2005 SUMMARY OF ENGINEERING RESEARCH

A Report of Activities during 2004

This .pdf is part of the larger 2005 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 2004 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.

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The 2005 Summary of Engineering Research is produced by the Office of Engineering Communications, University of Illinois at Urbana-Champaign.

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Renowned for the quality of its undergraduate and graduate programs, the Department of Mechanical and Industrial Engineering educates engineers who stand at the head of their fields. With rigorous research programs in nearly two dozen disciplinary areas, the department generates and applies new knowledge that strengthens the engineering profession and responds to societal needs.

While addressing the broad spectrum of areas long associated with mechanical and industrial engineering, such as automotive systems, controls and dynamics, energy systems, manufacturing, and operations research, research in the department also explores such emerging areas as nano-, micro-, and meso-technology and bioengineering. Innovative research directions reflect the interests and creativity of the faculty and students. Educating new generations of researchers is integral to the department’s mission.

The Department of Mechanical and Industrial Engineering is committed to meeting the needs of the State of Illinois and the nation through both fundamental and applied research. Driving the research mission of the department are the desires to generate new knowledge and to transfer it into practice. Several departmental center initiatives focus on research and technology transfer in the areas of air conditioning and refrigeration, building systems, continuous casting, fracture control, and machine tool systems. The department also houses the Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems (Nano-CEMMS), a National Science Foundation Nanoscale Science and Engineering Center, and the Center of Advanced Materials for Purification of Water with Systems (WaterCAMPWS), a National Science Foundation Science and Technology Center. Through these and other research initiatives, the department continually expands its cooperative research efforts with state and federal government agencies as well as its partnerships with industry.

The department is strongly committed to cross-disciplinary research as well and works closely with other departments within the College of Engineering and across the university. The Beckman Institute for Advanced Science and Technology, the National Center for Supercomputing Applications, the Frederick Seitz Materials Research Laboratory, and other campus resources add strength and diversity to the department’s research.

*Richard O. Buckius was department head during this reporting period.

Faculty and Their Interests

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Design methodology and tribology

Chia-Fon Lee
Automotive systems, combustion and propulsion, computational science and engineering, energy systems and thermodynamics, environmental engineering, fluid dynamics, heat transfer
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<td>Xudong Zhang</td>
<td>Bioengineering, computational science and engineering, human factors and ergonomics</td>
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Automotive Systems

Integrated Vehicle Dynamics
A. G. Alleyne,* Y. Li
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.

Design and Investigation of an Optically Accessible Diesel Reformer for Fuel Cells
C. F. Lee,* A. T. Edwin
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, D. 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.

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.

Modeling and Experiments of Lean Direct-Injection, Four-Stroke Spark-Ignition Engines
C. F. Lee,* D. L. Chang, J. W. Powell
National Science Foundation, CTS-9734402

A lean direct-injection spark-ignition engine concept has the potential of reducing fuel consumption and increasing performance while obtaining cleaner exhaust gas and greater driver comfort. The key research need of this type of engine is to develop a better understanding and control of in-cylinder fuel injection, atomization, vaporization, and mixing. The objective of this research program is to study the fuel sprays and air mixing process in direct-injection, four-stroke, spark-ignition engines using the latest multidimensional modeling and laser diagnostics techniques. Direct injection strategies currently under consideration by industry will be used, and the effects of key variables such as injector timing, atomization quality, air motion, and engine geometry will be investigated.

Modeling of Air/Fuel Mixing in a Stratified Gasoline Direct Injection Engine Using Multicomponent Fuel Representation
C. F. Lee,* D. Wang, Y. B. Zeng* (Bombardier)
University of Illinois at Urbana-Champaign; Bombardier Motor Corporation

A numerical study was performed on the air/fuel preparation process in a direct-injected, spark-ignition engine under stratified conditions. A four-component fuel with a distillation curve similar to that of actual gasoline was used. The multicomponent droplet and film vaporization models included major mechanisms such as nonideal behavior in high-pressure environments, preferential vaporization, internal circulation, surface regression, and finite diffusion in the liquid phase. A tumble-flow guided engine was studied. Computations with varying operation parameters were conducted to analyze relations between operation parameters and mixture stratification quality. The effects of the multicomponent models on fuel vapor distribution were also demonstrated.

Modeling of Blow-By, Ignition, Combustion, and Emissions of a High-Speed Diesel Engine
C. F. Lee,* J. X. Zhao, R. I. K. Shazi
Ford Motor Co.

One promising engine for passenger cars that are cleaner, more efficient, and more powerful is the high-speed,
direct-injection (HSDI) diesel engine. Currently, the main drawbacks of this engine include greater pollutant production of NOx and particulate matter. A better understanding of the combustion process inside the engine is needed. The latest engine spray, ignition, and combustion models will be used to obtain simulated data and compare that data to experimental data obtained from an optical HSDI engine. This is done to validate the spray and combustion models. Then, with reasonable confidence, the computed and measured data will be used to determine the parameters affecting pollutant formation and ways to reduce it.

