2006 SUMMARY OF ENGINEERING RESEARCH

A Report of Activities during 2005

This report is part of the larger 2006 Summary of Engineering Research, available on the Web at www.engr.uiuc.edu/research and on CD-ROM. The Summary of Engineering Research represents the extensive engineering research program conducted in 2005 at the University of Illinois at Urbana-Champaign. Detailed statistics about research in the College of Engineering are included in the Directory of Engineering and Engineering Technology Programs and Research, published by the American Society for Engineering Education, Washington, D.C.

How to use the Summary of Engineering Research: Research projects are listed by title, followed by the names of the investigators and the sponsoring agencies. Projects are sorted by major topic areas. Project descriptions are brief. Additional information on each project may be obtained from the investigator in charge (denoted by an asterisk). Mailing addresses are provided on the introductory page.

How to obtain publications: Please consult academic and public libraries for the journal articles, papers, and books listed in this report. Information about technical reports is available from the Engineering Documents Center, Grainger Engineering Library Information Center, 1301 West Springfield Avenue, Urbana, IL 61801, USA. To search the center’s collection on the Internet, please visit the website at search.grainger.uiuc.edu/top. Copies of theses can be found at the University of Illinois Library, www.library.uiuc.edu, or may be purchased from University Microfilms, 300 Zeeb Road, Ann Arbor, MI 48106, USA, www.umi.com.

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Abbreviation key for College of Engineering departments and major labs:

- Advanced Transportation Research and Engineering Laboratory (ATREL)
- Aerospace Engineering (Aerosp. Engr.)
- Agricultural and Biological Engineering (Ag. & Biol. Engr.)
- Bioengineering (Bioengr.)
- Chemical and Biomolecular Engineering (Chem. & Biomol. Engr.)
- Civil and Environmental Engineering (Civil & Environ. Engr.)
- Computer Science (Comput. Sci.)
- Coordinated Science Laboratory (CSL)
- Electrical and Computer Engineering (Elect. & Comput. Engr.)
- Frederick Seitz Materials Research Laboratory (FS-MRL)
- General Engineering (Gen. Engr.) or Industrial & Enterprise Systems Engineering (Indus. & Enter. Syst. Engr.)*
- Materials Science and Engineering (Mat. Sci. & Engr.)
- Mechanical and Industrial Engineering (Mech. & Indus. Engr.) or Mechanical Science and Engineering (Mech. Sci. & Engr.)*
- Micro and Nanotechnology Laboratory (MNTL)
- Nuclear, Plasma, and Radiological Engineering (Nucl., Plasma, & Radiol. Engr.)
- Physics
- Theoretical and Applied Mechanics (Theoret. & Appl. Mech.)*

*In August 2006, the Industrial Engineering program was merged with the General Engineering Department, which became the Industrial and Enterprise Systems Engineering Department. The Theoretical and Applied Mechanics Department merged with the Mechanical and Industrial Engineering Department, which became the Mechanical Science and Engineering Department. Please check department links at www.engr.uiuc.edu for current faculty lists.
Building upon the longstanding strengths of programs in mechanical engineering and in mechanics, the University of Illinois Department of Mechanical Science and Engineering (MechSE) is taking a bold, new approach to research and education that will enable it to address some of the most pressing problems facing the nation and the world. A new paradigm has been created, one that integrates biology, chemistry, applied mathematics and applied physics with mechanical engineering and engineering mechanics disciplines. The result will be leading-edge research that serves some of society’s greatest needs: for clean, affordable and reliable sources of energy; for better methods of disease detection; for more effective identification of threats to national security; for cost-effective and non-polluting modes of transportation; for manufacturing solutions that will facilitate the transition of nanoscale discoveries from the laboratory to the public; and more.

We offer rigorous curricula in engineering mechanics, mechanical engineering and theoretical and applied mechanics. Our graduate curriculum in theoretical and applied mechanics offers core courses in applied mathematics, fluid mechanics and solid mechanics. These courses constitute the backbone of doctoral programs, not only for students of theoretical and applied mechanics, but also for students of mechanical engineering, aerospace engineering and civil engineering. In mechanical engineering, we offer courses in emerging areas, integrating biology and mechanics from the cell to tissue to organ levels, as well as courses in thermal sciences, materials and nano-fabrication. Our undergraduate curriculum offers courses in mechanics that serve students across the College of Engineering, as well as foundational and advanced courses in biomechanics; combustion, propulsion and heat transfer; controls and dynamics; fluid mechanics; manufacturing; MEMS and nanomechanics; and solid mechanics and materials.

More than 85 percent of our faculty members are currently conducting research with federal funding. Our professors are advancing the state of knowledge in relation to the mechanical properties of artificial bone, low temperature combustion, the mechanical signatures of healthy and diseased cells, fuel cells and hydrogen fuel, and flow and mass transport through microfluidic channels, among other things.

MechSE houses two major research centers: a National Science Foundation Nanoscale Science and Engineering Center called the Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems (Nano-CEMMS), that is working to develop a reliable, robust and cost-effective nanomanufacturing system to make nanostructures from multiple materials, which will allow advancements and discoveries in nanoscience to move from the laboratory to production; and The Center of Advanced Materials for Purification of Water with Systems (The WaterCAMPWS), a National Science Foundation Science and Technology Center that is developing revolutionary new materials and systems to purify water safely and economically for the peoples of the U.S. and the world, and to develop the human resources to advance the science and technology of water purification.

We are leading the campus response to the Global Enterprise for Micro-Mechanics and Molecular Medicine (GEM4) initiative and the College of Engineering Center for Intracellular Mechanics. We also are a key participant in the Midwest Structural Science Center and an Air Force Office of Scientific Research Multi-University Research Initiative on Cooperative Networked Control of Dynamical Peer-to-Peer Vehicle Systems. In addition, MechSE houses a Department of Energy Graduate Automotive Technology Education center focused on advanced automotive bio-fuel combustion engines, and four other research centers devoted to research on air conditioning and refrigeration, the continuous casting of steel, fracture control and machine tool systems.

MechSE offers a new approach to education and research that combines theoretical and applied mechanics’ strong tradition of rigorous analysis with mechanical engineering’s longstanding excellence in the practical application of scientific knowledge to solve pressing societal problems. We are proud of the outstanding opportunities we provide to our students and faculty to
make significant contributions in the high technology, research and policy arenas. Explore the website to learn more about MechSE.

Editor's note: This department was the Department of Mechanical and Industrial Engineering during the reporting period. This report reflects the scholarship and research of faculty, students, and staff in the department in 2005.

## Faculty and Their Interests

### Andrew G. Alleyne
Automotive systems, control systems

### Narayan R. Aluru
Bioengineering, computational science and engineering, engineering mechanics, fluid dynamics, nano-, micro-, and meso-technology

### Armand J. Beaudoin
Bioengineering, materials behavior, materials processing

### Joseph Bentsman
Control systems, dynamic systems

### Lawrence A. Bergman
Dynamic systems

### M. Quinn Brewster
Combustion and propulsion, heat transfer

### Richard O. Buckius
Combustion and propulsion, fluid dynamics, heat transfer

### Clark W. Bullard, Emeritus
Energy systems and thermodynamics, environmental engineering, heat transfer

### Sahraoui Chaieb
Bioengineering, computational science and engineering, engineering mechanics, fluid dynamics, materials behavior, nano-, micro-, and meso-technology

### John C. Chatto, Emeritus
Bioengineering, energy systems and thermodynamics, heat transfer

### Xin Chen
Computational science and engineering, operations research, production management

### Thomas F. Conry
Nano-, micro-, and meso-technology, tribology

### Harry Dankowicz
Automotive systems, bioengineering, control systems, dynamic systems, engineering mechanics, nano-, micro-, and meso-technology

### Jonathan A. Dantzig
Computational science and engineering, engineering mechanics, fluid dynamics, heat transfer, materials behavior, materials processing

### Richard E. DeVor, Research Professor
Engineering statistics and quality control, environmental engineering, manufacturing systems, nano-, micro-, and meso-technology

### Geir E. Dullerud
Control systems, dynamic systems

### William E. Dunn
Computational science and engineering, control systems, energy systems and thermodynamics, fluid dynamics, heat transfer

### Placid M. Ferreira
Design methodology and tribology, manufacturing systems, nano-, micro-, and meso-technology, production management

### John G. Georgiadis
Bioengineering, computational science and engineering, energy systems and thermodynamics, fluid dynamics, heat transfer, nano-, micro-, and meso-technology

### Nick G. Glumac
Combustion and propulsion, energy systems and thermodynamics, materials processing

### Pega S. Hrnjak
Energy systems and thermodynamics, fluid dynamics, heat transfer

### K. Jimmy Hsia
Experimental solid mechanics, fracture, micromechanics, plasticity

### Elizabeth Hsiao-Wecksler
Bioengineering, control systems, dynamic systems, engineering mechanics

### Yonggang Huang
Computational science and engineering, engineering mechanics, materials behavior, nano-, micro-, and meso-technology
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<td>Shiv G. Kapoor</td>
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<td>Diego Klabjan</td>
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<td>Herman Krier</td>
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<td>Dimitrios Kyritsis</td>
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<td>Chia-Fon Lee</td>
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<td>Chang Liu</td>
<td>Microfabrication, microfluidics, MEMS for nanotechnology (M4N), nano-, micro-, and meso-technology, sensors, wireless networks</td>
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<td>Thomas J. Mackin</td>
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<td>Prashant G. Mehta</td>
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<td>Norman R. Miller, Emeritus</td>
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<td>Arne J. Pearlstein</td>
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<td>Andreas A. Polycarpou</td>
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<td>M. Taher A. Saif</td>
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<td>Huseyin Sehitoglu</td>
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<td>Uday V. Shanbhag</td>
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<td>Mark A. Shannon</td>
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Automotive Systems

Integrated Vehicle Dynamics
A. G. Alleyne*
University of Illinois at Urbana-Champaign; Ford Motor Co.

Presently, components of the vehicle act independently of one another to control various aspects of the vehicle's dynamics. In this research, the dynamics of a moving vehicle are controlled by coordinating and integrating the various subsystems of the chassis. Wheel torque, steering forces, and suspension forces are combined in a synergistic approach to achieve levels of vehicle performance and safety that are superior to previous approaches. Extensive use of modern control techniques is made to determine the optimal combination of forces.

Experimental Investigation of the Effect of Electrostatic Fields on Electrically Charged Sprays of Liquid Fuels at Elevated Pressure and Temperature
D. C. Kyritsis,* E. K. Anderson
American Chemical Society

A focused experimental investigation of the use of electrostatic fields in order to achieve controllable fuel distribution in the high-pressure, high-temperature environments, which are typical in the combustion chambers of power generating devices, is performed. Since, in principle, charge and mass are two independent quantities, there is the attractive possibility of accurate fuel distribution control through electrostatic fields. The charged sprays of gasoline and diesel fuel are set up in a test chamber of controlled temperature and pressure and are probed with laser diagnostics. The effect of the electric field on droplet size and dispersion is investigated with phase Doppler anemometry. Distributions of liquid fuel and fuel vapor are measured with laser induced fluorescence techniques. We will control the intensity of ambient turbulence to investigate how electrostatic steering will interact with the inertia of the ambient gas. Also, we will record the levels of voltage and electric power, which will be necessary for a substantial effect on the fluid dynamics in order to determine whether the application of these ideas is a significant departure from current industrial practice. The results can lead to the realization of the thermodynamic advantages of stratified combustion, which have never been applied reliably with classical injection schemes.

* Denotes principal investigator.
Design and Investigation of an Optically Accessible Diesel Reformer for Fuel Cells
C. F. Lee,* A. T. Edwin, C. H. Wu
University of Illinois at Urbana-Champaign; Argonne National Laboratory

Fuel cells provide attractive energy efficiency and low pollution emissions, but their use is prohibited by the limited distribution network of hydrogen. The advantage for on-board reforming of diesel fuels is that it provides highest volumetric and gravimetric densities for hydrogen. However, the optimization of the diesel reformer requires detailed information of the in-cylinder spatial gas composition of the reformer. Modeling and laser diagnostics can provide the needed information. Therefore, the optical access into the interior of the reformer is required. A reformer and its accessories will be designed and constructed to simulate an existing reformer with an optically transparent injection zone window, heated intakes, and heated catalyst regions. Laser diagnostics and numerical calculations will then be conducted to evaluate and optimize the reformer operation.

Design, Modeling, and Experiments of Homogeneous Charge Compression Ignition Engines
C. F. Lee,* Y. Xu, T. Fang, R. C. Wang
Grainger Emerging Technologies Grant

Homogeneous Charge Compression Ignition (HCCI) engines, in which a lean mixture ignites at numerous locations in the cylinder under piston compression, should largely eliminate NOx and particulate emissions when compared with conventional spark-ignition and diesel engines. Under part-load conditions, HCCI engines will increase fuel efficiency and reduce emissions but would shift to other ignition schemes at full load. The major technical challenges of HCCI operation are the control of combustion phasing and the reduction of unburned hydrocarbon and carbon monoxide emissions. This requires detailed knowledge of in-cylinder spray evaporation, fuel/air mixture formation, and combustion processes. Innovative laser diagnostics experiments will be combined with state-of-the-art computer modeling to devise strategies for optimizing and controlling HCCI engine performance and reducing emissions over the speed-load range of interest in applications.

Diesel Spray Visualization in a Constant Volume Injection Bomb
C. F. Lee,* Y. Xu
Caterpillar, Inc.

A constant volume injection bomb simulating the cylinder of large-bore diesel engines has been developed with excellent optical access for studies of a Caterpillar diesel injector. Optical access consists of an end window view of the full bore and a large cylinder ring window. The Hydraulic Electronic Unit Injector allows for the easy adjustment of injection duration and pressure with variation in injector pulse width and hydraulic oil pressure. The effects of injection pressure, injection duration, and gas density on the sprays are studied using laser diagnostic and visualization techniques.

Fuel/Air Mixing and Combustion in a High-Speed Direct-Injection Diesel
C. F. Lee,* R. A. White,* R. E. Coverdill,* T. Fang,
W. S. Mathews

The objective of the proposed work is to provide detailed information on the mixing and combustion processes in a small-bore HSDI engine through in-cylinder measurements of fuel spray penetration, mixing, and interaction with the bowl geometry using exciplex planar laser-induced fluorescence; ignition and combustion using natural flame emission; and soot formation using laser-induced incandescence as a function of engine operating conditions. The experiments will be conducted on a single cylinder research engine based on the Ford Diata modified for optical access using a Bowditch piston arrangement.

Graduate Automotive Technology Education (GATE) Centers of Excellence: Advanced Automotive Biofuel Combustion Engines
C. F. Lee,* A. C. Hansen,* D. C. Kyritsis*
U.S. Department of Energy, DE-FG26-05NT42621

The GATE Center of Excellence will provide comprehensive advanced training in issues related to automotive combustion of biofuels and will address both the mechanical and biological aspects of this emerging technology. A uniquely constructed set of graduate course offerings will provide an integrated biofuel combustion training to students of varying backgrounds. In parallel, research activities will leverage available faculty expertise and research resources since groups approaching the issue from entirely different perspectives will collaborate synergistically. The educational experience will be complemented by industrial research collaborations and internships that will expose the students to relevant industrial problems. The combination of strong mechanical and agricultural/biological expertise, as well as the obvious relevance of issues relating to the status of agricultural economy and the environment to the interests of young engineers from our broad geographic area, will allow us to

* Denotes principal investigator.
organize an effective collaboration between established researches and motivated young students that will provide thrust to an emerging environmentally friendly technology.

**Investigation of Alternative Fuels for the Emission Reduction of Diesel Engines Using In-Cylinder Laser Diagnostics**

C. F. Lee,* C. J. Mueller (Sandia Natl. Lab.); G. C. Martin  
* Sandia National Laboratories, SNL-19316

Interest in alternative fuels for diesel engines has grown in recent years due to their ability to reduce regulated pollutant emissions, displace foreign oil imports, and provide an environmentally friendly, renewable energy source. Many alternative fuels have physical, chemical, and combustion characteristics that are significantly different from those of traditional diesel fuel. The effects of these fuel-property changes on in-cylinder processes will be investigated using in-cylinder laser diagnostics. The primary goal is to determine the most important mechanisms by which alternative fuels can reduce soot and NOx emissions while maintaining high cycle efficiency.

**Investigation of Biodiesel Fueled Engines under Low-Temperature Combustion Strategies**

C. F. Lee,* A. C. Hansen,* V. L. Stringer, J. P. McCrady, J. R. Beasley  
* U.S. Department of Energy, DE-FG26-05NT42634

Biodiesel has been found to be a very promising alternative to petroleum diesel; however, its utilization has been limited to some extent by its higher NOx emissions relative to petroleum diesel in traditional direct injection (DI) diesel engines. Low temperature combustion (LTC) engines, on the other hand, have the potential to dramatically reduce NOx emissions while keeping similar fuel efficiency as DI diesel engines. This project will investigate how to use biodiesel in LTC engines and improve the fuel efficiency and reduce the exhaust emissions of the engines. The objective is to provide detailed information on the performance and emissions of biodiesel in LTC engines through computational modeling, experimental investigation of biodiesel in a metal engine running in HCCI mode, and visualization of combustion process, soot evolution process, and NO formation using laser diagnostics. It will also improve the understanding of the fundamental mechanisms of biodiesel combustion in LTC engines, such as fuel-air mixing, low-temperature ignition, and combustion chemistry process.

* Denotes principal investigator.
processes of the bubbles. The impact of the bubble dynamics on the injector flow will also be studied.

**Optical Investigation of Low Temperature Combustion and Emission Formation in a Large-Bore High-Speed Diesel Engine**
C. F. Lee,* R. P. Buchanan, W. L. Cheng
Ford Motor Co.

In order to meet the more stringent emission legislations of the future, a huge step has to be taken regarding the feed gas emissions of the diesel engine. New combustion concepts, such low-temperature combustion or HCCI (Homogeneous Charge Compression Ignition), show the highest potential. In order to apply those new technologies, more knowledge about the physical and chemical processes in those combustion regimes has to be developed. This project will focus on laser diagnostic and high-speed imaging measurements of fuel/air mixing, of combustion process, and of NO and soot formation in a large-bore HSDI (high-speed direct-injection) diesel engine to help determine the fundamental mechanisms at work in reducing NOx and soot emissions as engine design and operating conditions are changed. This information will be used to compare with, and to support the further development of, computational modeling efforts currently under way at Ford, with the ultimate goal of providing the physical insight needed to optimize large-bore HSDI diesel engine design parameters for minimum emissions.

**Simulation of Spray Formation, Fuel Impingement, and Film Vaporization in Gasoline Direct Injection Engines**
C. F. Lee,* A. T. Edwin
National Science Foundation, CTS-0204773

Gasoline direct injection (GDI) engines offer the potential for a significant reduction in fuel consumption. However, with this improved fuel efficiency, increased fuel impingement leads to film formation on the piston top as well as the cylinder walls, indicating a potential for emissions problems. This engine study examines use of the air-assisted injector as a means of reducing impingement in GDI engines. The effects of this spray-guided strategy on film formation and vaporization are compared with the current production swirl atomizer.

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**Bioengineering**

**Experimental Studies of the Flow within a Pediatric Ventricular Assist Device**
K. T. Christensen,* I. A. Cestari,* M. Muramatsu, E. Ferrara (Univ. Sao Paulo, Brazil)
Sao Paulo State Foundation; University of Illinois

Cardiac transplantation is a well-established treatment option for patients with heart failure, and ventricular assist devices (VADs) serve a vital role as a bridge to transplantation. However, the design of pediatric and neonatal VADs is complicated by the small dimensions of the devices and higher beating frequencies that can increase the occurrence of thrombosis and hemolysis. Prototype pediatric and neonatal VADs have been designed at the University of Sao Paulo, and a parameter-space study of the flow within these devices is being pursued using PIV. The goal is to identify flow behavior that can lead to thrombosis and hemolysis.

**Thermal Studies in Bioengineering**
J. C. Chato*
University of Illinois at Urbana-Champaign

Various aspects of thermal behavior of biological materials and systems, particularly the human body, are studied. The work ranges from morphological studies of the blood vessels that affect heat transfer to computer modeling of various organs as well as the entire thermoregulatory system. Typical applications are the prediction of the deep-body temperature in a hot bath, estimation of the maximum safe touch temperature of a heated surface, and thermal treatment of toenail fungus.

**Bone Fluid Flow**
J. A. Dantzig*
University of Illinois at Urbana-Champaign

We investigate the flow of fluids through bone under the action of applied loads. The objective is to better understand the transport of nutrients and the role of microstructure in bone remodeling.

**Bio-Inspired Active Membranes and Transepidermal Water and Ion Transport**
J. G. Georgiadis,* C. V. Falkenberg, L. G. Raguin
University of Illinois at Urbana-Champaign; National Science Foundation, CTS-0120978; Coordenação de Aperfeiçoamento de Pessoal de Nivel Superior (CAPES), Brazil

Driven by a parallel effort to develop synthetic ion gates and pumps, as well as the study of heat and mass transfer

* Denotes principal investigator.
through human skin, we are developing a model and a perm-selective membrane system with extended barrier functionality. The model accounts for the redistribution of water and active ion transport through a general poroelastic medium. The modeling effort is complemented by MRI experiments.

Compact MRI-Optical Scanners
J. G. Georgiadis,* D. Morris* (Natl. Instit. of Health), L. G. Raguin
University of Illinois at Urbana-Champaign; National Institutes of Health

Recent advances in miniaturization have allowed the design and fabrication of dual modality imaging systems combining magnetic resonance imaging (MRI) and standard systems using visible light. We have designed a compact MRI scanner based on a permanent magnet and millimeter-size radio frequency coils. The bore of the scanner allows optical access without degrading MRI resolution significantly. The miniature MRI scanner is positioned under the objective of a modified scanning confocal microscope. The setup allows the simultaneous imaging of a submillimeter focal volume by both instruments. This apparatus is motivated by applications in the areas of histopathology and tissue engineering.

Dynamic Hemodynamic Response and fMRI Signal
J. G. Georgiadis,* S. Honecker, L. G. Raguin
Defense Advanced Research Agency; University of Illinois at Urbana-Champaign

This is a joint experimental and numerical investigation of the hydrodynamic basis of the BOLD signal during functional MRI scanning of the brain. The first phase involves fabricating an elastomeric perfusion phantom that mimics the arterio-venous topology of the visual cortex. The second phase involves the solution of the inverse problem of localizing the injection site of a paramagnetic agent in the perfused phantom, which will ultimately elucidate the connection between the hemodynamic response and the fMRI BOLD signal.

Fast, High-Resolution Magnetic Resonance Angiography
J. G. Georgiadis,* D. Morris* (Natl. Instit. of Health), L. G. Raguin
University of Illinois at Urbana-Champaign; National Institutes of Health

This is a comprehensive investigation of Fourier, non-Fourier, and q-space magnetic resonance imaging sequences for the quantification of blood perfusion in the microvasculature system. Validation of the new sequences is pursued via attendant phantom experiments.

Biologically Inspired Acoustic Direction Finding for Soldiers
E. T. Hsiao-Wecksl,* A. Terrinoni* (Antek, Inc.)
U.S. Army Research Office, W911NF-04-C-0095

The objective of this project is to develop a system to increase the situational awareness of soldiers wearing either fully encapsulating "Objective Force Warrior" helmets or the current Kevlar helmets. Encapsulation of the soldier's head modifies the auditory cues, which provide information about the dynamically changing acoustical environment. This project will develop a hearing restoration system to restore near-natural listening ability of the soldier without compromising the ballistic, nuclear, biological, and chemical protection provided by the helmet.

Biomechanical Analysis of Aggressive Inline Skating: Landing and Balance on Grind Rail
E. T. Hsiao-Wecksl,* A. Beaudoin,* P. Kurath
University of Illinois at Urbana-Champaign

Aggressive in-line skating is a sport that emphasizes balance. A popular activity is grinding, where the skater jumps onto a grind rail—which may be a specially designed structure at a skate park, or a common handrail on a staircase. In grinding, skaters jump up and accurately place their skates on the rail, smoothly decelerate, and balance upon the rail while sliding (or "riding it out"). In-line skaters have developed a heuristic approach to training. Inherent to their training are exercises that emphasize the development of muscle control during eccentric, muscle-stretching contractions to smoothly decelerate the body. For example, before performing a grind, the skater would repeatedly jump upon an object and "stall"—that is, jump, place skates on the rail, decelerate, and hold that position. Our main focus is in the prevention of complete loss of balance, falls, and injury in the event of impact with the ground. In this novel study, we will collect data on limb motion and forces developed during deceleration activities, such as grinding and stalling. By performing controlled jumping and balancing experiments, this project allows us to gain insight into how these individuals are able to use eccentric contraction to assist with maintaining balance and, perhaps, minimizing impact force and energy.
Effect of Tai Chi on Balance and Movement Strategies  
E. T. Hsiao-Wecksler,* K. S. Rosengren  
* University of Illinois at Urbana-Champaign  

Tai Chi has been promoted to older adults as an exercise to improve physical and mental fitness. It has also been found to reduce the likelihood of falling in senior citizens. This project explores how Tai Chi experience may modify postural control mechanisms and movement strategies specifically during unexpected external perturbations to balance and while walking over level ground and obstacles. We are also investigating new techniques for assessing Tai Chi skill proficiency. Dynamic systems modeling, control theory, and movement analysis are used to examine these issues. We are conducting both cross-sectional studies on individuals with long-term Tai Chi experience (>2 years) and longitudinal studies on older adults who receive Tai Chi training for five months.

Gait Analysis of Labrador Retrievers with Cranial Cruciate Ligament Deficiency  
E. T. Hsiao-Wecksler,* D. J. Griffon,* G. J. Pijanowski  
* University of Illinois at Urbana-Champaign; American Veterinary Medical Association  

Cranial cruciate ligament (CCL) rupture is one of the most common injuries to the canine hind knee and is the leading cause of degenerative changes in that joint. Stress injuries are believed to result from a combination of conformation characteristics within the entire limb, resulting in a biomechanical imbalance between forces acting on the cranial tibial thrust. However, the exact role of each of these factors and their significance in relationship with CCL deficiency has not been defined. The objective of the current study is to examine whether there are distinct differences in the kinematics and kinetics of gait in healthy and injured Labrador retrievers. To perform the gait analysis, we are collecting motion data that will be augmented with segment parameter data derived from CT and radiographic images of each animal’s limb. Our long-term goal is to develop a mathematical model integrating a combination of morphometric parameters to estimate the risk of developing CCL deficiency in each dog.

Optimization-Based Inverse Dynamics to Reduce Errors in Estimated Joint Torques  
E. T. Hsiao-Wecksler,* X. Zhang  
* University of Illinois at Urbana-Champaign  

Inverse dynamics is a powerful tool for the biomechanical analysis of human movement, and is commonly used to calculate the net torques generated in various limb joints. Despite the widespread use of this method, past research has shown that the errors in joint torque calculations are relatively large. These errors are attributed to inaccuracies in the input variables of the inverse dynamics equations. We have determined that the primary contributor is inaccuracy in the measured motion (e.g., segment angle profiles), and the secondary contributors include inaccuracies in estimations of body segment parameters (i.e., mass, center of mass location, moment of inertia). To improve the accuracy of inverse dynamics estimations, it is necessary to find techniques to reduce the effects of these error sources. We propose the development of an optimization-based approach that can accommodate errors due to both measured motion and body segment parameters. The development of the optimization-based approach will include several studies. The proposed approach has the potential to change the way joint torque estimations are made, and will lead to better clinical and research tools for the analysis of human movement.

Postural Control during Mild Impulsive Perturbations  
E. T. Hsiao-Wecksler*  
* University of Illinois at Urbana-Champaign  

Investigating how individuals respond to disturbances to balance is essential to improving our understanding of the etiology of falls. Balance and postural control mechanisms during perturbed stance may change with age. These differences may manifest themselves in the behavioral characteristics of the postural response noted immediately after a perturbation. We are particularly interested in the response of the postural control system after a transient perturbation. Limited work has been done to explore postural responses to sudden, impulse-like perturbations. In this investigation, the impulse loading and impulse response control-theory paradigm will be used to examine the postural response to a mild, quick-release backward tug. While impulse response and its associated characteristics are rudimentary concepts in engineering control theory, we have only just begun to extend this paradigm to investigate postural control. The purpose of this study is to learn more about how to characterize responses to a transient perturbation, what these responses tell us about the postural control system in general, and how these responses may vary with age.

Postural Responses to Affective Pictures  
E. T. Hsiao-Wecksler,* C. H. Hillman,* E. Verona*  
* University of Illinois at Urbana-Champaign  

The purpose of this project is to extend our understanding of emotional states to behavior as measured through postural sway. In this study, we use an emotion-eliciting pictures strategy, which is a known measure of the behavioral set, to examine postural response, particularly

* Denotes principal investigator.
whole-body movement. The goal is to examine approach and avoidance behavior as measured by participants' tendency to move their bodies toward or away from the stimuli.

Quantification of Asymmetries in Gait Using Shape Analysis and Multivariate Statistical Techniques
E. T. Hsiao-Wecksler,* J. D. Polk, K. S. Rosengren, S. Hong
University of Illinois at Urbana-Champaign; Mary Jane Neer Research Fund

Acute lower limb injury may lead to chronic gait problems or even disability due to asymmetry between the injured and uninjured limb. Current clinical gait analysis techniques used for diagnosis and rehabilitation are qualitative in nature and do not quantitatively assess recovery. The overall goal of this project is to develop quantitative techniques to assist in the treatment and monitoring of lower limb injury and asymmetry. Gait is a dynamic behavior with considerable changes in joint and body positions throughout the gait cycle. We are developing a novel technique, integrated multivariate gait analysis (IMGA), to distinguish asymmetry in gait and identify the source of asymmetry. IMGA uses geometric shape analysis (generalized procrustes analysis) with multivariate statistical techniques (principal components analysis) to capture the dynamic nature of walking behavior that current univariate measures cannot capture.

