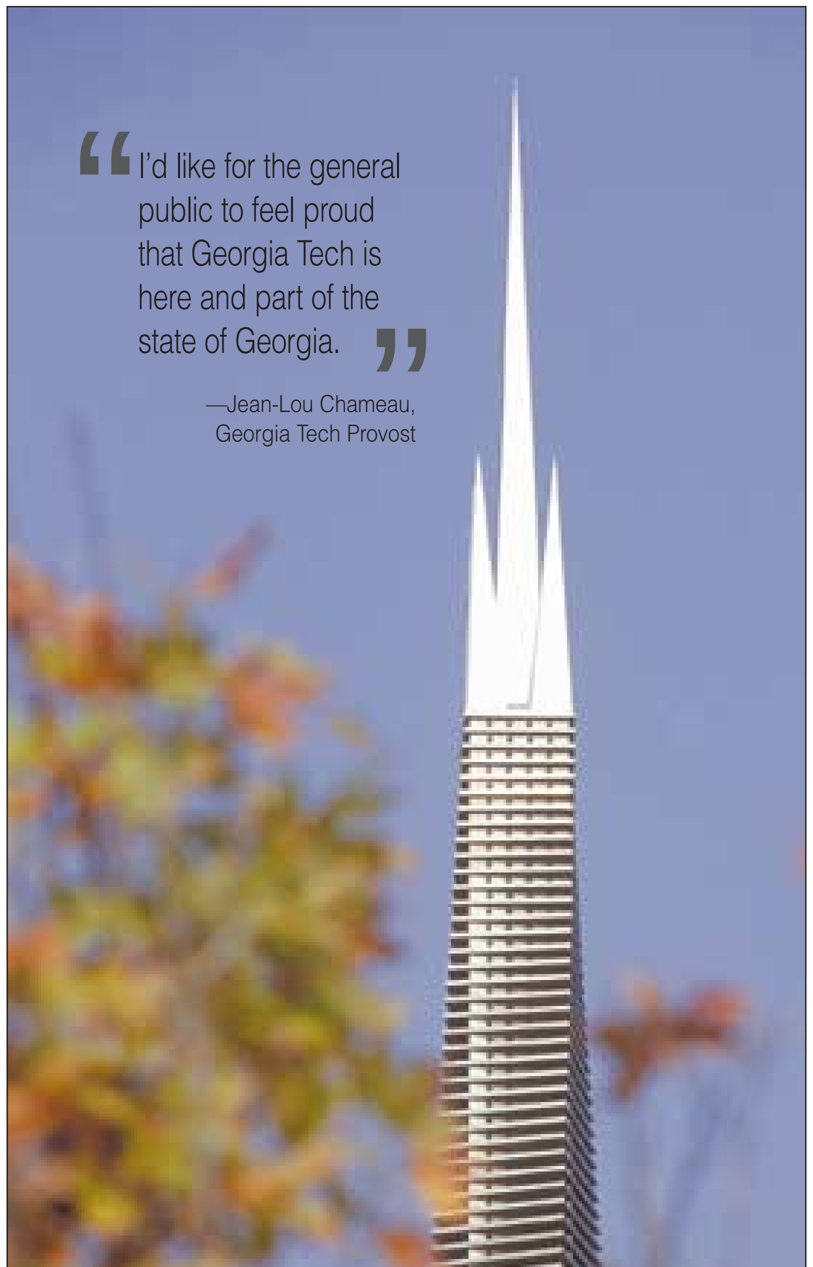


PHOTO BY STANLEY LEARY

Q: You have expressed "love" for and "dedication" to Georgia Tech. Why do you feel this way about this institution?

It is very strange. It has to do mostly with people, and it happened very rapidly for me. I came to this campus for the first time 10 years ago for an interview. I met a number of individuals on campus and related to them very well, and vice versa. There was a sense of entrepreneurship, a sense of dynamism among them, and I shared that. It was an environment where if you had ideas and were willing to work hard to promote them, there were not many barriers in front of you. So I fell in love with that kind of environment right away…. It has become even more of a reality over time.

Q: What impression do you want the general public to have when they think of Georgia Tech?

I'd like for the general public to feel proud that Georgia Tech is here and part of the state of Georgia. Even if they or their children didn't go to school here, I want them to be proud of Georgia Tech's successes and international reputation because they recognize that Georgia Tech contributes to the state and is a major reason for the state's success and a key asset for its future. **RH**

■ For the text of the complete interview, see **gtresearchnews.gatech.edu/reshor/rh-f01/default.htm**. For additional information, you may contact Jean-Lou Chameau, Office of the Provost, Georgia Tech, Atlanta, GA 30332-0325. (Telephone: 404-385-2700) (E-mail: jeanlou.chameau@carnegie.gatech.edu)

Research Notes

Here or there? More or less? Bigger or smaller?

Location. Location. Location. It matters in ozone pollution production as much as it matters in real estate, based on a study published in the journal *Science* this past spring.