**Modeling of Cavitating Flows in High-Pressure Fuel Injectors**  
C. F. Lee,* H. M. Wasfy  
_University of Illinois at Urbana-Champaign_

Flow cavitation is considered a major problem affecting the performance of a high-pressure diesel injector. The cavitating flow is a two-phase flow by nature with gaseous phase generally dispersed within the liquid phase in the form of minute bubbles. Since it is computationally impossible to simulate each bubble as it forms, the model is needed for calculating the amount of mass trapped in the bubbles to compute averaged fluid properties. The model also allows for tracking the formation and destruction processes of the bubbles. The impact of the bubble dynamics on the injector flow will also be studied.

**Modeling of Multicomponent Fuel Evaporation in Engines Using Continuous Thermodynamics**  
C. F. Lee,* D. Wang  
_Ford Motor Co._

The heating and gasification of liquid fuel droplets and films during the intake and compression strokes of an SI engine are important for fuel/air mixture preparation and cold-start emission. The amount of the liquid droplets entering the cylinder is strongly influenced by the type of fuel used. The complex fuel composition is described by a distribution function based on continuous thermodynamics for tracking gasoline, diesel, and JP-4 fuels. Evaporation models of multicomponent fuel droplets and films are developed. The models will be verified against vaporization measurements of single droplets. The model will then be used to study the detailed mixture preparation process.

**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.

**Simulations of Impingement from an Air-Assisted Fuel Injector and a Swirl Atomizer**  
C. F. Lee,* D. L. Chang  
_National Science Foundation, CTS 9734402_

Fuel impingement has been identified as a major contributor to increased hydrocarbon emissions because fuel film vaporizes more slowly than airborne droplets. Simulations of the impingement of an air-assisted fuel injector were made to determine whether fuel impingement from an air-assisted injector would be substantially less than that from a swirl atomizer, which is currently used in most production GDI engines. Impinging droplet characteristics such as diameter, Weber number, normal velocity, position, and splashing were predicted and compared for the two types of sprays.

**Bioengineering**

**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.

*Denotes principal investigator.
Mechanotransduction in the Vestibular Semicircular Canals
E. R. Damiano,* T. M. Stace
University of Illinois at Urbana-Champaign

The vestibular semicircular canal system is a phylogenetically old sensory apparatus responsible for transducing angular motions of the head. Fluid-structure interactions in the semicircular canals that result from head rotation give rise to spike initiation in afferent nerve complexes that encode the vestibular nerve. The aim of this research is to study the response dynamics of the semicircular canals. A new mathematical model of canal mechanics is under development that couples an asymptotic theory of pulsatile flow in curved circular ducts to a mechanoelectrochemical model of the charged mucopolysaccharide structures involved in the transduction process.

Microhemofluidics in Venules Using Microparticle Image Velocimetry
E. R. Damiano,* D. S. Long
University of Illinois at Urbana-Champaign; The Whitaker Foundation, TF-02-0024

Resistance to blood flow in microvessels depends on vessel dimension and the nonuniform local distribution of blood viscosity with microvessels, which is complicated by an unknown radial distribution of red cells. Using fluorescent microparticle image velocimetry to study microhemofluidics in glass capillary tubes in vitro and venules in vivo, we are developing a novel method for accurately and easily predicting distributions in velocity, viscosity, and local red-cell concentration that have not previously been directly measurable in vivo. These methods reveal details of microvascular blood flow that have implications for flow resistance, leukocyte adhesion, and mechanotransduction mechanisms.

Micro-Viscometric Studies of the ESL in Microvessels
E. R. Damiano*
The Whitaker Foundation, TF-02-0024; National Institutes of Health, R01 HL 076499-01

Our aims are to test whether the endothelial surface layer (ESL) expressed on vascular endothelium of microvessels increases resistance to blood flow in microvessels and quantitatively determine the Fahraeus and Fahraeus-Lindqvist effects in mouse skeletal-muscle venules in vivo; test whether a hydrodynamically relevant ESL exists on arterioles in vivo; test whether a physiologically typical ESL exists on the surface of a confluent monolayer of cultured endothelial cells; and test whether the ESL acts

as an anti-inflammatory barrier that prevents primary capture and subsequent rolling of leukocytes from the free stream in post-capillary venules in vivo.

The Mechanoelectrochemical Behavior of the Capillary Glycocalyx
E. R. Damiano,* F. H. El-Khatib
National Science Foundation, BES-0093985

Using brightfield and fluorescence microscopy, mechanical and electrostatic deformations of the glycocalyx surface layer on capillary endothelial cells will be observed in vivo in order to obtain estimates of the permeability properties and fixed-charged density of the layer. Combined with these experiments, a multidimensional mechanoelectrochemical model of the glycocalyx will be developed using continuum mixture theory. These investigations are aimed at providing a quantitative theoretical framework to explore the biophysical role of this structure in such diverse and important processes as immune response, cell adhesion, mass transport, and mechanotransduction of flow.

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 Nível 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 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-Wecksler,* 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” helmet 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-Wecksler,* 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 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. Two studies are currently in progress. One is a cross-sectional study, with healthy adults aged 25 to 63 years, exploring the effect of long-term tai chi experience (2 to 15 years) on balance, gait, and obstacle crossing behaviors. The other is a longitudinal study with older adults (65+ years) that is examining how balance and movement strategies may change as a result of 5 months of tai chi training.
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 and Acoustic Startle Probes
E. T. Hsiao-Wecksler,* C. H. Hillman,* K. S. Rosengren
*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. The startle reflex in humans is typically evaluated by measuring eye blink behavior (magnitude, timing). Postural response, particularly postural sway, to sudden and unexpected auditory noise has not been examined. One study is currently in progress. It combines the effects of an acoustic startle probe with viewing emotion-eliciting pictures, which is a known measure of the behavioral set. The goal of this study is to examine approach and avoidance behavior as measured by participants’ tendency to sway their bodies toward or away from the stimuli.