Tracking Falls and Fall-Related Events Throughout the Lifespan
E. T. Hsiao-Wecksler,* K. S. Rosengren*
University of Illinois at Urbana-Champaign Initiative on Aging

Much of the research related to falls in older adults has used retrospective self-reports of falls over the previous six months or year. We are developing a prospective slips, trips, and falls survey (STAF inventory) to better establish the incident rate of falls and fall-related behaviors. This survey evaluates the number of fall-related incidents as well as the environmental conditions, individual factors, and whether any injuries have occurred over a given study period. Falls and fall-related events are being tracked for a period of 30 days. The STAF inventory is being administered to college-aged, middle-aged, and older adults.

Variations in Balance and Postural Control Throughout Pregnancy and up to Six Months Postpartum
E. T. Hsiao-Wecksler*
University of Illinois at Urbana-Champaign

Pregnant women anecdotally state that balance changes as pregnancy progresses and the circumference of the trunk and body weight increase. However, no studies have examined how balance, and postural control that moderates balance, may vary throughout pregnancy and the subsequent postpartum period. This study will assess how balance and postural control may vary as a consequence of pregnancy by examining how a subject's postural sway varies over the nine-month pregnancy and a following six-month postpartum period.

BioMEMS-Based Microinstrumentation for In Situ Quantitative Investigations of Adhesion, Cell Structural Mechanics, and Mechanotransduction of Single Living Cells and Embryos
M. T. A. Saif,* S. Yang
National Science Foundation, ECS 0118003

There is increasing experimental evidence suggesting that extracellular and intracellular mechanical forces have a profound influence on a wide range of cell behavior, such as growth, differentiation, apoptosis, gene expression, adhesion, and signal transduction. It is thus important to understand how the external mechanical forces are transmitted into the cell and what corresponding molecular changes they initiate. In this project, we develop a class of bioMEMS-based sensors and actuators for biological investigations such as cell adhesion at a cellular and subcellular level in biohabitats where the environmental conditions—biochemical, electromagnetic, and ambient temperature—are controlled.

Mechano-Stimulation of Skin Cells
University of Illinois at Urbana-Champaign

Skin is a mechanically compliant organ that routinely undergoes large strains during normal physiological function. Several important questions on the 3-D cellular architecture and intercellular connectivity of the epidermis, composed primarily of keratinocytes that need answers include: the effect of mechanical strain on the formation, maturation, number density, and placement of desmosomes and hemidesmosomes; the effect of strain on the gap junction intercellular communication complex that regulates the equilibrium between keratinocyte growth

* Denotes principal investigator.
and differentiation; and the effect of local three-dimensional topography on the formation of a stratified squamous epithelium during keratinocyte culture on mechanical compliance. This project utilizes cell culture on microfabricated structures to measure the stress and strain within keratinocytes during different stages of development and the formation of mechanical junctions between cells.

**Mechanical Behavior of Bone Scaffolds with Multiscale Porosity: Effects of Ingrown Tissue and In Vivo Degradation**  
A. J. Wagoner Johnson,* R. Jamison, M. Wheeler, S. Clark  
*University of Illinois Research Board*

The objective of the research is to quantify the effects of *in vivo* degradation and tissue ingrowth on the mechanical behavior of hydroxyapatite (HA) tissue engineering scaffolds considered for load bearing applications. These scaffolds are unique in that they contain tailored multiscale porosity, the significance of which has not been adequately described. The insights gained from this research will advance the clinical utility of HA scaffolds for load bearing applications by quantifying the rates of tissue ingrowth and scaffold degradation; characterizing the three dimensional tissue distribution and HA degradation patterns; quantifying the effects of ingrowth and degradation on the mechanical properties; and characterizing the damage mechanisms following ingrowth and degradation. Results will not only strongly influence the design and fabrication of next-generation scaffolds, but will also provide guidelines for clinical rehabilitation for recovering patients.

**Nondestructive 3-D Imaging of Tissue/Scaffold Composites Using Microcomputed Tomography**  
A. J. Wagoner Johnson*  
*University of Illinois Research Board; Argonne National Laboratory*

Hydroxyapatite (HA) bone scaffolds are being developed to replace allograft and autograft bone, for which the risk of disease or other complications is significant. The tissue integration process must be carefully characterized. While several techniques are employed for full characterization, including scanning electron microscopy and histology, all are destructive in nature and can only represent the cellular activity in two dimensions. Furthermore, sample preparation for histology is time consuming and labor intensive. For this study, a nondestructive technique called x-ray microcomputed tomography is used to characterize cell and tissue distribution patterns in HA scaffolds with a resolution up to 5 mm. Scaffolds were seeded with cells and cultured for times between one day and four weeks. Cells and tissue were stained with osmium, which attenuates x-rays more than the HA and allows them to be distinguished. Cells can be mapped in three dimensions after one day. By three weeks, tissue covering the scaffold and in the interior can be imaged. Data are viewed as "slices" in cross-section or as a three-dimensional object using ANALYZE software.

**Biomechanical Energy Conversion Technology for Future Marine Corps Operations**  
*Office of Naval Research*

This interdisciplinary research aims to harvest the biomechanical energy produced by natural human bodily movement, in the most efficient and least perturbing manner, and then to convert it into an electrical form for portable use. It will be carried out through a unique collaboration of power electronic and biomechanics expertise. Potential applications of this research include mobile communications and electronics as well as portable performance data log devices.

**Effects of Shoulder, Low Back, or Knee Strength Degradation on Motion Control Strategies and Injury Risk during Manual Materials Handling**  
X. Zhang,* D. Bartlett, K. Li  
*National Institutes of Health; Center for Disease Control and Prevention*

The general objective of this research is to systematically investigate whether and how strength degradation in three major body joints—the shoulder, low back, and knee—affects the movement strategies and injury risk associated with the performance of manual materials handling. Our long-term goal is to develop quantitative tools and guidelines that integrate movement and strength information for the recognition, prediction, and prevention of musculoskeletal injuries. A successful completion of this project will lead to motion-based evaluation of muscle strength degradation for proactive ergonomics intervention, return-to-work assessment, and rehabilitative ergonomics implementation; guidelines and computerized simulation models for designing consumer products or workplaces to better accommodate special populations with compromised strength capabilities; and a better understanding of how muscle strength influences the motion control strategies and consequently the injury risk during manual materials handling tasks in specific and human movements in general.

* Denotes principal investigator.
Generating Extreme Speed and Force from Small, Simple Materials: Biologically Inspired Models from Striking Ability in Trap-Jaw Ants
X. Zhang,* A. Suarez (Entomol.), A. Vakis
Beckman Institute for Advanced Science and Technology
This collaborative research initiative seeks to study the extreme force and motion production abilities of trap-jaw ants and to understand and model the underlying principles. These principles are intended to inspire the design of novel mechanisms or devices that can generate, store, and release large amounts of force with relatively small, simple materials or organisms.

Combustion and Propulsion

Aluminum Agglomeration in Solid Propellant Combustion
M. Q. Brewster,* J. Mullen
U.S. Department of Energy Center for Simulation of Advanced Rockets, B341494
Agglomeration of aluminum at the burning surface of composite solid propellants is an important phenomenon that influences performance of the rocket. Observations of this behavior and measurements of agglomerate size are needed for validation and calibration of predictive models that are being developed. These observations need to be done under carefully controlled conditions; typical composite propellant conditions involve too much spatial inhomogeneity and time variability. In this study, a technique based on two-dimensional laminate propellants that has been successfully used for studying flame structure in nonaluminized propellants is extended to alumized propellants. The center fuel (pure binder or oxygenated binder) layer is loaded with aluminum and sandwiched between two outer oxidizer layers of ammonium perchlorate. Imaging (uv and ir) is used to observe agglomeration behavior and agglomerate size at the burning surface.

Radiative Properties of Burning Aluminum Droplets
M. Q. Brewster,* J. Harrison
U.S. Department of Energy Center for Simulation of Advanced Rockets, B341494
 Burning aluminum droplets are a significant source of thermal radiation in aluminized solid rocket motors for transferring heat to the burning solid propellant surface and inert surfaces such as insulators. As part of large-scale, integrated simulations of internal flows in solid rocket motors, it is important to be able to simulate thermal radiation heat transfer. Yet there is no proven, reliable understanding of the radiative properties of these burning aluminum droplets. The goal of this project is to develop a better understanding and model of burning aluminum droplet thermal radiation using experiments and modeling.

Simulation and Validation of Internal Rocket Motor Ballistics Using Space Shuttle RSRM Propellant
M. Q. Brewster,* W. C. Ross
U.S. Department of Energy Center for Simulation of Advanced Rockets, B341494
This project uses the RocBallist integrated code of the Center for Simulation of Advanced Rockets (CSAR) to investigate internal flow in solid rocket motors typical of the space shuttle reusable solid rocket motor (RSRM). The goal is to simulate the full 120-second burn of the RSRM motor.

Three-Dimensional Simulation of Solid Rocket Motor Grain Burnback and Internal Flowfield Modeling
M. Q. Brewster,* D. S. Stewart,* K. C. Tang, S. H. Yoo
brewster@uiuc.edu
U.S. Department of Energy Center for Simulation of Advanced Rockets, B341494
The burnback of a solid rocket motor propellant grain is simulated computationally in three-dimensional space. A new algorithm based on level-sets for propagating surfaces in 3-D space, called WaveTracker, is implemented. Coupling of solid propellant combustion (burning surface motion) to chamber gas dynamics is included to simulate ballistic performance of the rocket motor.

Combustion of Aluminum and Aluminum Hydride
H. Krier,* N. Glumac, T. Bazyn
U.S. Office of Naval Research, N00014-01-1-0899
Using a high-pressure shock tube to generate intense temperatures, we measure the combustion rates and temperatures of aluminum, boron, and aluminum hydride in atmospheres that closely simulate the environment in a solid rocket motor. Advanced spectroscopic techniques are used to probe the environment surrounding these burning particles in order to generate benchmark chemistry data that can be used to validate next-generation combustion models.

Modeling of Ultrafine Aluminum Particle Combustion
H. Krier,* N. Glumac, S. P. Vanka, K. Aita
U.S. Department of Energy Center for Simulation of Advanced Rockets, B341494
As aluminum particles become finer, burning rates and ignition times decrease, resulting in attractive burning behavior in solid rocket motors. Unfortunately, while such

* Denotes principal investigator.
particles can be manufactured, current models cannot accurately predict their behavior. For fine particles, the combustion becomes rate limited, and the quasi-steady approximation does not apply, leading to dramatically different burning behavior. This study will develop a model to predict the flame structure and combustion characteristics of ultrafine metal particles in solid rocket motor environments.

**Reactive Metals in Shaped Charge Applications**

H. Krier,* N. Glumac,* J. Felts  
*U.S. Office of Naval Research, N00014-03-1-0778*

There exists some experimental evidence that the use of reactive metal liners in underwater shaped charge devices can lead to enhanced energy release, resulting in greater penetration and/or target damage. This study is designed to examine the fundamental combustion processes that occur in hypersonic metal jets emanating from a shaped charge explosive as they traverse a water medium. This study uses the shock tube to investigate fundamental reaction rates of metal in water, as well as a powder gun facility with a 1.3 km/s capability.

**Solid Rocket Motor Aluminum Burning Models**

H. Krier*  
*U.S. Department of Energy Center for Simulation of Advanced Rockets, B341494*

This research is focused on developing quasi-steady burning rate models for both pure aluminum and agglomerated aluminum droplets produced from metalized solid propellants. Chemical kinetics for various propellant gas oxidizers must be considered. Models will be compared to data available in ongoing research at the University of Illinois at Urbana-Champaign.

**Experimental Investigation of Reactive Flows around Catalytically Coated Microcylinders**

D. C. Kyritsis,* K. Bijjula  
*National Science Foundation; University of Illinois Research Board*

An experimental investigation of the reactive, combusting flow around catalytically coated, small-scale cylinders in the regime of intermediate Peclet and Damköhler numbers of relevance to compact, autonomous power generation is performed. Early, device-oriented efforts in the regime of micropower generation have indicated the possibility for drastic miniaturization of catalytic reactors through the insertion of grids of microwires in the flow of reactants. However, the fundamental reasons for which this is possible have not been determined. Our objective is to probe experimentally the fundamentals of this flow using laser diagnostics as our tool. The hypothesis we will check is that, for medium Peclet numbers, thick thermal boundary layers develop around the microcylinders that induce chemistry in the gaseous phase, facilitating in this manner reactant conversion through a synergy of surface and gaseous reactions.

**Reactive Fluid Mechanics of Mesoscale Hydrocarbon-Based Power Generation**

D. C. Kyritsis,* S. A. Smyth  
*National Science Foundation (CAREER Award)*

Miniaturization to impressively small dimensional scales has already been demonstrated in information storage, electronics, manufacturing, and recently, micro-electromechanical systems (MEMS). However, development of equivalent small-scale power sources seems to be lagging in this quest for systems miniaturization. Currently available, grid-independent power sources are predominantly chemical batteries, which are devices of notoriously limited power density. Exploiting the high power density of hydrocarbons in "liquid fuel batteries" could increase drastically the autonomy of portable power sources and provide a substantial degree of independence of human activity from centralized grids. This research is a comprehensive experimental and theoretical investigation of the regime of reactive fluid mechanics that is relevant for mesoscale, hydrocarbon-based power generation. Using a combination of gaseous phase and surface experimental techniques, we investigate the flow elements that will be the "building blocks" of mesoscale burners, such as the flat plate boundary layer, the flow around a cylinder, as well as the flow around arrays of cylindrical and flat elements and through mesoscale channels. These flows are studied in the regime of intermediate Reynolds, Peclet, and Damköhler numbers that is relevant for small-scale power generation and where several usual approximations are not valid. A particular emphasis is placed on flows over catalytically coated surfaces, since the relatively small combustion temperatures desired in battery-size applications make catalysis a necessary prerequisite for stability. Laser-based techniques, gas analysis, as well as infrared techniques are the main experimental tools. Based on the experimental results, a refinement of early theoretical analyses of these flows, which relied on uniform surface temperature and infinite rates of surface reactions, is pursued.

* Denotes principal investigator.
Development of the Forward Illumination Light Extinction (FILE) Time-Resolved, 2-D Soot Measurement Technique
C. F. Lee,* Y. Xu
Grainger Emerging Technologies Grant
A new forward illumination light extinction (FILE) soot measurement technique was developed with the capability of obtaining 2-D time-resolved quantitative soot volume fractions in a single combustion event. By using a high-speed camera and a point light source, this technique can achieve a 2-D soot concentration measurement with only one window when studying confined combustion. Line of sight quantitative soot volume fraction is obtained by calculating the reflected light intensity with or without the presence of soot cloud. The technique was verified using measurement of the axisymmetric ethylene diffusion flame. The technique is under testing for various combustion systems.

Effects of Oxygenate in Diesel Fuel on Spray Structure, Combustion, and Emissions
C. F. Lee,* Y. Xu
Argonne National Laboratory, ANL-1F-01341; BP-Amoco; Caterpillar, Inc.
A promising solution for emission reduction being investigated is to blend oxygenates into diesel fuels in an effort to improve the in-cylinder combustion characteristics and thus reduce the NOX and particulate matter (PM) levels. Diesel combustion is generally characterized by three main processes: spray formation, droplet evaporation, and burning of the fuel/air mixture. A fundamental understanding of these processes will be developed through the experiment and modeling of droplets, sprays, and engines in order to determine the effectiveness and value of blending oxygenates into diesel fuel as a means to achieve the requisite NOX and PM levels.

Investigation of Low-Temperature Combustion in an Optically Accessible Diesel Engine
C. F. Lee,* T. Fang
Sandia National Laboratories, SNL-19316
Low-temperature combustion is a method to achieve homogeneous charge compression ignition in diesel engines. Late injection timing combined with high swirl ratio, high exhaust gas recirculation, and high injection pressure result in more homogeneous charge than conventional diesel engines and lower combustion temperature. This kind of combustion mode is also called MK (modulated kinetics) combustion. It offers great potentials in reduction of NOx and smoke emissions from diesel engines while still keeping the high thermal efficiency of diesel engines. The fundamental mechanism behind the lower temperature combustion will be investigated using laser diagnostics.

Numerical Investigation of the Effect of Increased Acceleration on Film Boiling and Film Vaporization
C. F. Lee,* R. K. Kapadia, W. L. Cheng
University of Illinois at Urbana-Champaign
Engine-out HC emissions resulting from liquid fuel, which escapes from the combustion process, give the motivation for researchers to better understand the film vaporization in a combustion chamber. Previous works theorized that the removal of liquid fuel from the combustion cycle was a result of the film boiling regime of the film boiling curve, otherwise known as the Leidenfrost phenomenon. The objective of this work is to develop a robust film boiling model, which incorporated the effects of increased acceleration on film boiling and, consequently, on film vaporization at high temperatures.

Two-Photon Fluorescence Detection of Nitric Oxide
C. F. Lee,* C. J. Mueller* (Sandia Natl. Lab.), G. C. Martin
Sandia National Laboratories, SNL-19316
As engine nitric oxide (NO) emissions are reduced, the sensitivity of laser-induced fluorescence (LIF) techniques must be improved to help understand how new modes of combustion work to enable these reductions. A two-photon LIF technique will be developed to overcome some of the difficulties of single-photon techniques, including the rejection of scattered laser light, fluorescence from other species including fuel, and the strong absorption of the excitation laser by combustion products in diesel engines. The two-photon technique will be verified in a flow cell and over a flat flame burner. This technique will subsequently be applied to diesel engine combustion measurements.

Computational Science and Engineering
Transport and Phase Behavior of Binary Fluids in Porous Media
J. G. Georgiadis,* A. Kalinichev (Geol.), D. C. Karampinos
NSF Center of Advanced Materials for the Purification of Water with Systems (CAMPWS), CTS-0120978
As an integral part of the computational activity under the auspices of the Center of Advanced Materials for the Purification of Water with Systems (CAMPWS), a
National Science Foundation Science and Technology Center, the project combines expertise in *ab initio*, Monte Carlo, molecular dynamics, and Lattice-Boltzmann methods. The common objective is to investigate hydrogen bonding in aqueous solutions, solute hydration and diffusion, ion cluster formation, phase separation, absorption, and electrokinesis in water-gas-salt systems in the bulk or near separation membranes or functionalized solid substrates.

**Time Zooming Strategies for Rocket Simulation**
D. S. Stewart,* M. Q. Brewster,* P. Battacharjee, S. Yoo, K. C. Tang, D. S. Stafford
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*Center for Simulation of Advanced Rockets, DOE-ASCI Center*

Work was carried out to accelerate simulation of stable configurations in rocket simulations. Asymptotics was used to develop a series of reduced models, and time integration strategies from computational aerodynamics was used to accelerate convergence to the steady state of realistic interior solid rocket motor cavity flow. Steady Euler solver techniques are being implemented in two-dimensional test geometries.

**Tools for Understanding Transients in Explosive Systems**
D. S. Stewart,* S. Yoo, J. Saenz, J. Park
dss@uiuc.edu
*U.S. Air Force Research Laboratory, Munitions Directorate, Eglin Air Force Base, Florida*

Work continued to developed advanced simulation tools for characterization of unsteady effects regarding condensed explosive systems, especially related to miniaturization. Special attention was paid to level-set methods used for simulation of front motion and material interface representations in multimaterial simulation. Experiments are being carried out at Eglin Air Force Base to confirm existing theories and simulations.

**Automatic Mesh Generation Algorithm for Hybrid Meshes**
D. A. Tortorelli,* B. Rangan
*University of Illinois*

We have developed an automatic mesh generation algorithm for the generation of hybrid meshes of quadrilateral and triangular elements using spatially based trees. The algorithm interfaces with the geometric modeler by means of specific functions that help to isolate the modeling and meshing modules. The algorithm is capable of handling multiple interfaces and embedded bodies. The resulting nonconforming mesh can be used in a discontinuous Galerkin solver.

**Control Systems**

**Advanced Dynamic Modeling and Control of Air Conditioning and Refrigeration Systems**
A. Alleyne,* M. Keir, B. Eldredge
28 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation

This project develops a dynamic simulation-modeling environment that is suitable for closed loop control of stationary and mobile a/c and refrigeration systems. The focus is on controlling quasi-steady transitions between operating states, instead of startup and shutdown transients, by modulating flow rates of both air and refrigerant. It builds upon previous models by making more extensive use of physical parameters, based on results from other research projects. The model development is supported by a parallel set of experiments conducted in a flexible test facility.

**Control of Fluid Power Systems**
A. G. Alleyne,* P. Gupta, B. Hencey, B. Edler, B. Morgan
*University of Illinois at Urbana-Champaign; National Science Foundation; Caterpillar, Inc.; U.S. Army Research Office*

The modeling and control of fluid power systems includes electrical, mechanical, hydraulic, and pneumatic subsystems. Various types of advanced controllers are applied to these complex nonlinear systems. Applications of these systems range from automotive engine systems to earth-moving vehicles to high-speed machine tool drives.

**Control of Nonlinear Systems**
A. G. Alleyne*
*University of Illinois at Urbana-Champaign*

The control of various nonlinear mechanical and electromechanical devices is studied. The techniques applied vary from standard linearization (Jacobian) to gain scheduling to nonlinear transformations (feedback linearization). The structure of the particular systems being controlled is exploited to facilitate control. The application of this is directed to the control of various mechanical systems.

* Denotes principal investigator.
Control of Systems in a Dimensionless Framework
A. G. Alleyne,* Y. Li, B. Morgan
*University of Illinois Research Board; National Science Foundation

This project examines the benefits of using dimensionless system representations for control system design. Dimensionless system representations afford benefits for parameter identification as well as dynamic uncertainty representation. These benefits translate into better adaptive control and robust control designs. Current investigations examine engineered systems, such as vehicles, as well as individual subsystems and components.

Integrated Chassis Control for Vehicles
A. G. Alleyne
*University of Illinois at Urbana-Champaign

Presently, components of the vehicle act independently of one another to control various aspects of the vehicle's dynamics. In this research, the dynamics of a moving vehicle are controlled by coordinating and integrating the various subsystems of the chassis. ABS braking systems, traction control systems, lateral stability control systems, 4-wheel drive (4WD), and controllable suspensions (active or semiactive) are combined in a synergistic approach to achieve higher levels of vehicle performance. The benefits of this approach are increased vehicle performance and safety.

Microscale Robotic Deposition
A. Alleyne,* P. M. Ferreira,* J. Lewis, D. Bristow, K. Barton, D. Mukhopadhyay, D. Hoelzle
*National Science Foundation, DMI-0140466

The objective is to develop new materials systems, manufacturing systems, control, and planning algorithms required for microscale robotic deposition (m-RD) of colloidal gels. An integrated approach will be directed toward the fabrication of 3-D periodic structures (feature sizes less than 10 mm) required for emerging photonic applications. Such novel structures provide the optical analogues to semiconductor materials at length scales relevant for optical communication and computing technologies.

Nano-CEMMS Systems Integration Testbeds for the Micro- and Macroscale
A. G. Alleyne,* P. M. Ferreira, M. Tharayil, K. Barton, R. Khanapure
*National Science Foundation, Nanoscale Science and Engineering Center, DMI-0328162

This work relates to the Center for Nanoscale Chemical-Electrical- Mechanical Manufacturing Systems (Nano-CEMMS) Center. We are developing systems integration tools and testbeds for rapidly identifying potential bottlenecks in the confluence of different core technologies associated with our nanoscale manufacturing efforts. The tangible results of this project will be the development of the earliest testbeds that are representative of the fully functional Nano-CEMMS system as it is currently envisioned. Additionally, this project will be able to provide systems-level planning and guidelines for the development of the overall research plan. The ability to provide planning input will grow throughout the project as better knowledge and understanding of the overall systems-level issues are developed.

X-by-Wireless Feedback Control of Coordinated Systems
A. Alleyne,* P. Kawka
*University of Illinois at Urbana-Champaign

The goals of this project are twofold. First, the project will examine direct feedback control of individual systems via wireless connections. This is fundamentally different from previous and current wireless investigations whereby command sequences are communicated to the system while the actual device-level control takes place "on-board." Second, this project will investigate the coordination of multiple wireless users acting together to perform a controlled action. The separate users will be able to develop a connection and coordinated control strategy that will be transparent to users being added or removed as long as there are sufficient agents to perform the task.

Hierarchical and Reconfigurable Schemes for Distributed Control over Heterogeneous Networks
*National Science Foundation, ITR 0085917

The research project deals with issues arising in controlling geographically distributed complex real-time systems over a heterogeneous communication network. It is aimed at developing the foundations of network-based control, from theory to applications. The overall objectives are the following: the design, analysis, implementation, and performance characterization of hierarchical and heterogeneous distributed control algorithms and middleware that are affected through hierarchical heterogeneous networks comprised of wired and wireless subnets; and specification and implementation of network services and support required for the development and

* Denotes principal investigator.
deployment of distributed control algorithms over hierarchical heterogeneous networks.

**Active Sensing Approach to Output-Based Control of Nonsmooth Dynamical Systems with Controlled Singularities**

J. Bentsman,* K. Zheng, J. Kim, B. Miller, E. Rubinovich  
*Denotes principal investigator.*

*National Science Foundation, CMS-0324630*

This project focuses on developing a mathematical framework for active sensing in systems with controlled singularities and applying it to power systems and high-performance electromechanical drives.

**Active Singularity Approach to Control of Nonsmooth Mechanical and Electromechanical Systems Using Wavelet-Based and Impulsive Control Methods**

J. Bentsman,* K. Zhang, B. Miller, E. Rubinovich  
*Denotes principal investigator.*

*National Science Foundation, CMS-0000458*

The goals of the project are to develop a mathematical framework for representing control actions and system motions during the singularity motion phase and combining them with regular motion phase; develop high-speed time-localized estimation and identification procedures that utilize nonsmooth data as well as feedback control laws applicable to singular and regular motion phases; and apply the technique developed to the high-speed fault clearing in power networks and impact motion control in electromechanical systems.

**Adaptive Control and Identification of Distributed Parameter Systems**

J. Bentsman,* J. Kim  
*Denotes principal investigator.*

*National Science Foundation, CMS-0324630; Electric Power Research Institute, EP-P93624722*

A large number of processes require infinite dimensional state space for their adequate descriptions. The application of regular finite-dimensional adaptive control algorithms to such processes might result in poor convergence properties and inadequate performance of adaptive controllers. The purpose of this research is to explore the methods of improving controller adaptation capabilities and identification methods for systems described by partial differential and functional equations.

**Biomorphic Flow-Sensor-Based Schooling Locomotion for Energy-Efficient Adaptive Sensor Networks**

J. Bentsman,* S. D. Kelly, C. Liu, Q.-D. Kim  
*Denotes principal investigator.*

*National Science Foundation, CMS-032463; ECS-05-01407*

The project goal is to create actively reconfigurable mobile platforms for environmental samplings and military reconnaissance.

**Control of Uncertain Time-Varying Systems Based on Robust Predictive Control Technique and Localized Time-Frequency Concepts**

J. Bentsman,* K. Zheng, J. Kim  
*Denotes principal investigator.*

*National Science Foundation, CMS-0000458*

The project focuses on the development of robust controllers for time-varying systems with uncertainties. The specific application is the control of startup and shutdown and transient dynamics of a boiler turbine power generation unit.

**Control-Oriented Modeling, Identification, and Controller Synthesis for Electrical Motors and Nonsmooth Electromechanical Systems**

J. Bentsman,* K. Zhang  
*Denotes principal investigator.*

*Grainger Center for Electromechanics; National Science Foundation, CMS-0000458; CMS-03-24630; University of Illinois Research Board*

The work proposed will focus on development of wavelet-based and ARMA model tools and methodologies for the real-time identification of the time-varying/nonlinear electrical motor and hybrid/impulsive electromechanical system dynamics; development of robust predictive self-tuning control laws for control of electromechanical systems; and investigation of nonsmooth dynamics in electromechanical systems and development of hybrid/impulsive control laws for active control of nonsmooth system behavior.

**Discrete-Time Polynomial Controller Synthesis**

J. Bentsman,* K. Zheng  
*Denotes principal investigator.*

*National Science Foundation, CMS-0324630; Electric Power Research Institute, EP-P9362/C4722 and EP-P15596/C7752*

A novel polynomial analytical and computational technique is being created that permits minimal order numerically efficient $H_2$ and $H_{\infty}$ controller synthesis using direct Diophantine equation decomposition.
Modeling and Identification of EMF-Induced Transitions in Lipids
J. Bentsman,* I. Dardynskaia, O. Shadyro, P. G. Glushonok
National Science Foundation, CMS-0000458
The project goal is to develop dynamic models of EMF-induced changes in lipids and lipid-modeling substances. Equations of chemical kinetics and stochastic H-infinity identification are used as the basic tools.

Robust Controller Design for Power Plant and Its Implementation on the Actual Boiler/Turbine Unit
J. Bentsman,* K. Zheng
Electric Power Research Institute, EP-P93624722, EP-P15596/C7752
The goal of this project is to design an H-infinity controller for a coal-fired power plant, test it on an EPRI simulator, and compare its performance with existing control laws.

Self-Tuning Robust Control of Multi-Input/Multi-Output Nonlinear Processes
J. Bentsman,* K. Zheng
Electric Power Research Institute, EP-P93624722, EP-P15596/C7752
This project is focused on combining recently developed H∞ predictive control techniques with the H∞ predictive identification to synthesize robust controllers for several classes of MIMO uncertain nonlinear systems. The application is currently focused on the stream generation processes in the industrial and utility boilers.

Cooperative Networked Control of Dynamical Peer-to-Peer Vehicle Systems
U.S. Air Force Office of Scientific Research; Defense Advanced Research Projects, Multidisciplinary Research Programs of the University Research Initiative, F49620-02-1-0325
The proliferation of computing and wireless communication technology has opened up tremendous possibilities for deploying large cooperative networks of smart vehicles to perform intricate and complex missions. It is evident that collaborative teams of aerial and ground vehicles can perform a plethora of highly beneficial tasks for achieving military objectives and civilian security. The major objective of our consortium is the development of a rigorous theoretical foundation, and scalable analytical tools and paradigms, so that systems can be systematically constructed and their performance formally verified. More generally, the activity of this program can be expected to have a dramatic impact on understanding and designing large-scale, robust, real-time distributed systems. Our goals are to make use of recent algorithmic developments to provide hard performance guarantees and bounds for systems performing sophisticated tasks in uncertain and dynamic physical situations.