A team of researchers that included a Georgia Institute of Technology scientist found that ozone pollution production associated with coal-burning power plants is affected by the geographic location and nitrogen oxide (NO_x) emission rates — and not necessarily the size — of those plants.

Study relates ozone production to location, emission rate and size of power plant.

The finding has implications for the U.S. Environmental Protection Agency's (EPA) efforts to control ozone pollution, suggesting the agency can no longer equally value power plant emissions across the nation. It also gives power companies insight into where they should build new power plants and the effect of their size on ozone production.

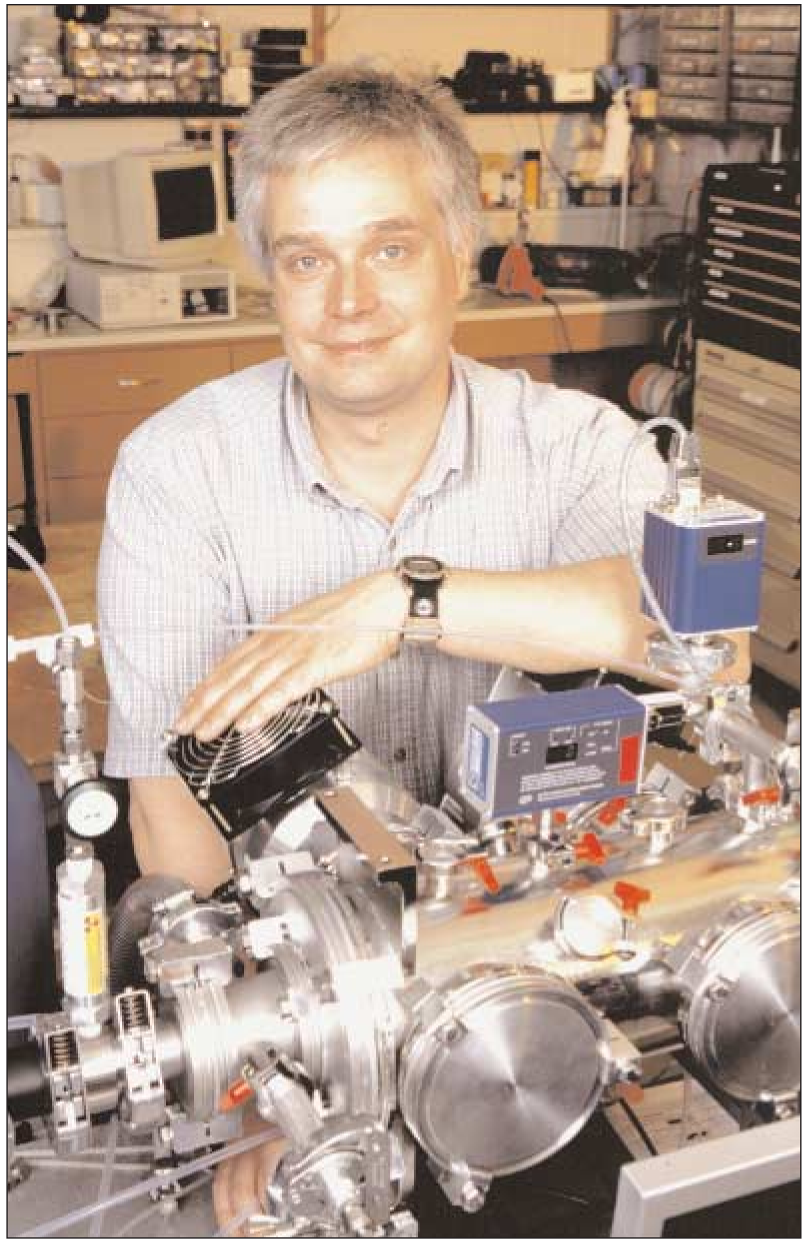
"We think that our research represents an opportunity to build on current efforts to improve air quality," says lead author Tom Ryerson of the National Oceanic and Atmospheric Administration's (NOAA) Aeronomy Laboratory in Boulder, Colo.

The researchers found that emissions from power plants located near hardwood forests result in more ozone pollution than those operating in agricultural or grassland areas. Trees, particularly oaks, emit volatile organic compounds (VOCs) such as isoprene as a

NOAA and Georgia Tech researchers collected atmospheric data downwind of coal-burning power plants. Two were Tennessee Valley Authority plants in rural areas where the many hardwood trees produce high VOC emissions. The third was in Missouri, where farms and grasslands have low VOC emissions.

IMAGE COURTESY OF TOM RYERSON

PHOTO BY T. MICHAEL KEZA



A team of researchers that included Georgia Institute of Technology scientist Greg Huey found that ozone pollution production associated with coal-burning power plants is affected by the geographic location and nitrogen oxide emission rates — and not necessarily the size — of those plants.

byproduct of photosynthesis. When VOCs released from the Earth's surface are oxidized in the atmosphere in the presence of NO_x, ozone is formed. Elevated levels of surface ozone can harm human health and vegetation.