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 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
University of Illinois Research Board, Institute of Communications Research; Argonne National Laboratory

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,* R. Jamison
University of Illinois Research Board, Institute of Communications Research; Argonne National Laboratory

Biomechanical Energy Conversion Technology for Future Marine Corps Operations
U.S. 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.
**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 aluminized 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.

**Heterogeneous Solid Propellant Combustion Simulation**
M. Q. Brewster,* R. P. Fitzgerald  
*U.S. Department of Energy Center for Simulation of Advanced Rockets, B341494*

The combustion of two-dimensional AP/HTPB laminate propellants is simulated computationally. The framework is mass and energy transport with simplified chemical kinetics. The predicted results include steady regression rate, propellant surface geometry (free surface), and gas-phase flame structure. These three quantities are also the basis for comparison with experiments for validation of the model. The goal is to develop a simplified kinetics and transport scheme that can be used in 3-D, unsteady simulations of composite propellants.

**Radiation Heat Transfer in Solid Rocket Motors**
M. Q. Brewster,* K. C. Tang  
*U.S. Department of Energy Center for Simulation of Advanced Rockets, B341494*

Thermal radiation is an important mode of heat transfer in rocket motor internal flowfields. The primary source of thermal radiation is the field of submicron, liquid phase Al₂O₃ “smoke” particles formed by aluminum droplet combustion. In addition, pressure-broadened line radiation from molecular gases such as CO₂, H₂O, and HCl is also important at the elevated pressures in rockets. A hybrid radiation model will be developed with an N-flux description near the propellant surface matched with a diffusion approximation in the core region. A k-distribution technique will be used to accommodate the continuum particle radiation and the molecular gas line radiation. Absorption of radiation by the propellant is being simulated by three-dimensional Monte Carlo.

**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 RocStar integrated code of the Center for Simulation of Advanced Rockets (CSAR) to investigate coupled phenomena of internal flow and solid mechanics interaction in solid rocket motors typical of the space shuttle reusable solid rocket motor (RSRM), such as segment joint inhibitor vortex interaction. Validation is done using shuttle propellant in a small-scale motor to compare with simulation predictions.

**Solid Propellant Radiant Ignition and Combustion Modeling**
M. Q. Brewster,* K. C. Tang, J. Cain  
*U.S. Department of Energy Center for Simulation of Advanced Rockets, B341494*

Ignition of AP-composite propellants is being simulated computationally. The simulation uses a modified Zeldovich-Novozhilov (ZN) theoretical approach, compatible with a nonlinear dynamic burning model that has already been developed and validated. Radiative energy is considered as the first ignition source, due to the strong role of radiation from burning metal in pyrotechnic igniters. Ammonium perchlorate (AP) composite propellant is the primary material considered. The effects of radiant flux level, spectral energy distribution, and propellant optical properties on ignition delay are investigated. The model will be used to predict ignition behavior of AP and AP-composite propellant and will be validated with experimental results for AP and space shuttle propellant.
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, M. A. Wilcox
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.

Hydrogen Synthesis via Combustion of Fuel-Rich Methane/Air Mixtures
N. Glumac,* H. Krier,* B. Lemke, C. Roodhouse
National Science Foundation

Intermediate solutions for the large-scale synthesis of hydrogen for transportation applications will likely require cost-effective conversion of methane into hydrogen and carbon monoxide. Current technologies such as steam methane reforming remain too expensive, largely as a result of the required energy input and catalyst use. This study investigates noncatalytic partial oxidation of methane/air mixtures at elevated pressures as a simple means to generate hydrogen on a large scale. The chemistry of these mixtures is largely unknown and is studied in our laboratory with a high-pressure flow reactor and spectroscopic diagnostics.

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, P. Vanka, K. Aita
U.S. Department of Energy Center for Simulation of Advanced Rockets, B3141494

As aluminum particles become finer, burning rates and ignition times decrease, resulting in attractive burning behavior in solid rocket motors. Unfortunately, while such 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
University of Illinois Research Board

An exploratory 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.

**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, D. Wang  
*Argonne National Laboratory, ANL-IF-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.

**Modeling of Microexplosion and Flash Boiling in Engines**

C. F. Lee,* D. L. Chang, D. Wang
*Center for Advanced Study; Ford Motor Co.*

Microexplosion and flash boiling phenomena affect both vaporization and atomization of fuel sprays. For multicomponent fuel droplets, light components are entrapped inside the droplet that possibly leads to a local super-heat region and produces bubbles inside the droplet. The droplet then undergoes a violent expansion resulting in secondary breakup (so-called microexplosion). Fundamentally, flash boiling is similar to microexplosion. Both are believed to have positive effects on engine performance because they tend to produce smaller droplets compared to conventional breakup mechanisms. The theory and model for the breakup due to microexplosion and flash boiling will be developed and verified.