Suppression of Catastrophic Loss of Stability of Low-Velocity Impacting Motions
H. Dankowicz*
Royal Institute of Technology, Sweden
The goal of this research plan is to design passive and active control strategies to suppress the discontinuity-driven catastrophic loss of stability of recurrent motions in a mechanical system that occurs due to low-velocity collisional contact with its environment. Specifically, passive and active changes in the system parameters characterizing the collisional discontinuities will be exploited to prevent a global transition to high-velocity impacting motions associated with increased noise production, fatigue failure, and derailment of tracked vehicles. The scientific merit of this research will be exemplified by applying the methodology to suppressing high-velocity impacting motions in an experimental model of a vehicle suspension.

Geometric Mechanics and Biomorphic Locomotion in Fluids
S. D. Kelly*
University of Illinois at Urbana-Champaign
Biomorphic robotic systems offer advantages over conventional autonomous vehicles in energy efficiency, agility, adaptability, and stealth. Biomorphic designs for underwater and aerial vehicles are particularly promising in these respects, but the superior performance of biological systems often reflects their ability to exploit complex dynamic phenomena in subtle ways. This project endeavors to realize reduced-order nonlinear models for the interaction of deformable bodies and vortical flows using contemporary techniques from Lagrangian and Hamiltonian mechanics and to develop tools for assessing and exploiting the controllability of such systems. Of particular interest are robotic systems that develop liftlike forces through periodic change in shape, the optimization of interactions among arrays of such systems, and the use
of vehicle-mounted flow sensors in the feedback control of agile maneuvers.

Architectures for Secure and Robust Distributed Infrastructures
S. Lall* (Stanford Univ.); C. Beck (Gen. Engr.);
S. Boyd (Stanford Univ.);
J. Doyle (California Technical Univ.); G. E. Dullerud;
C. Hadjicostis (Elect. & Comput. Engr.); B. Lesieutre,
M. Medard (MIT); B. Prabhakar (Stanford Univ.);
R. Srikant (Gen. Engr.); C. Tomlin (Stanford Univ.);
G. Verghese (MIT); V. Vladimerou; D. King
U.S. Air Force Office of Scientific Research,
F49620-01-1-0365

The major barrier constraining the successful management and design of large-scale distributed infrastructures is the conspicuous lack of knowledge about their dynamical features and behaviors. Until very recently, analysis of systems has primarily relied on the use of nondynamical models. These traditional approaches have enjoyed considerable success while systems are run in predominantly cooperative and “friendly” environments and provided that their performance boundaries are not approached. With the current proliferation of applications using and relying on such infrastructures, these infrastructures are becoming increasingly stressed, and the incentives for malicious attacks are heightening.

Chemical Management Services in Small and Medium Enterprises
T. Lindsey*
U.S. Environmental Protection Agency Region IV

This project includes three tasks as follows. The first involves working directly with small and medium enterprises (SMEs) to perform on-site chemical management assessments. During the assessments, total chemical-related costs and "headaches" will be determined in order to clearly demonstrate both the economic and operational value of pollution prevention and chemical management. In addition, SME managers will be surveyed to identify barriers to chemical management. The second component of the project involves working directly with chemical management suppliers. A supplier "working group" will be established and utilized to review and summarize information on SME management barriers, current economic barriers, and technology barriers that prevent chemical management diffusion in SMEs. The third component brings SMEs and chemical management suppliers together to resolve remaining barriers and initiate pilot projects that can be tested in SME facilities.

Ionic Liquids as Solvent, Catalyst, and Catalytic Support: Chemical Agent Decontamination and Detoxification
B. Nelson, T. Lindsey*
U.S. Department of Defense

This project will research the practical application of ionic liquids in the decontamination and detoxification of chemical agents. The goal of this effort is to create a new series of reagents that capture the best attributes of room temperature ionic liquids toward contaminant solubility and detoxification for the U.S. Army. In particular, formations of superior cleaning agents that catalyze chemical reaction will be developed. Such a series of cleaning agents would have immediate use in chemical detoxification and decontamination of a wide range of contaminants of importance to the Department of Defense (DoD).

GOALI: Online Dynamic Control of Cooling in Continuous Casting of Thin Steel Slabs
B. G. Thomas,* J. Bentsman,* Y. Meng, K. Zheng,
S. Vapalahti, J. Kim, A. Behera
National Science Foundation, GOALI DMI 05-00453 and
CMS 032463; Continuous Casting Consortium
(Accumold, Huron Park, Canada; Algoma Steel, Sault Ste.
Marie, Canada; Corus Strip Products, Ijmuiden,
Netherlands; Fundacion Labein, Bilbao, Spain; Mittal
Riverdale Steel, Riverdale, Ill.; LWB Refractories, York,
Pa.; Nucor Steel, Decatur, Ala.; POSTECH, Pohang,
South Korea; Steel Dynamics, Columbia City, Ind.)

Temperature variations during cooling cause quality problems such as cracks, especially under transient conditions such as those caused by changes in casting speed. Setting the spray water flow rates to maintain optimal temperature profiles during process changes becomes increasingly difficult when the casting speeds are high and response times must be fast. This project aims to develop a fundamentally based online system to dynamically control the water flow rates in order to continuously optimize and stabilize cooling conditions in the thin slab casting process. The system will use control laws for PDEs with moving boundary conditions, incorporating both online measurements of mold heat removal and a high-speed finite-difference model of heat conduction and solidification as a software sensor.

* Denotes principal investigator.
Design Methodology and Tribology

Controlled Tribological Experiments up to 2,000 psi (13.8 MPa) in a CO₂ Atmosphere
A. A. Polycarpou,* N. G. Demas
28 Company Consortium: Air Conditioning and Refrigeration Center

The Tribology Laboratory has acquired an ultra-high-pressure tribometer (UHPT) capable of tribological testing in CO₂ environment that is representative of realistic operating conditions (pressures and temperatures) in an air conditioning compressor, providing an enclosed atmosphere of up to 2,000 psi. This will permit the testing of material pairs in sliding contact under a range of contact pressures, temperatures, and speeds at the contact interface under a range of environmental pressures appropriate to CO₂ and other refrigerants. In this project, we will use the UHPT to further advance the tribological CO₂ studies, specifically, to study the wear, friction, and scuffing behavior of sliding surfaces in a CO₂ atmosphere with different lubricants.

Friction and Wear Studies of Reciprocating Compressor Surfaces
A. A. Polycarpou,* M. Cannaday
Arcelik S. A. Istanbul, Turkey

The main objective of this study is to experimentally investigate the friction and wear of tribomaterials used for reciprocating compressor surfaces under fully flooded and mixed lubrication conditions in a controlled environment that simulates application conditions. A high-pressure tribometer is used for the tests. It provides independent control of normal load, speed, temperature, pressure, and oil/refrigerant mixture supply rate at the interface.

Tribology of Coatings for Oil-Less Compressors
A. A. Polycarpou,* T. Solzak
28 Company Consortium: Air Conditioning and Refrigeration Center

The majority of compressor surfaces that experience tribological contact are metallic surfaces that may also contain some type of surface treatment and coatings. The focus of past research has been on compressor reliability with the replacement of CFC by HFC refrigerants. In modern compressors, the design engineer is forced to make design changes, such as smaller clearances and stringent operating conditions that place interfaces under severe operating conditions and possibly in the absence of lubrication. However, under such severe operating conditions, “bare” or “untreated” materials will be unlikely to succeed. Under such “dry” (oil-less) compressor conditions, one cannot simply rely on oxide formation and other surface reaction layers alone, and some kind of controlled surface hardening or hard coating will be required. In this research, we will perform experiments using different treated and coated materials in the presence of different refrigerants, sliding velocities, and temperatures typical to compressor surfaces.

Tripot Constant Velocity (CV) Joint Internal Friction Characterization
A. A. Polycarpou,* C. H. Lee
Delphi Automotive Systems

Constant velocity (CV) joints are an integral part of vehicles, significantly affecting steering, suspension, and vehicle vibration comfort levels. CV joints provide coupling forces and moments between connected substructures, as well as localized damping dissipation. In this research, we will experimentally and analytically investigate the internal friction in CV joints, with emphasis on CV tripot joints. Specifically, we propose to construct an instrumented CV joint test rig capable of testing actual CV joints to study their detailed internal friction and wear characteristics. Also, we propose to model the internal CV joint friction, and correlate experimental results with the proposed model. Lastly, design criteria will be established, linking CV joint design parameters, such as geometry and roughness to friction, wear, and performance in general.

Ultra-High-Pressure Tribometer for Tribological Studies of CO₂ Refrigerant
A. A. Polycarpou,* N. Demas
28 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation

This project will compare the effects of POE and PAG lubricants in a CO₂ refrigerant/lubricant mixture at several pressures up to the UHPT capacity (to be purchased separately) of 2000 psig. The results at 200 psig in the UHPT will be compared to the 200 psig results for a CO₂ refrigerant/lubricant mixture in the current HPT (as a baseline comparison with previous work) on the friction, lubrication, wear, and scuffing properties of various tribological pairs that may be used in compressors. The new UHPT order will be placed with a known tribometer manufacturer, and delivery will be taken in the first year. Upon receiving the UHPT, shakedown runs will commence and test protocols will be developed. After that phase of the project is completed, a formal testing and analysis program will commence.

* Denotes principal investigator.
Reliability-Based Topology Optimization
D. A. Tortorelli,* M. Silva
*Caterpillar, Inc.

Topology optimization modifies a structure to minimize its weight while simultaneously satisfying constraints on its maximum allowable stress, etc. These modifications consist of changes in the shape of the structure as well as the generation of interior holes. In our research, we are modifying existing topology optimization algorithms to design structures that are subjected to random loadings. As such, our constraints will be related to the probability that a maximum allowable stress, etc. is exceeded.

Topology Optimization and the Fictitious Domain Method
D. A. Tortorelli,* R. B. Haber* (Theoret. & Appl. Mech.); M. P. Bendsoe* (Technical Univ. of Denmark); J. Norato
National Science Foundation; ITR

Topology optimization of structures to design for (e.g., minimum weight subject to a compliance constraint) has become an area of rapidly increasing interest during the past decade. Here we take a novel approach by introducing a distinct geometry model that is projected onto a fixed domain. In this way, the structural analysis is simplified as it is performed on a fixed mesh using the fictitious domain finite element method, and the optimization is simplified by reducing the number of design parameters.

Dynamic Systems

Floor and Facility Vibration Mitigation Using Passive and Hybrid Nonlinear Energy Sinks
L. A. Bergman (Aerospace Engr.);* A. F. Vakakis,* D. M. McFarland (Aerospace Engr.);* M. Wise, F. Nucera (Univ. of Reggio Calabria)
National Science Foundation, NSF CMS 03-24433

This project explores the use of a novel nonlinear energy sink (NES) in a passive or hybrid isolation and control system in order to mitigate floor and facility vibrations. Recent investigations have verified that the presence of one or more essentially nonlinear oscillators coupled to a linear subsystem can induce the phenomenon of energy pumping from the linear to the nonlinear system. More specifically, transient vibrations in the directly excited linear system were shown, under certain conditions, to be transmitted out of the linear system and into the nonlinear one in a one-way, irreversible fashion. This energy pumping phenomenon was found to be robust and quite rapid, making it an excellent candidate for an efficient vibration mitigation system. The work proposed herein would investigate the application of this nonlinear energy sink concept to vibration isolation and control in large scale structures subjected to shock and vibration, studying various strategies for passive and/or hybrid isolation, quantifying its performance, and exploring new approaches for improving energy transfer.

A New Concept for LCO Suppression Based on Nonlinear Energy Pumping
L. A. Bergman,* D. M. McFarland (Aerospace Engr.);* A. F. Vakakis,* Y. S. Lee, G. Kerschen (Univ. of Liege)
lbergman@uiuc.edu
U.S. Air Force Office of Scientific Research, FA9550-04-1-0073

The principal goal of this project is the attenuation and elimination of limit cycle oscillations (LCOs) that occur in aeroelastic systems due to fluid-structure interactions through the use of nonlinear energy sinks (NESs). The NES is a fully passive device that is able to drastically modify the global dynamics of the system it is attached to despite being a local modification. We have demonstrated, through analysis and simulation, that the implementation of the NES on a Van der Pol oscillator, which is well known to exhibit limit cycle behavior, leads to suppression of the LCO over a wide range of the NES parameter space. We have examined the well-known and long utilized aeroelastic scenario of a cubically nonlinear rigid wing in a quasi-steady flow field and shown, for the first time, that LCO formation is a consequence of a series of resonance captures and escapes, and that the heave mode is the unique trigger for the pitch mode LCO. Finally, we have implemented the LCO on the aeroelastic system and have shown that, as in the VDP system, suppression occurs over a broad range of NES parameters in one of three distinct flavors: burst and elimination; complete elimination, and attenuation. All predictions have been confirmed in a series of wind tunnel tests in the NATA at Texas A&M University.

Minimum-Contact Tapping-Mode Atomic Force Microscopy for Nondestructive Characterization of Soft Nanostructures
H. Dankowicz,* M. Paul (Virginia Tech), C. Prater (Veeco, Inc.)
National Science Foundation

The invention of the atomic force microscope has paved the way for direct measurements of intermolecular forces and atomic-precision topographical mapping in a wide array of materials including semiconductors, polymers, carbon nanotubes, and biological cells. Of the different

* Denotes principal investigator.
imaging modalities, intermittent-contact (TappingModeTM), the invention of the atomic force microscope has paved the way for direct measurements of intermolecular forces and atomic-precision topographical mapping in a wide array of materials including semiconductors, polymers, carbon nanotubes, and biological cells. Of the different imaging modalities, intermittent-contact (TappingModeTM) atomic-force microscopy greatly reduces the effects of adhesion and friction on the probe tip. Here, however, the destabilizing influence of the intermittency of contact may result in probe-tip oscillations with high contact velocity and destructive, nonrepeatable, and unreliable characterization of the nanostructure. This research effort aims to develop and experimentally demonstrate the feasibility of innovative design and control strategies for minimum-contact, tapping-mode atomic force microscopy to successfully and nonintrusively characterize soft physical structures at the nanoscale. Successful application of the proposed control strategies is expected to dramatically improve the repeatability of structure scans and to provide a more faithful representation of surface properties while significantly reducing damage to the measured structure. A direct link to industry-relevant problem formulations and a channel for long-term commercialization is provided through a formalized collaboration with Veeco Instruments Inc., a leading provider of nanoscale metrology equipment. This research effort is also integrated with educational and outreach activities of the investigators, through the inclusion of modules on principles of nanoscale characterization in the senior-level undergraduate and first-year graduate-level course "Modeling MEMS and NEMS" and through the creation of a promotional brochure on nanoscale science aimed at local and regional high schools.

PECASE: Analysis and Design of Discontinuity-Driven Bifurcations
H. Dankowicz*
National Science Foundation

This award focuses on the analysis and design of nonsmooth dynamical systems, characterized by abrupt and discontinuous changes in the systems' properties, and commonly encountered in mechanical, biological, and electronic models. Of particular significance are the potentially dramatic changes in character and stability of motions of such systems that occur at the onset of weak interactions with the environment, here referred to as discontinuity-driven bifurcations. For example, in the case of human gait, premature, low-velocity ground contact of the swing foot may result in loss of stability of the sustained gait and subsequent fall, particularly in individuals with muscular disorders, or the elderly. The objectives of this project are to develop a comprehensive predictive methodology for discontinuity-driven bifurcations of recurrent and transient motions and to formulate design criteria for reducing or eliminating the detrimental effects of unintentional collisions between a mechanical subsystem and its surrounding environment—in particular, the prevention of fall-related injury due to premature ground contact during gait. The research work will closely integrate with an effort to develop a closed-ended-design course at the junior level emphasizing performance verification tests for mechatronic systems and the evaluation of a system's response in the presence of smooth and discontinuity-driven bifurcations. This project was originally funded as a Faculty Early Career Development (CAREER) program award and was converted to a Presidential Early Career Award for Scientists and Engineers (PECASE) program award in September 2004.

Modeling, Simulation, Analysis, and Control of Retinopathy of Prematurity
S. D. Kelly,*
C. H. Simmons (Cedars-Sinai Medical Center)
University of Illinois at Urbana-Champaign

Maturation of the human fetal inner retina is regulated by the delivery of oxygen to differentiating cells along the growing retinal frontier; neovascularization of the retina to deliver this oxygen is mediated by the production of angiogenic growth factors by hypoxic retinal cells. Retinopathy of prematurity (ROP), a leading cause of blindness among children, constitutes abnormal vascularization of the developing retina in premature infants receiving supplemental oxygen to compensate for underdeveloped lungs. This project seeks to develop a mathematical model for the physiology of retinal development that elucidates the phenomenology of ROP and to use model-based feedback control design to realize a closed-loop scheme for regulating the delivery of oxygen to a premature infant—possibly in conjunction with other dynamic therapeutic interventions—based on periodic, minimally invasive blood gas measurements and/or novel retinal imaging.

Numerical Analysis for the Characterization of Impact-Induced Head-Disk-Interface Damage During Operational Shock
A. A. Polycarpou,* N. Yu, R. Katta
Seagate Technology LLC

Currently, mobile hard-disc drive products have to meet operational shock (op-shock) specs ranging from 250-300...
G (1 G=9.81 m/s²) and 2 ms duration half sine pulses. In the future, as the spectrum of portable electronic devices into which mobile drives are integrated expands, the op-shock requirements to be met by such drives are expected to rise. At the same time, the higher magnetic storage areal density requirement that will have to be met in the future will render HDIs, in general, inherently more susceptible to contact-induced damage. In this research, we will develop analysis models for the characterization of relevant op-shock phenomena. Such models will enable the formulation of effective knowledge-based criteria for the design of mobile (and otherwise) disc drives with superior op-shock performance.

Energy Systems and Thermodynamics

CO₂ Emission Quantification for Vehicle Air Conditioning Operation under California-Specific Conditions
C. W. Bullard,* P. S. Hrnjak*
State of California

The test procedures used for measuring automotive fuel economy throughout the world are conducted using a dynamometer under laboratory conditions. The air conditioner is off during the test. This has led to development of compact and lightweight air conditioning systems without regard for energy efficiency. In some cases, existing test procedures overestimate vehicle fuel economy by 20 percent. This project aims to develop a technically sound test procedure that balances tradeoffs among accuracy, cost, and complexity.

 Including Material Cost and Strength Constraints in Heat Exchanger Design
C. W. Bullard,* I. Davidson
28 Company Consortium: Air Conditioning and Refrigeration Center

This project extends analysis of heat exchanger design tradeoffs in response to two emerging trends: demands for increasing thermal performance while reducing material costs are beginning to raise structural issues; and new manufacturing technologies are enabling designs that lie outside the envelope of existing empirical databases and performance correlations. Optimization methods will be used to explore both conventional and unconventional designs in this broader parameter space, including material cost and strength constraints.

Refrigeration Systems with Simpler Expansion Devices
C. W. Bullard,* I. Davidson
28 Company Consortium: Air Conditioning and Refrigeration Center

This project examines how refrigerant mass flow requirement varies with operating conditions and proceeds to develop specifications for an active or passive expansion device capable of delivering that flow. The objective is to identify opportunities for developing expansion devices that are simpler and more reliable than the thermal and electronic valves currently used, while delivering higher performance than conventional orifice tubes and captuves. By focusing on the way mass flow requirements relate to other system states, and analyzing the way in which component designs and charge management can alter those states, results can be generalized to many kinds of a/c and refrigeration systems.

University of Illinois Solar Decathlon 2007
P. Chapman, M. McCulley, D. Schejbal, W. Sullivan, T. A. Newell*
http://www.solardecathlon.uiuc.edu
U.S. Dept. of Energy: multiple sponsors

A University of Illinois team will compete in the 2007 Solar Decathlon. Twenty teams, from colleges and universities around the globe, will design and construct solar-powered houses. The Solar Decathlon's research goals include reducing the cost of solar-powered homes and advancing solar technology.

Mesoscopic Thermomechanical (MTM) Desalination
J. G. Georgiadis,* M. A. Shannon,* L. G. Raguin, M. Nsumuna
NSF Center of Advanced Materials for the Purification of Water with Systems (CAMPWS), CTS-0120978

The objective is to resolve several critical issues associated with the function of the mesoscopic thermomechanical (MTM) desalinizer, which is a low-cost, mass-producible water purifier that uses phase change for separating ions from water. The main theme is to realize the full potential of desalination via freeze-distillation by synthesizing and optimizing the materials that are necessary for the development of a working prototype of the MTM desalination device. This project focuses on the extraction of the rejected brine and the development of rotor coatings that permit the control of ice formation and detachment.

* Denotes principal investigator.
Carbon Dioxide as a Refrigerant in Secondary Loops and Cascade Systems
P. S. Hrnjak,* J. Jang
Wolverine, Inc.
Carbon dioxide has excellent thermophysical properties at low refrigeration temperatures. Combined with good material compatibility and environmental friendliness, it becomes an attractive option. System, defrost, heat transfer, and related issues are being studied in the project.

Charge Minimization in Components and Refrigeration Systems
P. S. Hrnjak,* K. Traeger
28 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation
Charge minimization is important for every fluid, but mildly flammable and toxic fluids might be used as refrigerant even in populated areas if charge is minimized. This is an experimental and model study to relate charge reduction to capacity and coefficient of performance (COP) of refrigeration systems.

Development of Transcritical CO₂ Systems for ECU Applications
P. S. Hrnjak,* X. Li, S. Elbel
U.S. Army; Modine
Natural fluids are not only ecologically attractive but also offer an advantage in logistics. The main issue is operation in extremely hot, ambient conditions.

Development of Transcritical CO₂ Systems for Mobile Applications
P. S. Hrnjak,* S. Peuker
U.S. Army; Modine
Two-evaporator application for HMMWV is a difficult challenge for transcritical CO₂ systems because of stability in the control system.

Effect of Oil on Evaporation of R744 in Round Smooth and Enhanced Tubes
P. S. Hrnjak,* C. Y. Park
28 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation
R744 (CO₂) has very good heat transfer characteristics but the reduction when oil is present seems to be also dramatic. What is the mechanism? Can we reduce these detrimental effects?

Effects of Oil Migration and Retention
P. S. Hrnjak,* S. Wujek
28 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation
The objective of this project is to determine effect of oil on capacity and efficiency of the system through heat transfer and pressure drop reduction.

Ejector in the Transcritical R744 System to Reduce Work Losses
P. S. Hrnjak,* S. Elbel
Daimler-Chrysler; U.S. Army; Modine
Work recovery is most important for R744 to reduce significant irreversibilities. An ejector is an excellent option.

Experimental and Modeling Investigation of Two Evaporator Systems
P. S. Hrnjak,* S. Peuker
28 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation
Both conventional R134a and R744 systems have difficulty in stable control and good oil return. A transient model in Modelica is being developed and experimental validation is progressing.

I-MAC 3-/50
P. S. Hrnjak,* X. Li, J. Che, A. Milosevic
Society of Automotive Engineers
Researchers are seeking a greater reduction in indirect and direct global warming effects. Improvements are demonstrated in every aspect: compressor, evaporator, condenser, internal heat exchanger. This project will arrange a system of the best components.

Improving Transcritical CO₂ Systems for Heat Pumping and Air Conditioning in Automotive Systems
P. S. Hrnjak,* S. Elbel
Daimler-Chrysler
Evaporation of carbon dioxide at close to critical temperatures shows different characteristics than conventional refrigerants. This project elaborates a new concept of evaporator and controller as well as new ways to utilize potential of expansion work.

Opportunities in Transcritical CO₂ Systems with Two-Stage Compressor
P. S. Hrnjak,* S. Elbel, J. Mott
Sanyo
Various options, including multistage expansion, mechanical subcooling, internal heat exchange and work

* Denotes principal investigator.
recovery options, are considered and elaborated in the project.

**Hypersonic Aerospace Vehicle Propulsion**
A. M. Jacobi,* A. Joarder
a-jacobi@uiuc.edu

*Critical Research Initiative (CRI)*

The project seeks to identify and improve heat exchanger technology. The goal is to find a design of air-liquefaction heat exchangers for propulsion systems such that the volume and mass can be reduced to levels suitable for the application. The project has focused on investigating the performance of offset-strip fin heat exchangers operating at high Reynolds numbers. In addition, an air-liquefaction heat exchanger was designed, built, and tested.

**Implementation of Vortex Generators on Heat Exchangers for Air-Conditioning and Refrigeration Applications: Optimal Design and Placement**
A. M. Jacobi,* A. Joarder
a-jacobi@uiuc.edu

*Advanced Heat Transfer*

In this project, we are trying to study the flow and heat transfer performance of winglet type vortex generators in two different categories of heat exchangers commonly used in refrigeration and air-conditioning applications. The heat exchangers are of two types: first, plain fin round/oval tube (inline pattern) geometry typically used as medium temperature refrigeration evaporator, and second, louvered fin round tube (staggered pattern) geometry typically used in such applications as air-conditioning condensers and heat-pump outdoor coils. The details of the heat exchanger geometry and dimensions have been supplied by the sponsors. The objective is to improve heat exchanger performance using vortex generators in order to reduce the size (and hence cost) of the heat exchangers by at least 10%. The primary approach is computational fluid dynamic (CFD) modeling of flow and heat transfer with validation of results using available correlations and experimental data from the literature as well as those performed at our laboratory. The validated CFD model will then be used for design optimization studies. All computations will be carried out using the commercial software Fluent©.

**Prediction and Control of an Exhaust-Heat Recovery System to Improve the Fuel Efficiency of Heavy-Duty Truck Engines**
A. M. Jacobi,* G. Cerpa
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*Cummins, Inc.*

A prediction model using artificial neural networks is developed for an organic Rankine cycle system designed to recover the exhaust heat from the diesel engine of a Class 8 tractor. Two feed-forward artificial neural networks coupled in a single model provide predictions of the pump power, mass flow rate of the working fluid, and net power generated by the system. Predictions from the artificial neural network are compared to predictions from an existing, validated mechanistic model, and the artificial neural network is found to predict pump power, working fluid mass flow rate, and power output to within 0%-8%. In contrast to mechanistic models of the system, the artificial neural network provides very fast predictions, allowing it to be implemented in real-time control of the system. Use of the artificial neural network for optimal, real-time system control is described. As part of this project, a Rankine cycle was designed and constructed in collaboration with an industrial partner. As part of this thesis, recommendations for instrumentation of the test cell are also provided.

**Ultra-Hydrophobic Surfaces for Heat Exchangers in Air-Conditioning Systems**
A. M. Jacobi,* Y. Xia

*28 Company Consortium: Air Conditioning and Refrigeration Center*

In air-conditioning systems, the evaporator usually operates with its surface temperature below the dewpoint of conditioned air. As a result, moisture from the air stream condenses and accumulates on the surface of the heat exchanger. Condensate retained on the air-side surface of the heat exchanger has a profound impact on its performance and on the air quality. Recent developments in materials processing have produced surfaces with extremely high contact angles, called ultra-hydrophobic surfaces (UHS), showing strong water-repelling characteristics. We propose to investigate condensate retention and thermal-hydraulic performance for the new surfaces. We will provide test data for the performance of UHS-based heat exchangers, compared to conventional coils, and for transient condensate retention over a range of operating conditions. We will expand our retention model to predict the amount of condensate on UHSs and, in particular, we will account for condensate bridges.

* Denotes principal investigator.
Using Mesoscale Devices to Integrate Fans and Heat Exchangers: Beehives for Heat Transfer
A. M. Jacobi,* A. Dubas
a-jacobi@uiuc.edu
28 Company Consortium: Air Conditioning and Refrigeration Center

We will design and build a meso-scale device using a bimorph piezoelectric approach to move air (we call the device a “bee”). We will loosely optimize our design, then replicate this design to build numerous such devices in an array (we call the array a “swarm”). Through a trial and error approach, we will find a swarm configuration that produces a reasonable flow through a model, plain-fin heat exchanger. Finally, we will characterize the flow performance, local, and average convective mass (heat) transfer performance of the system. This project is an exploratory effort toward an integrated prime-mover-heat-exchanger component that could be implemented as an evaporator or condenser in a vapor-compression system.

Experimental Optimization of Flame Stabilization in LPG and Natural Gas Cooking Stoves
D. C. Kyritsis,* T. Kang
Arcelik S. A. Istanbul, Turkey

An experimental study targeted to the optimization of LPG and natural gas combustion in the burners used in gas kitchen stoves is performed. Our objective is to determine the flame configurations that provide optimum heat transfer to the bottom surface of the employed kitchenware through complete and spatially uniform combustion of the gaseous fuel (LPG and natural gas). In order to achieve this target, we study the flames stabilized in these burners, using laser diagnostics as the main experimental tool to measure combustion species and temperature.

Salt Gradient Solar Pond Research
T. A. Newell*
Illinois Department of Energy and Natural Resources, STILENRAE25SLRPND129; International Salt Co.; Gundle Lining Systems

A half-acre solar pond has been constructed in the agriculture section of campus. Continuing research investigates the feasibility of solar ponds for low-temperature heating processes.

Technical Support of a Green Illinois Lighting Efficiency Demonstration Project
T. Rusk,* T. Lindsey
Illinois Environmental Protection Agency

This project will provide technical support to assist in the implementation and evaluation of efficient lighting systems at Starved Rock Convention Center and Read Mental Health center.

Engineering Mechanics

Application of Strain Gradient Plasticity—Modeling and Experiments
Y. Huang*
National Science Foundation, CMS-98-96285; University of Illinois Research Board; National Science Foundation of China

The purpose of this research project is to develop a microscale plasticity theory for applications from 0.1 to 10 microns, such as in nano- and micro-indentations, microelectronic devices, and nano-, micro-, and mesotechnology.

Dynamic Failure Modes of Marine Composite Materials under Blast Loading
Y. Huang*
U.S. Office of Naval Research

We study dynamic fracture of composite materials under blast loading.

Mesoscale Modeling of the Constitutive and Failure Response of the Solid Propellant and the Case
Y. Huang,* A. J. Beaudoin; E. de Sturler (Comput. Sci.); P. H. Geubelle (Aerosp. Engr.)*
U.S. DoE Accelerated Strategic Computing Initiative (ASCI) Center; University of Illinois at Urbana-Champaign

We develop constitutive models for solid propellant accounting for the nonlinear debonding process of the interfaces between energetic particles and polymeric binders.