Because coal-burning power plants are largely concentrated in rural areas of the eastern United States — where there are more VOC-producing trees — ozone pollution has been a significant issue for the East, and for the Southeast in particular. Coal-burning plants contribute about 25 percent of the nation's overall NO_x pollution, which leads to ozone production. The ozone issue affects rural areas and cities because ozone pollution can travel up to 100 miles downwind. Cities are also fighting ozone associated with vehicle emissions, which account for 53 percent of NO_x emissions.

"The Southeast traditionally has had an ozone attainment problem," says Greg Huey, one of the study's authors and an associate professor in the School of Earth and Atmospheric Sciences at Georgia Tech. "The Southeast is more rural than the Northeast, but you have hardwood forests emitting a lot of VOCs such as isoprene. So you're stuck with high VOC levels. The Southeast is also hot, sunny and humid, and sunlight and water vapor are two of the essential ingredients to initiate photochemistry in the atmosphere. The Southeast is a photochemical pressure cooker, and all you need are NO_x emissions to produce ozone."

For the *Science* study, NOAA and Georgia Tech researchers collected atmospheric data while flying downwind of three coal-burning power plants. Two were Tennessee Valley Authority plants — Cumberland and Johnsonville — located in rural Tennessee where there are a lot of hardwood trees with high VOC emissions. The third was a Thomas Hill, Mo., plant surrounded by farms and grasslands, which have low VOC emissions.

In comparing the two Tennessee plants to the Missouri plant, researchers found that VOC concentration — which is associated with location — is also a key factor in ozone production. The Thomas Hill plant produces 2 ozone molecules per molecule of NO_x emitted, and it emits 4 tons of NO_x per hour. Meanwhile, the Johnsonville plant makes about 7 ozone molecules per molecule of NO_x emitted and emits 2 tons of NO_x per hour. So even though the Thomas Hill plant emits twice as much NO_x as the Johnsonville one, it produces only about half the total ozone because of differences in VOC concentration.

Researchers found that the large Cumberland plant emits 14 tons of NO_x per hour and makes 2 ozone molecules per molecule of NO_x emitted. Consequently, the Cumberland plant only makes about twice as much ozone as the Johnsonville plant, which emits a factor of 7 less NO_x per hour than the Cumberland plant. The Johnsonville facility is more efficient in producing ozone, yet the two plants have an identical concentration of VOCs in the surrounding atmosphere. Researchers attribute the difference in ozone production to differences in the NO_x concentration around the plants. The high concentrations of NO_x associated with the large Cumberland plant promote a series of reactions that don't form ozone, but eliminate the available NO_x, Ryerson explains.

"So if you went to the trouble of cutting the Cumberland plant's NO_x emissions, you may still get the same amount of ozone in the end because it's just going to get more efficient in producing ozone," Huey explains. In fact, Cumberland has reduced its NO_x emissions by half in the past six years, yet its total ozone yield has stayed about the same.

"What we learned in this study is the need to think about how we make power plants cut NO_x emissions," Huey says. "Also, it might be better to build one bigger power plant than a lot of smaller ones. Again, you have Cumberland, which is a larger plant than Johnsonville, but it produces ozone much less efficiently."

"The other thing this study shows is that it's probably better to build a power plant in an area where you don't have a lot of VOCs — the other fuel for making ozone," Huey says. — *Jane M. Sanders*

■ For the full text of this article, see **gtresearchnews.gatech.edu/reshor/rh-f01/default.htm**. For more information, you may contact Greg Huey, School of Earth and Atmospheric Sciences, Georgia Tech, Atlanta, GA 30332-0340 (Telephone: 404-894-5541) (E-mail: greg.huey@eas.gatech.edu); or Tom Ryerson, Aeronomy Laboratory, NOAA, 235 Broadway St., Boulder, CO 80303 (Telephone: 303-497-7531) (E-mail: tryerson@al.noaa.gov)

Paper Partnership

Paper: it pervades every part of our life. Its forms are myriad, from the paper in this magazine to the wallpaper in our homes. Accordingly, the pulp and paper industry plays a large economic role in the United States, accounting for revenues of nearly $170 billion a year.

Georgia Tech's new center for paper studies will address industry challenges.

Yet, in spite of its significance, the industry has suffered large setbacks in recent years. Profits have weakened, companies have been merged and acquired, and overall, shareholder values have deteriorated.

To address these issues, the Georgia Institute of Technology and the Institute for Paper Science and Technology (IPST) in Atlanta have joined forces with the paper industry to create a new research center, the Center for Paper Business and Industry Studies (CPBIS). The new center is funded largely by the paper industry and a $2 million grant from the New York-based Sloan Foundation. The center will offer value-added service to the paper industry, while providing unique educational opportunities to Georgia Tech and IPST graduate students.

The CPBIS is the 16th of 17 industry centers funded by the Sloan Foundation and is part of a major effort by the organization to create academic communities dedicated to completely understanding particular industries. The foundation requires cooperative industry funding and encourages a direct approach to industry research through regular contact between academics and industry leaders.