**Numerical Investigation of the Effect of Increased Acceleration on Film Boiling and Film Vaporization**

C. F. Lee,* R. K. Kapadia
*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 electrokinetics in water-gas-salt systems in the bulk or near separation membranes or functionalized solid substrates.

**Defects and Disorder in Photonic Bandgap Materials**

H. T. Johnson*
*University of Illinois Mechanical Engineering Gauthier Program for Exploratory Studies*

Defects and disorder strongly influence electromagnetic wave propagation in micron-scale periodic dielectric media. The objective of this project is to address this problem computationally to develop insights on current experimental studies of photonic bandgap (PBG) crystals. These novel materials rely on perfectly engineered line defects to function as optical waveguides, but suffer transmission losses due to improper surface preparation, point defects, grain boundaries, and other crystalline disorder. These features are studied using finite element analysis of electromagnetic wave propagation in realistic PBG materials.

*Denotes principal investigator.
Nested Newton Scheme for Domain Decomposition
L. Kale* (Comput. Sci.); D. A. Tortorelli,* D. Kulkarni
National Science Foundation; ITR

We introduce a domain decomposition approach based on a two-level Newton scheme for finite element analysis. The approach lends itself naturally to parallelization and allows for efficient handling of localized nonlinearities. A discontinuous Galerkin formulation is employed to handle nonmatching meshes across subdomain interfaces. The developed algorithm will be implemented in parallel using Charm++.

Control Systems

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.

Advanced Dynamic Modeling and Control of Air Conditioning and Refrigeration Systems
A. Alleyne,* C. W. Bullard,* P. S. Hrnjak,* M. Keir, B. Rasmussen
29 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. Hencsey, 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.

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,* Y. Li  
*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, D. Mukhopadhyay  
*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.

**Multi-Axial, Full-Scale, Substructured Testing and Simulation Facility**

A. Alleyne,* D. Kuchma, A. Elnashai, J. Ghaboussi, B. Spencer  
*National Science Foundation, DCM*

The primary objective of this project is to create a facility in which a full-scale subassembly can be subjected to complex loading and imposed deformation states at multiple connection points on the subassembly, including the connection between the structure and its foundation. The facility will have the following unique features: 6-DOF load and position control at multiple connection points; system modularity to allow for easy expansion and low-cost maintenance/operation; multiple dense arrays of noncontact measurement devices; and advanced visualization and data mining capabilities for integrated teleoperation and teleobservation.

**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.

*Denotes principal investigator.
Hierarchical and Reconfigurable Schemes for Distributed Control over Heterogeneous Networks


*Denotes principal investigator.

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 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

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,* H. Zhao, K. Zhang, B. Miller, E. Rubinovich

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

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. Kelly, C. Liu

National Science Foundation, CMS-032463

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,* H. Zhao, K. Zheng, J. Kim

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,* H. Zhao, A. H. Lee, K. Zhang

Grainger Center for Electromechanics; National Science Foundation, CMS-0000458

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,* H. Zhou, K. Zheng  
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 H₂ and H∞ 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,* H. Zhao, 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,* H. Zhao, 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.

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); Z. Di  
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 predominately 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).

**Control of Cooling Spray Zone in the Continuous Thin Slab Casting**

B. G. Thomas,* J. Bentsman,* K. Zheng

*National Science Foundation, CMS-032463; Continuous Casting Consortium (Algoma Steel, Canada; Corus Strip Products, The Netherlands; ISG Riverdale Steel, Illinois; LWB Refractories, Pennsylvania; Nucor Steel, Alabama; POSTECH, South Korea; Swedish Institute for Metals Research, Sweden)*

The project goal is to create transient models of continuous casting to predict temperature in real time and on its basis implement online spray cooling control algorithms.

**Design Methodology and Tribology**

**Tribological Studies on Scuffing Due to the Influence of CO₂ Used as a Refrigerant in Compressors**

T. F. Conry* (Gen. Engr.), A. A. Polycarpou,* N. Demas

*29 Company Consortium: Air Conditioning and Refrigeration Center*

This project will compare the effects of POE and PAG lubricants in a CO₂ refrigerant/lubricant mixture on the friction, lubrication, wear, and scuffing properties of various tribological pairs that are used in compressors. The proposed research will focus on the following two areas in an effort to explain the previously noted data scatter with CO₂ as the refrigerant: a characterization of the surface texture over the period of time between the initiation of a test through to the instant of scuffing; and a characterization of the physical, chemical, and mechanical properties of the surface and near-subsurface material.

**Dry Sliding Oil Pump Tests Using the High Pressure Tribometer**

A. A. Polycarpou,* T. Solzak

*Ingersoll-Rand Company Limited/Thermo King Corporation*

In this research we will use a special high pressure tribometer (HPT) to perform tests on the tribological performance of different oil pump samples. Specifically, actual parts from such units will be used and include current state-of-the-art materials as well as potential replacement materials.

**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 Coating Materials under High-Temperature Conditions
A. A. Polycarpou,* T. Solzak
Balzers A. G.

In this research, we use a high-temperature tribometer capable of testing up to 1,000ºC to perform controlled friction and wear tests of different hard coating materials. These hard coatings include diamond-like-carbon (DLC), tungsten/DLC as well as other newly formulated nanocoatings.