Thermal and Loading Dynamics of Energetic Materials
Y. Huang*
Los Alamos National Laboratory

We study the mechanical behavior of energetic materials under thermal and dynamic loading conditions.

A Crystal Plasticity Model to Study Aluminum Bendability
Y. Huang*
Alcan Aluminum Co.

The objective of this project is to develop a single crystal plasticity model and study the bendability of aluminum in automotive applications.

* Denotes principal investigator.
Ion-Beam Machining to Eliminate Stress-Induced Curvature in MEMS Optical Devices
H. T. Johnson,* T. G. Bifano* (Boston Univ.)
National Science Foundation, DMI-0223821

A combined experimental and computational approach is used to develop a method of stress-induced curvature reduction in freestanding microelectromechanical (MEMS) thin film structures. The method is based on a theoretical understanding of residual stress sources that lead to curvature in such structures. Using ion-beam machining techniques, it is then possible to impose compensating stresses in sufficiently thin surface layers of material that will restore the structures to planar configurations. The objective of the project is to develop an understanding and methodology for this new approach.

Damage Tolerance in Tank Cars
H. Sehitoglu,* D. Pecknold,* C. Barkan* (Civil & Environ. Engr.); S. Kibey
Federal Railway Administration

This research program is intended to develop information for the Federal Railway Administration and the tank car industry to apply durability concepts to improve the understanding of factors contributing to design, operation, and maintenance of tank cars. The technical emphasis is aimed at identifying the uncertainties on the overall durability analysis of tank cars and the sensitivity of the factors that produce high levels of variability in reliability analysis and design. It is expected that the underlying concepts developed for tank cars can be applied to other railroad systems.

Stresses under Contact Loading and Material Ratchetting
H. Sehitoglu,* Y. Jiang, D. Canadine, K. Verzial
Association of American Railroads, in collaboration with the University of Nevada, Reno

Based on a stress invariant hypothesis and a stress/strain relaxation procedure, an analytical approach is forwarded for approximate determination of residual stresses and strain accumulation in rolling contact. For line rolling contact problems, the proposed method produces residual stress distributions in favorable agreement with the existing finite-element findings. We study ratchetting behavior of 1070 steel under uniaxial tension-compression and axial-shear loadings experimentally. Strain ratchetting direction exhibits a complex dependence on the previous loading history, including nonconsistence with the mean stress direction. Different models to predict this phenomenon are proposed and compared to experiments.

Large-Scale Parallel Computing to Design Advanced and Miniaturized Explosive and Propellant Systems
D. S. Stewart,* J. Buckmaster, T. Jackson
dss@uiuc.edu
U.S. Air Force Office of Scientific Research; Apple Computer; University of Illinois at Urbana-Champaign College of Engineering

A 256-processor parallel supercomputer with approximately 1-Terabyte of memory has been obtained to carry out simulation of advanced and miniaturized explosive and propellant systems. These systems have heterogeneous character or geometric complexity with multiscale physics. The system supports the Air Force-sponsored research of the Stewart and the Buckmaster/Jackson research groups as well as other Air Force-relevant science and engineers. The housing and maintenance of the system is in collaboration with the College of Engineering and Computational Science and Engineering program.

Engineering Statistics and Quality Control

Biodiesel Production from Food Processing Wastes
T. Lindsey,* D. Bennett
Illinois Department of Natural Resources

The Waste Management and Research Center will work with various Illinois food processing facilities. Yellow and brown waste greases will be converted to biodiesel through chemical processes and tested with respect to performance in traditional diesel engines.

University of Illinois Chicago Energy Resources Center Total Assessment Audit Program
T. Lindsey*
University of Illinois Chicago Energy Resources Center

The goal of this project is to facilitate the implementation and evaluation of pollution prevention, health, and safety and regulatory compliance activities to three wood products sector companies.

The Cutting Edge Partnership: Technical Assistance to the Illinois Machining Sector
T. Lindsey,* K. Rajagopalan
U.S. Environmental Protection Agency

The Waste Management and Research Center will work with companies from Illinois’ machining and metal forming sectors to assist them in their efforts to evaluate and implement technologies that extend the useful life of machining fluids. In particular, technologies that reduce

* Denotes principal investigator.
environmental impacts and improve safety of the fluids are being investigated.

**Study and Develop Recommendations for Reducing Adverse Great Lakes Ecosystem Impacts from PBT Chemicals**

W. Nelson,* T. Lindsey
Tellus Institute, Inc.

The Waste Management Research Center (WMRC) will investigate the impact of persistent, bioaccumulative, and toxic (PBT) compounds in the Great Lakes from various industrial sectors. Additionally, WMRC will investigate modifications to industrial processes that could reduce the impacts of PBT chemicals.

### Environmental Engineering

**Science and Technology Center of Advanced Materials for the Purification of Water with Systems (CAMPWS)**

J. G. Georgiadis,* M. Shannon,* P. Bohn,* J. Economy, V. Snoeyink;* M. Reinhard (Stanford Univ.)

*National Science Foundation*

The research component of CAMPWS focuses on the development of innovative approaches to water purification through the synthesis of advanced materials and their integration into systems. The mechanical engineering team leads the Interdisciplinary Team 2, which focuses on desalination and water reclamation.

**Applicability and Scalability of Microfiltration for Recycling Semi-Synthetic Metalworking Fluids**

S. G. Kapoor,* R. E. DeVor,* J. Wentz

*Illinois Department of Natural Resources, Waste Management and Research Center*

Microfiltration has been shown to be a promising technology for recycling synthetic and semi-synthetic metalworking fluids, capable of achieving selective separations of external contaminants from base metalworking fluids. The objective of this research is to study the applicability of the microfiltration technology for a wide range of commercial metalworking fluids. The physical and chemical properties of metalworking fluids will be characterized, and filtration tests will study fouling of both tubular ceramic membranes and polymeric flat sheet membranes.

**Unstable Two-Phase Mixtures for Metalworking—A Greener Alternative**

S. G. Kapoor,* R. E. DeVor,* P. Bittorf

*Illinois Department of Natural Resources, Waste Management Resource Center*

Metalworking fluids (MWF) perform a number of useful functions such as cooling, lubrication, metal chip evacuation, and short-term corrosion protection. MWF become process effluents when the accumulation of contaminants, such as extraneous oil, particulate debris from machining operations, and bacteria, negatively impact functionality. Oil containing MWF is conventionally formulated to be a highly stable emulsion. These emulsions are difficult to maintain, recycle, and waste treat. Preliminary work has indicated that transiently stable emulsions can provide comparable lubrication. Transiently stable emulsions have the potential to be easily maintained and recycled, and these emulsions offer few problems for waste treatment. This proposal focuses on a rational approach to designing such transiently stable emulsions by elucidating the important factors affecting lubrication and cooling and phase separation.

**Integrating Electrical, Economic, and Environmental Factors into Flexible Power System Engineering**

P. Krein, P. Chapman, M. Pai, P. Sauer, D. Thurston* (Gen. Engr.)

*National Science Foundation*

A flexible power system is one in which redundancy and reliability are managed through localized control, distribution of energy sources, shifting among available sources, treating loads as a potential resource for operation and control purposes, and directing energy to the most critical needs. This project seeks to establish a firm science-based framework for integrating electrical, economic, and environmental factors into flexible power system design.

**Optimization of VaPRRS Technology for Commercialization**

M. Rood, D. Thurston* (Gen. Engr.)

*The Grainger Foundation Inc.*

Industries spend approximately $9x10^8 per year to remove volatile organics from gas streams in order to comply with air quality regulations. This project develops a technology that captures and reuses these constituents from industrial gas streams, recovering their economic value and preventing their discharge into the environment. The technology is being developed to provide a revenue-generating pollution control device, rather than one that imposes a financial burden.

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*Denotes principal investigator.
Decision-Based, Environmentally Conscious Design
D. Thurston* (Gen. Engr.), M. J. Rood
National Science Foundation

Certain engineering design projects are vulnerable to decision biases that result in irrational and inconsistent decision making. Environmentally conscious design (ECD) falls into this category. This project develops a rational, decision-based design framework for ECD that overcomes current difficulties. An adsorption, electrothermal-swing, air pollution control technology is used as the testbed for this research.

Randomized Distributed Data Structures for Product Design
D. Thurston* (Gen. Engr.), J. Welch (Comput. Sci., Texas A&M University)
thurston@uiuc.edu
National Science Foundation

The rapid expansion in computing and database systems has resulted in a wealth of data that previous generations of product designers could only dream of. Product take-back laws provide an ideal test-bed for exploiting this data to design for sustainability. This project develops a data-intensive decision model for component reuse and remanufacturing that simultaneously decreases cost, increases customer satisfaction, and reduces environmental impact.

Fluid Dynamics

Outer-Layer Structure in Wall Turbulence
K. T. Christensen,* Y. Wu
Oak Ridge Associated Universities (ORAU); University of Illinois

It is well established that the outer-layer of wall turbulence is densely populated by hairpin-like structures that tend to coherently align into large-scale packets. Such structures occur often in a variety of wall-bounded turbulent flows, including pipes, channels, and boundary layers. Particle-image velocimetry measurements have been made in turbulent channel flow and a zero-pressure-gradient turbulent boundary layer. These extensive datasets are used to evaluate the statistical significance and spatial characteristics of these structures.

Realistic Roughness Effects in Wall Turbulence
K. T. Christensen,* Y. Wu, V. Natrajan

Realistic roughness refers to highly irregular roughness patterns created by damage to a flow surface through scratching, pitting, and deposition of contaminants. Although the influence of both discrete and distributed roughness on the character of wall-bounded flows has been studied extensively in the past, recent research indicates that these “simulated” roughness conditions are not representative of the influence of realistic roughness. To this end, surface profiles from damaged turbine blades are replicated in a flat-plate turbulent boundary layer in order to document their effect on the behavior of wall turbulence.

Analysis of Flow and Transport in Subway Systems
W. E. Dunn,* M. Gresshoff
U.S. Department of Energy, DOE-ANL-1F-01541

The study involves a laboratory simulation of flow in a subway station. Results from these experiments will be compared with field measurements to verify proper scaling between the laboratory-scale experiment and the full-scale system. Once proper scaling is established, the results of the experiment will be used to improve computer models of flow in subway systems. These improved models will be used to improve air quality in the underground system.

Atmospheric Boundary Layer Modeling
W. E. Dunn,* S. Tschopp, M. Rhodes
U.S. Army; U.S. Department of Energy, ANL1F-00941

The atmospheric boundary layer determines the transport of pollutants and toxic materials in the atmosphere. The atmospheric boundary layer is constantly changing due to the solar heating of the ground. During the day, the ground heats the air and produces a convectively driven, unstable boundary layer. At night, the ground is colder than the air, and the boundary layer is stable. The transport model developed as part of this project treats the entire surface energy budget, including short wavelength solar heating, long wavelength radiation exchange, sensible and latent convective heat transfer through the plant canopy, and conduction heat transfer in the ground.

Experimental Study of a Bump Compression Model
J. C. Dutton,* E. Loth* (Aerosp. Engr.),* D. N. Patel,
B. J. Tillotson
Boeing Phantom Works

An experimental investigation is under way of a bump model immersed in a Mach 3 supersonic flow. The basic idea is that the secondary flow set up by the three-
dimensional pressure gradient on the bump drives the boundary layer flow off the bump, resulting in a thin boundary layer being ingested into an associated supersonic inlet. An optimized bump shape has been chosen for study via a separate design-of-experiments CFD investigation. The experimental methods used include shadowgraph photos, surface-flow visualizations, surface static pressure distributions via static taps and pressure-sensitive paint, and mean velocity and turbulence measurements obtained with laser Doppler velocimetry.

Three-Dimensional, Supersonic Base Flows
J. C. Dutton,* G. S. Elliott (Aerosp. Engr.)*
A. L. Kastengren
U.S. Army Research Office, DAAD19-01-1-0367

This project seeks to obtain nonintrusive, laser-based diagnostic measurements to identify the important flow mechanisms in three-dimensional base flows that are representative of high-speed objects flying at angle-of-attack. Important questions to be addressed include the steadiness of the overall flowfield, the interaction of the lee-side vortical flow with the base flow recirculation region, and the size and shape of the separated flow regions. Measurement methods used include Schlieren/shadowgraph photography, surface streakline visualizations, LDV, planar Rayleigh/Mie scattering, imaging (both single-shot and time-resolved sequences), and pressure-sensitive paint.

Unsteady Features of Supersonic Separated Flows
J. C. Dutton,* G. S. Elliott (Aerosp. Engr.)*
P. M. Cannon
U.S. Army Research Office, DAAD19-01-1-0367

In this work, we are investigating the unsteady aspects of supersonic base flows by obtaining and analyzing time-series measurements of base-pressure fluctuations. High-frequency response pressure transducers are located at various radial and circumferential positions across the base and the mean, rms, power spectra, and cross-correlations of the time-series data are obtained. In addition, the relation of the base-pressure fluctuations to the instantaneous turbulent structure in various regions of the flow is studied. The latter objective is accomplished by obtaining the time-series base-pressure data simultaneously with planar laser-sheet images.

Quantitative Visualization of Convective Heat and Mass Transfer in Complex Internal Flows
J. G. Georgiadis,* L. G. Raguin
National Science Foundation; National Center for Supercomputing Applications

In applications with complex internal flows, it is the unpredictability of the tortuous fluid particle trajectories that produces enhanced heat and mass transfer, beyond the level of simple molecular diffusion. The research program consists of a combination of noninvasive measurements with magnetic resonance imaging (MRI) and numerical simulation using Lattice-Boltzmann methods (LBM) of such internal flows. Two model systems have been considered: a Taylor-Couette reactor and a helical flow mixer driven by a pair of Rushton turbines.

Developing Adiabatic Two-Phase Flow after Expansion Valve
P. S. Hrnjak,* C. Bowers
28 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation

Exploration of two phase flow was predominantly, almost exclusively, done in developed regime. Nevertheless, location (distance) of the expansion valve to the inlet header plays a significant role in good distribution of two-phase refrigerants. The objective of this research is to better understand the physics and provide meaningful data for heat exchanger designs.

Flow Distribution and Pressure Drop in Microchannel Manifolds
P. S. Hrnjak,* T. A. Newell,* C. Bowers
28 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation

It is very difficult to distribute liquid and vapor refrigerant evenly into hundreds of small channels due to variable inertial forces because of changing mass flux. Effects are detrimental and studies are conducted to quantify effects and propose solutions.

Two-Phase Flow of Refrigerant with Oil in Small Channels
P. S. Hrnjak,* B. Fields
28 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation

Both with decrease in diameter and increase of surface tension and viscosity of refrigerant mixture intermittent flow regimes are becoming more dominant. Is it possible to find the oil that will work well in the compressor (maintain good tribological properties) but have less detrimental effects on pressure drop and heat transfer.

* Denotes principal investigator.
Enhanced Surfaces, Maldistribution, and Bundle-Depth Effects on Falling-Film Flow
A. M. Jacobi,* A. Pagan-Iglesias
28 Company Consortium: Air Conditioning and Refrigeration Center; Kritzer Endowment

In falling-film heat exchangers, a liquid is sprayed onto the top of a tube bundle and, as it falls from one horizontal tube to another below it, the flow may take the form of discrete droplets, jets, or a continuous sheet. The falling-film mode plays an important role in the wetting, heat transfer, and mass transfer characteristics of the heat exchanger. Ongoing research is about to yield new regime maps to include the effects of vapor shear on the falling film behavior. We now consider liquid-flow maldistribution effects on the local falling film mode, and we will incorporate the new maps into bundle simulations that will allow the study of overfeed rate, fluid properties, and heat duty effects on the flow regime from the top to the bottom of a bundle. Along with providing a critical assessment of maldistribution effects, this project will provide an engineering tool capable of predicting local mode behavior in spray bundles. To our knowledge, it will be the first tool of this kind available. The results will be highly valuable to those designing, building, or using spray evaporators.

Hydrocarbon Flame Propagation in Compositionally Stratified Media
D. C. Kyritsis,* T. Kang
University of Illinois at Urbana-Champaign

Flame propagation in compositionally stratified methane-air mixtures is studied experimentally as a function of the equivalent ratio distribution in the unburned mixture. Stratification is established in a controlled manner using a convective-diffusive balance in a very slow fuel-air mixture flow in an optically accessible test chamber. The flame speed has been shown to be significantly higher than the one corresponding to a homogeneous mixture of the local equivalence ratio of mixture compositions close to the lean flammability limit. Also a significant extension of the lean flammability limit was observed. It was established that the local spatial gradient of the equivalence ratio was not sufficient to describe the departure of stratified combustion from quasi-homogeneity. Instead, an appropriately defined integral parameter that depended on the history of flame propagation has been shown to determine when the flame could not be treated as a series of premixed flamelets propagation at the local adiabatic flame speed.

Quantitative Visualization of CO2-oil Mixtures in CO2 Expansion Flows
D. C. Kyritsis,* M. A. Scott
Air Conditioning and Refrigeration Center

An optically accessible flow test section has been constructed of quartz in order to simulate carbon dioxide flow through throttling devices in refrigeration systems. The existence of traces of lubricant oil [specifically polyolester (POE) and polyalkylene glycol (PAG)] in the working medium makes the flow amenable to laser-induced fluorescence (LIF) diagnostics. The molecular structure of these lubricants is rich in carbon–oxygen bonds that can cause fluorescence when excited by a laser in the near ultraviolet region of the spectrum. This technique was used to visualize the flow of three separate phases (two for CO2, and one for oil) through the ejector under various operating conditions. Upstream and downstream pressures as well as flow rates pertinent to CO2 refrigeration systems are the independent parameters of the experiment. The results of the measurements provide data on the concentration of the lubricant that is entrained by CO2 in the expansion device as well as information about the form with which the oil is transported through the ejector (liquid films, droplets, mist, and so forth). High magnification experiments also provide data on the measurement of droplet diameter and oil layer thickness in the test section. Results from these experiments will guide the design of practical ejector geometries and will also indicate the extent to which various flow models may be employed in the investigation of CO2 refrigeration systems with ejectors.

Development of Exciplex Fluorescence Planar Droplet Sizing Technique
C. F. Lee,* J. W. Powell
National Science Foundation, CTS-9734402 and CTS 01-16719

Planar droplet sizing (PDS) has the potential to supply droplet size information over an entire viewing region, rather than at discrete points, like phase Doppler anemometry (PDA). A PDS technique is developed to measure Sauter mean diameter (SMD). A transient spray is studied, and appropriate PDA data are taken to scale the PDS data and convert relative SMD into absolute SMD. Rather than using a traditional laser-induced fluorescence tracer, exciplex fluorescence is utilized. The use of laser-induced exciplex fluorescence can discriminate between fluorescent signals from liquid fuel and fuel vapor. This enables the application of the technique in high-temperature environment.

* Denotes principal investigator.
Effects of Ultrasonic Excitation on the Atomization of Sprays
C. F. Lee,* J. W. Powell
TECAT Engineering, Inc.

The atomization of sprays under ultrasonic excitation was investigated. A injector housing with viewing windows was constructed, allowing the observation of the ultrasonic horn during operation. High-speed videos were taken of the actual ultrasonic horn motion, as well as the resulting sprays. By using these videos, the effects of fuel pressure, horn-nozzle spacing, and ultrasound could be observed. The operation of the ultrasonic horn was found to induce a periodic instability in the spray, enhancing breakup. Bubbles are formed at the horn surface, and the bubbles affect the internal flowfield and the atomization process of the sprays.

Experimental Study of Particle Dispersion in the Turbulent Near Wake of a Circular Cylinder
C. F. Lee,* T. Fang
University of Illinois Research Board; National Science Foundation, CTS 01-16719

The aim of this research is to investigate the effect of vortex structure on the dispersion of solid particles in the turbulent near wake of a circular cylinder. The change in the particle dispersion pattern with the Stokes number will be explored. The goal is to improve the understanding of the particle/fluid turbulent interaction and also to investigate the control of particle dispersion by large, energetic vortices. In order to do this, a vortex identification technology for gas/particle flow based on phase averaging will be developed. The combination of a laser Doppler velocimeter (LDV) and a phase Doppler particle analyzer (PDPA) will be used in the experiment.

Investigation of Molten Droplet Impingement on a Flat Surface
C. F. Lee,* A. Fedorchenko,* A. B. Wang,*
(National Taiwan Univ.)
University of Illinois at Urbana-Champaign; National Science Council, Taiwan

The impingement of liquid droplets on solid substrate is of practical importance in many industrial applications. This phenomenon is the core of thermal spray coatings that can be an ideal method for microelectromechanical systems (MEMS) packaging because it is low-cost and environmentally friendly. A collaborative research study has been conducted on molten drop impact/coating for MEMS packaging. The volume of fluid method was used to track the free interface between the liquid and gas phases for various droplet materials and under different ambient and surface conditions. The computational results were then compared with experimental and analytical results.

Investigation of Refrigerant/Oil Mixtures in Horizontal Tubes
T. A. Newell,* J. C. Chato,* E. Jassim
28 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation

Void fraction and oil concentration will be investigated in a variety of refrigerant tubes and passageways.

Fluid Mechanics of Electrodeposition to High-Aspect Ratio Through-Holes in Printed Circuit Boards
A. J. Pearlstein,* D. L. Cotrell
University of Illinois at Urbana-Champaign; National Institute of Standards and Technology

Rapid and uniform deposition of copper on the inner surface of high aspect ratio "through-holes" of printed circuit boards is important in electronics manufacture. We are investigating a new approach using a rotating screw electrode (RSE) inside the hole. In addition to improving the electric field distribution, the RSE generates a 3-D flow that greatly enhances mass transfer. Experiments show that plating uniformity is excellent. We have developed a numerical code to compute this flow and have shown that the computed flow is in good agreement with two-component laser Doppler velocimetry.

Stokes-Flow Computation of Diffusion Coefficients and Rotational Diffusion Tensors for Globular Proteins
A. J. Pearlstein,* H. Zhao, J. T. Jeong
University of Illinois at Urbana-Champaign

We have established the convergence properties of a boundary element method (BEM) based computational approach for determining translational diffusion coefficients and rotational diffusion tensors for globular proteins and have shown how the approach can be used, along with the binary Nernst-Hartley equation, to estimate the effective charge on protein macroions. The approach has been applied to lysozyme and ten other proteins for which heteronuclear nuclear magnetic resonance (NMR) relaxation measurements of the rotational diffusion tensor are available.

* Denotes principal investigator.
Advanced Theory and Simulation of Compressible Reactive Flow
D. S. Stewart,* J. C. Foster, B. Taylor
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Work was carried out to develop asymptotic theory for motion of detonations, their stability, ignition transition, and their relation to the general theory of hyperbolic PDEs. Work was also carried out to develop advanced simulation strategies that track shocks. New work has started to simulate complex particle-laden explosive materials.

Investigations on Detonation Shock Dynamics
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dss@uiuc.edu
U.S. Department of Energy, Los Alamos National Laboratory

A broad set of theoretical, numerical, and experimental investigations were carried out to address ignition, detonation diffraction, stability, advance simulation strategies, equation of state and reaction rate law modeling, and advanced instrumentation for condensed explosive systems and related technology. Work is being carried out to model laser initiated detonators.

Agglomeration Multigrid Algorithm for Low- and High-Speed Flows
S. P. Vanka,* S. Ahlawat
Boeing Company; National Center for Supercomputing Applications

The objective of this project is to develop a general-purpose multigrid algorithm for fluid flows in complex domains using unstructured grids and agglomeration techniques. A general-purpose grid agglomeration software has been developed already. A Navier-Stokes code based on implicit Jacobian formulation is now under development and will be combined with a multigrid acceleration sequence and the agglomeration package.

Electro-Kinetic Flow in Complex Channels
S. P. Vanka,* J. Kwak
University of Illinois at Urbana-Champaign

Electro-kinetic flow in complex channels will be studied computationally with a finite volume method. The shapes of the channels to be considered are a T-junction, a U-bend, and discrete charged elements to create microvortices. Parametric studies will be conducted to maximize desired outcomes.

Heat Transfer to Complex Impinging Jet Configurations
S. P. Vanka,* B. Collins, J. T. Brown
University of Illinois at Urbana-Champaign

Large-eddy and Reynolds-averaged simulations are being conducted for several configurations of circular impinging jets with and without azimuthal swirl. The configurations include annular, co- and counter-swirling jets, pulsating and steady jets, and so forth. An unsteady, three-dimensional Navier-Stokes code is being used to solve the relevant governing equations.

Magnetic Stabilization of Convection during Compound Semiconductor Crystal Growth
J. S. Walker*
University of Illinois

Large single crystals of compound semiconductors are needed for future developments in wireless and optical communications. In the Czochralski process, an instability in the buoyant convection leads to a periodic and nonaxisymmetric liquid motion. The associated fluctuations in heat and mass transfer from the liquid to the crystal produce many defects in the crystal and nonuniform distributions of important additives. Magnetic fields are needed to eliminate this instability. Linear stability analyses are being developed to predict the minimum magnetic field strength needed to stabilize the buoyant convection for a given process. The results will be used to design future processes to grow larger crystals with few defects and uniform distributions of additives.

Heat Transfer

Radiation Heat Transfer Modeling with CFD in Solid Rocket Motors
M. Q. Brewster,* J. Y. Jung
ATK-Thiokol

A computational model is being developed for radiation heat transfer in aluminized solid rocket motors. Burning aluminum droplet produces hot, incandescent sub-micron aluminum oxide smoke particles. Both aluminum and its smoke oxide combustion product are strong sources of thermal radiation in the core internal flow of solid rockets. Yet the ability to simulate radiation heat transfer in these flow is limited by lack of robust and accurate models for the radiation field. In this project, a model is being developed that is consistent with the optical conditions in the motor and accounts for both burning metal drops and inert oxide smoke particles. The model will be validated with subscale motor test firing results.

* Denotes principal investigator.
Radiative Transfer in Absorbing and Scattering Media
R. O. Buckius,* J. He
University of Illinois at Urbana-Champaign

Radiation heat transfer models for absorbing and scattering media are being developed. The correlated-k approach has been developed and validated for thermal radiative transport in highly nonhomogeneous media containing mixtures of water vapor and carbon dioxide. The new models accurately characterize the entire infrared spectrum of water vapor and carbon dioxide, including band overlap regions, for temperatures up to 2500 K.

Thermal Radiation Scattering from Very Rough Surfaces
R. O. Buckius*
University of Illinois at Urbana-Champaign

This research program consists of a combined analytical and experimental investigation of the scattering from realistic interfaces and films, including those with surface length scales on the order of the wavelength. The objectives are to rigorously quantify the scattering of thermal radiation from electromagnetic theory, to develop approximate yet accurate models, and to experimentally determine reflection for such interfaces. Rigorous electromagnetic theory and approximate geometric optics and diffraction models have been developed and compared with experimental findings.

Heat Exchangers for Transcritical a/c Systems
C. W. Bullard,* J. Rajan
Samsung Electronics Co.

When carbon dioxide is used as a refrigerant for air conditioning systems, it operates on a transcritical thermodynamic cycle. This project explores innovative configurations for heat exchangers that can operate with reversed flow during the heating season and that also supply hot water while meeting heating or cooling demand.

Heat Transfer in Condensing CO₂ at Low Temperatures—Effect of Oil
P. S. Hrnjak,* J. Jang
Wolverine, Inc.; National Science Foundation

Carbon dioxide is an excellent refrigerant for low-temperature cascade systems and secondary loops in temperature range -50°C to -20°C. Heat transfer in round tubes and between plates is studied, with emphasis on small channels.

New Microchannel Heat Exchanger PF2: Operation in Dry, Wet, and Periodic Frosting Conditions
P. S. Hrnjak,* P. Zhang
Modine

Conventional serpentine fins in microchannel heat exchangers are not very good in wet or frosting operation. The new concept of heat exchanger surface is introduced. This project is quantifying effects and also elaborating new advantages.

Oil Effects on Heat Transfer and Pressure Drop in Small Channels
P. S. Hrnjak,* C. Seeton, B. Field
28 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation

Optimization of channel size drives diameters to lower and lower values but neglects effect of oil on pressure drop and heat transfer. The objective of this project is to explore phenomena related to oil-refrigerant mixtures in very small channels of less than 300 mm hydraulic diameters.

Refrigerant Lubricant Interaction in Transcritical CO₂ Systems
P. S. Hrnjak,* C. Seeton
Visteon

Obtaining the data for lubricant CO₂ mixtures and understanding their effect on heat transfer and pressure drop in heat exchangers and new operating regimes in the application of vehicular air conditioning systems, such as heat pumps, is the focus of this project.

Frost, Defrost, and Refrost on Superhydrophobic Surfaces
A. M. Jacobi,* J. G. Georgiadis,* Y. Zhong
28 Company Consortium: Air Conditioning and Refrigeration Center

Surface wettability has a significant impact on the initiation and subsequent growth of a frost layer on a fin. In our earlier work, a thinner frost layer was observed on a hydrophobic surface than on a hydrophilic surface for a mature frost layer. We attributed differences in growth behavior mainly to differences in local density and thermal conductivity. Early in the growth history, the density and thermal conductivity are larger near the fin for a hydrophilic surface than for a hydrophobic surface, and this behavior can be used to explain growth trends later in the growth history. To date, we have conducted no defrost and refrost experiments with hydrophobic surfaces, but it is clear the distribution of liquid water on a hydrophobic surface will differ from that on a hydrophilic surface, and that distribution will affect subsequent frost growth.

* Denotes principal investigator.
Moreover, the distribution of density and conductivity within the frost layer is likely to profoundly impact defrost behavior. From our prior work, it appears that mature frost may grow more slowly on a super-hydrophobic surface than on conventional surfaces, extending the period between defrosts. Moreover, nucleation, early growth, defrosting, and refrosting will all be affected by super-hydrophobic surfaces. In this new project, we will work to characterize and understand the effect of super-hydrophobic fins on frost growth.