Efforts at the CPBIS will concentrate on the business fundamentals affecting the U.S. paper industry within the context of the global industry, while generating focused research and producing experts for the future of this complex and competitive business. Initially, five areas of interest will be addressed: globalization, commercialization, community interactions, workplace transformations and enterprise effectiveness.

The work will be conducted by a diverse group of researchers from IPST and several Georgia Tech academic units, including the Ivan Allen College, DuPree College of Management and the College of Engineering.

"The creation of the center will help us channel the energies and the talents of the Georgia Tech faculty toward the pulp and paper industry," says Tom McDonough, a professor and senior research fellow at IPST, who will serve as the center's director. "We have excellent resources here, and now we have an opportunity to take advantage of them for the good of the industry."

The benefits of this collaboration are clear. Jim McNutt, new executive director of the CPBIS, explains, "The center will become a place where we seek to completely understand the industry, while providing high-quality research with practical outcomes from that research." Officials at the Sloan Foundation believe researchers must be "connected to the industry at the hip," an objective that McNutt says he is determined to meet.

The Georgia Institute of Technology and the Institute for Paper Science and Technology (IPST) in Atlanta have joined forces with the paper industry to create a new research center, the Center for Paper Business and Industry Studies (CPBIS). At the Visy Paper Mill in Conyers, Ga., CPBIS executive director Jim McNutt, left, and IPST associate director of business development David Bell, center, discuss the industry with David Kosboth, general manager of Visy.

PHOTO BY T. MICHAEL KEZA

McNutt also points out another benefit to the industry — the creation of a cadre of graduates who are in tune with and trained to address the business management and liberal arts needs of the pulp and paper industry. "The classes to be offered by the center and the hands-on experience from the ongoing research will give graduate students experience they cannot obtain elsewhere," he says. "It is this meshing of the theoretical and practical that makes the educational opportunities afforded by the center so valuable."

> "The classes to be offered by the center and the hands-on experience from the ongoing research will give graduate students experience they cannot obtain elsewhere."
>
> — Jim McNutt
> Executive Director
> CPBIS

While the administrative aspect of setting up the center is nearly complete, the business of running it has only just begun. Plans are under way to offer classes through CPBIS, and funding for seven research projects will begin soon. Additional projects will be added in the future, as well as seminars and an expanded internship program.

David Bell, development director of IPST, speaks enthusiastically about the first major project jointly undertaken by Georgia Tech and the IPST (i.e., the establishment of CPBIS). He notes that IPST has excellent contacts in the industry, while Georgia Tech provides liberal arts and management expertise. "We can use the great strengths of both institutions and apply those to the paper industry," he adds.

— *Patricia J. West,* freelance writer

■ For more information, contact David Bell, IPST, 500 10th St. NW, Atlanta, GA 30318-5794. (Telephone: 404-894-9592) (E-mail: david.bell @ipst.edu)

Controlling Epileptic Seizures

The same technology that senses an impending electrical failure in aircraft is being used to detect a human neurological system malfunction — epileptic seizures.

> Researchers find electrical pattern that precedes seizures.

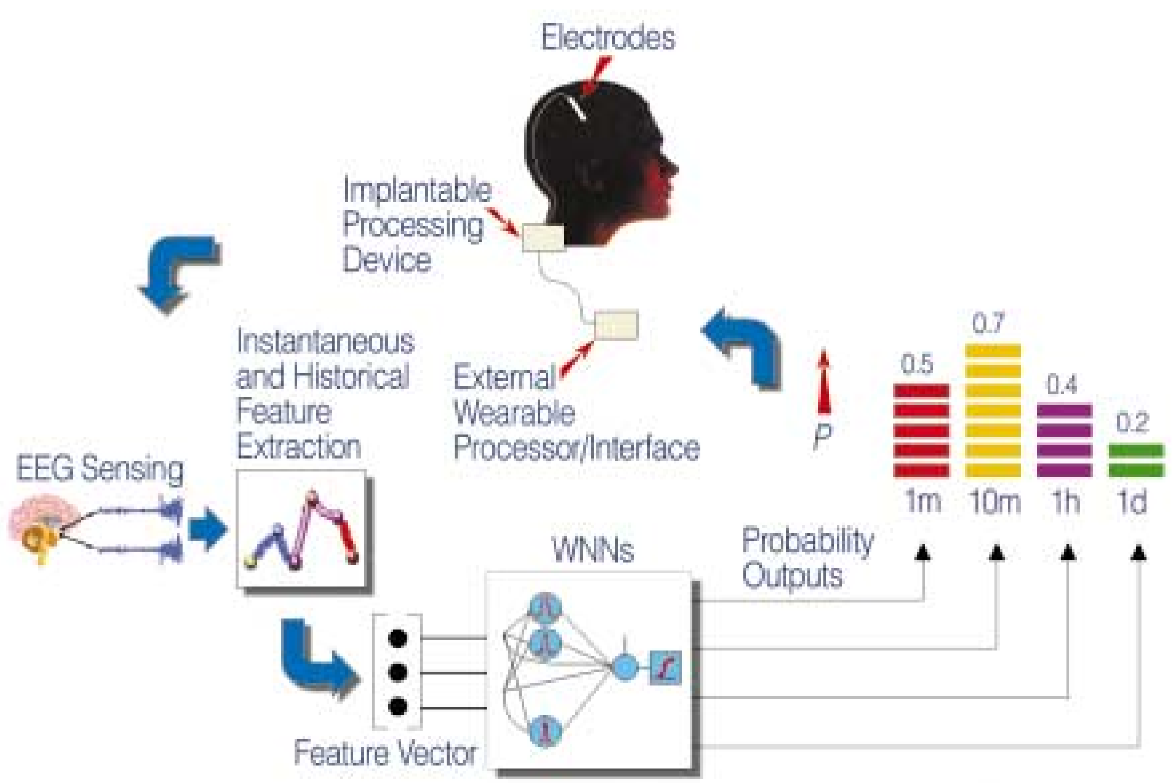
A collaboration between George Vachtsevanos, a professor in the Georgia Institute of Technology School of Electrical and Computer Engineering, and neurologists at the University of Pennsylvania and Emory University has found that a series of electrical blips and burps in the brain precedes seizures by as much as seven hours.