Tribology of Coatings for Oil-Less Compressors
A. A. Polycarpou,* T. Solzak
29 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.

Tribology of Polymer Composite Materials Relevant to Compressors Surfaces
A. A. Polycarpou,* M. Cannaday
29 Company Consortium: Air Conditioning and Refrigeration Center

The majority of compressor surfaces that experience tribological contact are metallic surfaces, including cast iron, aluminum, steel, and copper alloys. Even though polymer-based materials are used in many tribological applications, their use in air conditioning compressor surfaces seems to be somewhat limited or absent. Polymeric interfaces have major differences with metallic interfaces that need to be specifically addressed for their successful implementation and operation. In this research, we will use the high-pressure tribometer to perform scuffing experiments using different polymeric-based materials in the presence of refrigerant-lubricant mixtures, and 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
29 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.
Topology Optimization and the Fictitious Domain Method
D. A. Tortorelli,* R. B. Haber* (Theoret. & Appl. Mech.); M. P. Bendsøe* (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

Damping in Bolted Joints
Sandia National Laboratories, DOE SNL BF-0162

Mechanical joints are recognized to be responsible for much of the uncertainty in the behavior of otherwise linear structures. Two mechanisms that have been identified as both present and important are micro- and macroslip in the vicinity of connectors, such as bolts, and microslip between adjacent parts of a structure, particularly at high frequencies. Analysis and experiments have been used to characterize the behavior of two beams connected by a bolted lap joint, with work continuing on the development of predictive models.

Novel Passive Control Methods for Aerostructures
U.S. Air Force Office of Scientific Research

We are applying concepts of nonlinear localization and energy pumping to the vibration and shock isolation of structures representative of aircraft components. To achieve this, we use both analysis and experiments to gain a better understanding of the fundamental physics underlying both nonlinear localization and energy pumping. The research team is extending the energy-pumping concept to flexible continuous structures and to certain nonlinear systems. A model of a practical energy sink has been assembled and tested with excellent results on a beam-like structure subjected to broadband excitation. A patent on the concept has been filed and is pending.

A New Concept for LCO Suppression Based on Nonlinear Energy Pumping
L. A. Bergman (Aerosp. Engr.);* A. F. Vakakis;* D. M. McFarland,* Y. S. Lee
U.S. Air Force Office of Scientific Research, F49620-01-1-0208

Application of a nonlinear energy sink (NES) to an aeroelastic system has been successfully demonstrated by analysis and simulation. It was shown that the NES can be designed to drastically and robustly reduce, or even eliminate, limit cycle oscillations. Wind-tunnel tests on a model wing located at Texas A&M University are planned for summer 2005.

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.

Energy Systems and Thermodynamics

Analysis of Refrigerant Flow Modulation Concepts
C. W. Bullard,* S. Jain
29 Company Consortium: Air Conditioning and Refrigeration Center

Simulation and optimization modeling methods are employed to investigate and compare several new concepts for modulating refrigerant flow in air conditioning and
refrigeration systems. The focus is on vapor-injection into scroll compressor pockets, via a flash tank or subcooler, and tandem rotary or scroll compressors, combining single- and variable-speed drives. Preliminary results suggest performance advantages over modern variable-speed, single-compressor systems.

**Designing and Optimizing Systems with Compressor Rapid-Cycling**

C. W. Bullard,* P. S. Hrnjak,* M. Poort

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

This project explores an innovative method for mass flow regulation in refrigeration and air conditioning systems: rapid cycling of the compressor. Results to date have shown that cycle periods as long as 10 to 30 seconds can achieve efficiencies comparable to those obtainable with variable-speed compressors, potentially at lower cost. Experiments focus on identifying fundamental physical mechanisms affecting system performance and control and ways to design components for pulsed flow operation.

**Including Material Cost and Strength Constraints in Heat Exchanger Design**

C. W. Bullard,* I. Davidson

29 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

29 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 captubes. 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.

**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) desalinator, 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.

**Carbon Dioxide as a Refrigerant in Secondary Loops and Cascade Systems**

P. 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

29 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.
Control Strategies in Transcritical CO₂ Systems
P. S. Hrnjak,* A. Musser
Visteon

New application of transcritical systems with CO₂ for air conditioning and heat pumping require new component and control strategies. Steady-state and transient models are developed and experimentally verified.

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.

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.

Development of an Unbrazed, Flattened Copper Tube Condenser
T. A. Newell,* P. Hrnjak, T. Beavers, T. Gaddis
Copper Development Association

This project investigates flattened copper tubes with unbrazed fin structures for use in refrigeration condensers.

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

An Investigation of Electrochemical Processes for Refrigeration
T. A. Newell,* D. Gerlach, E. Mina
29 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation

This research focuses on investigation of electrochemical processes for producing refrigeration effects.

C. O. Pedersen,* R. J. Liesen,* R. Chilla
U.S. DOE Lawrence Berkeley Laboratory

This project includes research and development in the areas of building energy analysis and computer simulation of building systems. The context for this research is a computer program, called “EnergyPlus,” which is being developed under Department of Energy (DoE) sponsorship. EnergyPlus will include a detailed thermal zone model and a state-of-the-art heating, ventilation, and air conditioning (HVAC) system simulation. The zone model will accurately predict the performance of the building envelope and will calculate the effect of energy saving systems such as passive solar and advanced fenestration. The HVAC system simulation will be integrated with the zone model to allow for the analysis of processes such as moisture adsorption in building elements and hydronic radiant heating.