High-Performance Heat Exchangers for Air Conditioning and Refrigeration Applications (Noncircular Tubes)
A. M. Jacobi,* Y. Park, G. Michna, Y. Zhong
Air Conditioning and Refrigeration Technology Institute; U.S. Department of Energy, ARTI#605-20020:NC-HX

The objective of this research is to evaluate the heat transfer and pressure-drop performance of serpentine-fin, flat-tube heat exchangers (i.e., exchangers with noncircular tubes). This assessment will be conducted for smooth, corrugated, and louvered fins, over a range of geometrical and operating parameters representative of particular heating, ventilating, air conditioning, and refrigerating applications. The performance of serpentine-fin, flat-tube designs will be compared to that of conventional, plain-fin, round-tube heat exchangers. The range of operating conditions ensures that dry-surface, wet-surface, and frosted-surface performance will be examined.

Nanoparticles to Enhance Evaporative Heat Transfer
A. M. Jacobi*
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28 Company Consortium: Air Conditioning and Refrigeration Center

We will measure the effect of very dilute concentrations of nanoparticles on the two-phase flow and heat transfer of R-134a. The experiments will test the hypothesis that the documented enhancement in thermal conductivity found in other liquids will be manifest in halocarbons, and that the increased thermal conductivity of the liquid will result in dramatic increases in the evaporative heat transfer coefficient. We will also determine—at a first-cut level—whether there is significant particle hold-up in the test section. This is an exploratory project to assess the use of nanoparticles to enhance two-phase heat transfer in refrigeration and air-conditioning systems.

Super-Wettable Surfaces for Heat Exchangers in Air Conditioning Systems
A. M. Jacobi,* L. Liu
28 Company Consortium: Air Conditioning and Refrigeration Center

The evaporator in air conditioning systems normally operates with the air-handling surface colder than the dew-point temperature of the conditioned air. Therefore, moisture condenses and accumulates on the surface of the heat exchanger. Condensate retained on the air-side heat transfer surface has a profound impact on the performance of the heat exchanger and on the air quality. Very recently, material processing advances have produced fins with extremely low contact angles. We are studying condensate retention and its thermal-hydraulic effect for extremely wettable surfaces.

Super-Wettable Surfaces for Heat Exchangers in Refrigeration Systems
A. M. Jacobi,* A. Sommers
28 Company Consortium: Air Conditioning and Refrigeration Center

Current frost management schemes for refrigeration systems usually rely on achieving frost tolerance through geometric design. Specifically, fin spacing and fin staging are used with relatively simple fin geometries. This approach has constrained heat exchanger designers to consider only noncompact heat exchangers for refrigeration systems—the fin spacing is kept large in order to make the exchanger frost tolerant. We will explore a new way to achieve frost tolerance: super-wettable surfaces for refrigeration systems. Conventional aluminum fin materials have advancing contact angles as low as about 40 degrees with receding contact angles as low as roughly 10 degrees. Through new material processing methods, it is possible to achieve (and presumably maintain) contact angles below a few degrees. We plan to answer the question: How do such surfaces behave in refrigeration systems?

An Empirical Study of Frost Accumulation Effects on Louvered-Fin, Microchannel Heat Exchangers
A. M. Jacobi,* P. S. Hrnjak,* J. Georgiadis,* Y. Xia
28 Company Consortium: Air Conditioning and Refrigeration Center

In this project, frost growth on folded louvered fins with microchannel tubes is studied. The emphasis of this work is on experimental study over the complex parameter space of louvered fins. The research will provide an experimental assessment of frost growth and its effects on overall heat transfer and pressure-drop behavior for microchannel heat.* Denotes principal investigator.
exchangers. These experimental studies will result in performance correlations useful for the design of microchannel heat exchangers with folded, louvered fins in frost applications.

**An Experimental Investigation of Droplet Entrainment and Stokes Numbers in Accumulators**

C. F. Lee,* J. W. Powell

28 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation

Entrainment of liquid droplets into the vapor feed for refrigerant compressors is a serious issue, due to the compressor damage, which can be caused by slugging. It is critical that the accumulator separate out the phases to prevent compressor damage, and in order to separate the liquid droplets from the vapor phase, enough settling time is needed so that the droplets will fall out of suspension and into the liquid at the bottom of the accumulator. Knowing the Stokes numbers of the droplets will also give an indication of the average required settling time under different conditions. The objectives of the research are to provide qualitative imaging of the flowfield within the accumulator, as well as quantitative data showing the vapor and droplet velocities, turbulence intensity, droplet size, and Stokes number within the accumulator. Investigation of the two-phase flow inside the accumulator may lead to new insight in accumulator design. Eventually, this will lead to a more generalized and physics-based approach to accumulator design.

**Next-Generation Cookware: Improved Acid Resistance**

T. J. Mackin*
Calphalon Corporation

Modern cookware uses complex combinations of microstructures and materials to achieve the desired cooking and ease-of-cleaning properties. This project is evaluating the microstructure/properties relationships of cookware provided by Calphalon, one of the world's leading makers of cookware. We are developing a detailed mechanistic explanation of cookware performance with the aim of designing new cookware microstructures to further improve cookware performance.

**PHASE II STTR: Rapid, Nondestructive Residual Stress Determination in Semiconductor Materials**

T. J. Mackin,* J. Lesniak
National Science Foundation

This STTR Phase II project supports the continued development of a new scientific tool for inspecting bonded wafer devices. Semiconductor wafer bonding has been identified as an enabling technology for a wide variety of advanced technology applications, ranging from silicon-on-insulator microelectronic substrates to packaging of MEMS devices. Though modern processing is carried out in super clean-room environments, very small particles are always present and likely trapped with high residual stresses at bonded interfaces. Our inspection tool, developed using Phase I STTR support, breaks the diffraction limit for defect resolution by measuring the stresses associated with defects. It advances the state-of-the art by using a proprietary photoelastic grey-field imaging approach and will further advance inspection technology by developing this system into a real-time quantitative imaging system.

**A Theoretical and Experimental Approach to Rapid Screening and Design of Secondary Refrigerants**

National Science Foundation, CTS 0124751

Novel combinatorial optimization methods are developed to search the astronomical space of potential secondary refrigerants and select the most promising ones to be evaluated experimentally.

**Human Factors and Ergonomics**

**Optimization-based Human Motion Simulation Models for Computer-Aided Human Centric Design**

X. Zhang,* S. W. Lee
National Science Foundation

This research project seeks to integrate the development of a series of optimization-based models for digital human motion simulation and the synthesis of movement performance descriptors such that the developed models are physically realistic and computationally efficient. These models will have open structures to incorporate movement performance descriptors that can be formulated as objective functions, constraints, or parameters, and then be empirically synthesized, tested, and determined. In return, the determined or evaluated descriptors will allow the models to render complex simulated motions via efficient computations. The project will employ empirical databases of several types of complex human movements most relevant to computer-aided workplace and vehicle design as well as virtual prototyping.
Testing of Machinable Austempered Ductile Iron (MADITM)
R. E. DeVor,* S. G. Kapoor,* O. Bhattacharyya, J. Ballou, P. Sulikowski
Internet Corporation; National Science Foundation Industry/University Cooperative Research Center for Machine Tool Systems Research

The use of austempered ductile iron (ADI) in automotive applications has been increasing due to its strength-to-weight ratio, wear and impact resistance, and vibration damping capacity as compared to forgings and cast steels. The machinability of ADI in its fully heat-treated state, however, has not been investigated extensively. Recently, Intermet has developed a machinable austempered ductile iron (MADI). The goal of this project is to investigate the ways and means to aggressively machine MADI. The resulting machining strategy will lead to machining of MADI with costs comparable to those for pearlitic and ferritic ductile iron.

Decision Support Systems for Electronics Manufacturing
P. M. Ferreira,* T. Dong, D. Mukhaphadyay, A. Seth
Rockwell-Collins, Inc.

In this project, we develop software tools that integrate product design information from STEP AP210 models of printed wire-based assemblies, factory resource information, and processing know-how. The tools being developed include producibility decision support, process simulation software, and manufacturing systems configuration software.

Process Characterization of Vibrostrengthening and Application to Fatigue Enhancement of Aluminum and Titanium Components
P. M. Ferreira,* M. Sangid, T. Cox
The Boeing Corporation

The focus of this project is the development and characterization of a vibratory finishing process for fatigue enhancement of aluminum and titanium components. Preliminary experimental studies suggest that this process can compete favorably with shot peening for certain aerospace applications. Project tasks include the development of predictive process models, experimental process validation, and the development of application guidelines for production.

Study of Low Degree-of-Freedom Parallel Kinematics for Multiscale Manufacturing
P. M. Ferreira,* Q. Yao
National Science Foundation, DMI 0422678

Parallel-kinematic mechanics are proving successful as the basis of high-performance machine tools of conventional size. This project applies novel parallel kinematic schemes to developing two- and three-dimensional micro- and mesoscale stages. It also includes developing schemes for five- and six-axis systems through the conjugation of low degree-of-freedom systems. Research includes analysis, fabrication, and testing of these systems.

A Parallel Kinematics High-Speed Machine Tool
P. M. Ferreira,* J. Dong
National Science Foundation, DMI-0422687; University of Illinois at Urbana-Champaign

A high-speed, three-axis machine tool has been developed based on a novel parallel kinematics XY table (PKXYT). The PKXYT offers attractive performance characteristics including low inertia, dynamically matched axes, trivial kinematics, and high accuracy. In order to fully exploit the capabilities of this machine, we are developing planning and control strategies to maximize performance objectives while operating within the feasible region of the particular hardware. We are evaluating the capabilities of this machine in a variety of application domains, including graphite electrodes for the EDM process, biomedical implants, and small aerospace components.

Analysis of Tool Chipping Mechanisms in Metal Cutting Processes
S. G. Kapoor,* R. E. DeVor, S. Park
Kennametal, Inc.; National Science Foundation Industry/University Cooperative Research Center for Machine Tool Systems Research

Edge chipping is one of the dominant modes of tool failure for turning and milling processes. This project aims to develop a more thorough and phenomenologically based understanding of the mechanisms that drive the tool chipping problem and the associated factors that drive the onset of tool chipping by developing a model-based predictive capability that would project the likelihood of the occurrence of chipping for a given combination of tool material, tool geometry, workpiece material, and process conditions and geometry.

* Denotes principal investigator.
An Investigation on the Machining Performance of the Reaming Process
S. G. Kapoor,* R. E. DeVor,* O. Bhattacharyya
National Science Foundation Industry/University Cooperative Research Center for Machine Tool Systems Research

The objective of this research is to develop a more complete understanding of the cutting force mechanisms and process stability for the reaming process and their influence on the hole quality. Specifically, a mechanistic model for the reaming process that will predict torque, thrust, and hole quality in reaming based on given reamer geometry, machining conditions, specific workpiece material and a set of process faults experienced during the reaming process will be developed.

CAD-Integrated Cost Model for Sand Casting
M. L. Philpott,* M. Dobsch
mphilpot@uiuc.edu
aPriori, Inc.

This project is aimed at developing new mechanistic process cost models for sand casting, directed at CAD-integrated cost estimating. The project involves the study of all direct recurring and nonrecurring costs in commercial discrete part foundries. An important part of the study is the development of geometric cost drivers (GCDs) for patterns and cores. This is a tough challenge as there are a number of complex geometric interactions associated with the design and support of different pattern/core combinations. The work includes algorithms for feature extraction as well as process models for manual and machine-based molding. The goal of the project is the development of a fully integrated feature based costing solution for sand casting.

Enterprise Cost Management
M. L. Philpott,* E. A. Hiller
Lemelson Foundation

An enterprise model for feature-based costing (FBC) is being developed through this research. The FBC methodology developed through a six-year research project with John Deere forms the foundation, using mechanistic cost models to make real-time, accurate estimates, early in the design cycle, when cost information has maximum impact. We extract geometric cost drivers automatically from the part's CAD solid model as the engineer designs it. The proposed enterprise model extends the functionality to other disciplines involved in the product development process, including manufacturing engineers, purchasing professionals, and engineering managers. The purchasing functionality takes advantage of the already extracted geometric and material information to add bi-directional automated RFQ ability from vendor to user and from user to the next customer in the supply chain. The manufacturing functionality gives engineers with greater manufacturing knowledge the ability to translate the design estimate into a factory-specific, actual cost by letting the user route the part to specific work centers.

Feature-Based Costing for Sand Casting
M. L. Philpott,* M. Dobsch
aPriori, Inc.

The feature-based costing (FBC) methodology developed through a six-year research project with John Deere forms the foundation for this work. A commercial FBC application has been developed by aPriori under license from the university. A cost script language (CSL) has been developed and a cost model development environment was built into the product. The goal of this research is to develop mechanistic cost models for sand casting and to implement them into the FBC product. This will include both recurring and nonrecurring cost models, such as pattern and core making. The development environment provides direct access to a rich set of geometry variables extracted from a CAD solid model. Additional geometry variables may also be required, and a deliverable of this project is a detailed specification for these geometry requirements.

Parametric Cost Modeling
M. L. Philpott,* R. S. Schrader, S. Hogan
John Deere Harvester

The goal of this project is to develop a methodology for real-time, feature-based costing (FBC) integrated into a computer-aided design (CAD) system. The methodology utilizes a combination of innovative memory management combinations of possible manufacturing tool paths and routings. This process enables the user of a CAD system to find the most cost-effective method of manufacture in real time, feature by feature, when designing a part. Parametric feature information is extracted from the CAD system and mathematical models convert this information into recommended manufacturing processes and costs. Initial pilot implementation at John Deere has demonstrated functionality and accuracy of the methodology and high acceptance by design and manufacturing engineers.

* Denotes principal investigator.
Process-Conscious Tool Path Generation  
J. A. Stori,*  P. Jang  
University of Illinois at Urbana-Champaign; National Science Foundation, DMI-99-84214  
Tool-path generation for machining operations has traditionally been approached from a purely geometric perspective. When the cutting mechanics and process dynamics are considered, existing tool path strategies are found to be significantly lacking. Excessive plunging and slotting, sharp velocity discontinuities, and changing cut geometry limit production rates, reduce part quality, and increase tool wear. New algorithms are developed to reduce variations in cutter engagement and chip geometry, resulting in a stable, predictable, and controllable process. Particular emphasis is placed on accommodating the dynamic limitations of modern, high-speed machining centers.

Materials Behavior

Modeling of Delamination Fracture in Advanced Aluminum-Lithium Alloys  
A. J. Beaudoin,*  R. H. Dodds, P. Kurath,*  R. J. McDonald  
National Aeronautics and Space Administration  
Strength, toughness, and weight design requirements for the next generation metallic cryotankage has promoted development of aluminum-lithium alloys. This work combines characterization of microstructure, experimental studies of fracture and fatigue, and multiscale modeling of "delamination" cracking. A parallel computer code combines models for metal plasticity with cohesive zone elements for study of fracture at grain boundaries.

Mechanism-based Theories of Strengthening and Hardening for Alloy Design and Processing  
Y. Huang*  
National Science Foundation, CMS-0084980; ALCOA  
We use the theory of Mechanism-based Strain Gradient (MSG) plasticity to investigate the size effect in alloys.

Biaxial Nonproportional Testing of Aircraft Alloys  
P. Kurath*  
General Electric, 00-2711 RFA  
An age of many service aircraft invokes questions of safety and remaining useful service life. Most baseline fatigue data are uniaxial and inherently proportional. However, several major service events are nonproportional. Current efforts attempt to quantify the effect of these loadings on the service life at several temperatures.

Multiaxial High-Cycle Fatigue  
P. Kurath*  
Dayton Research Institute, RSC00011  
With many components, it is desirable to ascertain if their actual service life is longer than that for which they were originally designed. Most fatigue test data are obtained from uniaxial specimens, and the extension of this data to more complex stress states has not been verified. Hence, long life multiaxial fatigue tests will be performed to evaluate existing design algorithms with an emphasis on high cycle fatigue. Existing multiaxial fatigue life model predictions often differ by orders of magnitude. The most appropriate algorithm for this life range will be identified or, if necessary, an alternate approach will be suggested.

Residual Stress Simulations for Welded Structures  
P. Kurath*  
John Deere Company  
Residual stresses play a major role in fatigue durability assessment. The thermal cycle during welding can cause a complex three-dimensional residual stress field that can be altered by subsequent cyclic service deformation. Analytical techniques are being developed to examine welding variables affect on the residual stresses. Structural redistribution due to subsequent cyclic events is also being addressed. The redistribution may alter variable amplitude life predictions.

Durability of Advanced Materials  
Fracture Control Program  
Recent developments in processing technology have resulted in advanced materials with lower fabrication costs and improvements in microstructural uniformity. To utilize the full potential of these materials, new design tools have to be developed in collaboration with industry. Examples of such materials include metal matrix composites and short reinforcement fibers in epoxy matrices. The metal matrix composites with higher elastic modulus, higher temperature capabilities, and lower weight compared with their counterparts represent excellent opportunities for engine, brake, and rotating components in the ground vehicle industry.

* Denotes principal investigator.
Fatigue Crack Growth and Crack Closure
Fracture Control Program

The aim of this study is to develop a life prediction methodology for fatigue crack growth based on the changes in crack opening levels with maximum stress level, crack length, geometry, mean stress, and microstructure. The primary tool for the determination of opening stress is an elastic-plastic, finite-element simulation of fatigue crack growth. Stress-strain behavior in the model accounts for slip at the microlevel as well as elastic anisotropy. Fatigue crack growth data obtained under conditions of intermediate- and large-scale yielding, including low-cycle fatigue and biaxial loading, are successfully correlated only when closure-modified parameters are employed.

Probabilistic Methods
Fracture Control Program

A comprehensive fatigue damage model is being developed to address the following issues: What governs the nucleation of a microcrack within a single grain or other suitable microstructural unit cell? What governs the growth of this microcrack into adjacent microstructural unit cells? When does the microcrack develop enough plasticity to sustain its growth? These elements will be combined into a model for the entire fatigue damage process.

Determining the Mechanical Constitutive Properties of Metals as a Function of Strain Rate and Temperature: A Combined Experimental and Modeling Approach
I. Robertson* (Mater. Sci. & Engr.), C. Smith, J. Kimberley, A. Beaudoin,* J. Lambros,* H. Padilla, S. Varadham
U.S. Department of Energy, DEFG03-02NA00072

The focus of this program is to develop a physical-based plasticity model of the response of polycrystalline material under extreme thermomechanical loading conditions. A key element will be the interaction of the deformation processes with grain boundaries. Information on microstructure evolution will be obtained by combining high strain rate testing with quasi-static tests in situ in the transmission electron microscope (TEM). The experimentally determined deformation mechanisms and processes will form the basis of a constitutive model describing the mechanical response across grain boundaries. This will be implemented in plasticity codes for polycrystalline systems and the predictions verified experimentally.

Design of High Nitrogen Steels
H. Sehitoglu,* D. Johnson, S. Kibey, J. B. Liu
National Science Foundation, DMR 03-13489

This project is aimed at building a systems approach integrating structure and properties for design of iron-based materials that are critical to the U.S. economy. We use the FeMnAl system with nitrogen and carbon as a prototype to develop our computational materials design approach. We propose a combined experimental/modeling program that spans several length scales to advance our understanding of a new class of FeMnAl alloys with carbon and nitrogen that have great potential in structural applications. Although FeMnC alloy has been used extensively due to its exceptional strain hardening, we discovered that nitrogen and aluminum additions further improve the deformation resistance. There is an urgent need to develop advanced steels with high strength and wear properties in numerous industrial applications. The research will rely on electronic-structure calculations to establish stacking fault energy and short-range order that will provide input to a micromechanical model to predict the deformation response. Several model alloys will be produced with varying compositions of aluminum and nitrogen and deformed in tension and compression to study slip and twinning behaviors.

Detwinning and Hysteresis in NiTi Alloys
H. Sehitoglu,* R. Hamilton, H. Woo (Dongguk Univ., South Korea), H. J. Maier (Univ. of Paderborn, Germany), Y. Chumlyakov (Siberian Physical and Technical Instit., Russia)
National Science Foundation

Shape memory alloys (SMA) are widely used in biomedical, sensor, and actuator applications because of their large recoverable strains and pseudoelastic behavior that arises from a reversible martensitic phase transformation. This work focuses on two characteristics observed in NiTi SMAs—namely, detwinning of martensite and hysteresis under temperature cycling. The detwinning mechanism produces recoverable strains that exceed the theoretical strains predicted for martensitic
transformations in these materials. The thermal hysteresis, defined as the width of the strain-temperature cycle, depends on the heat treatment in NiTi. The aged microstructure produces a smaller hysteresis as compared to the solutionized case. In this work, we summarize the theoretically achievable strains in single crystal NiTi and study the transformation strains and thermal hysteresis experimentally for aged and solutionized conditions.

Fe-Based Transforming Single Crystals
H. Sehitoglu,* C. Efstathiou
U.S. Air Force Office of Scientific Research

The purpose of this work is to develop new materials, based on Fe-Co-Ni-Ti, that exhibit pseudoelastic and shape memory behavior. The Fe-based alloys hold strong promise as they have high strength and high transformation strains. Methods to limit slip and improve the reversibility of transformation are currently being explored.

Linking Rail Surface Yield Strength, Microstructure, and Wear
H. Sehitoglu,* A. A. Polycarpou,* D. Canadinc, K. M. Lee
Transportation Technology Center Inc.; Association of American Railroads

The durability of rails is a major concern for railroads due to the safety and high maintenance requirements. Pearlitic steels have been used in rails for some time. This material has good low-cycle fatigue and toughness properties. However, under heavy loads, the surfaces flow plastically, producing spallation, cracking, and ultimately, fracture. Because of the increasing severity of service conditions, new materials must be explored. An alternative material to the existing pearlitic composition is the bainitic microstructure. In this research, a new methodology for durability analysis that predicts the wear resistance from first principles will be developed. We utilize nanoindentation tests to characterize the surface properties, bulk deformation tests to understand the role of crystallographic texture, and the analytical procedure for ratchetting/fatigue.

Sensors: Magneto Shape Memory Effect Harnessed for Power Generation and Sensing
H. Sehitoglu,* N. R. Miller, J. Callaway
National Science Foundation

Magnetic shape memory is a new and exciting area of research strongly related to shape memory alloys. Reversible strains of 10% have been reported by the application and removal of a biasing magnetic field. Magnetic anisotropy is the driving force for such actuation. The axis with the highest magnetic permeability can be forced to align against the preferred orientation by the application of compressive stress. The purpose of this research is to evaluate power generation, necessary for data transmission, and load sensing from the magnetic permeability changes that result from microstructural motion driven by the application of compressive biasing stresses.

Twinning in Single Crystal Steels
H. Sehitoglu,* I. Karaman, D. Canadinc
National Science Foundation, CMS-99-00090

Orientation and stress state dependence of twinning is studied with novel experiments in materials with low stacking fault energy. These materials include Hadfield and austenitic stainless steels with nitrogen additions. One of the unusual attributes of these steels is that during deformation, an upward curvature in stress-strain curves develops. Considerable tension-compression asymmetry develops in these classes of materials because of the directionality of twinning. A micromechanics modeling effort, incorporating the twin volume fraction and twin evolution, will be undertaken for predicting the stress-strain response as a function of orientation, stress-state, and texture evolution.

Stochastic Crystal Plasticity
D. A. Tortorelli,* A. J. Beaudoin, M. R. Tonks
U.S. Department of Energy Accelerated Strategic Computing Initiative

Modeling the texture evolution in crystalline materials allows for the accurate prediction of their plastic deformation. Though these models are effective, currently they are deterministic (they do not account for variation in the model parameters). Our research investigates the effect of parameter variations on texture evolution.

* Denotes principal investigator.
Materials Processing

Numerical and Experimental Investigation of Solidification in Biological Systems
J. A. Dantzig,* A. Hubel (Univ. of Minnesota)
National Aeronautics and Space Administration

This project is a combined experimental and modeling effort aimed at understanding the interaction of solidification with cells in biological systems. The objective is to understand and improve cryopreservation protocols.

Phase Field Crystal Modeling of Microstructure Development
J. A. Dantzig,* N. Goldenfeld, B. Athreya
National Science Foundation

We advance use of computational methods to model the evolution of microstructure during solidification. This is a problem having multiple length and time scales, and we use the phase field crystal method coupled with adaptive grid techniques to resolve them.

Multiscale Models for Microstructure Simulation and Process Design
R. B. Haber,* J. A. Dantzig,* D. Johnson
National Science Foundation, DMR-01-21695

This is an interdisciplinary effort to simulate microstructure evolution during processing. The efforts range in scale from atomistic to macroscopic, coupling thermal, chemical, and mechanical response. We use large-scale parallel computation to attack these problems.

Diffusion Effects in Photopolymerization
A. J. Pearlstein,* G. Terrones (Los Alamos Natl. Lab.)
University of Illinois at Urbana-Champaign

Photopolymerization is important in fabrication of microelectronics, dental prostheses, and materials for a number of other applications. Since light is attenuated as it passes through the curing medium, nonuniformity is inherent to the process. We have recently shown how nonuniform photoinitiation leads to nonuniform conversion of monomer and nonuniform molecular weight distributions in photopolymerized materials. Current work focusing on effects of diffusion already has shown that diffusion can increase the degree of nonuniformity in the final material since initiator diffusion to the front of the layer leads to increased rates of initiation and monomer conversion there.

Contacting and Solidification in Casting-by-Design
B. G. Thomas,* J. Sengupta, A. Sundararajan
National Science Foundation, Collaborative Research, NSF DMI 04-23794

The continuous casting of thin aluminum strip with a single-wheel melt spinning process offers great potential for low-cost production of finished products with unique surface textures. To perfect this process requires fundamental understanding of the phenomena that control solidification shape, including flow oscillations in the melt pool, meniscus interaction with the wheel surface, intermittent solidification against the moving wheel, and thermal distortion. Aided by measurements by collaborators at Cornell University, advanced computational models are being applied at the University of Illinois at Urbana-Champaign to achieve this new understanding. Recent simulations match the contoured shape of the strip surface, based on the initial shape of the solidified meniscus, which is also the subject of model investigation.

Development of a Process to Continuously Melt, Refine, and Cast High-Quality Steel
B. G. Thomas,* K. Peaslee,* J. Peter, L. Zhang, J. Aoki
Department of Energy; University of Missouri-Rolla; Continuous Casting Consortium (Accumold, Huron Park, Canada; Algoma Steel, Sault Ste. Marie, Canada; Corus Strip Products, Ijmuiden, Netherlands; Fundacion Labein, Bilbao, Spain; Mittal Riverdale Steel, Riverdale, Ill.; LWB Refractories, York, Pa.; Nucor Steel, Decatur, Ala.; POSTECH, Pohang, South Korea; Steel Dynamics, Columbia City, Ind.)

Many operational problems and costs are associated with feeding the continuous casting process from the continuous electric furnace steelmaking operation using batch ladles. A multifaceted project combining plant experiments, lab experiments, and computational modeling aims to design a fully continuous process using a series of intermediate vessels where alloy addition and refining occurs at steady state. The University of Illinois at Urbana-Champaign role focuses on the computational modeling aspects of the project. Three-dimensional models of multiphase turbulent fluid flow, mixing, and particle motion are being developed to assist with the design calculations. The results will help to design a feasible process, while identifying and solving possible problems prior to the pilot plant stage.

* Denotes principal investigator.
Distributed Subwavelength Photonic Sensors for In-situ High Spatial and Temporal Resolution Monitoring in Manufacturing Environments

B. G. Thomas,* M. Okelman

National Science Foundation, SIRG DMI 05-28668; Continuous Casting Consortium (Accumold, Huron Park, Canada; Algoma Steel, Sault Ste. Marie, Canada; Corus Strip Products, Ijmuiden, Netherlands; Fundacion Labein, Bilbao, Spain; Mittal Riverdale Steel, Riverdale, Ill.; LWB Refractories, York, Pa.; Nucor Steel, Decatur, Ala.; POSTECH, Pohang, South Korea; Steel Dynamics, Columbia City, Ind.)

Monitoring of mold level and meniscus behavior is important for controlling quality during the continuous casting process. This project aims to develop new sensors to measure temperature in the mold very near to the meniscus, initially to use as a new research tool to investigate meniscus behavior to better understand defect formation. The ultimate goal is to revolutionize online thermal monitoring of industrial continuous casting molds. A process will be developed to insert sensors manufactured at University of Wisconsin-Madison into the mold coating layer. Tests of sensor integrity will be conducted, data collected, and the signals analyzed using computational models. The meniscus region will further be modeled computationally to predict events during an oscillation cycle, including modeling of the sensor itself. This will determine the relationship between the sensor signal and the actual meniscus events. Insights gained will enable optimization of the size and location of the new sensors and interpretation of their signals to gain maximum benefit from their installation into operating molds.

Entrapment of Bubbles and Inclusions during Flow in the Mold


Continuous Casting Consortium (Accumold, Huron Park, Canada; Algoma Steel, Sault Ste. Marie, Canada; Corus Strip Products, Ijmuiden, Netherlands; Fundacion Labein, Bilbao, Spain; Mittal Riverdale Steel, Riverdale, Ill.; LWB Refractories, York, Pa.; Nucor Steel, Decatur, Ala.; POSTECH, Pohang, South Korea; Steel Dynamics, Columbia City, Ind.)

Inclusion particles and bubbles carried by the turbulent flow of molten steel through the continuous casting nozzle and mold pool lead to serious surface and internal defects in the final product. Three-dimensional turbulent fluid-flow models are being applied to understand and quantify inclusion transport and entrapment for different casting conditions. The models incorporate the effects of nozzle clogging and inclusion entrapment by the solidifying dendritic interface. The computations are validated and augmented with measurements, metallographic analysis, and plant trials conducted at POSCO and elsewhere.

Flow Dynamics and Inclusion Transport in Continuous Casting of Steel

B. G. Thomas,* S. P. Vanka,* L. Zhang

National Science Foundation, GOALI DMI-0115486; Continuous Casting Consortium (Accumold, Huron Park, Canada; Algoma Steel, Sault Ste. Marie, Canada; Corus Strip Products, Ijmuiden, Netherlands; Fundacion Labein, Bilbao, Spain; Mittal Riverdale Steel, Riverdale, Ill.; LWB Refractories, York, Pa.; Nucor Steel, Decatur, Ala.; POSTECH, Pohang, South Korea; Steel Dynamics, Columbia City, Ind.)