Their study, published in the April 2001 issue of the journal *Neuron*, offers the hope that onset of seizures can be predicted and possibly halted in patients for whom medicines don't work and surgery is not an option.

Seizures are produced by abnormal electrical discharges in the brain and can cause convulsions and loss of consciousness. Most of the 50 million epilepsy patients worldwide do not know when a seizure will occur and many, especially children, cannot be treated.

Georgia Tech has applied for several patents on a technique Vachtsevanos and his graduate students developed to analyze brain wave activity based upon patient-specific prediction algorithms. A company is interested in licensing the technology to develop a miniature pulse-generating device. When implanted in the brain, it would continuously monitor brain wave activity, and detect and abort a seizure long before it occurs.

Georgia Tech researchers are able to predict the onset of an epileptic seizure based on brain waves. A new device — implanted in the brain to monitor brain wave activity — could detect and abort a seizure.



A team of researchers, including one from Georgia Tech, have found that a series of electrical blips in the brain precedes seizures by as much as seven hours. This diagram illustrates a technique, on which a patent is pending, for analysis of brain wave activity to detect and abort seizures before they occur.

ILLUSTRATION COURTESY OF GEORGE VACHTSEVANOS

Vachtsevanos' technique analyzes huge data sets of real-time information to predict when critical electrical systems, like those found in aircraft, might hiccup and begin to fail. Those systems can then be reset, avoiding interruptions of power.

A decade ago, Vachtsevanos began working with physicians at the Medical College of Georgia to understand the meaning of electrical signals as recorded by electroencephalogram (EEG) devices. Epileptics suffering a seizure will produce a jagged, highly fluctuating brain wave pattern, but so-called "normal" activity in advance of a seizure is hard to interpret, he says.

Four years ago, Vachtsevanos formed a new collaboration with former Emory University neurologist Brian Litt and his colleagues, who were able to provide reams of recordings taken from five patients monitored for weeks at a time by EEG electrodes implanted in their brains. These patients were also videotaped so that any changes in behavior could be matched to their brain waves.

By studying those patients and their brain waves, Litt, now at the University of Pennsylvania, Vachtsevanos and other researchers at Emory uncovered an early warning system. They found that bursts of electrical energy could be detected as much as seven hours before a seizure. And two hours in advance of a seizure, a series of frequent, tiny and symptomless seizures occurred, unbeknownst to patients.

Vachtsevanos is proud that the systems he developed to keep airplanes and helicopters flying smoothly may be able to keep a brain chugging along steadily, too, he says.

"These are very basic fundamental techniques that analyze signals and extract any abnormal deviation," Vachtsevanos explains, adding that there may be additional biological uses of such systems - such as predicting and stopping irregular cardiac rhythms before they produce a heart attack.

Similar diagnostic and prognostic technologies developed by Vachtsevanos' group are improving industrial product quality and process productivity by increasing uptime and conducting maintenance only when needed.

— *Renee Twombly,* freelance writer

■ For more information, contact George Vachtsevanos, School of Electrical and Computer Engineering, Georgia Tech, Atlanta, GA 30332-0250. (Telephone: 404-894-6252) (E-mail: george.vachtsevanos@ee.gatech.edu)

Mystery Under the Sea

Intriguing seafloor ecosystems in the Gulf of Mexico have prompted a unique, multidisciplinary study that may advance the understanding of marine microbiology and the adaptations of microorganisms to extreme environments that may exist elsewhere on Earth and on other planetary bodies.

> Researchers study hydrocarbon-based biological communities in unique ocean floor ecosystems.

Researchers from the Georgia Institute of Technology, the University of Georgia and Texas A & M University have begun a year's worth of data and sample analysis following a two-week underwater expedition in the Gulf in July. They are studying the biological communities associated with seafloor ecosystems called brine pools and hydrocarbon seeps.

