SIGNATURES

Bits-to-Chips:
An Interdisciplinary Educational Model

Taking the Toxic out of Pollution

The Hessert Center: Turning 10 and Still on Course

Engineering Advances at the University of Notre Dame

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Spring 2000

THE DEAN'S VIEW

We are pleased to provide you with a copy of the second issue of *Signatures,* an annual publication of the College of Engineering that chronicles special (signature) activities involving teaching, research, and service. The past year has witnessed significant progress in many areas, with nanotechnologies meriting special comment. Last summer the University approved formation of a Nano Science and Technology Center. Although leadership for the Center resides in the College of Engineering, its activities are truly multidisciplinary, involving faculty from across the Colleges of Science and Engineering. The creativity and synergism spawned by this collective involvement have not gone unnoticed by funding agencies, with an unrestricted $1,000,000 grant having recently been provided by the Keck Foundation for work in the field and funding from federal agencies for specific research activities expected to reach $3,500,000 for the year. Moreover, there is no paucity of fertile ideas among the faculty affiliated with the Center. They are well positioned to assume a leadership role in the nation's recently announced nanotechnology initiative.

In this issue of *Signatures,* we focus on two research activities and an educational initiative that we believe to be special. The article on the Hessert Center, a modern, well-equipped facility, traces the history of aerospace research at Notre Dame, beginning with Albert Zahm's 1882 construction of the first hand-driven wind tunnel in the United States. Since then, Notre Dame faculty have contributed significantly to the development of wind tunnel technology and related diagnostic tools for subsonic and supersonic flows. Although the 1990s witnessed a decline in the U.S. aerospace industry, the related technologies are much too important to the economic interests and security of the nation to permit continued erosion. The decline will one day be reversed, and at Notre Dame, we are committed to maintaining education and research programs that will provide a strong base for responding to new initiatives.

The article on environmental research at Notre Dame highlights the two-pronged approach we are taking, one having to do with pollution prevention and the other with remediation. Pollution prevention is a chemical engineering initiative, with research topics ranging from enhancing the effectiveness of catalytic converters to using supercritical fluids and ionic liquids as environmentally benign solvents. Research on mitigation is conducted largely in the civil engineering and geological sciences department and deals with issues such as biological treatment of hazardous materials, the storage of radioactive materials in geological formations, and the transport of pollutants by ocean currents.

Although much has been done to advance environmental protection technologies during the past 30 years, we believe that environmental research and education programs are critical to meeting needs of the 21st century, and we will continue to strive for relevance in meeting these needs.

The article on Bits-to-Chips describes a unique collaboration between the College's electrical engineering and computer science and engineering departments. Its objective is to provide students with a broad, but in-depth treatment of computer technology, from consideration of how transistors work to how microprocessors are designed and made, and how compilers convert a high-level language to one that's executable on a microprocessor.

The Bits-to-Chips courses involve numerous hands-on, team-based activities and provide the kind of cross-disciplinary, collaborative learning experiences that we seek to extend to more of the College's curriculum. One such extension involves two new first-year courses, prototype versions of which are being offered to 25 of this year's first-year engineering intents. The courses will be offered to all first-year engineering intents this fall and will involve participation of faculty from each of the College's five departments. Hands-on and collaborative activities of the courses will be offered in the College's new Learning Center, which is under construction and will be ready for occupancy in August.

As always, we welcome your interest in our programs and any input you may choose to provide.

Frank P. Incropera

Frank P. Incropera
McCloskey Dean of Engineering
Brosey Professor of Mechanical Engineering

There's a buzz of activity about the College of Engineering. Part of it is due to the development of a new Engineering Learning Center, scheduled to open August 2000. Standing in the new Center are: (front row, left to right) Salma R. Saddawi, associate professional specialist in chemical engineering; Frank P. Incropera, McCloskey dean of engineering; Lauren Destino, a senior in chemical engineering; Eugene W. Henry, professor of computer science and engineering; and (back row, left to right) Jason L. Garza, a sophomore in aerospace engineering; Scott T. Stender, a junior in computer engineering; and Justin L. Smith, a junior in computer engineering.

inside
Signatures

The Hessert Center for Aerospace Research and Other High-flying Traditions

On July 20, 1969, Neil A. Armstrong became the first man to walk on the moon. He and the crew of Apollo 11 — Michael Collins and Edwin E. "Buzz" Aldrin Jr. — flew 239,000 miles through space, landed in the Sea of Tranquility, planted the American flag, and with a single footprint focused the world's attention beyond its atmosphere. Even this, one of the most famous flights in history, was just another in a long line of dreams mankind has pursued in the quest for flight.

Two Decades Before Kittyhawk

As the 10th anniversary of the Hessert Center for Aerospace Research approaches, it is only natural to reflect upon the University's long and rich history in the physics of flight. In 1882, 21 years before Wilbur and Orville Wright recorded the first successful airplane flight at Kittyhawk, N.C., aeronautics pioneer Albert F. Zahm was testing his theories. He had already constructed a small wind tunnel on campus. Although it was hand-driven and fashioned by removing the vibrating screens from a winnowing blower, it could produce a steady wind. The most important aspect of the tunnel, however, was that it allowed Zahm to compare the lift and drag of his models to see which worked most efficiently. This tunnel was the forerunner of the first large wind tunnel, which was built by Zahm in 1901 at Catholic University.

Zahm's tests at Notre Dame continued for another decade, moving from the wind tunnel to glider flights, most of which took place at night because of concerns voiced by University administration. One of his more entertaining experiments culminated in the launching of a tethered glider from the ceiling of the then Science Hall (now the LaFortune Student Center). Apparently the custodian of the building, Brother Benedict, was extremely shaken the next morning when he noticed footprints high up on the walls of the building. They were made by the pilot as he pushed off the building to avoid crashing against its walls. In spite of Brother Benedict's reaction, Zahm persevered.

2500 B.C.
The kite is invented in China.

1100
The rocket is invented in China.

1493
Leonardo da Vinci draws a flying machine.

1783
Jacques Alexandre Charles and the Roberts brothers develop the hydrogen balloon.

1784
Launoy develops a model helicopter.

1872
The hydroplane is developed by Rev. Charles Meade Ramus.

1882
Albert F. Zahm constructs the first hand-driven wind tunnel in America on the Notre Dame campus.

Hafiz M. Atassi

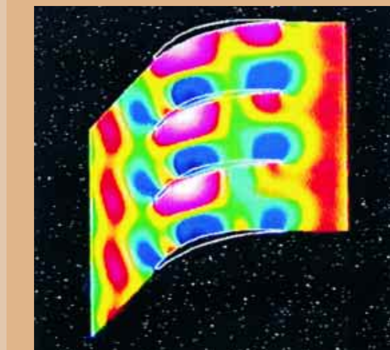
According to Viola D. Hank Professor Hafiz M. Atassi, there are currently two major issues for commercial aviation: noise and the pollution associated with emissions from jet engines. He, his students, and associates at the Hessert Center for Aerospace Research concentrate on the noise problem. They are working on several projects funded by the National Aeronautics and Space Administration's (NASA) Advanced Subsonic Transport Program, the Office of Naval Research, and the National Science Foundation (NSF).

> *"The major difficulty in capturing information about the sound produced in jet engines is that the energy contained in the sound is less than one percent of the total energy contained in the flow."*

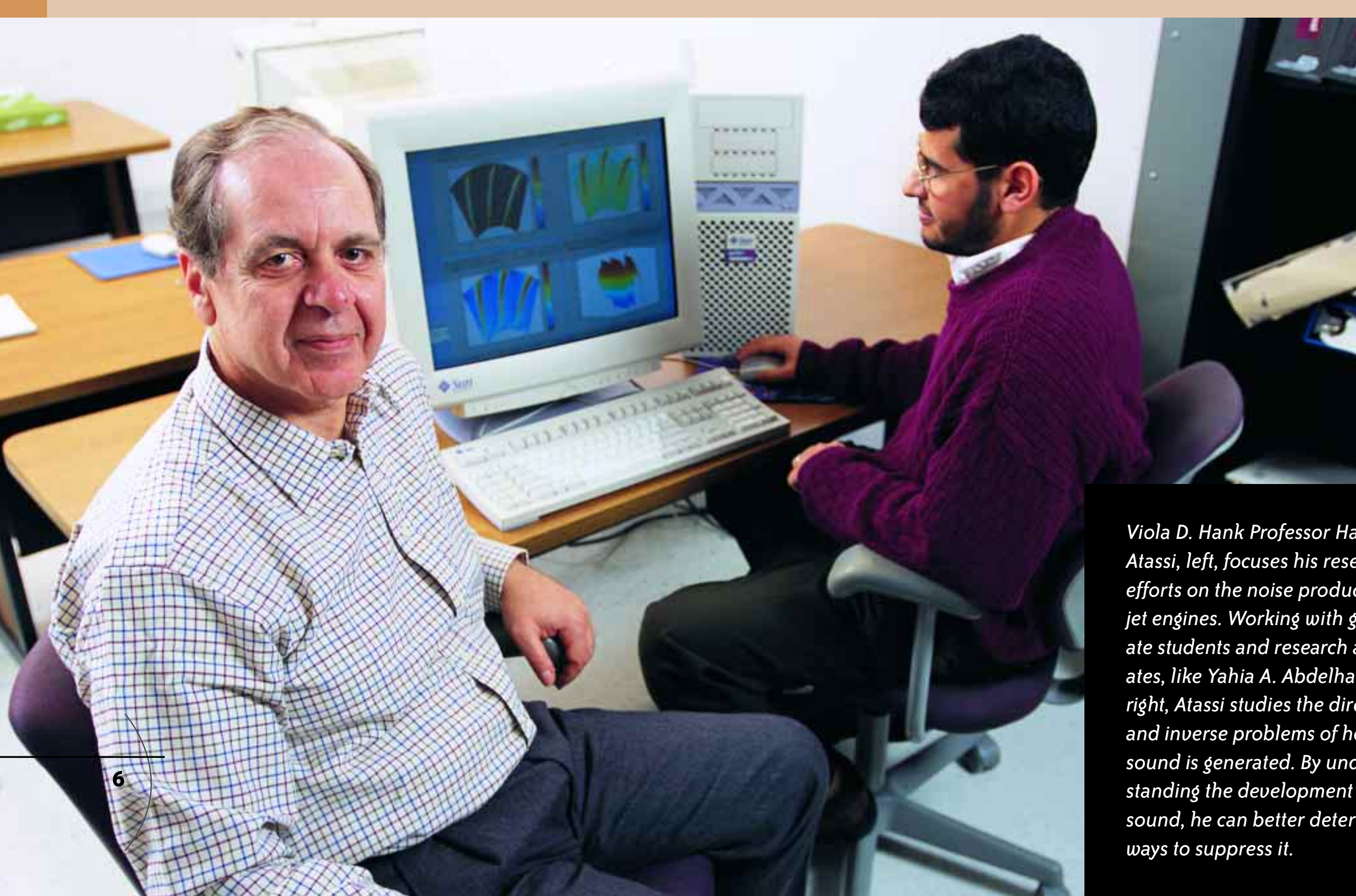
Under the NASA project, Atassi investigates the physical mechanisms of aerodynamic sound generation in non-uniform flows. Aerodynamic structures — such as airplane wings, propellers, and helicopter and turbomachine blades — operate in a turbulent environment that produces fluctuating forces. These forces, in turn, induce destructive vibrations and radiate unwanted noise. By developing computational models to simulate these processes, Atassi can describe and quantify how noise is generated and then determine optimal ways to suppress it. "In addition to close interaction with engineers at NASA and Pratt & Whitney," said Atassi, "what distinguishes this work is being able to capture the elusive one percent of the flow energy that is the sound."

The focus of the Office of Naval Research project is undersea sound generation and propagation. Atassi and his students are looking at how the sound is generated; this is called the "direct" problem. They also study the "inverse" problem, reviewing the sound not from where it is generated, but trying to pinpoint the source and location of the sound by the noise it creates. As Atassi explains, the fundamental question in the inverse problem is "Can you hear the shape of a drum?" He is developing mathematical methods for solving inverse problems using sound measurements from the direct problems in which the source of the sound is known. An important application of this work would be its use in a non-intrusive device for measurement and diagnosis of sound.

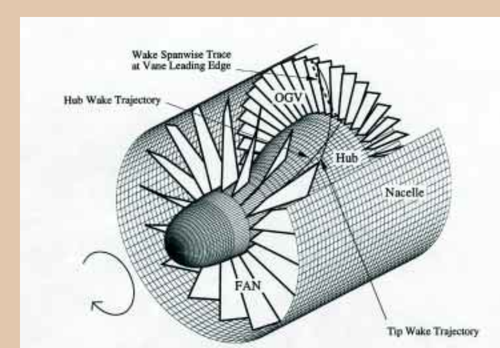
Direct computation of unsteady flows and aerodynamic sound requires a high level of accuracy and is computer intensive. Under a grant from the NSF Great National Challenges Program, Atassi and his associates have been developing domain decomposition algorithms for solving systems of large number equations — on the order of 10 to 100 million equations. Using a divide-and-conquer approach, Atassi's group separates the domain into multiple subdomains, which can be solved independently and concurrently, making the equations suitable for parallel computing. By applying this approach to aircraft noise, Atassi has developed very precise results. These algorithms are also being extended to simulate turbofan engine flows.



Atassi can generate computer simulations of sound generation and propagation in turbofans, like the one shown here. The red area indicates the highest level of sound and blue, the lowest.



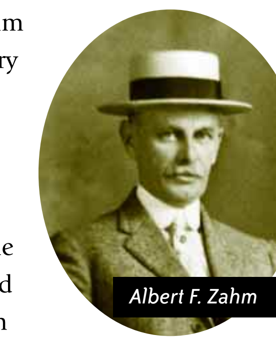
Viola D. Hank Professor Hafiz M. Atassi, left, focuses his research efforts on the noise produced by jet engines. Working with graduate students and research associates, like Yahia A. Abdelhamid, right, Atassi studies the direct and inverse problems of how sound is generated. By understanding the development of sound, he can better determine ways to suppress it.



Shown here is a schematic of the computational domain of a fan engine.

DURING HIS LAST YEAR AT NOTRE DAME, Zahm helped organize America's first International Aeronautic Congress, which was held in 1893 during the Chicago World's Fair. The two papers he presented at the Congress dealt with varying wind currents, detailed an anemometer — made at Notre Dame to record wind movements during open-field flying — and explained how to make a plane inherently stable so the craft could balance itself without a pilot's aid. This was the first paper in America to discuss the modern method of launching an airplane and controlling its flight by rotating parts of its wings to balance it laterally while using a double tail to balance it against pitching and yawing.

An important early influence on the College of Engineering and the field of aeronautics, Zahm was awarded an honorary doctorate by the University in 1921 and the Laetare Medal in 1925. Established at Notre Dame in 1883, the Laetare Medal is awarded annually to an American Catholic "whose genius has ennobled the arts and sciences, illustrated the ideals of the Church, and enriched the heritage of humanity."



Albert F. Zahm

1903
Wilbur and Orville Wright record the first successful airplane flight; it covers a distance less than the length of today's space shuttle.

1912
Cabin biplane, forerunner to the airliner, is developed by Igor Sikorsky.

1927
Charles Lindbergh, in the Spirit of St. Louis, completes the first solo nonstop transatlantic flight.

Other Early Achievements

AS THE AERONAUTICS PROGRAM AT NOTRE DAME GREW, College of Engineering researchers began to take the lead in another area as well: wind tunnel and smoke visualization research. In 1937 Dr. Frank Newton Mithery Brown developed his first smoke tunnel. Within three years he had also completed a three-dimensional smoke tunnel, which reached wind speeds of up to 28 miles per hour.

What made Brown's tunnel unique was a "rake" of four tubes positioned upstream of an anti-turbulence screen in the tunnel. The rake eliminated the turbulence other researchers were experiencing when they injected smoke into their tunnels, thereby skewing their results. Brown's revolutionary rake and screen, as well as a significant portion of the wind tunnel equipment since that time, were designed and constructed on campus with the help of Robert S. Eikenberry, professor of aeronautical engineering.

Frank N.M. Brown

1928
Amelia Earhart crosses the Atlantic Ocean for the first time.

1929
American explorer Richard Byrd is the first to fly over the South Pole.

1932
French explorer Jean Piccard explores the stratosphere in a balloon gondola.

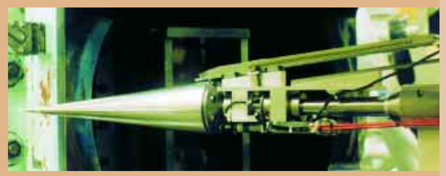
Thomas C. Corke

"Fluid instabilities are at the heart of many practical problems. Controlling them can improve the environmental impact and performance of aircraft."