Computational models of transient, multiphase fluid flow are being developed, validated, and applied to improve understanding of transient flow, inclusion transport, and defect formation in the mold region during the continuous casting of steel slabs. Process parameters, such as nozzle geometry and gas injection rate, which are easy to change and yet profoundly influence both flow and product quality, are being optimized. Models to compute the transport and entrapment of inclusion particles are being tested through water model experiments, steel plant trials, and metallographic measurements at several steel companies that are cosponsoring this research.

Fluid Flow, Heat Transfer, and Interfacial Phenomena in Nozzle Refractories

B. G. Thomas,* Z. Hashisho, A. Sundararajan

Continuous Casting Consortium (Accumold, Huron Park, Canada; Algoma Steel, Sault Ste. Marie, Canada; Corus Strip Products, Ijmuiden, Netherlands; Fundacion Labein, Bilbao, Spain; Mittal Riverdale Steel, Riverdale, Ill.; LWB Refractories, York, Pa.; Nucor Steel, Decatur, Ala.; POSTECH, Pohang, South Korea; Steel Dynamics, Columbia City, Ind.)

Dolomite nozzles differ from conventional nozzles in having higher resistance to alumina clogging but are more easily eroded. Fundamental modeling studies are being performed to understand and characterize the behavior of these nozzles, to compare them with conventional nozzles, and to optimize their use in service. Specific studies include an analysis of the flow of argon gas within the porous refractory walls to learn the gas distribution upon entering the molten steel. Heat transfer through the refractory walls is being modeled for a variety of realistic conditions to understand the role of steel skulling on clogging for different refractory properties. Finally, the interfacial...
behaviors that govern the clogging attachment, the dissolution of the refractory, and the thermodynamic reactions are being studied.

Initial Solidification and Meniscus Hook Formation in Continuous Slab Casting
Continuous Casting Consortium (Accumold, Huron Park, Canada; Algoma Steel, Sault Ste. Marie, Canada; Corus Strip Products, Ijmuiden, Netherlands; Fundacion Labein, Bilbao, Spain; Mittal Riverdale Steel, Riverdale, Ill.; LWB Refractories, York, Pa.; Nucor Steel, Decatur, Ala.; POSTECH, Pohang, South Korea; Steel Dynamics, Columbia City, Ind.)

The first few seconds of solidification at the meniscus create the final cast product surface and may include defects such as deep oscillation marks, surface depressions, and subsurface hooks in the microstructure, if conditions are not optimal. Computational fluid flow, heat flow, and stress models of the meniscus region are being developed and applied to simulate these phenomena. Plant measurements such as mold temperature, liquid surface shape, and metallographic examination of oscillation marks and hooks are being conducted on slabs cast at POSCO. Together, ways to optimize casting conditions such as speed, level control, superheat, mold oscillation practice, and mold powder composition are being investigated to minimize meniscus hook depth.

Investigation of Steel Cleanliness during Ingot Teeming
B. G. Thomas,* L. Zhang,* B. Rietow
Ingot Metallurgy Forum
Inclusions trapped during bottom-poured static-cast ingots lead to quality problems in the final product. Computational models of transient, multiphase fluid flow in this process are applied to improve understanding of inclusion transport and capture. Process parameters, such as teeming rate and runner geometry are being optimized. Plant experiments to measure inclusion locations, refractory wear, and other relevant phenomena are being conducted for additional insight and model validation.

Thermal Stress Analysis of Solidifying Steel Shells
B. G. Thomas,* S. Koric, J. Sengupta, K. Xu, C. Ojeda
Continuous Casting Consortium (Accumold, Huron Park, Canada; Algoma Steel, Sault Ste. Marie, Canada; Corus Strip Products, Ijmuiden, Netherlands; Fundacion Labein, Bilbao, Spain; Mittal Riverdale Steel, Riverdale, Ill.; LWB Refractories, York, Pa.; Nucor Steel, Decatur, Ala.; POSTECH, Pohang, South Korea; Steel Dynamics, Columbia City, Ind.)

A coupled, two-dimensional, transient finite-element model has been developed to predict temperature, shrinkage, and stress development in both horizontal and vertical sections through the solidifying shell as it moves down through the caster. The model includes the effects of the volume change during phase transformation, ferrostatic pressure, the generalized plane strain stress state, the constraining influence of the mold, creep plasticity, and the dynamic effect of solidification shrinkage on heat transfer across the interfacial gap between the mold and the shell. The model is being applied to simulate the early stages of solidification, ideal taper for different steel grades, maximum casting speed to avoid excessive bulging, and understanding crack formation. Finally, the model is being extended to simulate behavior in complex shapes including beam blanks, and thin slabs in funnel molds with full three-dimensional simulations.

Thermal Stress and Surface Crack Formation in Continuous Casting
B. G. Thomas,* J. Sengupta, K. Xu
Continuous Casting Consortium (Accumold, Huron Park, Canada; Algoma Steel, Sault Ste. Marie, Canada; Corus Strip Products, Ijmuiden, Netherlands; Fundacion Labein, Bilbao, Spain; Mittal Riverdale Steel, Riverdale, Ill.; LWB Refractories, York, Pa.; Nucor Steel, Decatur, Ala.; POSTECH, Pohang, South Korea; Steel Dynamics, Columbia City, Ind.)

Thermal stress in the steel shell as it moves down through the mold and between the rolls in the secondary cooling zones contributes to many different problems, including transverse cracks, slab shape problems, and support roll wear. Mathematical heat flow and stress models are being developed to predict the temperature, and the associated distortion, stresses, and strains, both in and below the mold. In addition, criteria for crack formation will be developed, based on steel ductility measurements and a model of grain size and nitride, oxide, and sulfide precipitation to track the susceptibility of different steel grades to ductility problems. Results will be compared with experience prior to establishing cracking criteria and applying the models to understand and explore ways of preventing cracking problems.

Computational Tools for Analysis of Chaotic Mixing
C. L. Tucker,* J. Phelps, M. Wilhelm
University of Illinois
Chaotic fluid motions, in which the velocity field is known exactly but particle positions are ultimately unpredictable,

* Denotes principal investigator.
provide the best possible mixing in laminar flow. We are developing computational tools to select and design chaotic mixing flows. One tool efficiently searches for flow protocols that are globally chaotic. Another characterizes the distributive mixing properties of a globally chaotic flow. These tools are applicable to polymer processing as well as to microfluidics.

**Fiber Orientation in Injection Molded Composites**

C. L. Tucker,* J. Wang  
*Delphi Automotive Systems*

Some injection-molded plastics are reinforced with short glass fibers. The flow patterns during mold filling cause the fibers to orient in specific directions, making the part stronger and stiffer in those directions, and weaker and more compliant in others. Proper design of these parts requires that we know these orientation patterns. We have combined 2-D and 3-D computational fluid mechanics software with a theory of fiber orientation to predict orientation patterns in molded features with complex geometry. Current work focuses on improving the accuracy of the model for small parts with short flow lengths.

**Fiber Orientation Modeling for Long-Fiber Thermoplastics**

C. L. Tucker,* J. H. Phelps  
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*U.S. Department of Energy, Pacific Northwest National Laboratory*

Long-fiber thermoplastics (LFTs) are polymer-matrix composite materials that can be injection or compression molded, but have much longer fibers than conventional short-fiber composites. As part of a project to develop predictive engineering capabilities for these materials, we are studying the applicability of existing process models to these materials, and developing new models. Issues include how to characterize the microstructural features of these materials (fiber orientation, fiber length distribution, fiber curvature), and how to predict the effects of processing flow on this microstructure. Preliminary results show that LFTs behave qualitatively like more conventional composites, but that we need improved models to get useful quantitative predictions of mechanical performance. We are developing those models.

**Flow-Enhanced Crystallization in Injection Molding**

C. L. Tucker,* T. N. Pham  
*ctucker@uiuc.edu*  
*Center for Advanced Engineering of Fibers and Films, National Science Foundation, EEC-973160*

Common polymers, such as polyethylene and polypropylene, crystallize much more rapidly when they are sheared in a flow field than without shear. For sufficiently high shear rates, the crystalline morphology changes from spherulitic to a row-nucleated structure. We are modeling the kinetics of this crystallization during flow, in situations typical of injection molding, and using the resulting microstructures to predict the mechanical properties of molded parts, such as stiffness and thermal expansion. The end goals are to provide a computer-aided engineering tool to optimize the dimensional accuracy and mechanical performance of molded plastic parts, and to improve the quality and reliability of these parts.

**Mixing and Microstructure Control in Polymer Processing**

C. L. Tucker,* T. Pham  
*Center for Advanced Engineering of Fibers and Films, National Science Foundation, EEC-9731680*

A polymer blend consists, at the microscopic level, of droplets of one polymer dispersed in a continuous matrix of another. The microstructure of a blend (i.e., the size, shape, and orientation of the droplets) has a major influence on the properties of the bulk material. We are developing theoretical models for how this microstructure arises during processing, due to deformation during mixing. We have also written numerical simulations to predict the microstructure in complex flows, particularly "smart blending devices" based on chaotic advection.

**Nano-, Micro-, and Meso-Technology**

**ITR: Computational Prototyping of Micro-Electro-Fluidic-Mechanical Systems**

N. R. Aluru*  
*National Science Foundation*

In this research we focus on a particular class of microelectromechanical systems (MEMS), referred to as microelectrofluidicmechanical systems (MEFMS). MEFMS are miniaturized sensors, actuators, devices, and systems, where mechanical, electrical, and fluidic energy domains play a central role. Many electrofluidicmechanical devices have been designed and fabricated (e.g., pressure sensors, accelerometers, gyroscopes, digital micromirrors, microphones, and other

* Denotes principal investigator.
devices). While fabrication approaches for these devices are mature enough, investigation of design alternatives for many of these devices is currently limited because of the lack of computational design tools. In this research, we are developing analysis and design tools for microelectrofluidic mechanical systems.

Development of Velocity and Temperature Measurement Methods for Complex, Three-Dimensional Microvascular Networks
K. T. Christensen,* S. White* (Aerosp. Engr.), E. Yamaguchi, V. K. Natrajan

Microscopic particle-image velocimetry is being adapted to the study of flow within three-dimensional microvascular systems. In addition, a laser-induced fluorescence method for measuring temperature fields in microfluidic systems is being developed and applied to assess the cooling capabilities of such systems. This work is part of a larger effort in the development of self-healing and self-cooling composite materials using complex microvascular networks.

Atomistic-Based Continuum Models of Micro- and Nanoscale Engineered Systems/Processes
R. E. DeVor,* S. G. Kapoor,* Y. Huang,* K. J. Hsia,* J. Samuel
National Science Foundation; Sandia National Laboratory

Carbon nanotubes (CNTs) possess extraordinary mechanical properties that make them an ideal reinforcement for polymer composite materials, particularly for applications in the emerging world of miniaturization technologies. However little is known about the manufacturability of such materials. In this project, the micromachinability of a polycarbonate nanocomposite containing multiwalled carbon nanotubes (MWCNTs) is investigated and contrasted with its base polymer (polycarbonate). Comparisons will also be developed with other, more traditional, fiber-reinforced polycarbonates.

Collaborative Research: Micro/Mesoscale Machine Tool (mMT) Systems
R. E. DeVor,* S. G. Kapoor,* X. Liu
National Science Foundation, DMI-0114717

Miniature components are needed for a wide range of applications from the aerospace to the biomedical industries. Given the part size and the cutting forces present during micromachining, use of large machine tools results in a very inefficient utilization of resources and costs. The goal of this project is to design and evaluate mesoscale machine tools that are capable of achieving relative accuracy between $10^{-2}$ and $10^{-4}$ when machining objects with dimensions between 50 and 5,000 μm and producing three-dimensional features.

Development of a Microscale Machine Tool System Testbed
R. E. DeVor,* S. G. Kapoor,* X. Liu, A. Phillip, A. Balasubramanian
Center for Nano-Chemical-Electrical-Mechanical Manufacturing Systems: National Science Foundation/Nanoscale: Science and Engineering Center

The ultimate realization of Nano-CEMMS will require the existence of concepts and methods that will enable the integration of nanoscale devices and subsystems into mission-oriented engineered systems, requiring manufacturing capabilities that include high relative accuracies and precision, complex three-dimensional feature generation, and excellent surface quality. To this end, this project proposes to design and construct a miniature fully functional, three-axis computer controlled milling and drilling center capable of creating holes, slots/channels, and sculptured surfaces in the range of 10 to 1000 microns, evaluate and assess the manufacturing capability of this machine tool in terms of quality and productivity metrics, and prove the concept through the manufacture of several features/components/structures of significance to the center, including certain aspects of microchannel array systems and other elements that ultimately will be part of the three testbeds that the center will develop in its five-year research plan.

Development of Micro- and Mesoscale Machine Tool Technology
R. E. DeVor,* S. G. Kapoor,* K. Bourne
Ingersoll Machine Tools, Inc.; National Institute of Standards and Technology/Advanced Technology Program

Miniaturization technology, innovatively applied to machine tool development, holds an important key to the manufacturing challenges now being created by the exploding world of micro- and mesoscale technology. To this end, the goal of this project is the development of the science and technology basis for the production of micro- and mesoscale components through the creation of “miniaturized” machine tool systems (referred to as meso-machine tools, mMTs). The proposed mMT Area Nano-, Micro-, and Meso-Technology will be a three- to four-axis machining center with a target size of 250 x 250 x 250 mm

* Denotes principal investigator.
or smaller. Capability will include machining three-dimensional precision surfaces, currently a major limitation of competing technologies in the MEMS area, at a cost reduction targeted to be at least one order of magnitude lower than existing ultraprecision machine tools ($250,000 versus our target of $10,000 to $25,000). At the completion of the project, prototype mMT testbeds will be available and will be tested for proof-of-concept using components now machined using conventional ultraprecision machine tool technology.

Microfactories for Precision Parts
ALION Science and Technology, Inc.

The goal of this project is to develop a second-generation microfactory for the precision manufacture of components for aerospace application. The defining characteristic of the second generation microfactory will be its ability to manufacture complex miniature products consisting of several discrete components with minimal external intervention. This will necessitate the development of processing throughput capabilities that are amenable to large-scale integration. In this microfactory configuration, microassembly and efficient material flow, including parts, tools, scrap, and such, will assume a central role. In addition, to facilitate maintenance with high system up-time, a plug-and-play architecture is being envisioned that will require the development of the underlying communication, information flow, and control structures.

Optical Negative Index Material for Imaging and Information Processing
N. Fang,* S.-Y. Wang* (HP Labs), X. Zhang (UC Berkeley), D. R. Smith (Duke Univ.)
Defence Advanced Research Projects Agency (DARPA)

We investigate a novel material concept: optical negative index materials (OptoNIM) to address ultimate demands in defense and civilian missions of information processing functions such as modulating and switching at small scales, by their broad applications in lightweight, compact, and optically switchable photonic devices.

A Resonant Photonic Superlattice Sensor with Large Enhancement Factor of Evanescent Waves
N. Fang*
NSF Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems (NanoCEMMS)

To provide the essential embedded sensing capabilities on the center's Micro-Nano toolbit, we propose to design and embed a set of small footprint and transparent photonic superlattice sensors that promise high enhancement of evanescent waves. A set of photonic superlattice sensors optimized at desired working wavelength will be designed and manufactured using standard cleanroom process technologies. We prototyped the initial design of sub-wavelength near-field sensor with surface plasmon controlled beaming. The giant enhancement factor, and thus the sensitivity of chemical species, will be experimentally established and calibrated.

Ab Initio Simulation of Electrokinetic Nanoflows
J. G. Georgiadis,* D. C. Karampinos
NSF Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems, DMI-0328162; NSF Center of Advanced Materials for the Purification of Water with Systems (CAMPWS), CTS-0120978

The role of this project is to develop quantum mechanical (ab initio) models that can combine with "best-practice" molecular dynamics and multiscale approaches in the simulation of electrokinetic nanoflows. These one-of-a-kind simulation tools will be used to understand and characterize the molecular gate technology employed in developing the micro-nano-fluid network toolbit of the Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems (Nano-CEMMS).

ITR/SY: Computational Design of Mixed-Technology Systems
National Science Foundation

The objective of this research is to develop new computational design tools with rigorous experimental validation to enable design and development of distributed, heterogeneous mixed-technology systems. At the component or the device level, the research will focus on four building blocks: microelectromechanical systems (MEMS), biological microelectromechanical systems (bio-MEMS), nanoelectromechanical systems (NEMS), and biological ion channels integrated with nanoelectronics (nanobioelectronics). Efficient computational design tools integrated with experimental validation will be developed for each of these building blocks. At the system level, the research focuses on integration of MEMS and bio-MEMS with conventional electronics. Device-level modeling research will focus on development of new, scattered-point computational methods for analysis of micro- and nanoscale devices.

* Denotes principal investigator.
development of multiscale approaches combining continuum and molecular approaches; and development of efficient, reduced-order modeling approaches. System-level modeling research will focus on development of new algorithms and techniques to integrate various microdevice partial differential equations solvers with the circuit simulator SPICE3. The experimental effort will focus on development of new fabrication approaches for realizing nanobioelectronics, NEMS, and systems-level integration of MEMS and bio-MEMS with conventional electronics.

Analysis of Micro- and Nano-Fluidic Network for Scheduling and Planning of Fluid Delivery
Y. Huang*
National Science Foundation Center for Nanoscale Chemical-Electrical-Mechanical-Manufacturing Systems; University of Illinois at Urbana-Champaign

We are developing multiscale models to study micro- and nano-fluidic networks for scheduling and planning of fluid delivery.

Mechanism-based Modeling and Simulation in Nanomechanics
Y. Huang*
National Science Foundation, CMS-01-03257; Mechanical and Industrial Engineering, Program for Exploratory Studies

We develop multiscale computational methods to link atomistic models with continuum analysis in order to study the nanoscale mechanical behavior of materials.

A Nanoscale Quasi-Continuum Theory with Applications to Carbon Nanotubes
Y. Huang*
Mechanical and Industrial Engineering, Program for Exploratory Studies; National Science Foundation, CMS-00-99909; Alexander von Humboldt Foundation; National Science Foundation of China; National Center for Supercomputing Applications

This study aims at developing a quasi-continuum theory for nanoscale applications. It incorporates the information from atomistic studies into a continuum framework through the constitutive modeling.

Atomistic Origins of Ion Bombardment Nanoscale Surface Instability
H. T. Johnson,* J. B. Freund
National Science Foundation, CMS 05-10624

Molecular dynamics and continuum models are used to explain the tendency of medium energy ions incident on an initially flat surface to preferentially amplify surface roughness, even as thermally activated mass transport tends to smoothen surfaces out to longer length scale features. Numerous possible stabilizing and ordering mechanisms occurring at the atomistic scale are investigated, including viscous relaxation, sputtered atom redeposition, and other short time-scale correlations between change in surface height and spatial derivatives of the local surface morphology. A large database of molecular dynamics results as a function of variables, including temperature, stress, incident angle, energy, and surface characteristics, is developed and compared to experimental data obtained by collaborators working in a range of processing regimes. The goal is to develop a comprehensive, accurate, atomistically informed continuum model that will be useful in not only explaining experimental observations but also in predicting results under new processing conditions. Calculations of the resulting nanostructure electrical and optical properties will lead to significant progress toward the nanomanufacturing of useful structures for application purposes.

Deformation and Disorder in Hydrogel Photonic Crystals
H. T. Johnson*
Petroleum Research Fund of the American Chemical Society, 42421-AC10

Hydrogel photonic bandgap materials are polymer systems with periodic microstructures designed to diffract particular frequencies of incident light. Large swelling and contraction in response to environmental stimuli such as changes in pH induce shifts in the frequencies of diffracted light. Thus, these systems are ideal candidates for a wide range of chemical and biological sensors, as well as for waveguides and other optical applications. This program seeks to understand two specific problems in developing these materials for real applications, focusing on issues identified in collaboration with experimentalists studying the same systems. The first area is the effect of deformation on the performance of hydrogel photonic crystals. Finite element analysis of the mechanics and electromagnetics of deformed hydrogel photonic crystals are used to understand how deformation affects optical response. Both the material elastic and dielectric properties may change significantly due to the large strains present. The second area is the effect of disorder on the performance of hydrogel photonic crystals. Finite difference time domain calculations of electromagnetic transmission are used to reveal how point, line, and planar defects, as well as disorder in feature size, shape, and position may have useful or deleterious effects in these materials. The project

* Denotes principal investigator.
will contribute to a new generation of novel hydrogel photonic materials that exploit deformation and disorder for devices with enhanced functionality, such as lower losses, better switching characteristics, and tunable spectral properties.

**Optimized Photonic Bandgap Devices with Nanoscale Disorder**

H. T. Johnson,* D. A. Tortorelli, K. D. Choquette, W. R. Frei

*National Science Foundation, ECS 05-08473*

Topology optimization is used to design photonic crystal systems enhanced by highly nonuniform nanoscale features that can be fabricated using advanced nanolithographic methods. By using optimization-based design, figures of merit for common photonic bandgap devices may be increased by as much as two orders of magnitude over the current state of the art. Entirely new photonic bandgap devices, with powerful new functionality, may be possible using this new design paradigm. Preliminary computational work is extremely promising; in this program the computational framework is extended, and nanofabrication techniques are used to implement and test the proposed designs. Specifically, the optimization approach is based on an adjoint method; the underlying electromagnetic scattering problem is solved using finite element analysis; and the nanofabrication makes use of electron beam lithographic methods. The separate objectives of the program are then to use topology optimization to computationally generate novel photonic bandgap devices that are currently not possible with existing design methods; constrain the optimization tool to yield nanomanufacturable devices, according to known fabrication constraints imposed by state-of-the-art nanomanufacturing tools; improve optimized designs by striving for robustness with respect to typical disorder introduced in nanomanufacturing; and fabricate and test the computationally identified designs as a way to validate the proposed approach.

**Strain Effects on Photonic Device Properties across Length Scales**

H. T. Johnson*

*National Science Foundation, CMS-0296102*

Computational and analytical models are used to study three separate but related fundamental problems in electronic and optical materials behavior. Applications of the research are in microelectronics and telecommunications devices. At the atomic scale, coupling of mechanical and electronic structure is studied using tight-binding atomistic methods. At the mesoscale or 10-100-nm level, strain effects on optical properties of quantum dots are studied using finite element analysis. At the continuum scale, residual stress effects on nano-, micro-, and meso-technology devices are studied using continuum analytical and coupled FEM-atomistic methods.

**Machinability of Carbon Nanotube Composites**

S. G. Kapoor,* R. E. DeVor,* K. J. Hsia,* Y. Huang,* A. Dikshit

*National Science Foundation*

This project is to assemble a multidisciplinary research team with complementary expertise to investigate fundamental scientific and technical issues related to the machinability of a class of very important material systems for nanotechnologies—carbon nanotube composites. The ultimate goal of this research project is to produce a composite with optimized properties and excellent machinability by tailoring the nanostructures. To achieve this, understanding the machining mechanisms related to the nanostructures of CNT composites and being able to identify critical nanostructural parameters through modeling of machining process are crucial.

**Mesoscale High Speed Milling**

S. G. Kapoor,* R. E. DeVor,* A. Honegger

*The Boeing Company*

This research has two main thrusts. First, error modeling and measurement techniques will be developed for mMTs. Second, the University of Illinois at Urbana-Champaign will assist Boeing with the design and assembly of a mesoscale machining testbed (mMT) for high-speed milling. The specific goals of the research are the application of existing error models to mMT, the identification and modeling of error sources unique to micromilling and mMT, the development of error measurement methods for mesoscale machine tools, and assisting design, assembly, and setup of a three-axis mMT for micromilling and drilling. Error model development will consist of two main research tasks: application of existing error models to mMT testbeds and modeling of error components specific to micromilling and mMTs. New error measurement techniques will also be developed.

* Denotes principal investigator.
Design Rules for High-Temperature Microchemical Systems
P. J. A. Kenis,* R. I. Masel,
E. G. Seebauer (Chem. & Biomol. Engr.);
M. A. Shannon;* D. Vlachos (Univ. of Delaware)
U.S. Department of Defense, Multiple University Research Initiative (MURI)

Microfabrication of high-band gap materials and MEMS programs are combined with the study of energetics to help advance a new technology: microcombustion. Noncatalytic, spontaneous gas phase combustion within extremely small cavities has long been thought to be impossible. However, Richard Masel at the University of Illinois at Urbana-Champaign had developed a surface reaction theory that suggests that microcombustion could be possible, if wall quenching could be suppressed in a unique way. This seed project, funded by the Defense Advanced Research Projects Agency Electronics Technology Office through DynCorp, demonstrates that a hydrocarbon flame could be initiated and sustained within a microcavity, using an engineered materials combustor. A patent has been awarded on this fundamental work. We have received a Multiple University Research Initiative grant from the Department of Defense and a Critical Research Initiative grant from the University of Illinois at Urbana-Champaign to conduct basic research to understand and exploit this strongly coupled phenomenon for high-temperature microchemical systems. The goal is to create new microreactors to perform chemical processing that is very difficult on the normal scale and to generate very high-power density power at the microscale.

Collaborative Research: Head-Disk Interface for Hard-Disk Drive Areal Data Density of 1 Terabit per Square Inch
A. A. Polycarpou,* J. L. Knight, C. D. Yeo
National Science Foundation

In magnetic recording hard-disk drives, the read/write transducer must be very closely separated from the rotating disk that carries the magnetic media in order to achieve extremely high areal data densities. Modern state-of-the art hard-disk drives are capable of storing 120 Gbits per square inch (1 Gbit is 80 billions bits), and it is projected that the magnetic spacing for 1 Tbit (trillion) per square inch will be 5-6 nanometers. In this collaborative research, the investigator and his colleagues will undertake a systematic study to investigate the head-disk interface instability, develop models to predict it, design head-disk interfaces based on these models, and fabricate them and test them, in collaboration with the Information Storage Industry Consortium and its industrial partners.

Dynamic Contact Modeling and Experiments on Miniature Systems
A. A. Polycarpou,* X. Shi, A. Y. Suh
National Science Foundation

In this five-year Faculty Early Career Development (CAREER) Program research, a systematic approach to dynamic contact studies of microsystems will be performed based on system-independent interfacial models that are coupled to the system dependent dynamics of the interface. A unique feature of the proposed approach is the direct incorporation of the intermolecular (adhesion) forces and kinetic friction models based on continuum mechanics into a dynamically moving contact interface. This will enable contact length scales from micrometer to millimeter range and beyond to be covered.

Friction and Vibration Interaction for Ultralow Fly-Height Head Disk Interfaces Intended for 1 Tbit/In² Areal Densities
A. A. Polycarpou,* A. Y. Suh
Information Storage Industry Consortium

The objective of this research is to study the interaction between friction, adhesion, and vibration of ultralow flying head disk interfaces and their effect on the fly-height and off-track motions of the recording slider. The focus of the research is to characterize the contacting interface and develop appropriate quasi-dynamic friction and adhesion models, develop linear and nonlinear dynamic models for the head disk interface system, and combine the adhesion, friction, and vibration models to accurately predict the instantaneous adhesion and friction forces, normal (fly-height/bouncing vibrations), and lateral (off-track) motions.

Surface Characterization and Capillary Adhesion for Microelectromechanical Systems (MEMS)
A. A. Polycarpou,* X. Xue
Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign

In this project, we are investigating the effect of surface texturing on MEMS surfaces on capillary adhesion and reliability. Specifically, adhesion experiments, using a specialized apparatus will be conducted using actual MEMS devices. Also, we will be developing improved capillary adhesive theory that accounts for rough surface contact as well as elasto-plastic contact.
**In-situ TEM and SEM Studies of Fundamental Deformation and Failure Processes of Nanograined FCC Metals Using MEMS Stages**
I. Robertson* (Mater. Sci. & Engr.); T. A. Saif,* J. Han, K. Hattar

*National Science Foundation, DMR 0237400*

The properties of materials at nanoscale regime are controlled by laws different from their large-scale counterparts. For example, the underlying mechanisms controlling the deformation of nano materials change from being dominated by dislocation to grain boundary processes. Understanding these processes at nanoscale is important if reliable devices and new structural materials are to be constructed intelligently. In this project, mechanical properties of nanograined materials are measured, *in situ* in the transmission electron microscope (TEM), using a novel microelectromechanical systems (MEMS) instrument developed at the University of Illinois. Through these measurements, it will be possible, for the first time, to directly correlate the macroscopic mechanical properties with the underlying mechanisms that govern such properties in nanograined materials.

**Effect of Grain Boundary and Size on Electro-Thermomechanical Properties and Internal Friction of Nanograined Thin Metal Films Using MEMS Devices**

T. A. Saif,* J. Rajagopal

*National Science Foundation, ECS-0304243*

Submicron metal films and wires are essential ingredients for micro/nanoelectronics as well as for microelectromechanical systems (MEMS) and nanomechanical systems. Such metal structures are typically polycrystalline in nature, with nanoscale grains that offer an abundance of grain boundaries. Such boundaries play a major role in determining the thermoelectromechanical properties of nanograined metals. Such properties at nanoscale are far from being fully understood. This project explores the role of grain boundaries in determining elastic and plastic properties, electrical and thermal conductivity, and internal friction of nanograined metals. MEMS sensors and actuators are employed in exploring these properties.

**Novel Test Methodology for High Temperature Micro- and Nano-Tensile Testing**

T. A. Saif,* J. Han

*U.S. Air Force, AFRL/MLLMD, 5-4784*

It is widely accepted that materials’ behavior, particularly failure characteristics, strongly depends on their size. Uniaxial tensile testing allows direct measurement of materials’ stress–strain data without any prior phenomenological model. The objective of this project is to develop a microscale apparatus that allows testing of miniature samples (fabricated separately from the apparatus) under tension and compression at various temperatures (as high as 500°C), and at different strain rates.

**Self-Assembled Nanowires**

M. T. A. Saif,* S. Mani

*Mechanical Engineering Gauthier Program for Exploratory Studies; National Science Foundation, ECS 024103*

Forming engineered nanostructures is a major challenge in the field nanotechnology. Here, we form self-assembled nanowires and investigate the underlying mechanics that govern the self assembly. We have shown experimentally that plasma-deposited silicon dioxide may crack when annealed due to residual stress. We form nanowires by simply depositing nickel in the cracks, which forms wires with lateral dimension of around 20 nm. The length of the wires can be several micrometers. We study the parameters that govern the dimension of the wires and their geometry, as well as their mechanical and transport properties.