Development of a Silicon Carbide Microcapillary-Pumped Loop
L. M. Phinney, T. J. Mackin,* L. J. Meyer
General Electric

As miniaturization of electronics and devices continues, thermal management at small scales is increasingly important and challenging. This affects the performance of computers, cellular phones, and consumer electronics as well as many other devices that are a part of everyday life in modern societies. This project is developing a microcooler and packaging scheme for power (low-frequency) applications. We are designing and fabricating a capillary-pumped, loop-based microcooler in silicon carbide.
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 meso-technology.

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.

Thermomechanical Fatigue of Cast Iron
P. Kurath*
Caterpillar, Inc.

During routine operation, many engine components can experience nonuniform or localized temperature changes. These temperature differences, in conjunction with structural constraint, can cause stresses to develop in addition to those caused by normal operating loads. The effects of these additional stresses and possible acceleration of fatigue damage from oxidation at extreme temperatures are being investigated. Extending the experimental observations from uniaxial testing into a multidimensional model applicable to actual components is also being investigated.

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. Canadin, K. Verzal
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

*Denotes principal investigator.
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.

Engineering Statistics and Quality Control

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.

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.

*Denotes principal investigator.
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/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.

**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.

**Fluid Dynamics**

**Analysis of Flow and Transport in Subway Systems**
W. E. Dunn,* M. Gresshoff
*U.S. Department of Energy, DOE-ANL-IF-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.), S. D. Kim, B. J. Tillotson, L. S. Chang
*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 Schlieren/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,* 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, and pressure-sensitive paint.

*Denotes principal investigator.
Unsteady Features of Supersonic Separated Flows
J. C. Dutton,* P. M. Cannon, J. R. Janssen
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 and velocity field 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 and PIV data.

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.

Maldistribution and Bundle-Depth Effects on Falling-Film Flow
A. M. Jacobi*
29 Company Consortium: Air Conditioning and Refrigeration Center

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 overflow 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.

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.

Experimental Investigation of Refrigerant/Oil Flows Using an Ambient Pressure Flow Visualization Facility
T. A. Newell,* X. Bai
29 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation, EEC 96-12120

A flow visualization loop using refrigerant R123 is being constructed. A novel optical measurement system is being developed for nonintrusive measurement of two-phase flow parameters.

Experimental Investigation of Viscous Two-Phase Flow in Microchannels
T. A. Newell,* P. S. Hrnjak,* J. Burr
29 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation

Void fraction and pressure drop of different microchannel tubes are being investigated. A variety of refrigerants at different mass flow rates and quality are examined.

Investigation of Refrigerant/Oil Mixtures in Horizontal Tubes
T. A. Newell,* J. C. Chato,* J. Crompton
29 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.

*Denotes principal investigator.
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.

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.

Flow Field in an Asymmetric Stenosis under Physiological Inflow Conditions
S. P. Vanka,* K. Cukierski
University of Illinois at Urbana-Champaign

The three-dimensional unsteady flow downstream of an asymmetric stenosis is being modeled using the FLUENT software. Several parametric tests of inflow Reynolds numbers and blockage ratios are being investigated. Peak fluid velocities and shear stresses are studied in spatio-temporal space.

Heat Transfer to Complex Impinging Jet Configurations
S. P. Vanka,* B. Collins
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, etc. An unsteady, three-dimensional Navier-Stokes code is being used to solve the relevant governing equations.

Mixing in a Curved Channel
S. P. Vanka,* D. C. Kyritsis, K. Christensen, K. Joyce
University of Illinois at Urbana-Champaign

The role of Dean vortices in scalar mixing in a curved channel is being studied using three-dimensional confocal microscopy, micro-PIV, and CFD. Two streams of fluid with different scalar concentrations are supplied to a curved channel at varying Reynolds Numbers (1-20). The scalar mixing and micro-PIV measurements of axial and radial velocities and numerical results are being compared with each other.

Magnetic Stabilization of Convection during Compound Semiconductor Crystal Growth
J. S. Walker,* B. C. Houchens, L. E. Gemeny
National Science Foundation, CTS-0346302

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.

*Denotes principal investigator.
Heat Transfer

Frictional Damping in Dynamic Contract Multiple Scale Experiments and Physics-Based, Scale-Bridging
E. R. Berger, T. J. Mackin,* M. R. Begeley
U.S. Air Force Office of Scientific Research

A thermoelastic stress analysis method based upon infrared imaging is used to measure the shear transfer length in model dynamic friction specimens. An indirect method for estimating the size of the slipping zone has also been developed, wherein a direct measurement of the frictional heating is used to determine the extent of partial slip at a frictional interface. These measurements, when combined with theoretical models provide a physics-based approach for designing friction damping into jet engines. Preliminary results show that this approach can explain anomalous frequency dependent behavior in friction damping systems.

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.