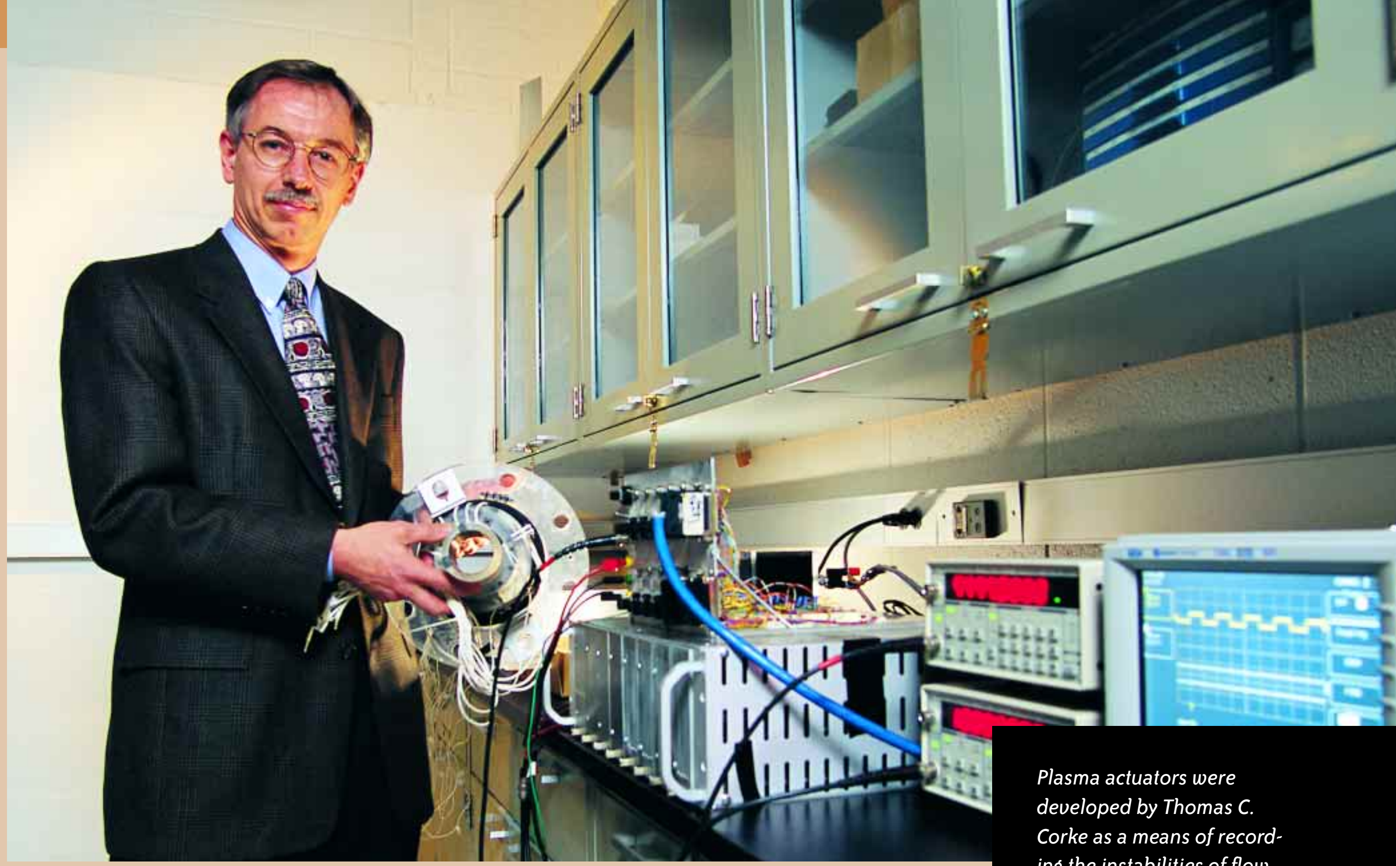
Clark Professor Thomas C. Corke focuses on fluid dynamics. His particular areas of interest are fluid instabilities, transition to turbulence, and control of unsteady flows. Examples of the problems caused by these fluctuations include the generation of sound and reduced efficiency of aircraft engines, the drag on aircraft, and turbulent heat transfer on hypersonic aircraft.

One of Corke's projects targets sound levels in commercial jet engines. By modifying the instability in jet flows, Corke can alter the sound produced. The objective is to shift the frequency of the sound to a range above what humans can hear. This work is currently funded by the Air Force Office of Scientific Research (AFOSR), but has also been supported by the NASA Langley Research Center and United Technologies' Research Center.

Another study involves the flow inside jet engines. The goal of this research is to improve the efficiency of a turbine stage by exciting an instability which will cause the flow through the turbine to better follow the curvature of the blades. Ultimately, this could impact the design of the turbine itself, making it lighter with fewer parts. This project is supported by NASA's Glenn Research Center.



Plasma actuators were first used on this Mach 3.5 nose cone.



Plasma actuators were developed by Thomas C. Corke as a means of recording the instabilities of flow over aircraft nose cones. He is currently using them on jet nozzles, shown above, to alter the sound related to aircraft jet engines.

Corke is also working in conjunction with United Technologies' Research Center and Sikorsky Helicopters on a similar project, which addresses ways to improve the performance of helicopters. This work is sponsored through a research grant from the Defense Advanced Research Projects Agency (DARPA) and revolves around exciting an instability in the flow over a helicopter rotor.

Problems in controlling flow instabilities have a common element — the use of "phased plasma" actuators for exciting the flow. By applying high-voltage AC signals to actuator electrodes, Corke and his students can cause air to break down into an ionized gas (plasma) and flow more efficiently over rotors. The advantage of this approach is that there are no additional moving parts to wear out or break. Precise control of the flow is accomplished by phasing the AC signals to an array of plasma actuators, thus producing a traveling wave.

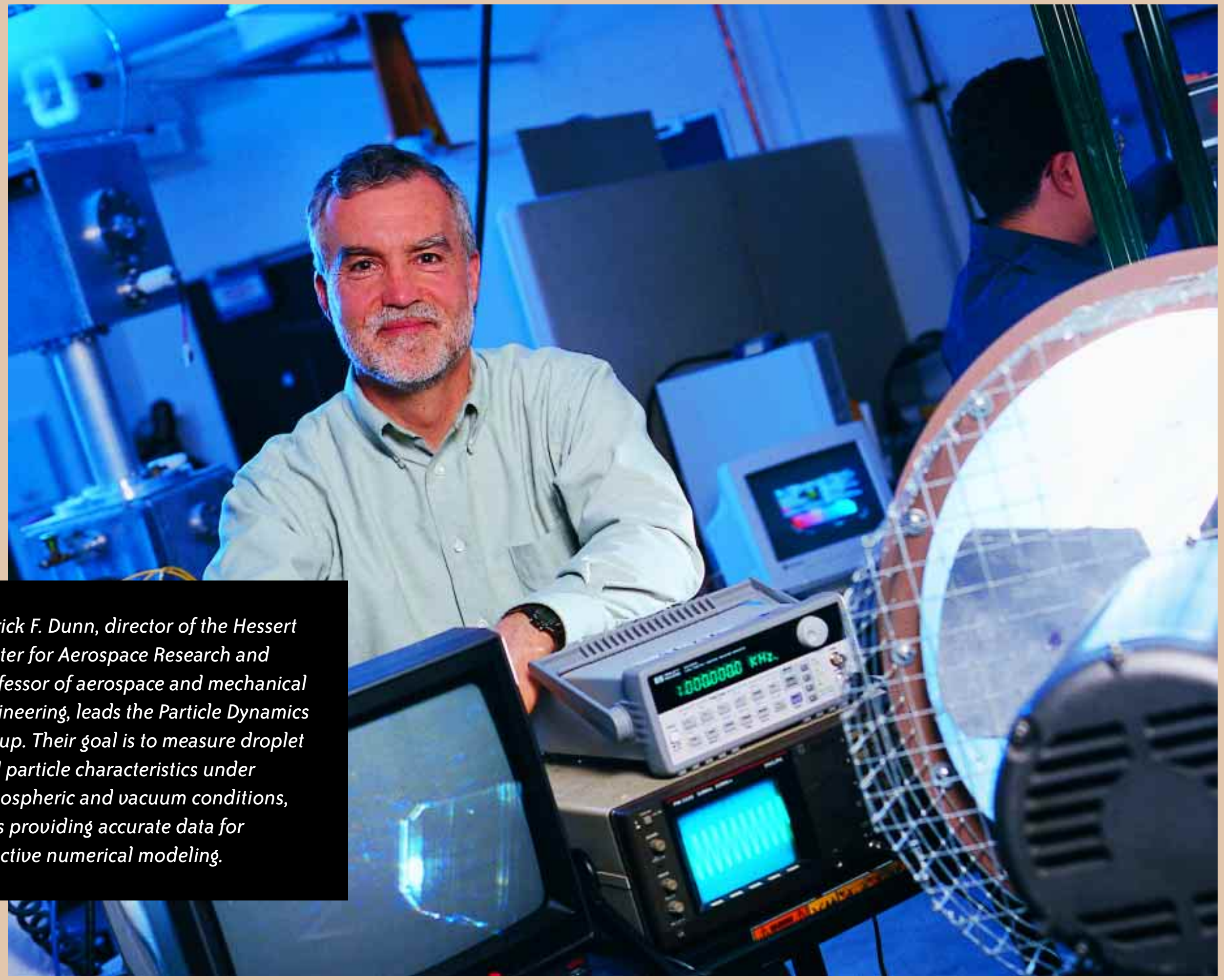
The ability to manipulate the flow in this way was first achieved by Corke and his students. Corke's group initially developed plasma actuators as a means of studying instabilities in the flow over nose cones at Mach 3.5. Using the actuators increased the accuracy of predicting if and where the flow would become turbulent, which is important for determining the amount of surface heat transfer on high-speed aircraft. This work with plasma actuators is sponsored by the NASA Langley Research Center and AFOSR, and it currently focuses on hypersonic, Mach 8, lifting bodies.

Other research supported by NASA's Langley Research Center involves developing a method for measuring turbulence in their cryogenic wind tunnels. Although these tunnels were developed to simulate flight conditions on aircraft, the delicate sensors used in other wind tunnels cannot withstand the cold temperatures or high velocities common in cryogenic tunnels.

Corke's approach is to indirectly measure the turbulence levels by measuring the amplitude of an instability which arises when turbulence impinges on the leading edge of a wing. Because the frequencies of this instability are low, robust sensors, which can tolerate the conditions in cryogenic tunnels, can be used. This theory is being tested in the wind tunnels at Notre Dame before being applied to the National Transonic Facility at NASA Langley.

The plasma, seen here as a bright band of light, was generated by 32 pairs of electrodes placed near the tip of the nose cone.

Patrick F. Dunn



Patrick F. Dunn, director of the Hessert Center for Aerospace Research and professor of aerospace and mechanical engineering, leads the Particle Dynamics Group. Their goal is to measure droplet and particle characteristics under atmospheric and vacuum conditions, thus providing accurate data for effective numerical modeling.

> *"Research in the Particle Dynamics Laboratory is providing experimentally validated models of how air contaminants adhere to surfaces."*

Patrick F. Dunn, director of the Hessert Center, also leads the research activities in the Particle Dynamics Laboratory. State-of-the-art equipment in the lab measures electrically neutral, as well as charged, droplets and particles ranging in size from ~1 to 200 microns in diameter. Fundamental questions that Dunn and graduate students Xinyu Li, Weidong Cheng, and Abdelmaged Ibrahim have been investigating over the past several years include: "How does the shape of a particle, its charge, and the quality of a surface, affect whether or not a particle will attach to a surface?" "When a particle is resting on a surface, how and under what conditions does it leave the surface?" And, knowing this, "Can the behavior of particles be predicted and modeled?"

Dunn and the Particle Dynamics Group have been measuring droplet and particle characteristics under both atmospheric and vacuum conditions with funding provided by the Electric Power Research Institute, the Center for Indoor Air Research, and the NASA Space Grant Consortium.

The laser light-sheet visualizations of an electrically charged microdroplet spray, shown here — a top view, right, and side view, left — employ a two-component Phase Doppler Particle Analyzer and a Particle Counter Sizer Velocimeter to capture particle velocity, concentration, and size. This helps characterize the motion of individual microdroplets during atomization and subsequent motion in the air.

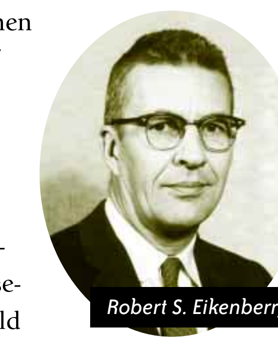
Current projects in the lab include the study of how microparticles are deposited onto surfaces and what happens during surface contact. Mathematical models are being developed to predict particle attachment and rebound for a broad range of particle shapes and materials, environmental pressures, and surface materials. Micro-videography is vital to this investigation, and Dunn has been able to capture various particle flows on film. The goal of this project is to produce experimentally validated models of how air contaminants — smoke particles, pollens, and spores — adhere to surfaces.

Another focus of his research is microparticle resuspension and transport from surfaces. Resuspension occurs when a particle leaves the surface and re-enters the air flow. Using microphotography, particle image velocimetry, and phase Doppler and hot-wire anemometry, in an eight-inch square wind tunnel, Dunn tracks the motions of individual microparticles during resuspension and subsequent flow in the air, with emphasis placed on the texture of the resuspension surface and the rotation rates of the microparticles. Companion models of these processes are then developed and compared to the experimental results.

He is also studying the electrohydrodynamic atomization of liquids — liquid droplets or streams similar to an asthma inhaler — measuring droplet velocity, size, and other characteristics. This, like his other projects, will provide accurate data for effective numerical modeling.

BY 1948 BROWN DEVELOPED ANOTHER SMOKE TUNNEL, this one with a moveable rake and an easily used kerosene smoke generator. With this system he could produce three-dimensional and stereo photographs of the flows he created, but none of the messy tar deposits that were typical of other smoke-production methods. This technique allowed him to be the first person to visualize Tollmien-Schlichting waves. These waves form the initial stage of the transition process from laminar to turbulent flow in a boundary layer and are vital in understanding and controlling the flow.

Brown was involved in sponsored research long before most of his University colleagues became involved with such activities. Still, he was frugal when it came to the purchase of equipment. Using war-surplus materials, Brown built his entire laboratory at no cost to Notre Dame. He salvaged six sets of vacuum pumps and 125-horsepower motors from a World War II naval vessel. He then sold three of the sets to the Bendix Corporation in neighboring South Bend and used the proceeds to build supersonic wind tunnels in the lab. In fact, the supersonic tunnels used today in the Hessert Center for Aerospace Research are still driven by those three sets of pumps and motors.



Robert S. Eikenberry

1938
Transcontinental Airways introduces the first pressurized airplane cabin in its Boeing 307 model.

1936
Henrich Focke develops the helicopter with contra-rotating rotors.

1939
Hans von Ohain develops jet aircraft.

A Supersonic Smoke Tunnel

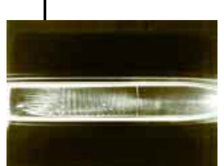
Vince P. Goddard

VINCE P. GODDARD, A COLLEAGUE OF BROWN'S, designed and constructed those first supersonic wind tunnels. In 1959 he expanded on Brown's research to produce the world's first supersonic smoke tunnel. This facility allowed simultaneous photography of both the smoke and shock-wave patterns in air flows.

Using the same techniques that Brown had developed for subsonic tunnels, Goddard was able to photograph smoke flowing at speeds up to 900 miles per hour. The perseverance of Brown, Eikenberry, and Goddard had paid off. Even today, much of the wind tunnel technology in federal, industrial, and academic laboratories can be traced to earlier developments at Notre Dame.

1940
Frank N.M. Brown develops and tests a revolutionary rake feature for smoke tunnels at Notre Dame.

1947
The first supersonic aircraft, the United States' Bell XS-1, takes its first flight. It is piloted by Chuck Yeager.



1957
By using smoke for visualization, Notre Dame's Frank N.M. Brown is the first to see Tollmien-Schlichting waves and vortex truss patterns in a transitional flow.

The Soviet Union's Sputnik 1 becomes the first satellite launched into orbit.

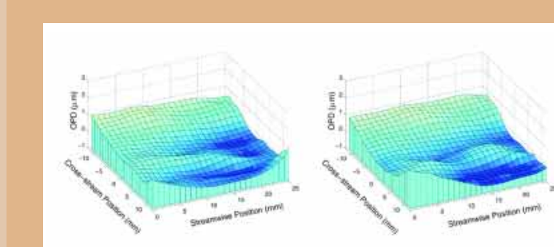
1959
Vince P. Goddard builds the world's first supersonic smoke tunnel at the University of Notre Dame.

Eric J. Jumper

Clockwise from left, Eric J. Jumper, professor of aerospace and mechanical and engineering, and doctoral candidates Edward J. Fitzgerald and James M. Cicchiello adjust equipment in the Aero-Optics Laboratory in the Hessert Center. The lab studies optical (wavefront) distortions.

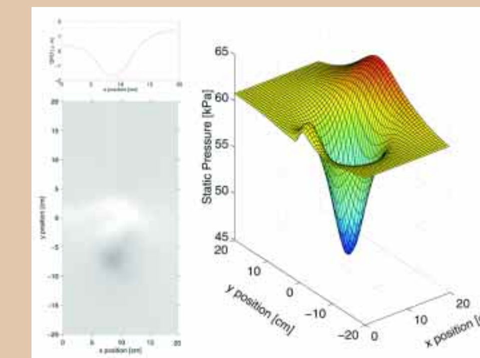
"The purpose of research in the Aero-Optics Laboratory is to study how an otherwise collimated light beam, a laser for instance, becomes distorted as it passes through turbulence."

Since the early 1990s and under the support of the Air Force Office of Scientific Research, Eric J. Jumper has been studying aero-optical distortions. These distortions are similar to the "waves" seen above a parking lot on a hot summer day. As the sun warms the air over the pavement more than the surrounding air, the resulting higher temperatures change the density of the air. This causes turbulence and creates the same effect as looking through dimpled glass. Air near the surface of a high-speed aircraft produces the same type of distortions. For military or civilian planes attempting surveillance photography or trying to lock on a target with a laser beam, this spells trouble.



These two-dimensional graphics of optical wavefronts are typical of what the Aero-Optics Lab has been able to develop using measurements captured by a high-speed wavefront sensor.

In 1992 when Jumper began his research, the only way to address this problem was to use time-averaged equations, an expected average of what would happen to an optical (wavefront) distortion over a period of time. Time-resolved wavefront data, information gathered from one instant to the next, was needed to correct these distortions. Unfortunately, the highest-speed wavefront sensors available at that time were on the order of 1,000 frames per second. That sounds fast, especially considering that television cameras capture information at approximately 30 frames a second. For these high-speed flows, however, Jumper needed to resolve the optical wavefronts at up to 100,000 frames per second. His first order of business was to develop a method of recording wavefront behavior as it occurred. Called the Small-Aperture Beam Technique, Jumper's invention allows moment-to-moment viewing of the distortion, how it evolves over time, and how it affects the airborne optical system. This technique will be critical to correcting optical distortions.