The Gulf of Mexico seafloor contains vast pools of liquid and gaseous hydrocarbons. Two unique features, brine pools, extremely salty areas on the ocean floor, and hydrocarbon seeps, where oil and gas leak from the ocean floor, occur in the Gulf. Here, methane combines with water and hydrocarbons to form ice-like clathrates called gas hydrates that can breach the ocean floor.

"This environment creates diverse and extreme niches promoting the growth of thriving communities of macro- and microorganisms living in the sediments of oil seeps, in brine pools and hydrates," says Patricia Sobecky, an assistant professor in the Georgia Tech School of Biology.

A 22-person research team explored and sampled the ecosystems in July using a four-person sub-

PHOTO BY HEATH MILLS

Georgia Tech scientist Joe Montoya caps off a sediment sample from a Gulf of Mexico brine pool research site. Montoya collected the sample by gravity coring off the side of the research ship.

PHOTO BY HEATH MILLS

Georgia Tech scientist Patricia Sobecky prepares for a dive to the ocean floor in the Gulf of Mexico aboard the Johnson Sea Link, a four-person submersible vehicle from the Harbor Branch Oceanographic Institute in Fort Pierce, Fla.

mersible vehicle, the Johnson Sea Link operated by the Harbor Branch Oceanographic Institute (HBOI) in Fort Pierce, Fla. The crew launched the Sea Link from the HBOI's research ship, the Seward Johnson. The research team was led by Sobecky, Georgia Tech Associate Professor of Biology Joe Montoya, Mandy Joye of the University of Georgia and Ian McDonald of Texas A & M. Each researcher, including undergraduate students, graduate students and technicians, took part in at least one dive to the sea floor.

Researchers reported being awed by the brine pool and hydrocarbon seeps they studied. Little is known about these ecosystems because of the time and expense associated with researching them. In addition to the Gulf of Mexico locations, these ecosystems also exist along the coast of Mexico and in the North Sea.

Montoya and Sobecky described thick bacterial mats that can cover extensive parts of the ocean floor in these ecosystems. Some of the mats were as large as 50 square meters. Researchers sampled these mats at depths of 500 to 600 meters while working from the submersible vehicle.

"Although analysis of samples from this cruise will take at least a year, preliminary results, including some data obtained while we were still at sea, demonstrate the profound impact of the hydrocarbon seeps on the bottom communities in the area," Montoya says. "In addition to the extensive bacterial mats, large aggregations of mussels and tube-worms and hosts of smaller, free-living invertebrates were near the seeps and around the brine pool. The influence of the hydrocarbon seeps may also extend upward into the water column, where plumes of gas bubbles and oil droplets may nearly reach the surface."

Each lab in this collaborative project brings a unique area of expertise to the study. For example, Sobecky's lab hopes to find biotechnology applications derived from the biological samples collected from the sea floor.

"We do a lot of searching for novel genes and novel mechanisms of adaptation," she says. "There may be accessory genetic elements in bacteria that allow them to adapt…. So you never know what you might find."

Meanwhile, Montoya's lab is investigating the movement of nitrogen and carbon in the sediments and invertebrate communities, as well as in the overlying water column.

Applications of the researchers' findings also could be found in energy and planetary exploration, they say. Some scientists have suggested the hydrocarbon methane, derived from methane hydrates on the ocean floor, as a potentially important fuel source. It may also be possible to extrapolate information on this ecosystem to learn more about the environments of places like the Jovian moon Europa. A large body of evidence indicates the existence of an ocean there; it may harbor environments similar to those around methane hydrate deposits on Earth, Montoya says. *(See related story on page 26.)*

This research is being funded by the National Science Foundation's Life in Extreme Environments Research Program and the National Oceanic and Atmospheric Administration's National Undersea Research Program.

To read reports posted while the researchers were at sea this past July, see the Harbor Branch Oceanographic Institute's Web site at www.at-sea.org. Follow the link to the mission titled "Diving to Extremes: Life in Hydrocarbon-Based Ecosystems."

— Jane M. Sanders

■ For more information, contact Patricia Sobecky, School of Biology, Georgia Tech, Atlanta, GA 30332-0230. (Telephone: 404-894-5819) (E-mail: patricia.sobecky@biology.gatech.edu); or Joe Montoya, same address. (Telephone: 404-385-0479) (E-mail: joseph.montoya@biology.gatech.edu)

RIGHT: Researchers collected samples from bacterial mats found in an exposed gas hydrate in the Gulf of Mexico.

PHOTO BY MANDY JOYE, UNIVERSITY OF GEORGIA

Like a Balloon

Study supports buoyancy explanation for how volcanic rock rises through the Earth's mantle.

A new study of the Earth's mantle beneath the ocean near Iceland provides the most convincing evidence yet that simple buoyancy of hot, partially molten rocks can play an important role in causing them to rise and erupt through the surface at mid-ocean ridges.