**Thermo Mechanical Studies of Cells with Nano Probes on a Si Substrate**

T. A. Saif,* S. Yang

*National Science Foundation, ECS 0524675*

Cell adhesion plays a fundamental role on a variety of cell functionality, such as growth and cell division, as well as on disease progression such as angiogenesis. Until today there is very little knowledge on the cooperative arrangements and synergistic interactions between adhesion sites, significance of their cluster size, shape, their characteristic length scales, and their dynamics. This project addresses some of the yet unanswered questions on cell adhesion and provides fundamental insight on the relation between cell mechanics and disease progression. The approach is to develop a novel Si substrate and a 3-D force sensor. The cellular investigations include size and strength of single adhesion sites; thermal activities during formation of the sites; and inter- and intra-cellular response of cells due to thermal stimuli applied at the sites.

**Active Nanopore Membranes**

M. A. Shannon*

*NSF Center of Advanced Materials for the Purification of Water with Systems (CAMPWS)*

The objective of this project is to develop a low-energy usage, active ion pump for separating ions from water. In desalination systems, water molecules are separated from the influent aqueous ionic solution that they reside in,

* Denotes principal investigator.
leaving a higher concentrated aqueous solution as the exfluent. In this project, we are developing a material system that will actively pump hydrated cations and anions from ionic aqueous solutions (> 20,000 to < 500 ppm) using electrical energy and diffusion to power active nanopore membranes. The goals are to reduce energy consumption required for ion separation, and to improve the understanding of the effect of eliminating concentration polarization impedance, a critical issue for aqueous ion separation.

**Characterization of Transport in Single Nanopores**

M. A. Shannon;* P. W. Bohn (Chem.)

*NSF Center of Advanced Materials for the Purification of Water with Systems (CAMPWS)*

The objective is to characterize transport in nanopores by studying the properties of isolated, single nanofluidic channels by measuring nanochannel flow and binding characteristics of individual fluorescent probe molecules, to elucidate mechanisms involved in removal of trace contaminants with advanced water purification materials. One fundamental problem that pervades all water purification and reclamation technologies is the understanding of fluid flow and chemical reactions in restricted geometries that for structures with nanometer characteristic dimensions are fundamentally different than the same phenomena in their larger mm-scale counterparts. Therefore, macromolecules may traverse a significant fraction of a nanometer-diameter channel while rotating through part of its range, thus significantly changing its transport and absorption probabilities.

**Chemical Synthesis of Piezoelectric and Ferroelectric Nanomaterials**

M. F. Yu*

*University of Illinois at Urbana-Champaign*

The materials behaviors at the nanoscale are expected to be very different from that at large scale. For piezoelectric materials, the ever-shrinking device dimension may ultimately approach the stability limit for the existence and applicability of piezoelectric or ferroelectric phase. However, from the application point of view, there still exists a high demand for ever-smaller devices down to nanoscale to acquire high speed, high sensitivity, and other unique engineering "figure of merits." The research is to synthesize nanowire, nanoparticle, and nanoribbon of piezoelectric and ferroelectric properties for the study of low dimensional piezoelectricity and ferroelectricity.

**Development of an Integrated and Versatile Testing Platform for High Precision Metrology and Nano-CEMMS Toolbit Evaluation**

M. F. Yu,* P. M. Ferreira

*NSF Center of Advanced Materials for the Purification of Water with Systems (CAMPWS)*

This project is aimed at developing a multifunctional and adaptive testing platform through the development and integration of nanometer resolution and multiple degrees of freedom motion station with nanometer positioning sensing mechanisms. The project will explore and evaluate approaches and control strategies to 3-D nanometer-resolution parallel positioning, position sensing, and calibration of planar surfaces that correspond to the Nano-CEMMS tool-bit-work piece interface. The project will extend to the integration of flexible and scaled-down tool-bit interfaces and will include the functions for the rapid characterization and evaluation of the performance of individual gated nanopores within the Nano-CEMMS tool-bit on a work piece.

**NER: Carbon Nanotube Absolute Displacement Encoder with Atomic Lattice Registry Sensitivity**

M. F. Yu,* P. M. Ferreira, Y. Huang

*National Science Foundation, CCF-0508416*

The goal of this research is to understand the fundamental issues related to the atomic lattice registry related interlayer tunneling in multiwalled carbon nanotube and to explore the development of novel devices based on this basic understanding. The research will exploit concurrently the unique structural, mechanical, and electronic properties of the carbon nanotube and engineer them for the application of the carbon nanotube in a new field: nanometrology. The research will ultimately lead to the development of a brand new type of nanometrology device, namely an absolute displacement encoder with sub-nanometer resolution, which has rarely been explored, but could find wide application in precision engineering and nanoscale fabrication.

**Piezo- and Ferro-Electricity of One-Dimensional Nanomaterials**

M. F. Yu*

*National Science Foundation, CMS-0324643*

The project is aimed to achieve fundamental understanding of the piezoelectric and ferroelectric effects at low dimension for the purpose of developing novel nanoscale devices critical for nanoscale electromechanical systems. The subject, which has not been extensively studied yet, is
critically related to the further advancement of nanoscale science and technology.

**Ultrahigh Sensitivity Parametric Sensing with Nanotube**
M. F. Yu*
*National Science Foundation, ECS-050195

The objective of the proposed research is to study the resonance sensing behavior of unique nanomaterials and apply the discovery for the development of ultrahigh sensitivity sensor. The research fundamental is based on the principle of parametric resonance, which exhibits instability in its resonance behavior that will be utilized for amplifying extremely small perturbation. The research aims to realize and characterize the parametric resonance of individual nanotubes with nanomanipulation inside the scanning electron microscope and transmission electron microscope; to prototype parametric resonance sensor integrated with excitation and sensing mechanisms; and to develop a device with microfabrication of parametric resonance sensor incorporating nanotubes.

**Wetting and Liquid Transport in Nanotube**
M. F. Yu*
*National Science Foundation and Engineering Center, DMI-0328162; University of Illinois at Urbana-Champaign

The project is to study liquid wetting and transport behavior at the nanoscale. Nanotubes, which readily provide nanoscale dimension features, are exploited to serve as the template for such a study. *In situ* liquid manipulation and characterization techniques developed in this project facilitate the flexible study of various liquids, such as water, polymer, and ionic solutions, and their related transport behavior under various experimental conditions.

**Operations Research**

**Risk Aversion in Inventory Management**
X. Chen*
*University of Illinois Research Board

Traditional inventory models focus on characterizing replenishment policies so as to maximize the expected total profit. We propose to incorporate risk consideration into a broad class of inventory models.

**Engineering the Economics of Combination Vaccines for Pediatric Immunization**
S. H. Jacobson,* S. N. Hall, H. Kaul
*National Science Foundation, DMI-0222597

Childhood vaccination has become the single greatest defense against infectious diseases among children in the United States. Moreover, biotechnology breakthroughs are making it possible for vaccine manufacturers to develop vaccine antigens for a rapidly growing list of additional diseases, including the development of vaccine products that combine several individual vaccine antigens into a single injection. The goal of this project is to design operations research models and tools that can be used to engineer the economic and implementation issues associated with pediatric combination vaccines. The potential impact of this research is that the tools developed can be used to evaluate the economic and implementation issues of any new pediatric combination vaccine products as they enter the market place.

**Pediatric Vaccine Formulary Optimization and Analysis**
S. H. Jacobson,* S. N. Hall, R. Proano
*University of Illinois Research Board, DMI-0457176

The objective of this project is to formulate and analyze operations research models and algorithms for addressing childhood immunization vaccine formulary design issues. Healthcare decision-makers are being faced with an overwhelming number of pediatric vaccine choices, with no basis for comparing and evaluating their different vaccine selection options. This project formulates discrete optimization problems, models, and dynamic programming algorithms that capture the key features of the recommended childhood immunization schedule, as well as the restrictions and requirements imposed by the Advisory Committee on Immunization Practices (ACIP) and the Food and Drug Administration (FDA). It also uses these models and algorithms to assess the economic and societal impact of new vaccines and immunization policy requirements, as well as providing a decision-making tool for healthcare administrators that is based on the problems and algorithms obtained, including the vaccine completion problem, the limited budget problem, and the balking problem.

* Denotes principal investigator.
A Heuristic Design Information Sharing Framework for Hard Discrete Optimization Problems
S. H. Jacobson,* L. A. McLay, S. N. Hall, H. Kaul, G. Kao

Intractable discrete optimization problems can be addressed using problem-specific algorithms or general search strategy heuristics. Such algorithms and heuristics are typically evaluated by applying them to a broad sample of problem instances and then comparing their effectiveness in finding near-optimal solutions in a reasonable amount of computing time. However, when two or more heuristics are applied to the same problem instance, the information being collected and used by one heuristic may be useful for improving the performance of the other heuristics. The goal of this project is to study and develop generalized hill climbing (GHC) algorithms as an algorithmic framework for information sharing in discrete optimization problems. The results of this research provide a structured mechanism to design new heuristics for discrete optimization problems, through a framework that allows several heuristics and/or neighborhood functions to be combined into a single hybrid heuristic model.

A Study of Aviation Access Control Security Systems
S. H. Jacobson,* L. McLay, A. Nikolaev, J. E. Kobza
National Science Foundation, DMI-0114499

International terrorism inflicted on the nation's aviation system poses a significant threat to the economic and political infrastructure of the United States. Aviation security technologies in airports throughout the United States provide an important line of defense against such threats. It is a challenge to determine how to optimally determine which security technologies to purchase as well as where to deploy such technologies and how to use them most effectively. The objective of this research project is to develop operations research models and algorithms to address these questions. The results of this project will be used to develop strategies to improve the security of the entire national airspace system through a systematic process of cost-effectively allocating aviation security resources.

Duality in Integer Programming and Its Application to Integrated Airline Planning
D. Klabjan*
National Science Foundation, DMI-0-322250

The strength of linear programming duality is well known and it is one of the most acclaimed results in theory and practice. On the other hand, it is usually taken for granted that duality is not achievable for integer programs. The objective of this proposal is to break the perception barrier by showing that indeed it is possible to compute an analog to the linear programming dual vector for an integer program. A new family of dual functions for integer programs is proposed. Several properties and many results with linear programming counterparts are given. More importantly, an algorithm is proposed that computes such a function for an integer program and it is shown that, in a reasonable amount of time, an optimal dual function can be computed. The proposed dual functions apply only to pure integer programs, and their extension to mixed integer programs is required. In addition, the framework for an algorithm that computes a dual function from the branch-and-cut tree is given. One of the applications of dual functions is in decomposition algorithms. We design a novel decomposition approach to integrated airline planning. Many decision support systems require sensitivity analysis of the underlying optimization models. For example, decision makers like to get estimates on the change of profitability if a unit of a resource is changed or piece of a product is modified by a small amount. Existing tools use ad-hoc techniques to perform sensitivity analysis. In this proposal, we explore the area of more scientific and practical approaches to sensitivity analysis. The proposed theory and algorithms also yield new methodology for solving large-scale models deemed so far intractable.

In-store One-to-One Marketing with RFID
D. Klabjan*
Intel

Radio frequency identification (RFID) offers numerous benefits in various areas of supply chain management: warehousing operations, asset tracking, marketing, etc. In marketing, the importance of one-to-one marketing has long been acknowledged by retailers. RFID brings a new perspective with the possibility of direct one-to-marketing during a shopping experience, i.e. while the consumer is shopping. In this project we develop models for in-store, one-to-one marketing. Based on the consumer’s shopping list, we consider routing the consumer in the store and offering coupons based on the current items in the shopping cart during the shopping experience. RFID technology enables instant reading capability of the items in the shopping cart and therefore the proposed models are technologically doable.

* Denotes principal investigator.
Market Optimization for Express Package Shippers
D. Klabjan*
FedEx Express

Express package shippers move large quantities of packages from several stations to the ramp with various conveyance types such as containerized or bulk trucks and aircraft. Packages are first sorted at each station and then many of them are resorted at the ramp based on the destination. From the ramp, the packages are then moved with larger aircraft to their hubs and then to the final destination. In this project, we streamline the transportation and sorting costs. Large cost savings can be obtained by appropriately forming containers at stations in order to bypass resorting at the ramp. On the other hand, transportation costs must be kept low. We model the problem as a large-scale optimization problem, which is very challenging to solve.

Optimal Pricing for a Product Assortment with Multiple Market Segments
U. S. Palekar,* M. Singh
University of Illinois at Urbana-Champaign

We consider the problem of determining the optimal prices of a set of items with different utilities and costs. Demand for an item is dependent on the price differential between the item and the next item with higher utility. Customers can be grouped into segments based on the lowest utility acceptable and the maximum acceptable price. We develop an algorithm to determine the optimal pricing based on product timing to maximize profit. We also consider variants such as ladder pricing and anchor items. Assortment decisions to add or drop products based on regularity conditions and optimality considerations are also considered.

Scheduling and Planning Fluid Delivery through Micro/Nano-Fluidic Networks
U. S. Palekar,* N. Aluru,* T. Dong, Z. Huang
National Science Foundation, Chemical-Electrical-Mechanical Manufacturing Systems

We consider the problem of routing fluids and fluid plugs through a three-dimensional micro/nano-fluidic network. We consider a dynamic routing model for fluid plugs as well as a quasi-static vertex disjoint path (VDP) model for fluid routing. The dynamic routing problem is a multicommodity network flow with additional source-sink connectivity constraints. The problem is being solved using a column generation scheme. The quasi-status VDP model, used to model dedicated fluid paths, is NP-Hard in the strong sense. We are currently developing conditions for the existence of feasible solutions and heuristic algorithms for finding feasible solutions. We are also considering design versions for the problem that study the required size of a network to guarantee feasible solutions.

BARON—An All-Purpose Global Optimization Package
N. V. Sahinidis*
Exxon Mobil Upstream Research Company

The area of global optimization software is so important and yet so underdeveloped. This project aims at the development of BARON: an all-purpose, high-performance global optimization methodology to support engineering design and manufacturing. BARON (branch-and-reduce-optimization-navigator) executes a global optimization strategy by navigating its way through user-provided subroutines. Its optimization strategy integrates conventional branch-and-bound with a wide variety of range reduction tests and branching schemes. Specialized modules have been developed for special problem classes including concave minimization over polyhedral, polynomial programs; mixed integer and quadratic programs; and factorable programs.

Branch-and-Reduce Algorithms for Global Optimization
N. V. Sahinidis*
Exxon Mobil Upstream Research Company

This project develops global optimization methodologies for escaping from local minima traps. The algorithms combine branch and bound with optimality- and feasibility-based range reduction, finite branching rules, tight bounding schemes, and efficient heuristics to accelerate convergence. Problems considered include the following: minimization of concave functions over polytopes, multiplicative programs, bilinear programs, integer programs, and factorable programs. We apply our algorithms to problems in supply chain management, portfolio optimization, and engineering design.

Planning in the Process Industry under Uncertainty
N. V. Sahinidis*
National Science Foundation, DMI-01-29283

As the chemical industry becomes increasingly competitive, tools to hedge against uncertainty become increasingly important. The project develops a two-stage stochastic optimization approach to the problem of planning in the process industries. We consider both discrete and continuous random parameters. In one research direction, we introduce the upper partial mean as a new measure of robustness and developed robust process planning algorithms under uncertainty. In another research

* Denotes principal investigator.
direction, we develop approximation algorithms for two-stage stochastic integer programs. We provide proofs that these schemes are optimal in expectation as the problem size increases.

Production Management

Combined Safety Stock and Graph Location Problem in a Three-Echelon Distribution System
U. S. Palekar,* D. Vandenbussche,* O. Akean
*University of Illinois at Urbana-Champaign

We consider the problem of finding the optimal locations on a graph for distributors and assigning the safety stock for a three-echelon distribution system. We assume that a single central depot will supply the distributors, which will in turn supply the retailers. The locations of the retailers and the central depot are given. All echelons operate under a periodic review base-stock policy. The goal is to find the optimal number and locations of the distributors, assignment of retailers to these distributors, and the safety stock allocation among the echelons while minimizing the sum of transportation and safety stock holding costs. For special cases, we demonstrate finite dominating set results for the candidate optimal locations of the distributors.

Optimal Pricing and Lead Times in a Supplier-Retailer Supply Chain with Elastic Demand
U. S. Palekar,* H. Shi
*Caterpillar, Inc.

We consider the problem of optimal pricing by a supplier-retailer dyad when demand is elastic. We identify static Nash equilibrium solutions when the retailer and supplier have complete information about each other’s costs. We investigate situations under which the retailer and supplier may choose to provide wrong information to each other to gain an unfair advantage at the cost of the other firm. Our model considers both manufacturing and inventory costs and seeks to find an optimal lead time to maximize profits.

Supply Chain Design for Multiproduct, Multilocation Production Systems
U. S. Palekar,* A. Kohli, H. Shi
*Caterpillar, Inc.

We consider the problem of designing the manufacturing supply chain for complex assembled products. We develop mathematical models and algorithms for multiproduct supply chains that share common parts as well as common resources. The model is a mixed integer program and can be used for assembly products with several thousand modes in the bill of materials. We extend the basic model to consider the joint optimization of production, transportation, and inventory costs. The model assumes a base-stock policy and determines the optimal placement of safety stocks and the allocation of production activities to various locations.

Journal Articles

Automotive Systems


* Denotes principal investigator.


Bioengineering


Combustion and Propulsion


Computational Science and Engineering


**Control Systems**


**Design Methodology and Tribology**


**Dynamic Systems**


Energy Systems and Thermodynamics


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**Engineering Mechanics**


**Environmental Engineering**


**Fluid Dynamics**


Christensen, K. T. and Wu, Y. Visualization and characterization of small-scale spanwise vortices in turbulent channel flow. *Journal of Visualization, 8*:2, 177-185 (2005).


**Heat Transfer**


**Manufacturing Systems**


Materials Behavior


**Materials Processing**


Nano-, Micro-, and Meso-Technology


Suh, A. Y. and Polycarpou, A. A. Adhesive contact modeling for sub-5-nm ultralow flying magnetic storage head-disk interfaces including roughness effects [art. no. 104328]. Journal of Applied Physics, 97:10 Part 1, 4328 (May 2005).


Tayebi, N. and Polycarpou, A. A. Reducing the effects of adhesion and friction in microelectromechanical systems (MEMSs) through surface roughening: Comparison between theory and experiments [art. no. 073528]. Journal of Applied Physics, 98:7, 3528 (Oct. 2005).


Operations Research


**Books**

**Automotive Systems**


**Book Chapters**

**Bioengineering**


**Combustion and Propulsion**


**Dynamic Systems**

Engineering Mechanics


Fluid Dynamics


Heat Transfer


Materials Processing


Nano-, Micro-, and Meso-Technology


Operations Research


Papers Presented at Conferences and Symposia

Automotive Systems


Fang, T., Coverdill, R. E., Lee, C. F., and White, R. A. Low temperature combustion within a small bore high speed direct injection (HSDI) diesel engine. 2005 Society of Automotive Engineers World Congress (Detroit, MI, Apr. 2005).


Xu, Y. and Lee, C. F. Investigation of fuel effects on soot formation using forward illumination light extinction (FILE) technique. 2005 Society of Automotive Engineers World Congress (Detroit, MI, Apr. 2005).

Bioengineering


Kelly, S. D. and Xiong, H. Controlled hydrodynamic interactions in schooling aquatic locomotion. 44th Institute of Electrical and Electronics Engineers Conference on Decision and Control and European Control Conference (Seville, Spain, Dec. 2005).


Salapaka, S. On combinatorial optimization problems with mobile sites and resources. 44th Institute of Electrical and Electronics Engineers Conference on Decision and Control and European Control Conference (Seville, Spain, Dec. 2005).


Combustion and Propulsion


Brewster, M. Q. and Begley, S. Radiative properties of nano-energetic materials. 6th International Symposium on Special Topics in Chemical Propulsion (Santiago, Chile, Mar. 2005).


Computational Science and Engineering


Control Systems

Alleyne, A., Ferreira, P. M., Bristow, D., Mukhopadhyay, D., Lewis, J., and Li, Q. Process planning and a new dual-ink write head for microscale robotic deposition. 2005 National Science Foundation Design, Service and Manufacturing Grantees and Research Conference (Scottsdale, AZ, Jan. 2005).

Bentsman, J., Miller, B. M., and Rubinovich, E. Y. Modeling and control of dynamical systems with active singularities and sensing in a singular motion phase. 16th World Congress of Automatic Control (Prague, Czech Republic, Jul. 2005).


Mehta, P. G. and Vaidya, U. On stochastic analysis approaches for comparing complex systems. 44th Institute of Electrical and Electronics Engineers Conference on Decision and Control and European Control Conference (Seville, Spain, Dec. 2005).


Design Methodology and Tribology


Lee, C.-H. and Polycarpou, A. A. Development of an apparatus to investigate friction characteristics of constant-velocity joints. 60th Society of Tribologists and Lubrication Engineers Annual Meeting and Exhibition (Las Vegas, NV, May 2005).


Norato, J., Haber, R. B., Tortorelli, D. A., and Bendsoe, M. P. Geometry projection and optimality criterion method using the topological derivative. 6th World Congress on Structural and Multidisciplinary Optimization (Rio De Janeiro, Brazil, May 2005).


Dynamic Systems


Energy Systems and Thermodynamics


Hrnjak, P. S. Major issues in transcritical CO\textsubscript{2} systems [keynote lecture]. 5th International Conference on Compressors and Refrigeration (Dalian City, People's Republic of China, Jul. 2005).


McEnaney, R. and Hrnjak, P. S. **Clutch cycling mode of compressor capacity control of transcritical R744 systems compared to R134a systems.** 7th Vehicular Thermal Management Systems Conference (Toronto, ON, May 2005).


Wu, W., Jones, B. G., and Newell, T. A. **Measurement and analysis of bubble behavior and associated flow field in sub-cooled boiling flows.** 13th International Conference on Nuclear Engineering (Beijing, People's Republic of China, May 2005).


**Engineering Mechanics**


**Fluid Dynamics**


**Heat Transfer**


**Materials Behavior**


Lee, K. M., Yeo, C.-D., and Polycarpou, A. A. Mechanical property measurements for sub-5 nm thick films: DLC on longitudinal and perpendicular media. 50th Magnetism and Magnetic Materials Conference (San Jose, CA, Oct. 2005).


**Materials Processing**


**Nano-, Micro-, and Meso-Technology**


Suh, A. Y. and Polycarpou, A. A. Analytical determination of the surface energy of sub-5 nm head-disk interfaces accounting for multi-layer effects. 50th Magnetism and Magnetic Materials Conference (San Jose, CA, Oct. 2005).


Operations Research


Bioengineering


Combustion and Propulsion


**Computational Science and Engineering**


**Control Systems**


**Energy Systems and Thermodynamics**


**Engineering Mechanics**


**Fluid Dynamics**


Heat Transfer


Human Factors and Ergonomics


Manufacturing Systems


Materials Behavior


Materials Processing


Nano-, Micro-, and Meso-Technology


Operations Research


Awards and Honors

Andrew G. Alleyne
Outstanding Graduate Student Instructor Award, 1990-1991
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Spring 1995, Fall 2004
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 1996
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 1998, 1999
Honorable Mention for paper (one of five finalist papers) at the XIVth International Federation of Automatic Control Congress, Beijing, Peoples' Republic of China, 1999
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2000
Best Paper Award, American Society of Mechanical Engineers International Mechanical Engineering Congress and Exposition, Fluid Power Systems and Technology Division, 2000
Who’s Who Among America’s Teachers, 2000
Accenture Award for Excellence in Advising, University of Illinois College of Engineering, 2001, 2003
Fulbright Fellowship, 2002-2003
College of Engineering Ralph M. and Catherine V. Fisher Professor, University of Illinois College of Engineering, 2002-2005
Student Best Paper Award, American Society of Mechanical Engineering International Mechanical Engineers Congress and Exposition, Dynamic Systems and Control Division, 2002
Best Paper Finalist (top 12 out of 150), 6th International Symposium on Advanced Vehicle Control, 2002
Ralph R. Teetor Educational Award, Society of Automotive Engineers, 2003
Distinguished Lecturer, Institute of Electrical and Electronics Engineers Control Systems Society, 2004-2007
Outstanding Young Investigator Award, American Society of Mechanical Engineers Dynamic Systems and Control Division, 2003
Invited Participant, National Academy of Engineering 19th Annual Symposium on Frontiers of Engineering, 2004
Fellow, American Society of Mechanical Engineers, 2005
Honorable Mention, Campus Award for Innovation in Undergraduate Instruction, University of Illinois, 2005
Honorable Mention, Campus Award for Excellence in Graduate and Professional Teaching, University of Illinois, 2006

Narayan R. Aluru
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 1999
Faculty Fellowship, National Center for Supercomputing Applications, 1999
Center for Middle Eastern Studies Distinguished Young Author Award, 2001
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2001
Willett Faculty Scholar Award, University of Illinois College of Engineering, 2002-2005

Armand J. Beaudoin
Invited Speaker, Fourth Annual Symposium on Frontiers of Engineering, National Academy of Engineering, 1998
Editorial Board, *Modeling and Simulation in Materials Science and Engineering*, 1998-
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 1999
Key Reader, *Metallurgical and Materials Transactions*, 1999-
Willett Faculty Scholar Award, University of Illinois College of Engineering, 2003-2006
Listed in the *Daily Illini* "Incomplete List of Teachers Ranked as Excellent by Their Students," Fall 2000, 2001; Spring 2002
College of Engineers Advisors List, 2002
Xerox Award for Faculty Research, University of Illinois, 2003
Accenture Award for Excellence in Advising, University of Illinois College of Engineering, 2003

Joseph Bentsman
Presidential Young Investigator Award, National Science Foundation, 1989
Andersen Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 1990
Member, Editorial Board, *Nonlinear Phenomena in Complex Systems*, An Interdisciplinary Journal, 1999-

Lawrence A. Bergman
Fellow, American Society of Mechanical Engineers
Associate Fellow, American Institute of Aeronautics and Astronautics
State-of-the-Art in Civil Engineering Award, American Society of Civil Engineers, 1983
Associate Editor, *Shock and Vibration Digest*, 1998-
Japan Society for the Promotion of Science (JSPS) Fellowship, 1998
Norman Medal, American Society of Civil Engineers, 1999
Editorial Board, *Probabilistic Engineering Mechanics*, 2000-
A. M. Freudenthal Guest Professorship, Universität Innsbruck, 2000
IASSAR Senior Award, Computational Stochastic Mechanics, Eighth ICOSASSAR, 2001
Charles E. Schmidt Distinguished Visiting Professorship, Center for Applied Stochastics Research, Florida Atlantic University, 2002

M. Quinn Brewster
Listed in the *Daily Illini* "Incomplete List of Teachers Ranked as Excellent by Their Students," Fall 1986
IBM Research Award, University of Illinois Research Board, 1986
American Men and Women in Science, 1992
Japan Long-Term Visit Grant to Mechanical Engineering Laboratory AIST-MITI, National Science Foundation, 1992-1993
Fellow, American Society of Mechanical Engineers, 1996
Associate Fellow, American Institute of Aeronautics and Astronautics, 1996
Japanese Ministry of Education Scholarship, Kyoto University, Japan, 1981-1982
Presidential Young Investigator Award, National Science Foundation, 1984
Outstanding Poster Presentation Award, 8th International Heat Transfer Conference, 1986
Office of Naval Research Young Investigator Award, 1987
University Scholar, University of Illinois, 1993
Hermia G. Soo
Professor, University of Illinois
Department of Mechanical and Industrial Engineering, 2000-2005
Associate Editor, *Journal of Propulsion and Power*, 2001-

**Richard O. Buckius**
Fellow, American Society of Mechanical Engineers, 1988
Associate Fellow, American Institute of Aeronautics and Astronautics, 1996
Dow Outstanding Young Faculty, Illinois-Indiana Section, American Society for Engineering Education, 1978
Stanley H. Pierce Faculty Award, University of Illinois College of Engineering, 1979
Everitt Award for Excellence in Undergraduate Teaching, University of Illinois College of Engineering, 1980
Two-Year Effective Teaching Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1980, 1987, 1994, 2000
Campus Award for Excellence in Undergraduate Teaching, University of Illinois, 1980
Western Electric Fund Award, American Society for Engineering Education, 1981
Five-Year Effective Teaching Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1982, 1989
Halliburton Engineering Education Leadership Award, University of Illinois College of Engineering, 1987
Beckman Associate, University of Illinois Center for Advanced Study, 1989
Centennial Memorial Fund, Tokyo Institute of Technology, 1990
Fellow, Committee on Institutional Cooperation Academic Leadership, 1990
Editorial Advisory Board, *Heat Transfer-Japanese Research*, 1990-
Editorial Advisory Board, *Microscale Thermophysical Engineering*, 1996-
Editorial Advisory Board, *Heat Transfer Research*, 1997-
Ralph Coats Roe Award, American Society for Engineering Education, 2003

**Clark W. Bullard, Emeritus**
Resident Associate, University of Illinois Center for Advanced Study, 1977

Listed in the *Daily Illini* "Incomplete List of Teachers Ranked as Excellent by Their Students," Fall 1984, Spring 1985
Visiting Associate Professor, University of Illinois Institute of Government and Public Affairs, 1985
Public Service and Civic Activities Award, Illinois Division, Izaak Walton League of America, 1985
Fulbright-Hayes Research Award, 1986
Visiting Fellow, Science Policy Research Unit, Sussex University, U.K., 1986
Guest Scholar, USSR Academy of Sciences, Institute for High Temperatures, 1987
Fellow, Royal Society of Arts, Commerce, and Manufacturers U.K., 1987-
Chevron Conservation Award, Chevron USA, 1990
Andersen Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 1992
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 1999, 2000
Fellow, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2001


J&E Hall Gold Medal, The Institute of Refrigeration, 2005
Distinguished Service Award, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2004

**Sahraoui Chaieb**
Collins Scholar Award, University of Illinois College of Engineering, 2001
Image of the Week, Image Technology Group, Beckman Institute, University of Illinois, Feb. 2001, Sept. 2001
Strathmore's Who's Who, 2002
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 2003
Grainger Foundation Gift for Emerging Technologies, University of Illinois College of Engineering, 2003
Fellow, Center for Advanced Studies and Beckman Fellow, University of Illinois, 2005-2006
Who's Who in Engineering Education, 2005