***The Small-Aperture Beam Technique,** which was developed at Notre Dame, is capable of recording wavefront behavior at up to 100,000 frames per second and has already produced new insights into high-speed flow behavior.*

Jumper is also studying the aerodynamic causes of high-cycle fatigue damage to jet engine compressor and turbine blades. He is engaged in a theoretical investigation of unsteady velocity disturbances and the accompanying unsteady pressure responses in compressible cascades. Additionally, he is running experimental cascade studies in Hessert's wind tunnels and taking jet engine measurements at the Air Force Academy. Aimed at developing longer-lasting jet engine components, this work has already identified new pressure response phenomena and has further demonstrated the importance of including acoustically-propagating potential disturbances in response predictions.

Graduate student Denis A. Lynch III adjusts the propeller dynamometer for the next round of experiments in the anechoic wind tunnel. He is part of the Anechoic Wind Tunnel Team, directed by Thomas J. Mueller, right. Currently, the team is studying the sources of propeller noise as part of a project for the Office of Naval Research.

Thomas J. Mueller

"It's uncommon in industry, and rare on the university level, to find a facility like Hessert's anechoic wind tunnel. But it's absolutely vital to providing accurate aeroacoustic measurements."

For almost 10 years Roth-Gibson Professor Thomas J. Mueller has been conducting research in Hessert's anechoic wind tunnel. Why? Because propellers, engines, and fans do not operate in steady or uniform flow environments. Unsteady or non-uniform flows enter the rotor, and they produce varying thrust components and pressure waves which radiate from the rotor, becoming noise in the far field.

As the population increases background noise from air conditioning fans, computers, and other electronic devices also increases. There are already stringent restrictions on the permissible sound levels of aircraft. Much of this noise is a nuisance, but carries few harsh penalties. However, sound generated by the propeller on a submarine, for instance, significantly increases its detection range. This places the crew and its mission in jeopardy, making it crucial for the Office of Naval Research to understand the sources of propeller noise.

"Noise," said Mueller, "is very difficult to measure, because the pressure variations are small. If there's any interference, the measurements will not be accurate." By running experiments in an anechoic chamber, the sound does not reflect off the walls of the chamber and cannot interfere with measurements. This is similar to what would happen in a real-world environment, where there are no walls present.

In addition to the unique capabilities the anechoic chamber offers, Mueller and graduate students have developed their own specialized equipment. For example, they built a low-turbulence, free-jet wind tunnel with an open test section in the chamber. With it they can create a low-turbulence stream to study the flow over airfoils and propellers. Since the project is sponsored by the Navy, the majority of Mueller's time has been applied to propeller noise.

Mueller and his students also created a low-cost unsteady pressure sensor with which they can capture aeroacoustic phenomena previously unmeasurable. This Notre Dame innovation took two years to develop, with much of that time focused on determining ways to calibrate the sensor so it could provide accurate measurements. Using these sensors, which are embedded in a model mounted in the anechoic wind tunnel, Mueller can correlate unsteady pressure with the far field noise, giving the Navy experimental verification of theoretical response models.

This synchronized stroboscopic smoke-flow visualization shows a three-dimensional, four-bladed propeller flow structure. The photo below shows a side view of the same visualization.

While he focuses on aeroacoustics, Mueller is also studying the aerodynamics of micro-air vehicles.The long-term goal of this project is to develop aircraft systems that weigh less than one ounce, have about a 3-inch wing span, and can fly for approximately 50 minutes at up to 30 miles per hour. These vehicles might carry visual, acoustic, chemical, or biological sensors. Currently, Mueller is testing the efficiency of various shapes of fixed and flapping wings with Reynolds numbers below 150,000.

IN 1964 AERONAUTICAL ENGINEERING WAS RENAMED AEROSPACE ENGINEERING, and in 1969 it combined with the mechanical engineering program to become the Department of Aerospace and Mechanical Engineering. By the mid-1970s Cushing Hall was bursting at the seams; the aerospace laboratory was still adjacent to the Joyce Center. Often called the "Aero Shack," it had been enlarged in the 1960s to handle growth in that area. Long-standing research efforts in the aerospace lab — such as developing and refining computer models of how fires spread within airplanes and on board ships, as well as the aerodynamic problems of small and low-speed aircraft — continued.

The College, however, needed much more than an addition. A new building was proposed and construction began. Named for its principal donor, Edward B. Fitzpatrick Jr. ('54, civil engineering), Fitzpatrick Hall of Engineering was dedicated in 1979.

Notre Dame continued its work in aerodynamics with students in the aerospace and mechanical engineering department submitting an entry in the 1987 Smithsonian and Apple Computer, Inc., "Race for Space Software Chase," a contest for colleges to create software to illustrate the ever-expanding role of computers in aeronautics. The University's entry, one of five finalists, was placed on permanent display in the Smithsonian National Air and Space Museum.

Professor Stephen M. Batill, right, and students Ken Visser, left, and Mike Brendel placed among the finalists in the "Race for Space Software Chase," sponsored in 1987 by the Smithsonian and Apple Computer. Their entry is part of a permanent display in the Smithsonian National Air and Space Museum.

A New Facility

THROUGHOUT THIS TIME AS THE COLLEGE OF ENGINEERING WAS GROWING, the aerospace and mechanical engineering department was also expanding. The need for a new research facility was becoming more evident. In 1989 the College received approval to renovate the mechanical engineering department's old Heat and Power Laboratory on the north end of the campus. Built in 1941, it had not been used in several years, and since the older portion of the building was made of reinforced concrete, it was ideal for the heavy equipment that would eventually be housed in the new facility.

1961
The Soviet capsule Vostok 1 becomes the first manned space flight. Cosmonaut Yuri Gagarin is the first person to orbit Earth.

1962
John Glenn, in Freedom 7, becomes the first American astronaut to orbit the Earth.

1966
Albin A. Szewczyk develops the first complete numerical solution of the flow around an impulsively-started circular cylinder at high Reynolds numbers.

1971
Salyut 1, of the Soviet Union, becomes the first earth-orbiting space station.

1973
The United States launches Skylab. It is not manned, but visited by three crews of astronauts.

Robert C. Nelson

"Notre Dame has a long and rich tradition of innovations in fluid mechanics and aeronautical research."

In much of his work over the years, Robert C. Nelson, chair of aerospace and mechanical engineering, has focused on flight dynamics and safety. Part of the tradition of aeronautical research at Notre Dame, he is standing in front of three 125-horsepower blowers obtained in the 1950s by Frank N.M. Brown, a former chair of the department.

Robert C. Nelson, chair of the aerospace and mechanical engineering department, is proud of the research that has been undertaken in the Hessert Center and its predecessor, the Aerodynamics Lab. He's also excited about the studies that are now taking place, investigations by his colleagues and himself.

Currently, he is working on two projects dealing with flight dynamics and safety. The first focuses on delta wing aerodynamics. Aircraft with slender wings, like the Concorde or the Space Shuttle, feature delta wings. While this shape is extremely efficient for supersonic and hypersonic flight, vortex flow over these wings during descent and landing can cause problems. Unlike other aircraft, these planes descend at a large angle of attack. The larger the angle, the stronger the leading edge vortices become. At some critical angle of attack, the vortices may break down, leading to loss of lift. These vortices can also produce "wing rock," an oscillation in which the wing rocks back and forth at a constant amplitude. Picture a stop sign angled at 45 degrees fluttering in a strong wind. That's wing rock. Nelson is conducting experiments in Hessert's subsonic tunnel to improve the basic understanding of what causes leading edge vortex breakdown and to thereby develop methods for controlling it.

He and Professor Eric Jumper are also studying trailing vortex wakes. Every airplane creates a wake, which is generated primarily by the wings. It trails after a plane and eventually dissipates. The flow in the wake could be compared to a horizontal tornado. Under normal operating conditions at cruising altitudes, wakes are not critical; the wake from one plane will not impair the flight of another.

However, when weather restricts visibility, all aircraft must descend through the same airspace to the runway. This is when the strong rotational flow in the trailing vortices can become hazardous to a following aircraft. For example, the wake from a Boeing 747 has enough energy to roll a plane the size of a DC-9 more than 90 degrees. Because of this influence, the Federal Aviation Administration does not allow smaller planes to land immediately after larger aircraft. This process is called aircraft separation and essentially paces the landing of aircraft to avoid trailing vortices. Nelson and Jumper are investigating different wing designs that would break up the wake and dissipate it more quickly without degrading the performance of the plane.

High-lift is another area of interest for Nelson. He and Professor Flint Thomas are studying various aspects of the flow around high-lift systems to eventually improve their performance.

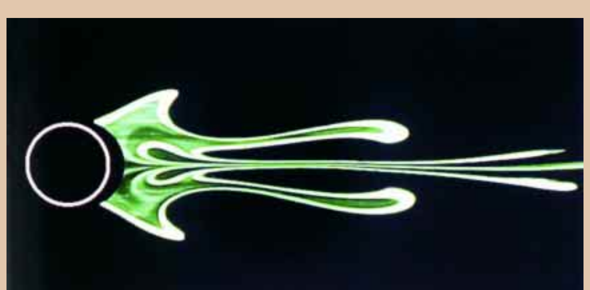
Research conducted by Robert C. Nelson and F. Payne produced these visualizations of leading-edge vortex flows.

Albin A. Szewczyk, professor of aerospace and mechanical engineering, runs a variety of experiments in the Hessert water tunnel. Working closely with graduate students, like doctoral candidate Fred L. Haan Jr., above left, he studies periodic wake flows and vortex-induced vibrations. By understanding the nature and cause of the vibrations, he hopes to develop control devices to reduce structural movement.

"In practical applications the control of vortex shedding is important for two reasons: drag reduction and the elimination of vortex-induced vibration."

Albin A. Szewczyk

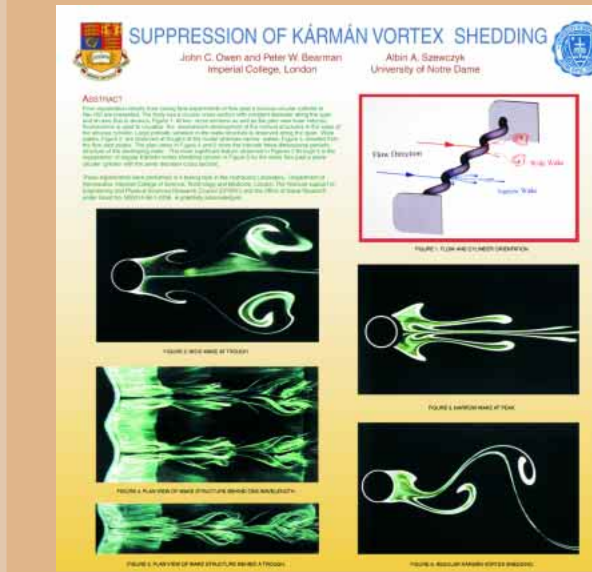
Albin A. Szewczyk specializes in measuring periodic wake flows, identifying the unsteady and three-dimensional effects on flows past bluff bodies. One of the experiments he's conducting in Hessert's wind and water tunnels focuses on the vortex-induced vibrations of long, flexible cylinders (mooring cable, deep-water petroleum risers, and piles used in marine structures, as well as chimney stacks and cooling towers). It is funded by the Office of Naval Research.



Specifically, Szewczyk is studying lock-in flows and the conditions under which they occur. Lock-in flows are those at which the body's natural frequency is the same as the vortex-shedding frequency. The resulting unsteady forces can lead to severe structural damage. By understanding the physical mechanisms involved in creating a lock-in flow, Szewczyk hopes to develop control devices to reduce the induced forces and limit the structural movement.

He is also studying the aerodynamics of long-span bridges as part of a multidisciplinary project with Moran Professor Ahsan Kareem, chair of civil engineering and geological sciences. The effects of wind gusts — their turbulence intensity and length scale — are being measured in Hessert's atmospheric wind tunnel using a scale model of a bridge section. Szewczyk and Kareem's goal is to determine the aerodynamic features and induced forces that arise from the interaction of the turbulent wind gusts and the bridge deck. Current data is not yet sufficient to develop reliable flow models. However, experimental work conducted by Szewczyk and Kareem is yielding methods for predicting the overall dynamic response of the bridge, which should help designers mitigate the effects of severe winds.

Additionally, Szewczyk, and colleagues at the Imperial College in London and Rosenstiel School of Marine and Atmospheric Science at the University of Miami-Florida, are investigating the best methods to control near-wake instabilities around bluff bodies. His tests are designed to examine the effects of wind shear and three-dimensional imposed disturbances on the flow. The purpose of this work, as with lock-in flows, is to better understand the mechanics involved in development, modification, and control of flows around bluff bodies.



A result of his collaboration with John C. Owen and Peter W. Bearman, of London's Imperial College, Dr. Szewczyk presented this winning poster entry, "Suppressing of Kàrmàn Vortex Shedding by Use of Sinuous Circular Cylinders" in the 17th Gallery of Fluid Motion at the American Physical Society, Division of Fluid Dynamics meeting in New Orleans in November 1999. It will be published in the September 2000 issue of the Physics of Fluids.

AS PLANS FOR THE STRUCTURE BEGAN TO TAKE SHAPE, Thomas J. and Marilyn Hennebry Hessert indicated their interest in the project. Hessert, president of T.J.H. Investment Company and lifelong aeronautics enthusiast, graduated from Notre Dame in 1948 with a degree in commerce. Long associated with the College as a member of the Engineering Advisory Council, he and his wife, Marilyn, who is a 1949 graduate of Saint Mary's College, were excited about the creation of a modern aerospace research and education facility at Notre Dame. It was their generosity that made the Hessert Center for Aerospace Research a reality.

The Hesserts

After the existing building was renovated, the largest portion of the addition — a lobby and main office area, faculty and graduate student offices, a conference room, and central data acquisition center — was attached to the front of the structure, nearly doubling the size of the original building to 38,000 square feet. The old building area would now become the main laboratory, housing several wind tunnels and an anechoic wind tunnel — one of the few such facilities in the country. To power the wind tunnels, the department also added a motor and fan room.

1975
Hafiz M. Atassi develops the first aerodynamic theory for lifting airfoils in gusts.

1976
America's Viking I and Viking II space probes land on Mars.

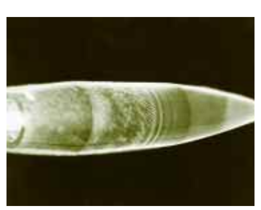
1977
NASA develops the space shuttle.

In 1990 **James D. Wetherbee** ('74, aerospace and mechanical engineering) piloted the shuttle Columbia on a 10-day mission, his first space flight. Although the purpose of the mission was to retrieve another spacecraft and capture video of the deforestation in Brazil, Wetherbee managed to take Albert Zahm's 1925 Laetare Medal and Notre Dame football's 1988 National Championship bumper sticker with him on the trip.

The University's Corby Award was presented to Wetherbee in 1991 in recognition of his accomplishment as the first graduate to make a space flight. Named for Reverend William Corby, twice president of the University and former chaplain in the Civil War, the Corby Award is presented annually to a graduate who has served admirably in the armed forces.

A veteran of four shuttle flights – two on Columbia and one flight each on Discovery and Atlantis – Wetherbee has logged more than 995 hours in space. He has served as both a pilot and a mission commander on shuttle flights and is currently Deputy Director of the Johnson Space Center. He has also received the Distinguished Flying Cross, the Navy Achievement Medal, and two Meritorious Unit Commendations.

1981
Notre Dame professors Thomas J. Mueller, Robert C. Nelson, and Jerry Kegelman (former doctoral student, now at NASA Langley) are the first to visualize the simultaneous appearance of Tollmien-Schlichting waves and cross-flow vortices on a spinning axisymmetric body.



1983
NASA's Pioneer 10 becomes first spacecraft to leave the solar system.

1985
Notre Dame students design, build, and fly an unmanned air vehicle.

Thomas J. Mueller organizes and hosts the first conference on low Reynolds number airfoil aerodynamics.

1986
Russia launches the MIR space station.

Flint O. Thomas

"We're providing real answers to people that need them in the aircraft industry, both military and commercial."

Flint O. Thomas' recent experiments focus on the generic flow elements that make up a high-lift system. What is a high-lift system? Picture a commercial airplane wing; it's not a single component. It has a leading edge, and there are a variety of flaps that deploy at different times during take-off and landing. That is a high-lift system. And, without one, the plane isn't going anywhere.

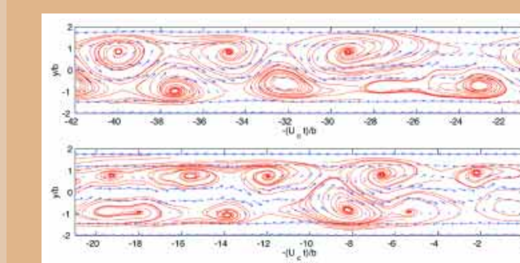
Air flow around these types of systems is extremely complicated. The systems themselves are high-maintenance, and there is an industry-wide push to develop simpler high-lift systems that perform better aerodynamically and require less maintenance. Thomas, in conjunction with Robert C. Nelson, is working on several projects that specifically address these systems.

Wakes: In a multi-element airfoil like the wing of a commercial plane, upstream elements create wakes. How an upstream wake grows and interacts with a downstream element affects a system's performance. To study these wakes, Thomas places a body in the wind tunnel to generate a wake and then imposes pressure on the wake and records how it develops. The physics of the information he extracts applies directly to high-lift systems. This research is sponsored by NASA's Langley Research Center.

Airframe Noise: One of the outcomes of higher bypass ratio engines is that engine noise has been reduced. However, noise induced by the airframe is still higher than the stringent guidelines NASA has set as acceptable around airports. Sponsored by NASA's Ames Research Center, Thomas is attempting to pinpoint how and where the noise on the airframe is being generated. With this information, he will develop a flow control strategy that can be used to quiet the system.