Radiative Properties and Reactive Wave Propagation Mechanisms in Nanoenergetic Material
M. Q. Brewster,* S. Begley
Los Alamos National Laboratory, 54961-001-2

The objective of this research is to investigate the reactive wave propagation mechanisms in nanoenergetic metastable intermolecular composite (MIC) materials by determining the relative importance of radiative and conductive energy transport. Radiative properties are being measured using both absolute and relative light scattering and extinction measurements. Radiative transfer theory is used to deduce the radiative properties of densely packed powders, including the effects of multiple scattering.

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, including general multidimensional gaseous absorption, 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 developed approach models 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.

Enhancement of Air-Side Heat Transfer in Offset-Strip Fin Arrays Using Unsteady Forcing
J. C. Dutton,* A. M. Jacobi,* J. M. Brutz
29 Company Consortium: Air Conditioning and Refrigeration Center

In this work, mechanical excitation (via oscillating vanes) of the flow through an offset-strip fin array is used to obtain enhanced air-side heat transfer. The basic idea is to use low-amplitude forcing at appropriate frequencies to trigger natural instabilities in the flow, such that large-
scale flow fluctuations (unsteadiness, vortex shedding, etc.) with amplitudes far in excess of the forcing are obtained. These fluctuations, in turn, will lead to greatly enhanced air-side heat transfer and should do so with a minimal increase in array pressure drop. Dye-in-water flow visualizations, convective heat transfer data, and particle image velocimetry (PIV) velocity field information are being obtained.

Heat Pipes and Thermosyphons for Air Conditioning and Refrigeration Applications
P. S. Hrnjak,* A. M. Jacobi, Z. Gu
29 Company Consortium: Air Conditioning and Refrigeration Center

Heat pipes and thermosyphons have been used in a wide range of applications and industries. Recent advances in design and manufacturing have resulted in reduced cost for this technology, making it even more attractive in contemporary thermal management systems. The potential for broader application of heat pipes and thermosyphons is compelling in air conditioning and refrigeration systems, where they can be used instead of a single-phase secondary loop, or where the extremely high thermal conductivity can be exploited to achieve a significant performance improvement. The goal of this project is to explore the use of heat-pipe and thermosyphon technologies in air conditioning and refrigeration (AC&R) systems.

Heat Transfer in Condensing CO2 at Low Temperatures
P. 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.

In-Tube Condensation of Ammonia in Smooth and Enhanced Tubes with and without Miscible Oil
P. S. Hrnjak,* T. A. Newell, J. Vollrath, H. Komadiviarya
American Society of Heating, Refrigerating, and Air-Conditioning Engineers

Experimentally obtained data for condensation of ammonia in horizontal tubes, with and without oil, will be used to generate heat transfer and pressure-drop correlations.

Oil Effects on Heat Transfer and Pressure Drop in Small Channels
P. S. Hrnjak,* C. Seeton, B. Field
29 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.

Air-Side Condensate Accumulation and Shedding Effects on the Thermal Performance of Automotive Air Conditioning Evaporators
A. M. Jacobi,* J. Pienkos
Ford-Visteon

Our research has been aimed at developing design methods and guidelines for condensate management in automotive air conditioning evaporators. The research is pursued through an approach combining experimental methods and analytical modeling. The specific goals of the current work are to quantify the air-side condensate retention in automotive evaporators as a function of fin and heat exchanger geometry; to quantify the effects of surface and operating conditions on condensate retention; to quantify the effects of retained condensate on heat transfer and pressure-drop performance; and to develop an engineering tool to predict condensate retention and its effect on thermal performance.

Falling Film Behavior: Maps to Include Vapor Shear, Dry-Out, and Flooding
A. M. Jacobi,* A. Pagan
29 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation

This research extends our earlier work, which resulted in the first generalized flow-pattern map for predicting whether a liquid film falling from one horizontal tube to another below it will take the form of discrete droplets,
jets, or a continuous sheet. Flow pattern maps will be
developed for a falling liquid film in the presence of a
flowing vapor. Experiments use a falling-film bundle
constructed within a wind tunnel, allowing visual access
during experiments with a vertical up- or down-flow of the
vapor. Fluid properties and flow rates are measured and
images of the flow are recorded.

**Frost, Defrost, and Refrost on**
**Superhydrophobic Surfaces**
A. M. Jacobi,* J. G. Georgiadis,* Y. Zhong
*Air Conditioning and Refrigeration Center (ACRC)*

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.
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.

**Super-Wettable Surfaces for Heat Exchangers**
**in Air Conditioning Systems**
A. M. Jacobi,* L. Liu
*29 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*
*29 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. Hrnjak*
29 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation

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 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 and Analytical Study of Condensate Retention on Air-Side Heat Transfer Surfaces: Condensate Management
A. M. Jacobi,* A. ElSherbini
29 Company Consortium: Air Conditioning and Refrigeration Center

This project builds on the successes of this earlier work to provide further wet-exchanger performance data (for a microchannel geometry), to extend the simplified retention model to handle important geometric complexities, and to explore new methods for managing condensation. This project represents a new direction in our work, and may help lead to surface designs that provide better condensate drainage and less fly out. The ultimate outcome of this work will be a new approach in modeling wet heat exchanger performance—an approach based on a rational prediction of condensate retention and its effect on air-side heat transfer and pressure drop.