The study also shows that heat from a volcanic hotspot in Iceland can affect normal mantle convection activities at a nearby ridge, according to an article published in the Aug. 31, 2001 issue of *Science* by James B. Gaherty, an assistant professor in the Georgia Institute of Technology's School of Earth and Atmospheric Sciences.

The motion of the Earth's surface plates is driven by a convection cycle in which cold material sinks into the deep mantle and hot material rises toward the surface. At most mid-ocean ridges, scientists believe that hot rock rises passively to fill the gap created by the separation — or spreading — of the plates.

But a detailed analysis of seismic waves passing through regions of upwelling rock provides new evidence that another mechanism — buoyancy much like that of a hot-air balloon — helps drive partially melted rocks from the Earth's mantle up to the surface at these ridges. The effect is especially pronounced at the Reykjanes Ridge, a portion of the mid-Atlantic ridge that gains significant heating from Iceland's volcanic hotspot. This additional heating adds 30 to 80 degrees Kelvin to the mantle temperature there and may play an important role in powering the buoyancy at this location. *— John Toon*

■ To read the complete article, see **gtresearchnews.gatech.edu/newsrelease/BUOYANT.html**. For additional information, contact James Gaherty, School of Earth and Atmospheric Sciences, Georgia Tech, Atlanta, GA 30332-0340. (Telephone: 404-894-1992) (E-mail: gaherty@eas.gatech.edu).

Stopping Atoms (Extremely) Cold

Researchers develop first all-optical technique to produce Bose-Einstein condensates.

Georgia Institute of Technology physicists have demonstrated the first all-optical technique for producing Bose-Einstein condensates, a form of matter in which atoms cooled to a fraction of a degree above absolute zero stop their normal motion — and enter a single quantum state in which all atoms behave identically.

Operating inside a vacuum chamber, the technique uses powerful carbon dioxide lasers to confine gaseous rubidium-87 atoms and produce the final cooling step needed to form the condensate.

The Georgia Tech method is simpler, faster and more flexible than the magnetic confinement technique used to produce the condensates since 1995. Dispensing with magnetic confinement should allow the new technique to be used on a wider variety of atoms, atomic mixtures and even molecules.

Michael Chapman, an assisant professor of physics, and his colleagues Murray Barrett and Jacob Sauer described their work in the July 2, 2001 issue of *Physical Review Letters*. *— John Toon*

■ To read the complete article, see **gtresearchnews.gatech.edu/newsrelease/BOSE.html**. For additional information, contact Michael Chapman, School of Physics, Georgia Tech, Atlanta, GA 30332-0430. (Telephone: 404-894-5223) (E-mail: michael.chapman@physics.gatech.edu)

PHOTO BY GARY MEEK

Georgia Tech researchers Michael Chapman and Murray Barrett adjust the optics of lasers used to cool and confine Bose-Einstein condensates in their lab.

Putting Randomness to Work

New research into the activity of a key "motor" protein suggests that a unique form of random motion powered by thermal energy may play a vital role in moving enzymes and other chemicals inside cells. Beyond providing a better understanding of sub-cellular functions, the National Science Foundation-sponsored work may offer a new mechanism for generating motion in future nanometer-scale machines.

Unique form of nanoscale random motion may perform key cellular functions.

Within the cells of the body, kinesin proteins work like "cellular tow trucks" to pull tiny sacks of chemicals along pathways known as microtubules. The accepted explanation for this motion is that the kinesins use their two leg-like "heads" to walk along the microtubule paths in a deliberate way, fueled by the energy molecule adenosine triphosphate (ATP).

But in a paper published in the May 2001 issue of *Physical Review E*, Georgia Institute of Technology physicist Ronald Fox argues that what appears to be a walk along the microtubule is really random motion cleverly constrained by chemical switching carried out by ATP. *— John Toon*

■ To read the complete article, see **gtresearchnews.gatech.edu/newsrelease/KINESIN.html**. For additional information, contact Ronald Fox, School of Physics, Georgia Tech, Atlanta, GA 30332-0430. (Telephone: 404-894-5260) (E-mail: ron.fox@physics.gatech.edu).

From Scientists to Senators

In Chemical Engineering 4600 at the Georgia Institute of Technology, chemical formulas, thermodynamic equations and process flow diagrams take a back seat to invention disclosures and congressional position papers.

Unique course teaches engineers to communicate with diverse audiences.

For an entire semester, Mark Prausnitz helps his engineering students analyze audiences and study how a broad range of communication tools can help them reach their real-world goals. He makes that point through a case study of a real product — and a series of weekly guest speakers that include state senators, graphic communicators, lobbyists, company CEOs, patent attorneys, regulators and others who may help determine the product's ultimate success.

"Communications is really important to the success of a professional engineer," explains Prausnitz, an associate professor in Georgia Tech's School of Chemical Engineering. "The world of a professional engineer intersects with law, business, politics, ethics and all the different pieces of the modern world. There is a lot more to it than the narrow scope of things students tend to encounter in a typical college class."