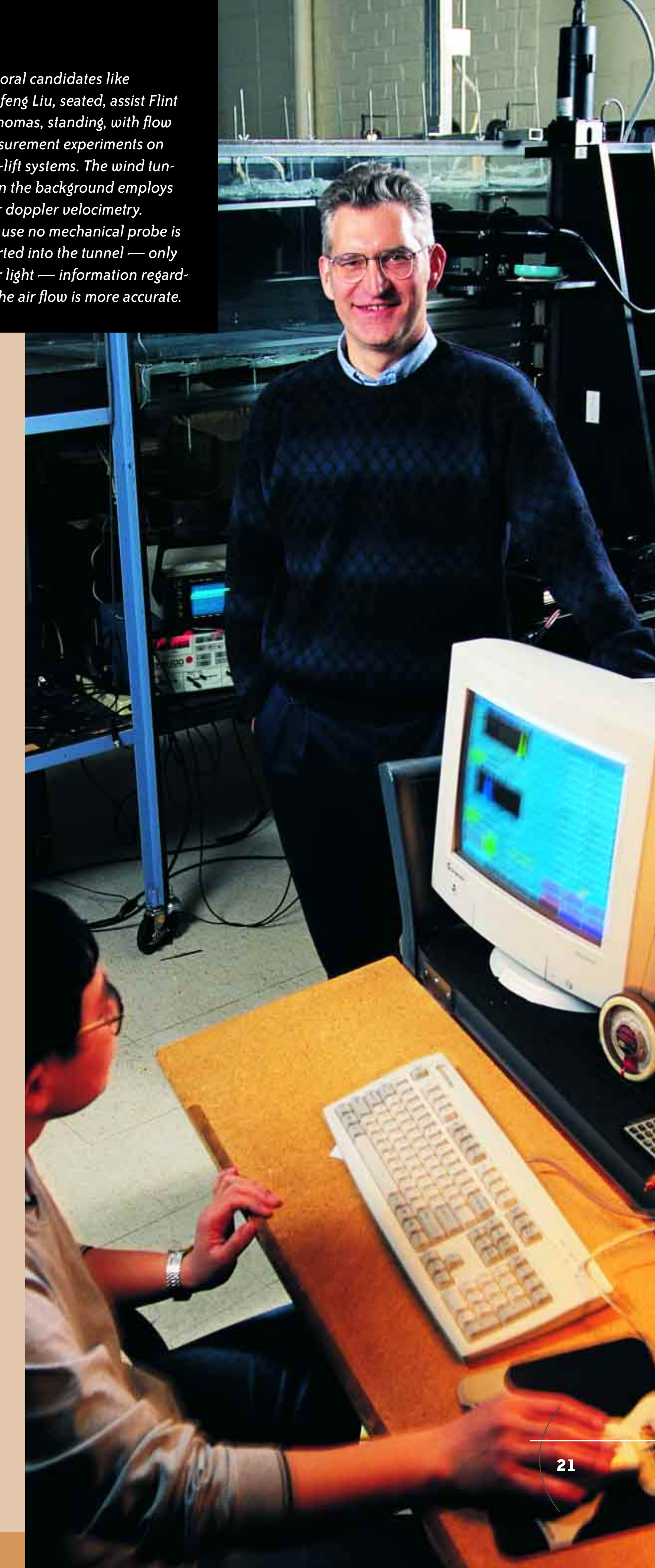
Relaminarization: When the level of turbulence on the surface of a wing suddenly, because of strong flow acceleration, becomes laminar — moving in distinct and separate lines — the aerodynamics of a high-lift system changes drastically. Thomas is investigating conditions under which relaminarization is likely to occur. Is it important? How can designers, manufacturers, or pilots compensate for this phenomenon? He has been working with NASA's Dryden Flight Research Center for approximately two years and hopes to be able to mount his experiment on the underside of an F-15 in the near future. Inflight experiments like this are important because research is typically conducted in wind tunnels at much slower speeds. Using an F-15 will provide much higher Reynolds and Mach numbers.

Jet Screech: A diamond pattern in the exhaust of a jet during take-off is associated with "shock cells." When the cells interact with the exhaust, extremely high levels of sound — around 165 decibels — are produced. Noise levels are so high that military fighter planes may experience inflight sonic fatigue failure of their nozzle flaps. Removing the flaps is a quick remedy but results in a severe drag penalty. Thomas' studies in the supersonic tunnel provide audio and turbulent flow measurements, which when correlated with the noise, offer a better understanding of screech tones and their origins. The information is being used by McDonnell Douglas to predict screech resonance.



Using advanced signal processing methods, Flint O. Thomas and Stanislav V. Gordeyev have extracted order from the chaotic motions of a turbulent jet. Modeling and control of these motions are key to reducing flow noise and enhancing mixing performance.

Wavelets: By applying wavelet analysis techniques, used in conjunction with plasma actuators developed by Thomas C. Corke, Thomas is attempting to promote boundary layer flow attachment and enhance the efficiencies of gas-turbine engines. Work for this project is sponsored by NASA's Glenn Research Center.



Doctoral candidates like Xiaofeng Liu, seated, assist Flint O. Thomas, standing, with flow measurement experiments on high-lift systems. The wind tunnel in the background employs laser doppler velocimetry. Because no mechanical probe is inserted into the tunnel — only laser light — information regarding the air flow is more accurate.

1988
Robert C. Nelson and Andrew Arena Jr. develop a theory for wing rock based upon unique flow measurements.

1991
The Hessert Center for Aerospace Research at Notre Dame is dedicated.

1992
Eric J. Jumper and Ron Hugo develop the Small-Aperture Beam Technique, a high-speed wavefront sensor with a frequency response of 100KHz.

1994
Patrick F. Dunn and Raymond M. Brach perform the first individual-event experiments and modeling for microparticle/surface impacts under vacuum conditions.

1995
NASA's Galileo space probe becomes first craft to orbit Jupiter.

1997
The Pathfinder probe lands on Mars, and NASA releases the rover Sojourner to carry out the first mobile exploration of another planet.

1998
NASA launches the Lunar Prospector, the first NASA moon launch in 25 years.

At 76 John Glenn returns to space aboard the shuttle Discovery.

1999
Thomas C. Corke successfully uses phased plasma actuators to control high-speed flows.

Flint O. Thomas and Stanislav V. Gordeyev perform novel experiments using proper orthogonal decomposition and wavelet transform techniques that lead to the development of a dynamic systems model of a turbulent jet.

A MACHINE SHOP, receiving dock, and several specialized laboratories — such as the Aero-Optics Lab, Particle Dynamics Lab, Flight Simulation Lab, Electronics Lab, and Design Lab — were placed below the main lab. Test section storage, an area for future expansion, and a photographic darkroom were also placed on the lower level. All of the labs, as well as the wind tunnels, have state-of-the-art measurement equipment and control systems. They are equipped with the latest safety systems and are also handicapped accessible.

WHEN THE WORK WAS COMPLETE, the Hessert Center for Aerospace Research was dedicated on November 7, 1991, as part of the University's sesquicentennial celebration. Almost 10 years later, the Hessert Center continues the traditions of excellence and innovation in aerospace research set in motion by Zahm, Brown, Eikenberry, Goddard, and colleagues. Testing in the subsonic and supersonic wind tunnels, the water tunnel, anechoic chamber, and many of the specialized labs is being co-sponsored by organizations like the National Aeronautics and Space Administration, the Office of Naval Research, the National Science Foundation, and several aircraft manufacturers.

Zahm and those who followed him would be delighted with the research being conducted within the Hessert Center by Notre Dame faculty, staff, and students. Such facilities are commonly found in industrial and government laboratories. To find them in a university setting being used for graduate and undergraduate research is unusual.

A New Era

LOOKING BACK it is easy to see that the pace for aeronautical research at Notre Dame was set by Zahm long before Kittyhawk. It gained momentum through contributions made by Brown, Eikenberry, and Goddard. Today, the influence of Notre Dame on aeronautics continues to grow. On a daily basis, faculty and students at the Hessert Center use the latest experimental and theoretical methods to address a broad spectrum of issues. They are working to develop faster and quieter aircraft. They are searching for ways to produce more efficient helicopters. They are investigating the flow of aerosols and using lasers to advance military and industrial applications. And, in their quest to develop micro-air vehicles, they — like Zahm — are using gliders. Perhaps the best is yet to come.

For more information on research at the Hessert Center or any of the faculty members highlighted in this article, visit www.nd.edu/~ame.

Looking Back to the Future

A retrospective from the former director of the Hessert Center for Aerospace Research

Stephen M. Batill, professor of aerospace and mechanical engineering, served as the Director of the Hessert Center from its inception in 1991 until 1998. Currently, the Associate Dean for Educational Programs in the College of Engineering, he believes the Hessert Center is unique as a research facility and an educational tool. "From the very beginning," said Batill, "the Hessert Center has provided an excellent environment for diverse research interests and allowed for the continued growth of many programs and projects that had their roots in the old 'Aero shack.'"

While at Hessert, Batill's activities included work in high-angle-of-attack and bluff-body aerodynamics, dynamic system modeling, and parameter identification with a variety of flight vehicle applications. The experiences he gained at Hessert allowed him to extend his activities into the area of multidisciplinary design.

Batill's current research involves the development of methods for the computer-assisted, simulation-based design of aerospace and mechanical systems. His primary goal is to provide system designers with the tools necessary to make decisions when faced with the massive amounts of information available from computer simulations of system performance. Collaborating with mechanical and computer engineers within the College, Batill is attempting to exploit the developments in soft computing and artificial intelligence as a means of providing quantitative representations of complex design issues.

> "The Hessert Center has provided an excellent environment for diverse research interests and allowed for the continued growth of many programs ..."

In addition to expanding faculty research, the Hessert Center has encouraged the development of a number of important educational activities, several of which Batill spearheaded. For example, the capstone design class in the aerospace engineering program has evolved to include a product-development process similar to that practiced in industry. This activity gives students the opportunity to build and demonstrate a product or process that they design. Particular care is taken to include activities that promote student communication, teamwork, and project planning skills. Central to this project-based, team-oriented course is strengthening students' abilities to perform engineering analysis and modeling, which are vital to effective systems design.

Likewise, in the early years of the Hessert Center, NASA — through the Universities Space Research Association — and Boeing provided significant resources that allowed several programs to "get off the ground," opening up exciting new opportunities. The lower level of Hessert became the department's design studio, serving as a prototype for the current Systems Design Studio and the new College Learning Center. The CAD/CAM capabilities available at Hessert have proven extremely helpful in undergraduate design courses, particularly since in recent years student-designed aircraft have included onboard avionics systems and imbedded microprocessor control. In fact, a student design team developed Notre Dame's first fully autonomous unmanned air vehicle in the spring of 1998.

Throughout the years, the success of Hessert projects has been due in part to the support given by Mike Swadener, the Hessert machinist; Joel Preston, the electronics specialist; and Marilyn Walker, administrative assistant for the Center. The technical and administrative staff have contributed much to the research and educational programs that take place in the Center, and their work is far from finished. "The College will, of course, continue to foster multidisciplinary activities within the Hessert Center," said Batill. "The research facilities are a major part of this dynamic Center, but faculty, staff, and students must be diligent in maintaining the traditions of excellence and the quest for knowledge that has long been part of the aerospace program at Notre Dame."

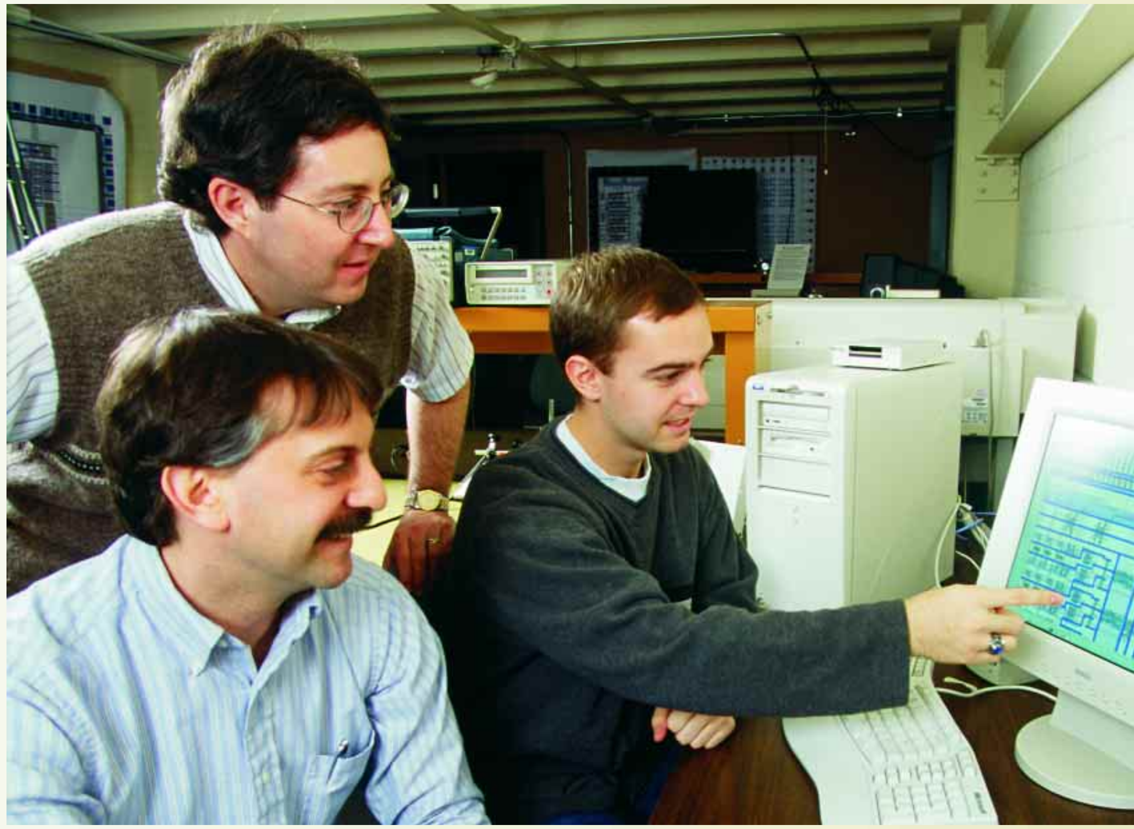
Former director of the Hessert Center for Aerospace Research, **Stephen M. Batill** invigorated the senior-level design class by having students design, construct, and test actual devices or processes. This gives students hands-on experiences similar to those encountered in industry. Batill is currently Associate Dean for Educational Programs within the College of Engineering.

from bits to chips and everything in between

In the course "Frontiers in Microelectronic Systems," the culmination of the Bits-to-Chips Program, students design, build, and test their own CMOS large-scale integrated circuit. Each chip contains approximately 3,000 transistors, making it slightly more complex than the world's first microprocessor, which was developed in 1971.

THREE YEARS AGO electrical engineering and computer science and engineering students at Notre Dame expected to sit in the same courses, study from similar textbooks, and conduct experiments in the same types of labs as their counterparts in other institutions. The Bits-to-Chips Program changed all that.

Like other National Science Foundation sponsored programs, Bits-to-Chips started as a proposal. Pooling their talents and goals for the program, electrical engineering faculty Gary H. Bernstein, Robert J. Minniti Jr., and Gregory L. Snider, along with computer science and engineering faculty Jay B. Brockman and Peter M. Kogge, began outlining an interrelated set of courses that would emphasize the technical and human aspects of microelectronic system development. They focused on how the two disciplines — computer science and engineering and electrical engineering — would interact, now and in the future.



Gary H. Bernstein, professor of electrical engineering, standing; Jay B. Brockman, associate professor of computer science and engineering; and Matthew Wiedemer, a senior in the Bits-to-Chips Program, review the design of a integrated circuit using the Mentor Graphics Computer-aided Design Program.

"We looked at all components of the curriculum and made major changes in the way the material was presented to create a seamless transition across the courses," said Bernstein. Students basically work on one very long project, and they learn to work in teams.

This *collaborative learning* is an essential part of the course sequence, since it reflects the interaction between disciplines that occurs in industry. "In the past when discussing technical matters, there was skepticism in the academic world when people heard the word 'team,'" said Brockman. "The first thing that came to mind was 'fluff,' an absence of technical content. Bits-to-Chips employs team concepts to solve complex engineering problems."

In short, the program builds on the strengths of the electrical engineering and computer science and engineering departments by providing a comprehensive program in microelectronic systems. "Our goal," said Kogge, "was to give these students a very broad background so they could understand computer technology, how transistors work, and how to build them." This helps students begin to understand the interactive nature of the world they are entering. They must learn to think of themselves not only as experts in a particular field, but also as part of an interdisciplinary team.

Although the initial groundwork for Bits-to-Chips is laid in the sophomore year, when the students officially enter the College of Engineering, the program kicks into high gear in junior-level classes. For example, the Computer Architecture course gives students the opportunity to design two microprocessors using Mentor Graphics CAD tools. Students then implement their designs in Xilinx field-programmable gate arrays. The first design is a simple 12-bit accumulator

... collaborative learning is an essential part of the course sequence ...

machine; the other is a Java Abstract Machine that executes Java byte code.

Seniors, who are now in their third year of this program, have already completed a course in VLSI (very large-scale integration) design — where they studied interactions between the physical layout of a chip and its electrical properties. They have also taken the course “Introduction to IC (Integrated Circuit) Fabrication Laboratory.” In the IC course student teams learned the fundamentals of fabrication by building 4-micron polysilicon gate, CMOS, mask programmable ICs with approximately 3,000 transistors each.

> “Bits-to-Chips awakens students to the interfaces among all the aspects of IC design and manufacturing ...”
>
> — Gary H. Bernstein

Gregory L. Snider, assistant professor of electrical engineering, left, directs Ronald Setia as he cleans silicon wafers in the College's Fabrication Laboratory.

All of this work is completed on campus in College of Engineering labs and is atypical of university curricula, especially at the undergraduate level.

Bits-to-Chips seniors are currently enrolled in a course on compiler design and the program's capstone course, “Frontiers in Microelectronic Systems.” They are developing compilers that will map programs written in high-level language to machine code that will be executable on the integrated circuits they built as juniors.

In the “Frontiers” course the seniors will be completing the physical layout and mask of their microprocessors, committing their designs to glass, and processing the wafers. They will also test their programs on an automated probe station and write detailed

reports discussing the results and conclusions, including an analysis of team performance. “The key element in the capstone course,” said Kogge, ”is that the students experience the step-by-step process of creating a system.”