John C. Chato, Emeritus
Fellow, American Society of Mechanical Engineers, 1975
Fellow, American Institute for Medical and Biological Engineering, 1993
Postdoctoral Fellow, National Science Foundation, 1961
Distinguished Engineering Alumnus Award, University of Cincinnati, 1972
Associate Editor, Journal of Biomechanical Engineering, 1976-1982
Fogarty Senior International Fellow, National Institutes of Health, 1978-1979
Charles Russ Richards Memorial Award, Pi Tau Sigma and American Society of Mechanical Engineers, 1978
Russell B. Scott Memorial Award, Cryogenic Engineering Conference, 1979
Honorary Visiting Professor, University of New South Wales, Australia, 1986
Andersen Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 1989
H. R. Lissner Award, American Society of Mechanical Engineers, 1992
Engineering Council Advisors List for Outstanding Advising, University of Illinois, 1996
Travel Fellowship, Japan Society for the Promotion of Science, 1997
Dedicated Service Award, American Society of Mechanical Engineers, 2000
Fellow, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2003
Distinguished Alumnus Award, University of Illinois Department of Mechanical and Industrial Engineering, 2005

Xin Chen
Honorable Mention, George Nicholson Student Paper Competition, 2002
Second Prize, MSOM Student Paper Competition, 2002

Kenneth T. Christensen
Ford Foundation Predoctoral Fellowship (declined), 1995

Xin Chen
Honorable Mention, George Nicholson Student Paper Competition, 2002
Second Prize, MSOM Student Paper Competition, 2002

National Science Foundation Graduate Fellowship, 1995-1998
Clark B. Millikan Fellowship and Special Institute Fellowship, Caltech, 1995
SURGE Fellowship, College of Engineering, University of Illinois at Urbana-Champaign, 1996-2000
Larson Graduate Fellowship, Theoretical and Applied Mechanics Department, University of Illinois at Urbana-Champaign, 2000
Stanley J. Weiss Outstanding Thesis Award, Theoretical and Applied Mechanics Department, University of Illinois at Urbana-Champaign, 2001

Thomas F. Conry
Fellow, American Society of Mechanical Engineers, 1988
Dedicated Service Award, American Society of Mechanical Engineers, 1994

Harry Dankowicz
Cannon Faculty Scholar, 2005-2008

Jonathan A. Dantzig
Listed in the Daily Illini "Incomplete List of Teachers Ranked as Excellent by Their Students," Spring 1985; Fall 1986; Spring 1989, 1992; Fall 1993; Spring 1999, 2001; Fall 2002; Spring 2003
Fellow, American Society for Metals International, 1998
Arnold O. Beckman Award, University of Illinois Research Board, 1982
Union Oil Young Faculty Award, 1985-1988
Best Poster, National Science Foundation OPAAL Program Review, 1999

Who's Who in the Midwest, Who's Who in Engineering, Phi Beta Kappa
W. Grafton and Lillian B. Wilkins Professor, University of Illinois Department of Mechanical and Industrial Engineering, 2003-2008
Bruce Chalmers Award, TMS, 2005

Richard E. DeVor, Research Professor
Fellow, Society of Manufacturing Engineers
Fellow, American Society of Mechanical Engineers
Five-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1981, 1990, 2005
Two-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1981, 1989, 1995, 2002
Blackall Machine Tool and Gage Award, American Society of Mechanical Engineers, 1983, 1997
Everitt Award for Excellence in Undergraduate Teaching, University of Illinois College of Engineering, 1985
Campus Award for Excellence in Undergraduate Teaching, University of Illinois, 1987
Halliburton Engineering Education Leadership Award, University of Illinois College of Engineering, 1989
Society of Manufacturing Engineers Education Award, 1993
Grayce Wicall Gauthier Chair Professorship, University of Illinois Department of Mechanical and Industrial Engineering, 1995-2000
Distinguished Service Award, University of Wisconsin-Madison College of Engineering, 1997
Member, National Academy of Engineering, 2000
Distinguished Professor of Manufacturing, University of Illinois College of Engineering, 2000-2001
Distinguished Emeritus Professor of Manufacturing, University of Illinois College of Engineering, 2001
William T. Ennor Manufacturing Technology Award, American Society of Mechanical Engineers, 2003

Geir E. Dullerud
National Sciences and Engineering Research Council of Canada Initiation Grant, 1996
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 1999
Willett Faculty Scholar Award, University of Illinois College of Engineering, 2002-2005
Listed in the Daily Illini "Incomplete List of Teachers Ranked as Excellent by Their Students," Fall 2004

William E. Dunn
Two-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1991

Andersen Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 1992
Five-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1994
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 2000

Placid M. Ferreira
Outstanding Young Manufacturing Engineer, Society of Manufacturing Engineers, 1990
Andersen Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 1990
Presidential Young Investigator Award, National Science Foundation, 1991
Listed in the Daily Illini "Incomplete List of Teachers Ranked as Excellent by Their Students," Spring 1990, 1992
Department Editor, Manufacturing Processes and Devices, IIE Transactions on Design of Manufacturing, 1993-

Geir E. Dullerud
National Sciences and Engineering Research Council of Canada Initiation Grant, 1996
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 1999
Willett Faculty Scholar Award, University of Illinois College of Engineering, 2002-2005
Listed in the Daily Illini "Incomplete List of Teachers Ranked as Excellent by Their Students," Fall 2004

William E. Dunn
Two-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1991

Andersen Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 1992
Five-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1994
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 2000

Placid M. Ferreira
Outstanding Young Manufacturing Engineer, Society of Manufacturing Engineers, 1990
Andersen Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 1990
Presidential Young Investigator Award, National Science Foundation, 1991
Listed in the Daily Illini "Incomplete List of Teachers Ranked as Excellent by Their Students," Spring 1990, 1992
Department Editor, Manufacturing Processes and Devices, IIE Transactions on Design of Manufacturing, 1993-

Placid M. Ferreira
Outstanding Young Manufacturing Engineer, Society of Manufacturing Engineers, 1990
Andersen Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 1990
Presidential Young Investigator Award, National Science Foundation, 1991
Listed in the Daily Illini "Incomplete List of Teachers Ranked as Excellent by Their Students," Spring 1990, 1992
Department Editor, Manufacturing Processes and Devices, IIE Transactions on Design of Manufacturing, 1993-

John G. Georgiadis
Engineering Research Initiation Award from the Engineering Foundation and the American Society of Mechanical Engineers, 1988
Presidential Young Investigator Award, National Science Foundation, 1991
American Men and Women of Science, 1992
Guest Associate Editor, Journal of Fluids Engineering, 1996
Member, Editorial Advisory Board, Journal of Porous Media, 1996-
Certificate of Appreciation, American Society of Mechanical Engineers, 1998-1999
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 1999
Centre Nacional de la Recherche Scientifique Researcher, Institute of Fluid Mechanics of Toulouse, Toulouse, France, 1999
Listed in the Daily Illini "Incomplete List of Teachers Ranked as Excellent by Their Students," Spring 2001, Fall 2002, Spring 2003
Richard W. Kritzer Distinguished Professor, University of Illinois Department of Mechanical and Industrial Engineering, University of Illinois, 2004-2009

Nick G. Glumac
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 2001
Cannon Faculty Scholar, Department of Mechanical and Industrial Engineering, 2003-2006
Listed in the Daily Illini, "Incomplete List of Teachers Ranked as Excellent by Their Students," Fall 2004

K. Jimmy Hsia
Research Initiation Award, National Science Foundation, 1992
Max-Plank Society Scholarship, 1998
Fellowship, Japan Society for the Promotion of Science Scholarship, 1999
Participant in Establishing a Student Exchange Program between the University of Illinois at Urbana-Champaign and Nagoya University, Japan, 1999
Gold Medal, Best Student Research Composition (Rahul Panat, co-author), Fall Meeting of Materials Research Society, 2002
Engineering Council Award for Excellence in Advising, University of Illinois, 2002, 2004

Elizabeth Hsiao-Wecksler
Biology of Aging Research Scholar, American Federation for Aging Research and Glenn Foundation, 1998
New Investigator Recognition Award, Orthopaedic Research Society and American Geriatrics Society, 1999
Fellow, Center for Advanced Study, University of Illinois, 2004-2005
Campus Award for Excellence in Guiding Undergraduate Research, Honorable Mention, University of Illinois, 2005

Yonggang Huang
Wakonse Fellow, University of Arizona, 1993
Junior Investigator Award, National Science Foundation, 1995
Faculty Award, Alcoa Foundation, 1995, 1996
Faculty Award, Motorola Foundation, 1997
Faculty Award, Ford Foundation, 1998
Outstanding Young Investigator Award, National Science Foundation of China, 2000
Research Award for U.S. Scientists and Scholars, Alexander von Humboldt Foundation, 2001
Editorial Advisory Board, International Journal of Plasticity, 2002-
Beckman Associate, University of Illinois Center for Advanced Studies, 2002
Faculty Fellow, National Center for Supercomputing Applications, University of Illinois, 2002
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Spring 2003; Spring and Fall 2004; Spring 2005
Gustus L. Larson Award, American Society of Mechanical Engineers, 2003
Grayce Wicall Gauthier Professor, University of Illinois Department of Mechanical and Industrial Engineering, 2003-2004
Melville Medal, American Society of Mechanical Engineers, 2004
Co-advisor of Ph.D. Student, H. Jiang of Tsinghua University, Peoples' Republic of China, whose dissertation received the National Excellent Doctoral Dissertation Award, 2004
Shao Lee Soo Professor, University of Illinois Department of Mechanical and Industrial Engineering, 2004-2005
Regional Editor and Member of the Editorial Board, International Journal of Fracture, 2004-
Editorial Board, International Journal of Multiscale and Interactive Mechanics, 2004-
Chang Jiang Chair Professor, Department of Engineering Mechanics, Tsinghua University, Peoples' Republic of China, 2005-

Anthony M. Jacobi
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Spring and Fall 1993; Fall 1995; Spring and Fall 1996, 1997, 1998; Fall 2000; Spring 2003; Spring 2004, 2005
Stanley H. Pierce Faculty Award, University of Illinois College of Engineering, 1994
Two-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1996, 2002
Sheldon H. Jacobson
Research Initiation Award, National Science Foundation, 1994
Best Paper Award, Industrial Simulation Track, European Simulation Multiconference, Istanbul, Turkey, 1997
Application Award, First Place (with J. E. Kobza), Operations Research Division, Institute of Industrial Engineers, 1998
Willett Faculty Scholar Award, University of Illinois College of Engineering, 2002-2008
Associate, Center for Advanced Study, 2002-2003
Best Paper Award (with J. E. Kobza), IIE Transactions: Focused Issue on Operations Engineering, 2003
Guggenheim Fellowship, John Simon Guggenheim Memorial Foundation, 2003
Operation Research Meritorious Service Award, 2003

Harley Johnson
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 2001
Cannon Faculty Scholar, Department of Mechanical and Industrial Engineering, 2003-2006
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Spring 2004, 2005

Shiv G. Kapoor
Fellow, American Society of Mechanical Engineers
Fellow, Society of Manufacturing Engineers
Everitt Award for Excellence in Undergraduate Teaching, University of Illinois College of Engineering, 1984
Two-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1986
GM-CAM Professor, University of Illinois Department of Mechanical and Industrial Engineering and College of Engineering, 1997-2000
Outstanding Service Award, American Society of Mechanical Engineers (Manufacturing Engineering Division), 1998
Dedicated Service Award, American Society of Mechanical Engineers, 1999
James W. Bayne Professor, University of Illinois Department of Mechanical and Industrial Engineering, 2000-2005
Scientific Committee Chair, Transactions of the North American Manufacturing Research Institution, Society of Manufacturing Engineers, 1998-2000
President, North American Manufacturing Research Institution, Society of Manufacturing Engineers, 2003-2004
William T. Ennor Manufacturing Technology Award, American Society of Mechanical Engineers, 2003
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Fall 2004
Grayce Wicall Gauthier Chair in Mechanical and Industrial Engineering, University of Illinois College of Engineering, 2005-
Engineers Education Award, Society of Manufacturing, 2005
Distinguished Professor, Indian Institute of Technology, Kanpur, India, 2005
**Scott D. Kelly**
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Spring 2002, Spring and Fall 2004, Spring 2005

**Diego Klabjan**
Fellowship for Exceptionally Talented Students, University of Ljubljana, Ljubljana, Slovenia, 1989-94
Preseren's Award for the best B.A. thesis, University of Ljubljana, Ljubljana, Slovenia, 1994
Transportation Science Dissertation Award, International Award, Institute for Operations Research and the Management Sciences, 2000
Anna Valicke medal (joint with graduate student Rivi Sandhu), International Award by the Airline Group of the International Federation of Operational Research Societies (AGIFORS), 2004

**Herman Krier**
Fellow, American Institute of Aeronautics and Astronautics
Two-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1985
Five-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1988
Best Paper Award in Plasmadynamics and Lasers, American Institute of Aeronautics and Astronautics Conference on Plasmadynamics and Lasers, 1997
American Institute of Aeronautics and Astronautics Wyld Award, 1998
Richard W. Kritzer Distinguished Professor, University of Illinois Department of Mechanical and Industrial Engineering, 1998-2004
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 2000
Plenary Lecture, 4th International Conference on Internal Ballistics and Combustion Process in Solid Propulsion Systems and Guns, Russian Academy of Sciences, Moscow, Russia, 2002

**Chia-Fon Lee**
GE Scholar, University of Illinois, 1997
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 1998
Ralph R. Teetor Educational Award, Society of Automotive Engineers, 2000
Fellow, University of Illinois Center for Advanced Study, 2000
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Fall 2001
Editorial Board Member, Atomization and Sprays, 2004-
W. Robert Marshall Award (Best Paper), Institute for Liquid Atomization and Spray Systems, 2004
Who's Who in Science and Engineering, 2006

**Chang Liu**
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Spring 2001
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 2000
Elected Senior Member, Institute of Electrical and Electronics Engineers, 2002
Inducted into the University of Illinois, Office of Technology Management Inventor Hall of Fame, 2003
Faculty Associate, Center for Advanced Studies, University of Illinois, 2004
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2004
Willett Faculty Scholar Award, University of Illinois, College of Engineering, 2005

**Thomas J. Mackin**
Listed in the Daily Illini "Incomplete List of Teachers Ranked as Excellent by Their Students," Spring 1994, Spring and Fall 1995, Spring 1999
Everitt Award for Excellence in Undergraduate Teaching, University of Illinois College of Engineering, 1996
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 1996
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 1996
AT&T Special Opportunity Award, 1996
Two-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1998
Robert E. Miller Award for Excellence in Teaching Mechanics, University of Illinois Department of Theoretical and Applied Mechanics, 2000
Accenture Award for Excellence in Advising, University of Illinois College of Engineering, 2001
White House Executive Office Fellow, American Society of Mechanical Engineers, 2002

Prashant G. Mehta
Outstanding Teaching Assistant Award, University of Massachusetts Department of Electrical and Computing Engineering, 1994
Best Working Model Award, All India Academic Meet, APOGEE, India, 1994
Best Paper in Session, American Control Conference, 1998
Outstanding Achievement Award, United Technologies Research Center, 2005

Norman R. Miller, Emeritus
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Fall 1981; Spring 1982; Spring 1983; Spring 2003
Andersen Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 1990
Engineering Council Advisor List for Outstanding Advising, University of Illinois, 1997
Society of Automotive Engineers Award for Excellence in Oral Presentation, Society of Automotive Engineers World Congress, 2001

Ty A. Newell
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Spring and Fall 1982, 1983; Spring, 1984; Spring and Fall 1985, 1986; Spring 1987; Spring and Fall 1993, 1994; Spring 1995; Spring and Fall 1996; Spring 2005
Andersen Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 1989, 1990, 1993
Two-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1990, 1999, 2001, 2003, 2004
Fulbright Scholarship, Universidad Nacional de Salta, Argentina, Summer 1992
Commander's Award for Distinguished Public Service, U.S. Army Construction Engineering Research Laboratory, 1992
Invited Lectureship, Ain Shams University/Egyptian Government, 1993
Everitt Award for Excellence in Undergraduate Teaching, University of Illinois College of Engineering, 1995

Five-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1995, 2001, 2002, 2003, 2004
College of Engineering Award for Teaching Excellence, University of Illinois, 1997
Campus Award for Excellence in Undergraduate Teaching, University of Illinois, 2000
Alumni Association Educator’s Award, University of Illinois Alumni Association, 2000
BP Amoco Award for Innovation in Undergraduate Instruction, University of Illinois College of Engineering, 2003
Rose Award for Teaching Excellence, University of Illinois College of Engineering, 2005
Senior Design Team First Place, overall, First Place, marketability, manufacturability, and cost categories for $18K, Parker Hannifin "Chainless Challenge" Hydraulic Bike Competition (co-advisor with Prof. H. T. Johnson), 2005
Honorary Knight of St. Patrick, University of Illinois College of Engineering, 2006

Udatta S. Palekar
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Spring 1988; Fall 1989, 1993; Spring 1994, 2003, 2004
Outstanding Young Manufacturing Engineer Award, Society of Manufacturing Engineers, 1990
Andersen Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 1992
Finalist, Outstanding Mentoring of Graduate Students, University of Illinois, 1997
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 1999
Accenture Award for Excellence in Advising, University of Illinois College of Engineering, 2002

Arne J. Pearlstein
Presidential Young Investigator Award, National Science Foundation, 1985
Union Oil Young Faculty Award, 1985-1988
Andersen Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 1993
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 1995, 1997
Accenture Award for Excellence in Advising, University of Illinois College of Engineering, 2002

Michael L. Philpott
Senior Fulbright Scholarship, 1988
Initiation Award, National Science Foundation, 1991
CIM LEAD Award, 1993-1994
Marquis Who's Who in Science and Engineering, 1995
Stanley H. Pierce Award, University of Illinois College of Engineering, 1995
Five-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1996
Two-Year Effective Teacher Award, University of Illinois Department of Mechanical and Industrial Engineering Alumni Board, 1997
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 1997-1999
Accenture Award for Excellence in Advising, University of Illinois College of Engineering, 2001
Collins Award for Innovative Teaching, University of Illinois College of Engineering, 2003
Global Business Plan Competition Finalist, 2003
Harvard Business Plan Competition Winner, 2003
Fred Merryfield Design Award Nominee, American Society of Mechanical Engineers, 2004
Cozad Business Plan Winner, University of Illinois, 2004

Andreas A. Polycarpou
Fellowship, Israel Council for Higher Education on Tribology, Haifa, Israel, 1995, 1996
Reviewer of the Year Award, Journal of Tribology, 1997
Burt L. Newkirk Award, American Society of Mechanical Engineers, 2001
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Fall 2001, Spring 2005
Who's Who in Engineering Education, 2002
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 2003
Kritzer Faculty Scholar, Department of Mechanical and Industrial Engineering, 2003-2006
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2005

M. Taher A. Saif
Honors in B.S. with rank (1/209; one of only two students to receive annual honors), Bangladesh University of Engineering and Technology, 1984
Invited Member, Honor Society of Phi Kappa Phi, Cornell University Chapter, 1992
Executive Board Member, International Students Programming Board, Cornell University, 1990-1991
Ralph Bolgiano, Sr., Outstanding Teaching Assistant Award, Sibley School of Mechanical and Aerospace Engineering, Cornell University, 1991
Teaching Assistant Fellow, College of Engineering, Cornell University, 1991-1992
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 1998
GE Scholar, University of Illinois, 1998
Strathmore’s Who’s Who, 2002-2005
Who's Who in Engineering Education, 2002
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2003
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Spring 2003, Spring 2004
Willett Faculty Scholar Award, College of Engineering, 2003-2006
Associate, Center for Advanced Study, University of Illinois, 2004-2005

Srinivasa Salapaka
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 2005

Huseyin Sehitoglu
Institution of Mechanical Engineers Award, The City University, London, England, 1979
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Fall 1984, 1985; Spring and Fall 1986; Fall 1987; Spring 1988; Fall 1995
Research Initiation Award, National Science Foundation, 1984
Research Award, Ford Foundation, 1987
Certificate of Recognition, American Society of Mechanical Engineers, Pressure Vessel and Piping Division, 1988
Director, Mechanics and Materials Program, National Science Foundation, 1991-1993
Beckman Associate, University of Illinois Center for Advanced Study, 1993
Marcus Grossman Award, American Society for Metals International, 1998
Grayce Wicall Gauthier Professor, University of Illinois Department of Mechanical and Industrial Engineering, 2000-2005
Best Presentation Award, American Society of Testing Materials, 2003
Fellow, American Society of Mechanical Engineers, 2003
C. J. Gauthier Professor, University of Illinois Department of Mechanical and Industrial Engineering, 2004-2009
Interim Head, Department of Mechanical and Industrial Engineering, University of Illinois, 2004-

**Uday V. Shanbhag**
SIAM Travel Award, 2002
International Conference on Continuous Optimization Travel Award, 2004
Tenth International Conference on Stochastic Programming Travel Award, 2004
Reviewer, Institute of Electrical and Electronic Engineers *Transactions on Power Systems*, 2005
Reviewer, *Mathematical Programming*, 2005

**Mark A. Shannon**
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Fall 1998, Spring 2002; Spring 2004
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 1997
Accenture Award for Excellence in Advising, University of Illinois College of Engineering, 2002, 2003
Kritzer Faculty Scholar, University of Illinois Department of Mechanical and Industrial Engineering, 2003-2006
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2004
Willett Faculty Scholar Award, University of Illinois College of Engineering, 2004-2007
James W. Bayne Professor in Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign, 2006

**Darrell F. Socie, Emeritus**
Listed in the *Daily Illini* "Incomplete List of Teachers Ranked as Excellent by Their Students," Spring 1984
Fellow, American Society for Metals International, 2001
Fellow, American Society for Testing and Materials, 2000
Ralph R. Teetor Educational Award, Society of Automotive Engineers, 1980
National Aeronautics and Space Administration Summer Faculty Fellow, Lewis Research Center, 1983
Commander's Award for Distinguished Public Service, U.S. Army Construction Engineering Research Laboratories, 1990
Distinguished Alumni Award, College of Engineering, University of Cincinnati, 1991
Annual Fatigue Lecture, American Society for Testing and Materials, 1991
Fatigue Achievement Award, American Society for Testing and Materials, 1992
Arch T. Colwell Award, Society of Automotive Engineers, 1994
Japan Society for the Promotion of Science Fellowship, 1997
Oral Presentation Award, Society of Automotive Engineers, 1997, 1998
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 2000
Award of Merit, American Society for Testing and Materials, 2000
Wohler Medal, European Structural Integrity Society, 2000
Fellow, American Society for Metals International, 2001
Honorary Member, Deutscher Verband für Materialforschung und-prüfung, 2003

**Petros Sofronis**

**Donald Scott Stewart**
Fellow, American Physical Society, 1998
Listed in the *Daily Illini* "Incomplete List of Teachers Ranked as Excellent by Their Students," Spring 1988, Spring 1999, Spring 2000
Outstanding Advisor Award, University of Illinois at Urbana-Champaign College of Engineering, 1999, 2006
Fellow, Institute of Physics, 1999
Associate Fellow, American Institute of Aeronautics and Astronautics, 2004
Phi Kappa Phi, University of Illinois, 2004

James A. Stori
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 2000
Society of Manufacturing Engineers Outstanding Young Manufacturing Engineer Award, 2003

Brian G. Thomas
Presidential Young Investigator Award, National Science Foundation, 1989
Included in Marquis Who's Who in America, 1990
Outstanding Young Manufacturing Engineer Award, Society of Manufacturing Engineers, 1990
Best Investment Casting Paper, American Foundry Society, American Foundry Society Transactions, 1990
Xerox Award for Faculty Research, University of Illinois College of Engineering, 1991
Rossiter W. Raymond Memorial Award for Best Paper, American Institute of Mining, Metallurgical, and Petroleum Engineers, 1991
John Chipman Award for Best Paper, Iron and Steel Society, 1996
Steelmaking Conference Award, Second Best Paper, Authors under 40, Iron and Steel Society, 1997
Frank B. McKune Award, Best Paper, Authors under 40, Iron and Steel Society, 1997
Marcus A. Grossmann Young Author Award (Best Paper, Authors under 40), American Society for Metals International, 1997
Andersen Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 1998
Robert W. Hunt Silver Medal for Best Paper, Iron and Steel Society, 1998
Extraction and Processing Technology Award (Best Series), Minerals, Metals, and Materials Society, 1998
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 1998
Best Experimental Paper Award, Modeling of Casting, Welding, and Advanced Solidification Processes VIII Conference, 1998
Charles H. Herty, Jr. Award for Best Paper, Iron and Steel Society, 1998
Robert W. Hunt Silver Medal for Best Paper, Iron and Steel Society, 1999
Best Paper Award, Metallurgical Society of the CIM, 1999, 2000
Dr. J. Keith Brimacombe Lecturer, Electric Furnace Conference, Iron and Steel Society, 2001

W. Grafton and Lillian B. Wilkins Professor of Mechanical and Industrial Engineering, University of Illinois, 2003-2008
Robert W. Hunt Silver Medal (Best Paper, jointly with Q. Yuan and P. Vanka), Association for Iron and Steel Technology, 2004
Adjunct Professor, Graduate Institute of Ferrous Technology, Pohang University of Science and Technology, Pohang, South Korea, Sep. 9, 2005

Daniel A. Tortorelli
General Motors Advanced Engineering Staff Fellowship, 1986-1988
Teaching Fellowship, University of Illinois Department of Mechanical and Industrial Engineering, 1987
Listed in the Daily Illini "Incomplete List of Teachers Ranked as Excellent by Their Students," Spring 1995
Arnold O. Beckman Award, University Research Board, University of Illinois, 1991
Associate Technical Editor, Inverse Problems in Engineering, 1992-1997
Young Investigator Award, National Science Foundation, 1993
Associate Editor, Mechanics of Structures and Machines, 1997-
Editorial Board Member, Structural Optimization, 1999-
Treasurer, Executive Committee, International Society of Structural and Multidisciplinary Optimization, 2000-
Schaller Faculty Scholar, University of Illinois Department of Mechanical and Industrial Engineering, 2003-2006

Charles L. Tucker
Fellow, American Society of Mechanical Engineers, 1996
Ralph R. Teetor Educational Award, Society of Automotive Engineers, 1980
Everitt Award for Excellence in Undergraduate Teaching, University of Illinois College of Engineering, 1981
Two-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1983, 1992, 2005
Five-Year Alumni Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1987, 1998, 2000
Union Oil Young Faculty Award, 1983
TRW Postdoctoral Award in Manufacturing Engineering, 1984
Presidential Young Investigator Award, National Science Foundation, 1984
Outstanding Young Manufacturing Engineer Award, Society of Manufacturing Engineers, 1985
Best Paper Award, Society of Plastic Engineers Annual Technical Conference, Engineering Structure and Properties Division, 1988
Harriet and Charles Luckman Undergraduate Distinguished Teaching Award, University of Illinois, 1994
Fellow, American Society of Mechanical Engineers, 1996
W. Graffon and Lillian B. Wilkins Professor, University of Illinois Department of Mechanical and Industrial Engineering, 1998-2003
Member, Editorial Board, *International Polymer Processing*
Accenture Award for Excellence in Advising, University of Illinois College of Engineering, 2003
Alexander Rankin Professor, University of Illinois Department of Mechanical and Industrial Engineering, 2003-2007

**Alexander F. Vakakis**
Research Initiation Award, National Science Foundation, 1992
Young Investigator Award, National Science Foundation, 1994
Fellow, Center for Advanced Study, University of Illinois, 1994-1995
Junior Xerox Award for Faculty Research, University of Illinois College of Engineering, 1995
University Scholar, University of Illinois, 1996
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2000

**Dieter Vandenbussche**
Listed in the *Daily Illini* "Incomplete List of Teachers Ranked as Excellent by Their Students," Fall 2004

**S. Pratap Vanka**
Fellow, American Society of Mechanical Engineers, 1997
Associate Fellow, American Institute of Aeronautics and Astronautics, 1992
Editorial Board, *Journal of Numerical Heat Transfer*, 1998-
Associate Editor, *Journal of Heat Transfer*, 2002-2005
Robert W. Hunt Silver Medal (Best Paper, jointly with Q. Yuan and B. G. Thomas), Association for Iron and Steel Technology, 2004

**John S. Walker, Emeritus**
Fellow, American Society of Mechanical Engineers, 1994
Pi Tau Sigma Gold Medal, American Society of Mechanical Engineers, 1976
Halliburton Engineering Education Leadership Award, University of Illinois College of Engineering, 1985
Campus Award for Excellence in Undergraduate Teaching, University of Illinois, 1990
C. J. Gauthier Professor in Mechanical Engineering, University of Illinois Department of Mechanical and Industrial Engineering, 1999-2004
Accenture Award for Excellence in Advising, University of Illinois College of Engineering, 2002
Listed in the *Daily Illini* "Incomplete List of Teachers Ranked as Excellent by Their Students," Spring 2004

**Robert A. White, Emeritus**
Associate Fellow, American Institute of Aeronautics and Astronautics
Fulbright Scholarship, 1960-1961
NATO Senior Fellowship in Science, 1968
Thord-Gray Fellow in Physics, Scandinavian-American Foundation, 1968
Ralph R. Teetor Educational Award, Society of Automotive Engineers, 1986
Outstanding Faculty Advisor Award, Society of Automotive Engineers, 1991, 1996
Department of the Air Force, Medal and Award for Meritorious Civilian Service, 1991

**Xudong Zhang**
Industrial Ergonomics Best Student Paper Award, Human Factors and Ergonomics Society, 1996
Editorial Board Member, *International Journal of Industrial Ergonomics*, 1999
Career Development Award (K01 Award), Center for Disease Control and Prevention/National Institutes for Health, 2003
Xerox Award for Faculty Research, University of Illinois
College of Engineering, 2004
Industrial Ergonomics Best Student Paper Award (as advisor), awarded to Sang-Wook Lee (advisee), Human Factors and Ergonomics Society, 2004