To prepare them for leadership roles in engineering, business and society, he helps students develop the communication skills they'll need in a broad range of areas: influencing legislation and the political process, pushing new products through patenting and marketing, persuading management to try new approaches and explaining complex issues to non-technical audiences. *— John Toon*

■ To read the complete article, see **gtresearchnews.gatech.edu/newsrelease/ENGCOM.html**. For additional information, contact Mark Prausnitz, School of Chemical Engineering, Georgia Tech, Atlanta, GA 30332-0100. (Telephone: 404-894-5135) (E-mail: mark.prausnitz@che.gatech.edu).

PHOTO BY GARY MEEK

Georgia State Senator Mike Polak talks about the legislative process with students from Chemical Engineering 4600. The class session was held in the historic Georgia State Senate chambers.

Faculty Awards and Honors

Michael Amitay, a research engineer in the Georgia Tech Research Institute (GTRI) received the American Institute of Aeronautics and Astronautics Best Paper Award for "Aerodynamic Flow Control Using Synthetic Jets" with co-authors A.M. Honohan and A. Glezer. Amitay also won the 2000 Moody Award from the American Society of Mechanical Engineers for the best paper dealing with a topic useful in mechanical engineering practice.

Dale Blair, a principal research engineer in GTRI, was named 2001 Young Engineer of the Year by the Institute of Electrical and Electronics Engineers Aerospace and Electronic Systems Society.

Ronald A. Bohlander, a principal research scientist at GTRI, was elected to the Society of Manufacturing Engineers' College of Fellows. He was honored for leadership in promoting collaboration between universities and industry, and for expanding the role of university-based research and development in manufacturing and new product realization.

Robert J. Butera Jr., an assistant professor in the School of Electrical and Computer Engineering, received a James S. McDonnell Foundation 21st Century Scientist Award "for hybrid complex systems-a case study using neuronal dynamics."

W. Russell Callen Jr., a professor in the School of Electrical and Computer Engineering, received the El Paso Energy Award for Faculty Achievement "for exceptional dedication as an educator and mentor."

Jim Coleman, a senior research scientist in GTRI, won the Leadership Award from the Armed Forces Communications and Electronics Association International.

Jeffrey A. Davis, an assistant professor in the School of Electrical and Computer Engineering, received a National Science Foundation (NSF) CAREER Award "for interconnect dominant ULSI (ultra large-scale integrated) designs: a new paradigm for 21st century IC design and education."

Faramarz Fekri, an assistant professor in the School of Electrical and Computer Engineering, received a NSF CAREER Award "for finite-field wavelets for cryptography and error control coding." A first-year assistant professor, Fekri also received the Sigma Xi Outstanding Doctoral Thesis Award for his dissertation titled "Finite-field Wavelet Transforms and Their Application to Error Control Coding."

Thomas K. Gaylord, the Julius Brown Chair and Regents' Professor in the School of Electrical and Computer Engineering, received the honorary "Professional Degree in Physics" from the University of Missouri-Rolla in May 2001. Gaylord is an alumnus of the University, where he received a bachelor's degree in physics and a master's degree in electrical engineering.

Jiri Janata, the Georgia Research Alliance Eminent Scholar in Sensors and Instrumentation in the School of Chemistry and Biochemistry, was elected an honorary foreign member of the "Learned Society of the Czech Republic" for his contributions to the fields of environmental analytical chemistry and electrochemistry.

Nan Marie Jokerst, a professor in the School of Electrical and Computer Engineering, was named a fellow of the Optical Society of America "for hybrid integration of optoelectronics onto hosts such as silicon CMOS circuits and polymers, with application to interconnections and computation."

Robert Loewy, chair of the School of Aerospace Engineering, was elected to the executive committee of AHS International, a technical professional society for the advancement of vertical flight technology and its applications.

Suresh Sitaraman, an associate professor in the School of Mechanical Engineering, received the Best Paper of 2000 Award from the journal IEEE Transactions on Components and Packaging Technologies. He co-authored the paper with graduate students Rajiv Raghunathan and Carlton Hanna.

C.P. Wong, Regents' Professor in the School of Materials Science and Engineering, received the IEEE Educational Activities Board Meritorious Achievement Award in Continuing Education "for exemplary and sustained contributions to continuing education in polymer materials for electronics packaging and interconnection worldwide."

John Zhang, an associate professor in the School of Chemistry and Biochemistry, received the U.S. Department of Energy's Defense Programs Early Career Scientist and Engineer Award. The award was recognizes the contributions of outstanding scientists and engineers in the nation's research universities to the department's national security mission.

Georgia Tech professors and researchers are recognized for contributions ranging from manufacturing to aerospace engineering.

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PHOTO COURTESY OF NOAA/NATIONAL SEVERE STORMS LABORATORY

Severe weather forecasting may be improved by a 3D visualization system under development by researchers in the Georgia Tech College of Computing and Georgia Tech Research Institute. Here, a NOAA photographer captures multiple strikes of cloud-to-ground and cloud-to-cloud lightning during an evening thunderstorm.

(See story on page 29.)

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