“Frontiers” students and faculty will also be discussing the limitations of today's technologies and what may happen a decade or two down the road, an important period of the students' careers. This discussion focuses on a Semiconductor Industry Association (SIA) document called the National Technology Roadmap for Semiconductors, an industry forecast of the state of technological advances and the need for innovations over the next 15 years.

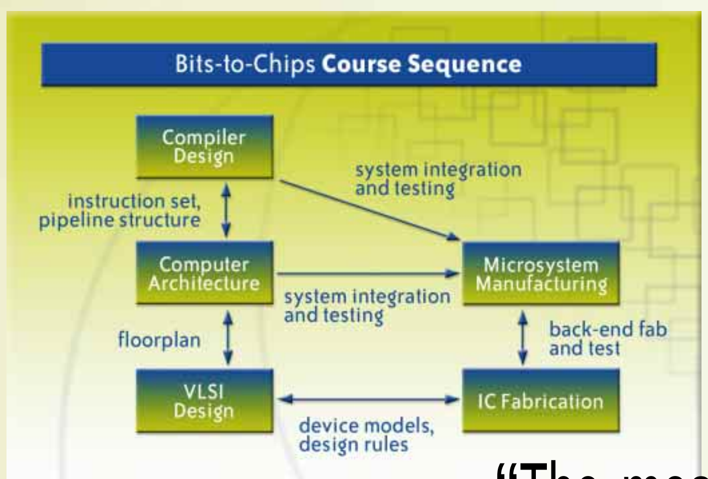
Graduate student Christopher Harris inserts prepared wafers into the oxidation furnace, which operates at 1100° C. This process melds the circuits onto the silicon wafers.

A STUDENT'S PERSPECTIVE

Senior Chris Russo, a double major in electrical engineering and philosophy from Detroit, Mich., believes that knowledge of how the design and fabrication of microprocessors are integrated, coupled with the experience he's gaining from the computer science and engineering side of microelectronics, is invaluable. In other colleges students follow a more traditional core structure than Russo and the other Bits-to-Chips students. Electrical engineering students take electrical engineering courses, while computer science and engineering students take classes in computer science and computer engineering. There's little integration of the two disciplines. For example, students may become very well versed in device design but not understand the implications of architecture or fabrication on that design. While typical for the academic setting, many corporations are seeking those engineers who understand the “bigger picture.”

Another vital aspect of Bits-to-Chips is teamwork. “Learning group cooperation and leadership skills, as well as just working and being involved with other team members is essential to any type of work I'll do in the field,” Russo said. Bits-to-Chips encourages each team member to take on many roles and responsibilities – in allocating the work load, coordinating the project, and communicating team progress. It builds skills not found in textbooks and provides undergraduates with the opportunity to design, fabricate, and test their own microprocessor. In the words of Chris Russo, Bits-to-Chips has been “extremely rewarding.”

Seated clockwise are David Morrow; Gregory L. Snider, assistant professor of electrical engineering; Jon Vloet; Ronald Setia; Peter M. Kogge, Ted H. McCourtney professor of computer science and engineering; and Chris Russo. This grouping is typical of the interactive nature of class sessions, with team members discussing the different aspects of the project and updating one another on their progress.



The fact is that the CMOS technology used in today's chips may not last much beyond 2012; there are physical barriers that are even now coming into play. "That's the whole point of this interaction between faculty and students and within the student teams," said Bernstein. "Bits-to-Chips awakens students to the interfaces among all the aspects of IC design and manufacturing — technological, intellectual, architectural — so they can accept change as something they will constantly be facing in their careers."

While the faculty team examined how to arrange the technical components of the program, Dr. Barbara E. Walvoord, Director of the Kaneb Center for Teaching and Learning, focused on the educational aspects of Bits-to-Chips. The Kaneb Center serves faculty and teaching assistants in their roles as educators by providing individual consultation on teaching, workshops on how to teach with technology, and supporting departments and colleges in curricular changes. It is Walvoord's role to assess Bits-to-Chips and determine how to measure its effectiveness.

"The most important thing to realize about Bits-to-Chips is that students will gain a good knowledge of both fabrication and design."

— *Barbara E. Walvoord*

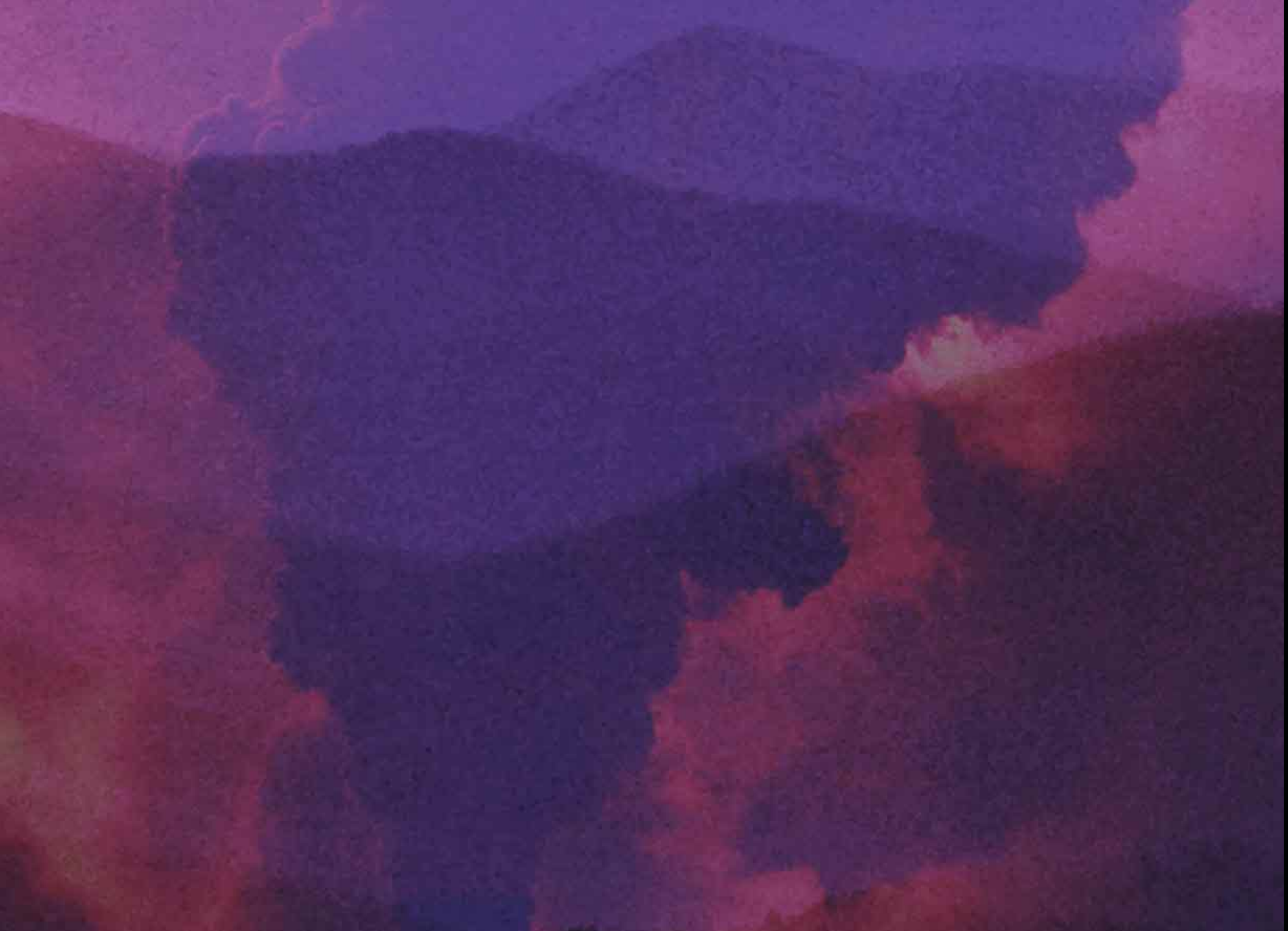
That's a hard thing to do. It's relatively easy to test students on factual knowledge and verify that one set of students knows more than another set. It is more challenging to measure students' conceptual learning: in this case, the ability to make complex judgments in which design and fabrication skills coalesce.

Because this is a novel course sequence, Walvoord is not immediately able to compare Bits-to-Chips students with those who follow a more traditional electrical or computer science and engineering curriculum. "The most important thing to realize about Bits-to-Chips is that students will gain a good knowledge of both fabrication and design," said Walvoord. "They will be able to make judgments that are informed by knowledge in both fields."

For purposes of the proposal and any future changes to the course sequence, Walvoord is looking for evidence that Bits-to-Chips students changed or revised their projects as they developed in light of questions or input from the interdisciplinary courses they were taking. Kaneb Center staff will also be looking at the class projects to determine the level of student performance. Ideally, this will give Bits-to-Chips faculty a realistic assessment of the level of accomplishment in the course sequence.

Even now the program has an Industrial Advisory Board consisting of representatives from major manufacturers of integrated circuits — Delco, IBM, Intel, Hewlett Packard, Lockheed Martin, and Motorola. They met on campus last spring to review the program and provide feedback from a corporate perspective. According to these industry experts, Notre Dame's Bits-to-Chips Program is definitely headed in the right direction.

Bits-to-Chips participant Chris Russo tests a chip on the analytical probe station located within the Department of Electrical Engineering. This is the final step in the Bits-to-Chips Program.



Reclaiming Those Amber Waves

"O beautiful for spacious skies, for amber waves of grain, for purple mountain majesties above the fruited plain ..." Is anything more incredible, more awesome than creation? There are certainly few things more humbling than the God-given task of mankind to use ingenuity, creativity, and responsibility in the development and protection of the Earth's resources.

Man's track record in pollution prevention and remediation, however, has been less than ideal. As far back as Hippocrates, people recognized that some waters promoted good health, while others produced disease. But instead of purifying waters that were bad, they focused on selecting the most "healthy" water. Waste was handled in much the same way; it was kept away from polite society.

Although many U.S. cities were developing public water supplies as early as the 1800s, conservation as a way of life didn't begin gaining popularity until Theodore Roosevelt's much publicized 1903 western trip with John Muir, one of America's most famous and influential naturalists. In 1935 Franklin Roosevelt established the Soil Conservation Service, which focused on the reduction of agricultural erosion. And, the Pittman-Robertson Act, which established a fund for state fish and wildlife programs, was passed in 1937.

World War II ushered in a new concept in preservation of the land — ecology. Media stories detailed radioactive fallout and its effect on food, the dangerous state of urban water supplies, and the deterioration of air quality in many larger cities. This modern idea of environmentalism sought not only to preserve the Earth, but to regulate and punish those who polluted it.

Decades later Presidents Kennedy and Johnson sensed the ever-increasing tide of public opinion toward preservation and championed the environment in many speeches and legislative programs. Johnson also signed the Highway Beautification Act in 1965. Wanting to capitalize on its popularity, Nixon established an Environmental Quality Council in his cabinet and a Citizens' Advisory Committee for Environmental Quality just four months after his 1969 inauguration.

He observed the activities of the first Earth Day in April 1970 from the Oval Office. But it was much later that year when he declared his intention to establish the U.S. Environmental Protection Agency (EPA). Its mission was to: Establish and enforce environmental protection standards consistent with national environmental goals; sponsor research on the adverse effects of pollution and methods for pollution control; and assist the Council on Environmental Quality in developing and recommending to the President new policies for the protection of the environment. On December 4, 1970, the EPA opened its doors.

But the EPA was just getting started. Even with much publicity, there was not a strong environmental movement in the country. More important, people did not have a clear understanding that when a waste product was discharged — on the surface of the ground or below it — the waste would contaminate and be transported by groundwater systems.

The past 30 years have brought about many changes in environmental policies dealing with water, soil, and air-quality issues. What has also changed is the way engineers and scientists look at pollution, how to prevent it and reclaim contaminated areas.

Researchers within the Department of Civil Engineering and Geological Sciences and in the Department of Chemical Engineering have developed cutting-edge programs to prevent and remediate pollutants in the environment. They focus on three areas: water development, water treatment and methods to avoid water pollution in developing countries; pollution prevention in developed countries; and remediation efforts. What follows is an overview of how each of these departments addresses the problems of pollution.

Working with graduate students like Yong Peng, kneeling, Stephen E. Silliman, associate professor of civil engineering and geological sciences, directs several projects in the Groundwater Hydrology Laboratory. His Groundwater Group combines probabilistic methods with new field techniques to understand how activities on the ground surface — the development of new subdivisions, expansion of roads, and construction of industrial parks — might affect municipal water-supply wells.

The Department of Civil Engineering and Geological Sciences

According to Associate Professor Stephen E. Silliman, the most encouraging aspect of pollution prevention in developing or Third-World countries is that these nations are just beginning to establish their industrial bases. They can benefit by not making the same mistakes the U.S. and other developed nations have made in producing and handling waste products. Another plus is that, although some of the water is tainted, many of the water resources in Third-World countries are untapped and as yet unpolluted. The University has initiated programs in Haiti and Mexico to assist in the development of clean water supplies. Silliman is also working to establish a research link between Notre Dame's Groundwater Hydrology Group and the Universite National du Benin in western Africa.

As exciting as the work in developing countries is, it is only a small portion of the work performed by the Groundwater Group. The bulk of their research focuses on developing strategies for the protection of groundwater resources in the U.S. One of these projects highlights wellhead protection programs. State and local governments are mandated to maintain programs that ensure safe groundwater supplies.

If groundwater flowed downstream like a river, protecting the area immediately upstream of a municipal wellhead would prove sufficient. Water, however, follows circuitous paths, responding to variations in the subsurface geology of a region and making precise prediction of groundwater flow impossible.

In light of this, Silliman and his group are investigating ways to identify a "protection area" around a wellhead — an area that provides a factor of safety. Using probabilistic and numerical models of groundwater flow and chemical transport, field measurements, and physical models in the Groundwater Hydrology lab, they can more accurately predict the flow of subsurface water, as well as chemical and microbial transport through groundwater systems.

This is vital, but it is also very controversial. Why? "The regions we're protecting can be several kilometers long and hundreds of meters wide," said Silliman. "When you add a factor of safety to the wellhead, the land mass that has to be guarded is suddenly much larger." Local governments would have to control industry in that area and sample for contaminants, increasing the costs in proportion to the factor of safety. Silliman's group is studying ways to keep the factors of safety as small as possible while maintaining the integrity of the groundwater.

Water … follows circuitous paths, responding to variations in the subsurface geology of a region …

Identifying, developing, and protecting domestic water in Benin

Stephen E. Silliman, associate professor of civil engineering and geological sciences, and the Groundwater Group at Notre Dame have identified several areas of service within Third-World countries where they believe they can make a difference. In addition to Haiti, which was covered in the last issue of *Signatures*, the group is in the early stages of developing two projects within the Republic of Benin in western Africa.

In a joint effort with the Universite Nationale du Benin (UNB) and Lifewater International, Notre Dame has received support from the National Science Foundation to improve the siting of wells in northern Benin. Due to fractured crystalline rock below the surface, it is difficult to obtain a reliable water supply. The Groundwater Group will combine remote sensing, geology, geochemistry, and local knowledge to form a database that will increase the probability of drilling a successful well.

A second component of the work in Benin deals with academic links between Notre Dame and UNB. Since both institutions maintain programs in civil engineering, earth sciences, and environmental science, long-term goals include the development of joint research programs and the exchange of graduate students, undergraduate students, and faculty.

Another focus of Notre Dame's environmental research is the movement of contaminants in groundwater systems. Funded by the National Science Foundation and the American Chemical Society, Associate Professor Jeremy B. Fein applies chemical thermodynamics to environmental geomicrobiology. He studies the biochemical interaction of water, rocks, and bacteria and focuses on determining the effects of bacteria on the adsorption of contaminants and on the precipitation of those contaminants into mineral structures. "These bacteria, which are not pathogenic, have a huge affinity for picking up metals and organics," said Fein. "We knew this qualitatively years ago, but until now we were not able to develop quantitative models for those interactions which can be applied in remediation efforts. Ours is the only program in the country studying bacteria-water-rock interactions on this level."

According to Fein, the Department of Energy is pushing bioremediation using bacteria. The ideal situation would be to introduce bacteria into the subsurface, have them scavenge radionuclides and other heavy-metal contaminants that are polluting the groundwater, and then to be able to extract the bacteria or immobilize them.

Notre Dame is a leader in bioengineering, which focuses on the biological treatment of municipal and industrial wastewater and hazardous materials. "Simply put, remediation," said Professor Robert L. Irvine, "refers to waters and soil that are contaminated and need to be cleaned up." The basic issues are: what needs to be remediated and how long will it take? Irvine's research employs sequencing batch reactors (SBRs), which were initially developed at Notre Dame and are currently the fastest-growing water treatment systems in the world.

Jeremy B. Fein, professor of civil engineering and geological sciences, right, and graduate student David A. Fowle prepare experiments in the Environmental Geochemistry Laboratory to study the effects of bacteria on contaminant metal transport in groundwater. In addition, Fein, Bruce A. Bunker, chairman of the physics department, and researchers at Argonne National Laboratory are using the Advanced Photon Source synchrotron, located at Argonne, to determine how heavy metals interact with bacterial surfaces.

Robert L. Irvine and doctoral candidate Kara M. Young discuss the operating strategy for an experiment they are conducting in a bench-scale sequencing batch reactor. They are monitoring the treatment potential of the organisms within the reactor. The results of their research will eventually be applied to wastewater treatment plant operations.

Following the principle that many of the by-products considered hazardous to society are food sources for microorganisms, Irvine grows those organisms that use the contaminants as a food source. "We're not introducing any new microbes," he said, "just giving them the things they need to grow and 'eat' the contaminants. And, we do it using periodic processes."

A common problem in industry is that organisms are accustomed to receiving a constant supply of "food." Thus, when a surge of hazardous materials comes along, they cannot handle the excess. By using a periodic process — providing the organisms with a sharp influx of waste followed by no waste, a feast/famine cycle — Irvine has created a system that can handle fluctuations in waste amounts due to events such as accidental spills. This is particularly helpful in wastewater treatment plants.

Lloyd H. Ketchum Jr., right, and Enos C. Inniss, a doctoral candidate in the Department of Civil Engineering and Geological Sciences, sample the amounts of contaminants in water. Ketchum specializes in water and wastewater treatment plant design, water supply and wastewater treatment in developing nations, and pollution prevention.

One of the collaborators in SBR research has been Associate Professor Lloyd H. Ketchum Jr. In addition to his work in the lab and in the classroom, Ketchum has developed off-campus opportunities for students. For example, in the "Pollution Prevention Challenge Program" (P2) at Notre Dame, pretreatment personnel from Elkhart, Ind., and undergraduate investigators from Notre Dame tour the facilities of corporations that are significant users of the city's municipal wastewater treatment plants. During each tour, the pretreatment personnel and students identify pollution prevention opportunities, which they then document for implementation by the companies.

P2 was funded in part by the Indiana Department of Environmental Management (IDEM). Its purpose was to facilitate the implementation of pollution prevention practices in Elkhart, to provide guidance to the pretreatment managers of other cities wishing to implement a similar program, and to identify pollution prevention research needs within the city's industrial community.

Working with Arthur K. Umble, an employee of the city and an adjunct assistant professor at Notre Dame, Ketchum has also created a community mentoring center. In the mentoring center engineering undergraduates are teamed with plant operators. This pairing gives students real-world experience through interaction with practicing professionals, and provides the plant operators with access to the latest research results. Ideally, this mentor program will serve as a prototype for other universities and large cities or small communities throughout Indiana. It is being supported by IDEM and its Office of Technical Assistance.

Perhaps one of today's hottest topics in pollution prevention and remediation concerns the safe geologic disposal of nuclear waste. That's the focus of Henry J. Massman Associate Professor Peter C. Burns' work. He studies low-temperature minerals, which form naturally in the upper portions of the earth's crust. There are approximately 3,300 of these minerals, and they include elements such as uranium, mercury, lead, cadmium, and selenium. By studying the behavior of these minerals in natural systems, Burns can identify the safest ways to store radioactive waste, and what is likely to happen to the waste over time — say the 10,000 or so years before it is no longer a threat to society.

Burns is a leading authority in this field, having received the 1999 Donath Medal from the Geological Society of America for his research concerning uranium. He was also one of three faculty from U.S. institutions recently invited to discuss remediation of radioactive wastes with members of the Russian Academy of Sciences.

Currently, there are more than 70 sites in the U.S. that store nuclear wastes. The government's goal is to collect all high-level waste in one geologic site, and Nevada's Yucca Mountain is the only containment site

The Environmental Mineralogy Research Group, led by Henry J. Massman Associate Professor Peter C. Burns, studies environmentally pressing issues such as radionuclide contamination and the disposal of nuclear waste in geological repositories. Shown with Dr. Burns is Sarah Scott, a graduate student in the Department of Civil Engineering and Geological Sciences.

Directed by Clive R. Neal, associate professor of civil engineering and geological sciences, right, and managed by Jinesh C. Jain, assistant professional specialist, **the Inductively Coupled Plasma Mass Spectrometry (ICP-MS) Facility** provides a precise analytical method for obtaining high-quality multi-element analyses at trace (part-per-million to part-per billion) and ultra-trace levels (part-per-trillion and lower). The ICP-MS is being used to investigate a number of environmental problems, including the feasibility of using inexpensive biomass – such as corn-cob waste – to remove heavy metal toxins from groundwater and mine wastewater. Filtering this water through certain types of biomass produces clean water and concentrates the toxins into a more manageable form for removal. Another project examines platinum pollution of local soils and crops due to the attrition of automotive catalytic converters. Platinum, if it becomes part of the food chain, is a carcinogen. According to Neal, measurable platinum is present along some South Bend streets. Additional studies continue to determine if the platinum has been absorbed by plants in those areas. A new investigation within the ICP-MS facility focuses on radioactive waste dispersal – specifically the amount of neptunium in the environment and the ability of this nuclear power by-product to be transported in the surface and near-surface environments. Details on each of these projects is available at www.nd.edu/~cneal; information on the ICP-MS is available at www.nd.edu/~icpmslab.

This map indicates the location and levels of platinum found in the South Bend area. Students and faculty are using the ICP-MS facility to determine if platinum has been absorbed by plants in the area.

designated by Congress for further study. It has not yet been licensed by the Nuclear Regulatory Commission; that may occur in 2002. The research Burns is conducting will help the government ascertain the feasibility and reliability of this site.

As a solid, according to Burns, spent nuclear fuel remains stationary and would, therefore, not make its way through the groundwater table below Yucca Mountain. However, if it breaks down chemically, it can be dispersed in the environment. Burns is looking at the nature and consequences of that chemical alteration. What he has found is that with alteration, hexavalent uranium phases develop, which is exactly what one sees in nature when a uranium ore deposit weathers. Burns believes that these phases will form in vast quantities in the repository, and that they will incorporate radionuclides from the spent fuel into their alternation phases. This, says Burns, will prevent the radionuclides from leaving the repository. "The minerals forming and picking up the radionuclides is a very big plus for repository performance," said Burns. "From our study of natural systems, we know that these alteration minerals can exist for 100,000 years, and we know that they are very stable chemical species."

For more information on pollution prevention and remediation efforts in the Department of Civil Engineering and Geological Sciences, visit www.nd.edu/~cegeos.

WWW

Going with the Flow:

The Importance of Surface Water Currents in Determining the Fate of Pollutants

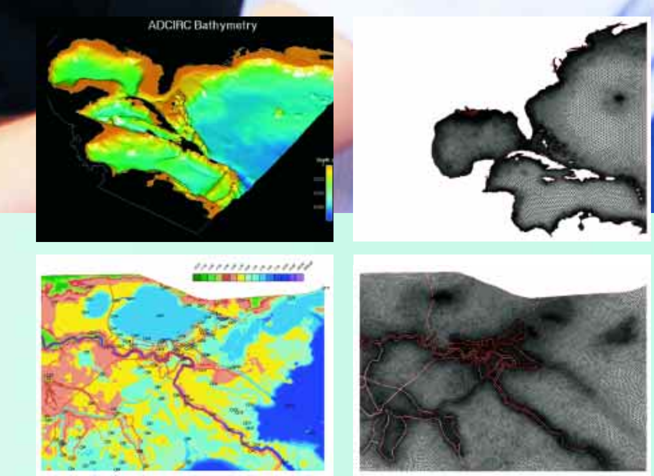
Ann Mukai, far right, and Kwabena Adu-Sarkodie are two of the students who work in the Environmental Hydraulics Laboratory with Joannes J. Westerink, associate professor of civil engineering and geological sciences, standing. For the past two decades lab efforts have focused on developing and testing numerical algorithms and the associated computational model codes in order to predict surface water currents.

The fate of pollutants in the environment — the path along which they move and where they settle — depends on the speed and direction of the carrier fluid. Directed by Joannes J. Westerink, associate professor of civil engineering and geological sciences, the Environmental Hydraulics Laboratory (EHL) at Notre Dame develops and applies computational models to predict the flow of surface water bodies such as lakes and coastal oceans. These free surface water models are quite similar to weather models, which predict atmospheric pressure, air flow, and temperature.

Westerink and students in the EHL have been using these models to predict the flow and transport in waters along shelves, coasts, and within estuaries. The flagship model, developed by EHL in cooperation with investigators at the University of North Carolina at Chapel Hill, the University of Texas at Austin, and the University of Oklahoma at Norman, is ADCIRC (Advanced Circulation). Funded by the U.S. Army and U.S. Navy, ADCIRC has been applied extensively over the past 11 years to coastal ocean regions worldwide, including the western North Atlantic, Gulf of Mexico, Caribbean Sea, Eastern Pacific Ocean, North Sea, and Mediterranean Sea. The ADCIRC model is capable of computing flows for domains of unprecedented size and detail.

Applications for ADCIRC range from determining the fate of pollutants — those discharged in ocean sewage outfalls, ocean garbage disposal, and power plant waste heat — to predicting the transport of toxic-laden sediments during dredging and dredging disposal operations. ADCIRC has also been used to evaluate coastal inundation and erosion during hurricane storm surge and tsunami events. When used to model these events, the predictions of ADCIRC help assess flooding probabilities and provide information for the design of coastal protection systems such as levees, which are crucial for saving lives and property in coastal regions. In addition, ADCIRC has been applied to the study of water currents for ship navigation as well as tracking the movement of fish larvae in important fisheries.

For more information about the EHL or ADCIRC, visit www.nd.edu/~coast and www.nd.edu/~adcirc.



Computational models of flow and transport in coastal waters, like those shown above, are used for a variety of applications, from calculating real-time storm surges to assessing sediment and pollutant transport on the continental shelf. Sponsors include the U.S. Army Waterways Experiment Station, U.S. Naval Research Laboratory, National Science Foundation, Army Research Office, and the Texas Water Development Board.

Bayer Professor Hsueh-Chia Chang, standing left, Associate Professor David T. Leighton Jr., standing right, graduate student Jason Keith, kneeling, and undergraduate researcher Eric Sherer have developed an automotive catalytic converter that ignites faster than current models. Although still testing the device, the team can currently reduce pollution from a converter by more than 50 percent.

The Department of Chemical Engineering

Pollution prevention is a relatively new thrust of chemical engineering. Previous environmental efforts in the field have focused on remediation techniques, such as biological waste disposal or thermal processing. Current research, however, seeks to prevent pollution by using fundamental principles of chemical engineering to develop pollution-free processes.

This push for new and better processes or products has been driven by economic and ecological factors. Corporations competing for larger portions of the global market are searching for ways to cut the costs of manufacturing. The bottom line is that chemical processes that are safer, cleaner, and more efficient are ultimately less costly.

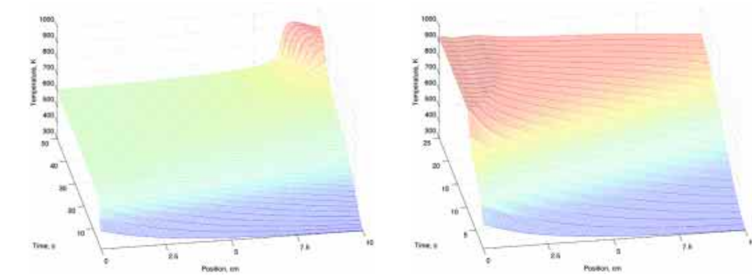
Another proponent in the search for environmentally-friendly processes is the federal government, which regulates the transport, storage, and disposal of hazardous materials, as well as emissions from factories and vehicles.

One of the projects in the chemical engineering department examines the effect of two-phase thermal dispersion on the ignition and stability of catalytic converters. Bayer Professor Hsueh-Chia Chang and Associate Professor David T. Leighton Jr. direct this research. While the current converter initiates reaction fairly rapidly — in less than five minutes — it takes 30 minutes of driving time before the entire length of the converter heats up enough to be fully effective. Consequently, only a small fraction of the emitted pollutants is "reacted away." Since the average driving time for most Americans is 25 minutes per trip, little of the time spent on the road is actually earth-friendly. Additionally, the converters on older vehicles do not meet the requirements of the new Clean Air Act, and even converters on relatively new cars are not up to federal standards.

Chang and Leighton have been investigating ways to improve the light-off time of a converter by using a combination of an electrical preheater, a catalytic pre-ignitor, and a controllable bypass. They have been working on the device for approximately five years and are now testing it with the help of graduate student Jason Keith. The net effect is that they can increase the temperature of the gas faster, leading to a more rapid reaction — 15 minutes — for an estimated pollution reduction of 50 percent. As this project continues, the group expects to make adjustments to the converter design that could reduce pollution as much as 90 percent below current levels.

Combining experimental, theoretical, and computational studies, Arthur J. Schmitt Professor Arvind Varma investigates pollution prevention through waste minimization. Since the early 1980s, he has investigated a number of novel concepts in catalytic reaction engineering to maximize reactions, thus creating more desired products and minimizing waste. In addition to his other research on optimal distribution of catalyst in pellets and inorganic membrane reactors, Varma has teamed with Mark J. McCready, chair of the chemical engineering department, to enhance the performance of multiphase reactors. These reactors are used widely in the chemical, petroleum, and pharmaceutical industries.

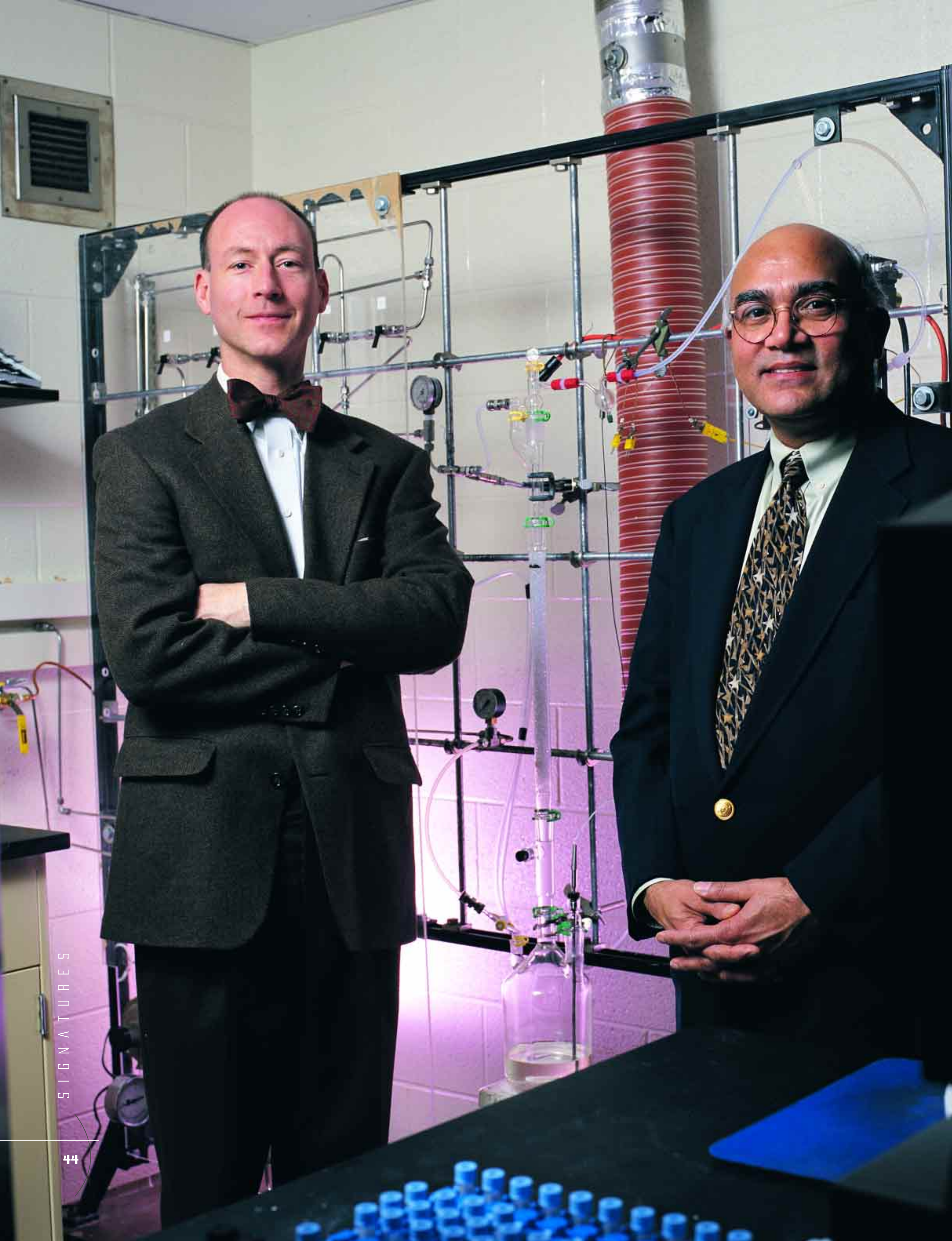
"We're looking at the fundamental interactions of transport processes, including fluid mechanics, mass and heat transfer, with catalytic reactions," said Varma. "When we understand these interactions, we can design and operate multiphase reactors from a rational viewpoint and maximize the yield



These temperature profiles show the difference between a standard catalytic converter, left, and the converter design Bayer Professor Hsueh-Chia Chang and Associate Professor David T. Leighton Jr. are investigating. The red areas indicate how long each converter takes to reach operating temperature. While ignition in a standard converter occurs near the exit of the converter, ignition in the Notre Dame converter occurs near the entrance of the device and is more stable. This type of leading-edge ignition employs the use of a bypass channel and an electric preheater and reduces pollution by more than 50 percent.

of desired products." For example, when the gas and liquid flow rates are such that the reactor operates in the "trickle" regime — a rather sedate condition of gas bubbling through liquid within the solid catalyst packing — an inefficient reaction occurs that favors an undesired product. However, higher flow rates cause the much more energetic "pulsing" regime. Pulses are strong organized disturbances that travel through the reactor and cause very efficient mixing, leading to a reaction that favors the desired chemical product. The key is increased mixing, combined with the inherent unsteady nature of pulsing flow that allows a "tuning" of the reactor to change the reaction outcome.

"What is most important," said McCready, "is that this research, which is being accomplished by faculty, graduate students, and undergraduate students, is contributing to fundamental knowledge in chemical processing. Without this knowledge, industry cannot continue to develop." This collaborative effort of faculty, who are experts in a variety of areas, and students defines the department's approach to pollution prevention. It combines different perspectives and people to solve real-world problems.



Mark J. McCready, left, professor and chair of the Department of Chemical Engineering, and Arthur J. Schmitt Professor Arvind Varma study ways to reduce pollution by minimizing undesired products in multiphase systems. They believe the key to creating an efficient reaction in these systems is by controlling the dynamics of the gas and liquid flow.

It is always easier and less costly to avoid creating pollution than it is to clean up.

Minimizing unwanted by-products is indicative of the growing appreciation by industry and governmental laboratories of the impact of chemical manufacturing processes on the environment. It is always easier and less costly to avoid creating pollution than it is to clean up. Linking ecology with engineering processes must occur in industry, but the groundwork needs to be established in the educational process. Teaching students how to design and operate chemical processes that minimize the production of pollutants is one of the goals of the Combined Research Curriculum Development Program (CRCD), a cooperative effort between the University of Notre Dame, the University of Nevada at Reno, and West Virginia University. The program is funded through grants from the National Science Foundation (NSF), the Camille and Henry Dreyfus Foundation, and the Shell Oil Company Foundation.

As part of CRCD, Notre Dame Professors Joan F. Brennecke, Roger A. Schmitz, Mark A. Stadtherr, and McCready have developed two new courses: “Environmentally Conscious Chemical Process Design” and “Topics on Ecology and the Environment for Chemical Engineers.” “In Topics on Ecology,” said Schmitz, “we examine the effects of human-caused disturbances, such as those resulting from the release of pollutants and other environment-altering activities, on natural processes and food webs.” According to Schmitz, the major components of this course are mathematical modeling and computer simulations. The group is working to integrate aspects of this course into all courses in the chemical engineering curriculum.

In the Environmentally Conscious Chemical Process Design class, the emphasis is on pollution prevention rather than remediation and includes consideration of environmental law as well as new technologies. The course also uses case studies, comparing old and new technologies in the development of solutions. More efficient processes are studied, and the role of mathematical modeling in assessing process effectiveness is being stressed. The reason, according to Stadtherr, is that in order to design a commercial process, chemical engineers need to investigate many different types of operating conditions — including a variety of temperatures, pressures, and solvent ratios. It is not possible to study every individual situation in a laboratory, and this is where mathematical modeling comes in.

Funded by the NSF, the EPA, and the Department of Energy, Stadtherr has developed highly reliable mathematical methods. “Basically,” said Stadtherr, “if we have a set of equations we’re using to model a process, our method allows us to get all the solutions for that particular set of equations ... and from that we will find the right one — meaning the one that is physically as well as mathematically correct.” The standard modeling methods other researchers employ may not be able to find all the solutions for a set of equations, thus they limit their chances of finding the right solution.

Stadtherr has been developing these methods over the past few years, and they have paid off. He and the chemical engineering department have been sharing these methods with other faculty, students, and industrial colleagues.

... in order to design a commercial process, chemical engineers need to investigate many different types of operating conditions ...

The final component of the CRCD program at Notre Dame involves research on the use of supercritical fluids and ionic liquids for extraction and separation processes. Brennecke directs much of the activities in these areas.

A supercritical fluid is a compound that has been heated or pressurized above its critical point, which is the highest temperature and pressure at which its vapor/liquid equilibrium can exist. It fills a container like a gas but has a density more similar to that of liquids. Because they're non-toxic, non-flammable and extremely inexpensive, the two most popular supercritical fluids are carbon dioxide (CO_2) and water.

The key property of supercritical fluids is that, with minimal pressure or temperature changes, their densities change dramatically. "We're interested in the density of supercritical fluids," said Brennecke, "because they can be controlled. And, then, anything depending on the density — like solubility — can also be controlled." The higher the pressure, the higher the density and the more viable a supercritical fluid becomes as an environmentally-benign solvent.

Supercritical fluids are already used in the food industry. Much of the world's coffee and tea is decaffeinated using supercritical CO_2. The process is less expensive and more environmentally-friendly than traditional methods.

One of the CRCD student projects involved comparing the conventional method of extracting soybean oil with an extraction process using supercritical CO_2. In the conventional process, hexane effectively removes the oil — about 20 percent of the bean — but it also removes phospholipids that then have to be washed out. Additionally, hexane causes the unrefined oil to become dark brown, which has to be reversed using yet another process. Hexane is also flammable and volatile, often resulting in landfill fires.

Students found that the oil extracted using supercritical CO_2 was lighter in color and of a higher quality than the hexane-extracted product. And, it contained no phospholipids. There were some disadvantages — the process required very high pressures — but the study gave the students a glimpse of the opportunities offered by using a supercritical fluid.

Other options Brennecke and the CRCD group are studying include using supercritical CO_2 in tandem with ionic liquids. An ionic liquid is a room-temperature organic fluid whose behavior mimics that of a common organic solvent but also behaves electronically like salt. What sets ionic liquids apart from other solvents is that the ions remain fluid over wide temperature ranges. They have very low vapor pressures, making them safe to handle, and they are chemically versatile.

Unfortunately, getting high-boiling point products out of ionic liquids still requires extraction and the use of hazardous solvents. Brennecke and colleague Eric J. Beckman of the University of Pittsburgh discovered that supercritical CO_2 extracts organics from ionic liquids safely. They forced supercritical CO_2 through a solution of naphthalene dissolved in an ionic liquid. The CO_2 pulled out the naphthalene, leaving behind only the ionic liquid. The separation was clean, and both the ionic liquid and the CO_2 were residue-free.

These are just a few examples of the exciting breakthroughs in pollution prevention and remediation that are taking place at Notre Dame. As materials processing techniques and reaction chemistry in supercritical fluids continue to develop ... as more information is uncovered about bacteria/rock/water interactions ... as these engineers continue their quest for solutions to society's needs, it is likely that their research will be translated into commercial applications that benefit mankind without harming the environment.

For more information on pollution prevention efforts in the Department of Chemical Engineering, visit www.nd.edu/~chegdept.

Shown left to right, Professors Mark A. Stadtherr, Joan F. Brennecke, and Keating-Crawford Professor Roger A. Schmitz — along with Mark J. McCready, not shown — spearhead an initiative to integrate aspects of ecology and environmentally-friendly manufacturing processes into courses in the Department of Chemical Engineering.

Center for Nano Science and Technology Established at Notre Dame

The recently established Center for Nano Science and Technology culminated 15 years of faculty research and educational development. Its purpose is to explore the concepts of nanoscience and develop unique engineering applications using nanoprinciples. Led by the College of Engineering's electrical engineering department, the Center is actually a multidisciplinary task force of researchers from several departments throughout the University, which include electrical engineering, computer science and engineering, chemistry and biochemistry, as well as physics.

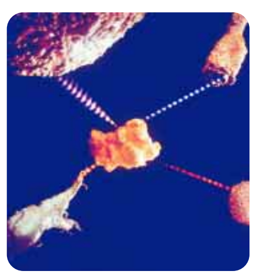
"Nanoscience and technology," says Dr. Gerald J. Iafrate, the Center's director and associate dean for research in the College of Engineering, "offer enormous potential for new applications and industries." Long-term industrial forecasts estimate that the growth of nanotechnology will parallel that of the semiconductor industry. Development of the Center continues the University's leadership in this field. It will help train students for immediate participation in nanoscience and technology, allowing them to be productive and competitive in the markets of the future.

Focusing on nanoelectronics, the study of molecule-sized elements, the Center will integrate research in molecular and semiconductor-based nanostructures, device concepts and modeling, nanofabrication and characterization, and information processing architectures and design to address application goals — such as computing with quantum dots or producing high-speed nano-based circuits. However, the main goal of the Center is to serve as a national resource, a think tank, where technologists from industry can come to explore nanoconcepts for engineering applications. Realization of this goal will benefit students and provide industry with long-range opportunities.

Research in the area of nanoscience is not new to the College or the University. The faculty and staff who comprise the core team of the new Center have received federal research grants in excess of 10 million dollars from the National Science Foundation, the Air Force Office of Scientific Research, the Office of Naval Research, the Army Research Office, and the Defense Advanced Research Projects Agency (DARPA) of the Department of Defense. While nanoscience is a vital and exciting field for the next generation, it is also one of the best examples of a campus-wide effort that involves engineers, physicists, chemists, and computer architects.

AN INDUSTRIAL REVOLUTION ... ONE ATOM AT A TIME

In December 1999 the W.M. Keck Foundation – one of the nation's largest philanthropic organizations focused on supporting medical research, science, and engineering – awarded the University of Notre Dame a $1 million grant for the Center for Nano Science and Technology. The Foundation is not alone in recognizing nanoscience as the basis for an important emerging technology. For example, earlier this year President Clinton asked Congress to almost double the federal government's investment in this area for the coming year – from $270 million to $497 million, representing one of the largest percentage increases in the federal budget. Additionally, in a report subtitled "Shaping the World Atom by Atom," the White House Office of Science and Technology Policy stated that nanotechnology could lead to another industrial revolution. The Center and its multidisciplinary teams will continue to develop the unique capabilities of nanoscience while educating the next generation of leaders in the field.



Nano-based transistors on commercial circuits will one day be measured in nanometers instead of microns. A micron is one millionth of a meter or 1,000 nanometers. Since researchers are projecting the ability to produce transistors as small or smaller than 0.05 microns (50 nanometers), both the right photo, which shows human immune system cells, and the left photo, which shows pollen as seen through a microscope, are larger than the transistor of the future.

Humboldt Foundation Honors Two College of Engineering Faculty

Daniel J. Costello Jr., professor of electrical engineering, and **Mohamed Gad-el-Hak,** professor of aerospace and mechanical engineering, were recently awarded the Alexander von Humboldt Prize, Germany's highest research award for senior American engineers and scientists. Among past winners of this prestigious prize are 31 Nobel laureates. Established in 1953 by the Federal Republic of Germany as an expression of gratitude to the United States for its post-World War II aid, the Humboldt Prize is awarded to no more than 40 scholars each year. It includes 12 months of research support at a German university or one of the Max Planck Institutes.

Daniel J. Costello Jr.

Recognized for his contributions in error control coding related to digital communications, Costello is the third faculty member in the electrical engineering department to have received this honor in the last three years. Ruey-Wen Liu received the Humboldt Prize in 1999, and Anthony N. Michel received it in 1998. Costello will continue his research in error control coding with Dr. Joachim Hagenauer at the Technical University of Munich.

Mohamed Gad-el-Hak

Gad-el-Hak will spend his 12 months in Germany continuing his research in fluid mechanics with an emphasis on the performance of future air and water vehicles, as well as microelectromechanical systems (MEMS) involving fluid motion. He holds a patent for drag reduction for airplanes and underwater vehicles, as well as one for a lift-control device for delta wings. He has also been recently honored with the Japanese Government Research Award for Foreign Scholars and was granted a similar honor by the South Korean Government.

Engineering Student Center Opens

For years engineering students have needed space in the Cushing/Fitzpatrick engineering complex to meet or simply relax between classes. Thanks to the generosity of Charles B. Kitz, an alumnus and member of the College of Engineering's Advisory Council, that space now exists in Room 217 of Cushing Hall.

Room 217 went through many changes before it became the new Student Center. Originally, it was the engineering library. Over the years it was converted to a student center and used primarily as a meeting place and storage facility for different engineering student organizations. Later, Room 217 was needed for office space. Yet, as the College continued to grow, the need for a student area became more pronounced. It was this need that Dean Incropera, Robert Cunningham, director of budget and operations for the College, and the Dean's Student Advisory Council began to address in April 1999. At this time Kitz ('58, mechanical engineering) heard of the project and donated $75,000 for remodeling and development of Room 217, and the work began.

On November 18, the Charles B. Kitz Engineering Student Center was dedicated. Kitz and his wife, Betty, were present for the opening, as were members of the College of Engineering Advisory Council who had begun their annual meeting earlier that morning. Students who attended the dedication expressed their appreciation for the gift, and the facility is now playing an important role in building a strong sense of community among engineering students.

Charles B. Kitz and his wife, Betty, cut the ribbon during the dedication of the new Engineering Student Center.

The Engineering Student Center serves as a meeting place for student groups and a place of relaxation and discussion between classes. Center hours are from 7:00 a.m. through 11:00 p.m. daily.

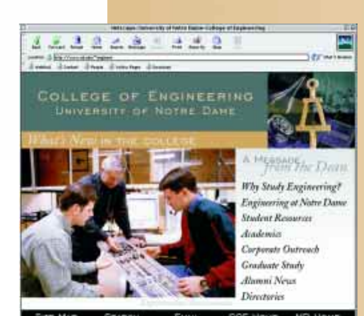
EG111/112 — *Courses for a New Century*

Hands-on engineering ... that's the focus of two courses for first-year students. Prototype versions of the courses EG111 and 112 are currently being offered to 25 first-year engineering intents. This fall all engineering intents, more than 300 students, will participate in these courses.

Stressing a *multidisciplinary, experiential, interactive,* and *collaborative* environment for learning, EG111 and 112 are designed to teach students how to solve engineering problems and understand systems from a multidisciplinary viewpoint. To foster this approach, the courses are taught concurrently by faculty from each of the College's five departments.

Students work in teams to design, build, and test systems. They learn how to use computers in different ways, all in the context of engineering applications. For example, they employ a structured programming language to solve mathematical models that simulate the systems they are studying or designing. The students also learn how to program embedded microprocessors used to control the systems and how the computer may be used to acquire and process data that characterize system performance. And, finally, they learn the importance of effectively documenting and reporting their results.

Through guest lecturers, special projects, and by using computers to solve a variety of practical problems, students are able to explore the different disciplines of engineering and the many fields open to them as engineers. This helps students develop a better appreciation for areas such as biotechnology and biomedical engineering, telecommunications, energy conversion and utilization, computer hardware and software, automotive systems, pollution prevention and environmental remediation, materials processing, aircraft systems,and civil infrastructures. Most important, EG111 and 112 will assist students in making more informed decisions regarding an engineering program of study in order to find the discipline that best meshes with their interests and talents.



NEW WEB FOR COLLEGE OF ENGINEERING

Surfers exploring the College of Engineering web site will find new features throughout the site. Spotlights on laboratories and research, an on-line version of College publications, an alumni link, a current events section – and more – will prove helpful in finding information or contacting College faculty and staff. The address is www.nd.edu/~engineer. The new site will be posted in stages, and users will be able to access all current information, as well as new material that will be added, until the site is completed later this spring.

Industry Day '99

Organized by the Joint Engineering Council and the Society of Women Engineers, the College of Engineering's annual Industry Day again highlighted the mutually beneficial partnership between education and industry. A total of 69 companies participated in this student-run event. While students explored different career opportunities, corporations met a new pool of well-educated potential employees.

Although Industry Day typically starts with a banquet — an informal setting where students and corporate representatives can meet and get to know one another — the main thrust of the event is a career fair. Companies increase their recognition among engineering students, schedule interviews with prospective employees, and discuss internship opportunities.

Through internship programs companies get a qualified summer employee and a good look at a potential full-time candidate. The activity saves them time and money on recruiting efforts while increasing the quality of the applicant pool. Students gain valuable experience and the chance to link what they're learning with how best to use that knowledge. They gain a competitive edge over other engineering students who do not pursue internship opportunities, and they learn how to work in teams, bringing diverse experiences together to find solutions. Many students have started their careers by taking advantage of this annual opportunity.

Christopher Bailey, a mechanical engineering student from East Grand Rapids, Mich., interned at the Tech Center of DaimlerChrysler in Auburn Hills, Mich. After graduation this May, he will begin his career as a vehicle engineer for the company.

The Siemens Competition: Supporting Education in Engineering, Math, and Science

In November 1999 Notre Dame hosted one of the regional sections of the Siemens Westinghouse Science & Technology Competition. A program of the nonprofit Siemens Foundation, the Competition encourages innovation, research, and educational involvement by high school students in the fields of engineering, math, and science.

This year, judges from the College of Engineering and other departments throughout the University awarded one individual and one team prize totalling $50,000. Feng Zhang of Des Moines, Iowa, won the individual regional competition and received a $20,000 scholarship. Seetharam Chadalavada and Melinda Sloma, both of Battle Creek, Mich., won the team competition; they shared a prize of $30,000.

For their originality, creativity, academic excellence, and communications skills, all of the students were recognized at a banquet whose keynote speaker was Leon Lederman, Nobel Prize winner and physicist.

While Notre Dame hosted this regional competition, other participating institutions were Carnegie Mellon University, Georgia Institute of Technology, Massachusetts Institute of Technology, the University of California — Berkeley, and the University of Texas — Austin. Six individual and six team winners presented visual and oral demonstrations of their research projects to a panel of distinguished university faculty members and scientists of national laboratories in Washington, D.C., in December.

The winners included Lisa Harris, a senior high school student from New York City. She won the final individual competition and a $120,000 scholarship for developing a procedure to identify four common carrier genes of Cystic Fibrosis. The identification of these genes could allow doctors to inform individuals of their risks in having a child with Cystic Fibrosis.

Team winners Daniar Hussain of Johnstown, Penn., and Steven Malliaris of Winnetka, Ill., collaborated over the internet to develop their project, which involved original computer programming. These seniors applied Darwin's theory of human evolution — survival of the fittest — to basic computer functions in order to improve methods of data storage and retrieval. The pair will share a $120,000 scholarship.

Nobel Prize winner and physicist Leon Lederman gave the keynote speech during a banquet honoring Notre Dame competition participants.

Feng Zhang won the regional individual prize of the Siemens Westinghouse Science & Technology Competition hosted at Notre Dame in November 1999.

EARTHQUAKE ENGINEERING HITS THE HILL

Senator John D. Rockefeller IV, D-West Virginia, left, was one of the participants in a daylong summit on Capitol Hill in September 1999. Sponsored by The Science Coalition, this event highlighted recent advances made by federally supported research projects at America's colleges and universities. Notre Dame was one of only eight institutions asked to attend. Shown with Lynn Yanyo of the Lord Corporation, middle, and B.F. Spencer Jr., Leo Linbek professor of civil engineering and geological sciences, Rockefeller is experimenting with a tube of magnetorheological (MR) fluid. MR fluid plays a key part in the research Drs. Spencer and Michael K. Sain, Freimann professor of electrical engineering, are conducting in the University's Structural Dynamics & Control Earthquake Engineering Laboratory. The new buffering system they have developed uses MR fluid, acting like a shock absorber, in the protection of structures during natural disasters such as earthquakes and hurricanes.

AEROSPACE AND MECHANICAL ENGINEERING

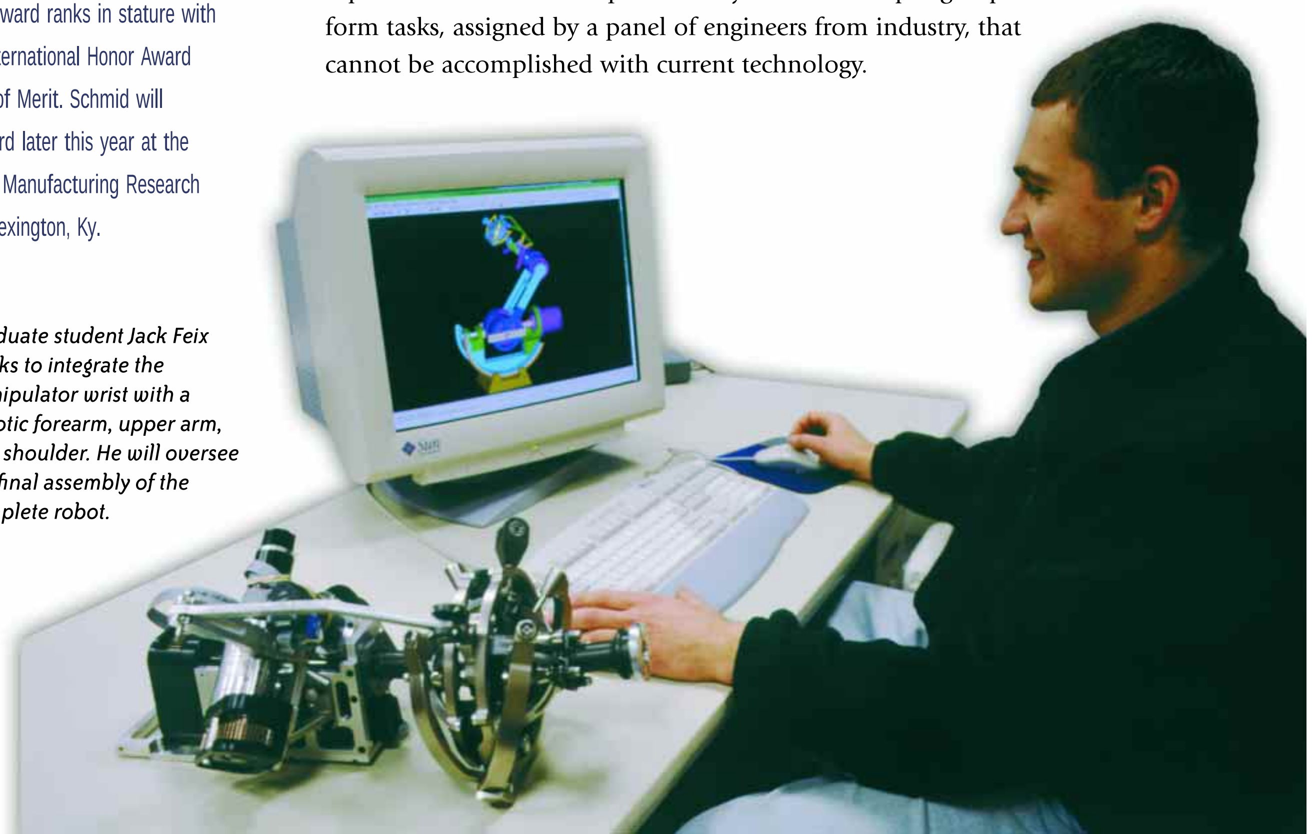
SCHMID NAMED OUTSTANDING YOUNG MANUFACTURING ENGINEER

Steven R. Schmid, associate professor of aerospace and mechanical engineering, was one of nine recipients selected to receive the 2000 John T. Parsons Outstanding Young Manufacturing Engineer Award. Conferred each year by the Society of Manufacturing Engineers in recognition of significant achievements and leadership in the field of manufacturing engineering by young engineers, the award ranks in stature with the Society's International Honor Award and the Award of Merit. Schmid will receive the award later this year at the North American Manufacturing Research Conference in Lexington, Ky.

Steven R. Schmid

Four-course Sequence Introduces New Technology

THE DEVELOPMENT OF A COMPLETE MANIPULATOR, or robot, is part of a National Science Foundation (NSF) grant to the Department of Aerospace and Mechanical Engineering. Provided by the NSF's Combined Research and Curriculum Development Program, the $364,000 grant showcases a new technology and teaches students about the electromechanical aspects of robots. As part of the program, Michael M. Stanisic, associate professor of aerospace and mechanical engineering, has created a four-course sequence that gives senior engineering students and entry-level graduate students hands-on experience with the design and manufacture of manipulators. The sequence also introduces them to a new form of technology — a vision control program known as Camera Space Manipulation, which was developed at Notre Dame by Steven B. Skaar, professor of aerospace and mechanical engineering. To date students have designed and built the wrist of the robot and are currently integrating it with the shoulder, upper arm, and forearm, which they have also created. This spring students will be using the wrist and other parts of the manipulator in the capstone course of the sequence. They will be attempting to perform tasks, assigned by a panel of engineers from industry, that cannot be accomplished with current technology.



Graduate student Jack Feix works to integrate the manipulator wrist with a robotic forearm, upper arm, and shoulder. He will oversee the final assembly of the complete robot.

CHEMICAL ENGINEERING

New Atomic Force Microscope Added to Chemical Engineering

WHILE MANY ELECTROCHEMISTRY LABS list an atomic force microscope as part of their standard operating equipment, most do not have the onboard potentiostat and software that accompanies the piece of equipment found in the Department of Chemical Engineering's Electrochemistry Laboratory. The addition of a potentiostat gives College researchers like Michael M. Crouse, chemical engineering graduate student, and Dr. Albert Miller, professor of chemical engineering, the ability to measure and image nano-sized objects, as well as examine surface reactions while they occur. The ability to run reactions, watch the evolution of the surface, and monitor those reactions in relationship to the surface characteristics is vital to obtaining a better understanding of corrosion and how it can be prevented.

Graduate student Michael M. Crouse prepares the Department of Chemical Engineering's new atomic force microscope for the next round of readings. Although the microscope portion of this machine is standard, the ability to use the onboard potentiostat and associated software is unique.

CIVIL ENGINEERING AND GEOLOGICAL SCIENCES

Rupp Memorial Fund Designated for Development of Field Teaching Laboratory

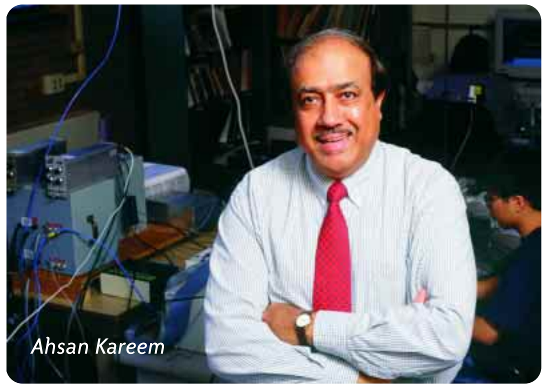
THE FAMILY OF PAUL RUPP JR. has established the Paul Rupp Jr. Endowment for Excellence Fund, which will be used to develop and maintain a field teaching laboratory for the Department of Civil Engineering and Geological Sciences. Located on a site close to campus, the lab will give up to 100 undergraduates the opportunity to gain experience in water treatment and groundwater systems. Lab activities will include remediation technologies, resource management studies, and the study of water supply. In addition, the lab will focus on training students and adult volunteers as part of a developing nations program aimed at treating water supplies in Third-World countries.

Paul Rupp Jr.

Creation of this laboratory provides the University with a unique resource for education on issues related to water supply and pollution control. In the years to come, the Rupp Fund will continue to support undergraduate research activities in the lab, field trips for undergraduates studying hydrology and water supply, and travel to Third-World locations as part of the developing nations program.

Kareem Named Department Chair

PROFESSOR AHSAN KAREEM has been named chair of the Department of Civil Engineering and Geological Sciences. A leading researcher in probabilistic structural dynamics, fluid-structure interactions, structural safety, and the mitigation of natural hazards — specifically earthquakes, waves, and wind — Kareem has been a member of the faculty since 1990.



Ahsan Kareem

In addition to his duties within the department, Kareem will continue to serve as chief editor and associate editor for two major international journals and will remain on the editorial boards of five journals dealing with wind, wave, and earthquake issues.

Throughout his career, he has received numerous honors, including the 1984 Presidential Young Investigator Award from the National Science Foundation and the 1997 Engineering Award from the National Hurricane Conference, in recognition of his contributions to the development of the ASCE7-95 Standard for Minimum Design Loads for Buildings and Other Structures.

SPENCER APPOINTED TO PRESIDENTIAL COUNCIL

B.F. Spencer Jr., Leo Linbeck professor of civil engineering, has been appointed by the White House Office of Science and Technology Policy to serve on a committee conducting an advisory study of U.S.-Japan Science and Technology Relations. Formation of the committee is the result of a 1999 meeting between Japan's Prime Minister Obuchi and President Clinton. Its goal is to define a joint research agenda for the U.S. and Japan for the next decade, one aimed at addressing critical issues, such as natural hazard mitigation, energy, health, environmental protection, new scientific frontiers, the education and improvement of the public's understanding of science, and the ethics and responsibilities of the technological community.

Aftermath of an Earthquake: What an Engineer Sees

A team of 18 engineers — including Notre Dame's **Yahya C. Kurama,** assistant professor of civil engineering and geological sciences, and graduate student Kenneth Farrow — spent a week in Turkey as part of an earthquake reconnaissance squad. During the December 1999 visit, the team obtained structural data from a variety of low to mid-rise reinforced concrete buildings and rated each building's performance. In addition, they searched for surface ruptures along the North Anatolian Fault, performed ground excavations, and toured portions of the Trans-European Motorway viaduct system, which sustained substantial damage during the August and November tremors. The November quake registered 7.2 on the Richter Scale, leaving more than 400 people dead and over 800 injured; its epicenter was located in the town of Duzce, the site of the team's visit. More than 17,000 people were confirmed dead and in excess of 50,000 injured in the August quake. At a magnitude of 7.4, it was the largest temblor to hit the country since 1939.

Teaching a New Robot More Tricks

Matthias Scheutz, visiting assistant professor of computer science and engineering, is "teaching" Trilobot to interact with its environment.

ACCORDING TO MATTHIAS SCHEUTZ, visiting assistant professor of computer science and engineering, robots can be "taught." Currently Trilobot, the 15-pound droid made by Arrick Robotics Inc. of Hurst, Texas, identifies itself during start-up and can perform a few simple tasks. What students in the Computational Models in Cognitive Science class will be working on this spring is writing programs that will give the robot intelligence, using models from behavior-based robotics and cognitive science.

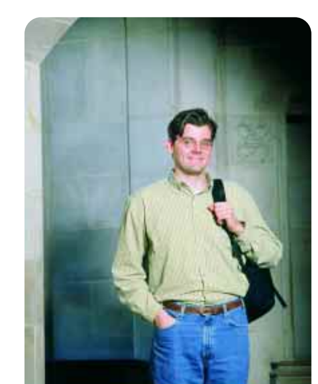
Scheutz and his students, who have taken courses in artificial intelligence and neural networks, will add more sophisticated characteristics to the robot. This will enable the droid to react to various stimuli in its environment. First, they will program simple insect-like intelligence — reflexes, obstacle avoidance, and other movements. Students will then add more complex behaviors — mapping the environment, planning actions, or acting according to preferences. Eventually, the robot will be able to adapt to its environment by using learning methods found in cognitive science. It will mimic animal movements and follow people around the room using an air link, a transmitter/receiver linking the robot to a powerful desktop computer that acts as its brain.

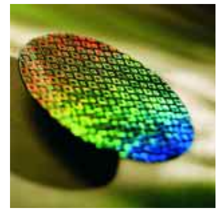
The Computational Models course stresses the interdisciplinary nature of research in cognitive science and computer modeling. It covers how to cope with concrete engineering issues while attending to abstract mathematical models of cognitive functions.

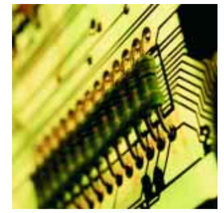
Scheutz believes that in the near future autonomous robots could be "taught" and "teach themselves" to interact with their environments, responding dynamically and carrying out higher cognitive functions like reasoning and planning, to accomplish tasks far beyond mowing the lawn or following a path. In fact, intelligent toys that recognize their owners, can interact using spoken language, and react in seemingly emotional ways, will be the forerunners of more serious robotic agents that will take on the mundane tasks humans perform today.

Student Paper Receives High Honors

When Michael T. Niemier, a graduate student in computer science and engineering, and Michael J. Kontz, currently a senior in computer science and engineering, submitted their paper on design tools titled "A Design of and Design Tools for a Novel Quantum-dot Based Microprocessor," to the student paper competition at the Design Automation Conference (DAC), they were hopeful. Neither were prepared for the response they received. DAC, the premier conference in the world on computer-aided electronic design, informed Niemier and Kontz that not only had their paper won an award, but conference officials wanted Niemier to present the entry in a regular session. "This is outstanding recognition for our students," said Peter Kogge, McCourtney professor of computer science and engineering and Niemier's thesis adviser, "and only a sign of the many things to come from our Center for Nano Science and Technology."







Electrical Engineering Faculty Honored by IEEE

THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS (IEEE), the world's largest technical professional society, selected faculty members Panos J. Antsaklis, Daniel J. Costello Jr., Ruey-Wen Liu, James L. Merz, and Anthony N. Michel as Third Millennium Medal recipients. This honor is bestowed on IEEE members for their outstanding contributions in their respective areas of activity. A non-profit organization, the IEEE is composed of more than 320,000 members who participate in 147 countries. Technical objectives of IEEE focus on advancing the theory and practice of electrical, electronics, and computer engineering and computer science. Additionally, the IEEE promotes the development and application of electrotechnology and allied sciences for the benefit of humanity, the advancement of the profession, and the well-being of its members.

Golden Jubilee Medals were awarded to Yih-Fang Huang, professor and chair of the department, Liu, Michel, and Michael K. Sain. The medal honors IEEE Circuits and Systems Society members who have distinguished themselves in technical leadership and exceptional contributions toward advancing the goals of the Society during its first 50 years.

In addition to receiving a Golden Jubilee Medal, Huang was also named a Distinguished Lecturer for the Society. The Distinguished Lecturer Program was initiated by the Society to serve the needs of its members, particularly those engineers working in industry, by helping them keep in touch with the latest research contributions and the practical applications of those breakthroughs. Huang's invited lecturers will center on adaptive signal processing and its applications to modern communications systems.

GRADUATE STUDENT TAKES FIRST PLACE IN MERRILL LYNCH INNOVATION AWARDS

Top prize in the 1999 Merrill Lynch Innovation Grants was awarded to Islamshah Amlani, a doctoral candidate in electrical engineering. He came to Notre Dame in 1994, under the direction of Drs. Gary H. Bernstein and Gregory L. Snider as part of the nanodevices team investigating quantum-dot cellular automata (QCA), a transistorless approach to computing.

Since coming to the University, Amlani has played a vital role on the QCA team as they developed a single electron sensing scheme to detect movement in a QCA cell, demonstrated the first ever QCA cell and binary line of QCA cells, and demonstrated the first logic gate based on QCA, proving the theory of transistorless computing.

Amlani's winning proposal, "Quantum-dot Cellular Automata: A Transistorless Digital Logic Paradigm," demonstrated the use of the positions of individual electrons in quantum-dot cells to encode binary data. This could help usher in an era of "quantum" computing that offers smaller, faster, and better digital devices.

In 1998 Alexander Balandin, also a graduate student in electrical engineering, placed third in the Innovation Grants for "Artificially Engineered Quantum Solid Materials."

Electrical Engineering Buys a Piece of the Frequency Spectrum for New Wireless Communications Testbed

THE DEPARTMENT OF ELECTRICAL ENGINEERING recently received a major research instrumentation grant from the National Science Foundation for the development of an experimental radio facility and the purchase of related equipment. With this grant faculty members Daniel J. Costello Jr., Oliver Collins, Patrick J. Fay, Thomas E. Fuja, and Yih-Fang Huang are creating a wireless digital communications testbed.

What's unique about the facility is that it already has its own spectral allocation, a slice of spectrum — about 200 kilohertz in the 220 megahertz bandwidth. About a year ago, Collins suggested that the department consider buying a piece of the spectrum for research. What started as Collins' brainstorm became reality as the department, in conjunction with the College and the University, purchased a small section of spectrum from a Federal Communications Commission auction. The frequency band has a three-to-four county range in South Bend and surrounding areas. "This is a very high-frequency band that is difficult to use for commercial applications because of the specialized equipment needed to operate at those frequencies," said Costello, "so it wasn't highly sought after. But, it's ideal for our experiments."

It is extremely unusual for a university to have its own frequency bandwidth. Only a handful of other institutions across the country even have testbeds due to the multiple technologies that come into play to operate a facility of this type. When complete, the Notre Dame testbed will consist of two base stations, a number of mobile units, and an array of supporting test equipment that will facilitate research into the devices and algorithms that make wireless digital communications possible. Graduate students and faculty will be able to examine different ideas concerning signal processing, modulation, and algorithms that relate to transmitting binary code — ones and zeros — in a real setting. Experiments in reliable communications, interference mitigation, and different multiple access methods, as well as the design and fabrication of devices and high-speed circuits for receivers will be studied.

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Based on Tradition

For more than a century, faculty of the **College of Engineering** have nurtured the educational aspirations of thousands of students and, through their research, have contributed much to the generation of new knowledge and technologies. However, we are not about numbers.

Relative to many of our peers, we have a small college, with approximately 700 undergraduate students, 275 graduate students, 95 faculty, and five departments. Hence, we must choose our targets carefully, and what we do must be done well.

We are committed to providing an undergraduate education that is rich in technical content, relevant to the needs of the 21st century, and fosters the growth of moral character and a spirit of service among our students. In our research we must have foci which are linked to important needs and opportunities and prepare our students for leadership in the development and application of new technologies.

Bound for Tomorrow