An Experimental and Analytical Study of Dynamic Carry-Over
A. M. Jacobi,* A. ElSherbini
29 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation

The problem of condensate carry-over (or fly out) is important to maintaining occupant comfort in the conditioned space. Carry-over occurs when condensate on the air-side surface is stripped into the air stream by shear and pressure forces; the droplets entrained into the airflow are carried downstream where they either land in the air-handling ducts or discharge into the conditioned space. In either case, carry-over can present significant problems. We are conducting an experimental and analytical study of the dynamic carry-over behavior for air-conditioning evaporators. Experiments are conducted to measure the onset of shedding for various condensate loading conditions and to understand the distance a droplet is carried downstream by the air. By characterizing carry-over in terms of the transient retention behavior and thermal performance, measuring droplet trajectories, and applying new predictive tools, we hope to develop useful design guidelines for avoiding or mitigating carry-over.

A Study of the Application of Vortex Generators to Enhance the Air-Side Thermal Performance of Heat Exchangers
A. M. Jacobi,* A. Sommers
29 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation

Passively generated streamwise vortices can enhance air-side heat exchanger performance. Our earlier work has shown that vortex generation applied to a plain fin-and-tube heat exchanger with a large fin spacing will increase the area-goodness factor, j/f, by up to 34% at relatively high air flow rates. This new research project is focused on full-scale implementation of vortex enhancement in systems for which frost growth occurs on the air-side surface and for heat exchangers with high compactness (surface-area-to-volume ratio exceeding 2000 m⁻¹).

Design and Fabrication of MEMS-Based Biosensors
T. J. Mackin*
Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign

This project aims to design, fabricate, and functionalize several MEMS-based sensor geometries as real-time detectors of biological markers of disease. These designs are prototyped and demonstrated using prostate specific antigen, polymerization free volume change, and protein adsorption using rabbit IgG and antigen. The proposed sensor geometries include arrays of fixed-fixed microbeams, each of which is functionalized by affixing specific reactive molecules to each microbeam surface. In the presence of the target molecule, the beams deflect and generate an optical interference pattern that indicates the presence of the antigen. Our beams will differ from competitive prototypes by utilizing a critical load sensing approach rather than the continuous approaches currently under investigation. The sensor geometry is chosen for extreme sensitivity and real-time detection for point-of-delivery health care/sensing/monitoring. The goal is to develop a design paradigm that will enable the fabrication of microdevices to provide real-time assay for a range of biological molecules.

*Denotes principal investigator.
In-Situ Film Thickness and Stress Measurement Using Infrared Sensing
T. J. Mackin*
National Science Foundation

The research project is developing a new method for measuring the thickness of thin films using a nondestructive, noncontacting infrared imaging system. The method is amenable to quality control in high throughput production environments. As such, the technology developed in this project will significantly improve coating processes and dramatically decrease the time and expense required to improve coating performance and reliability. The infrared sensing technology developed in this program can be used to measure film thickness, integrity, and stress at any stage of the coating process, both during deposition and/or after manufacture. The ability to monitor film thickness in-situ is a critical need for many applications, as current techniques are based largely on empirical processing studies and post-priori destructive evaluation. Add to that the ability to quantify stress and the method emerges as a significant contribution to the technology of thin film processing and characterization with a broad range of industrial applications, including (but not limited to): microelectronic fabrication and assembly, MEMS fabrication and performance, thermal barrier coatings used in the energy conversion industry, metallic coatings on glass, and paint or protective coatings in everything from airplanes to cell phones.

Microscale Thermal Sensing and Actuation Using MEMS
T. J. Mackin,* L. M. Phinney
National Science Foundation, CTS-0240020

The rapidly developing microelectromechanical systems (MEMS) technology has applications in the automotive, health care, aerospace, environmental sensing, and consumer products industries. MEMS devices have been used to extend thermal measurement capabilities to greater sensitivities and smaller spatial resolutions than those achieved by traditional methods. Additionally, some MEMS devices are thermally actuated. For example, bimaterial cantilevers deform when heated because of mismatches in the thermal expansion coefficients and have been used to actuate MEMS devices. This project investigates using MEMS devices to measure heat transfer performance, thermophysical properties, and thermal actuation schemes.

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.

Investigation of Refrigerator Heat and Mass Transfer Cabinet Loading during Open Door Conditions
T. A. Newell,* W. Terrell, C. Gutierrez
29 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation

Experimental investigation of combined heat and mass transfer in open cavities is being conducted.

Radiative Interactions with Microstructures
L. M. Phinney,* T. J. Mackin,* J. W. Rogers, S. B. Koppaka
National Science Foundation, CTS-9984979

Mechanical structures with dimensions as small as a few microns are being used in conjunction with electrical...
circuits to create microelectromechanical systems (MEMS). These devices offer low weight and batch production methods, which are advantageous for many applications. Controlling and optimizing laser processing of microdevices during fabrication requires a thorough understanding of radiative interactions with microstructures. A novel method for repairing adhered surface-micromachined, polycrystalline silicon structures has been developed using short-pulse lasers. This project experimentally, analytically, and computationally examines the effect of radiation on microstructures.

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

Supporting Exploratory Sequential Data Analysis with MacSHAPA
P. Sanderson*
University of Queensland, Australia; New York University

Human factors and cognitive engineering researchers often have to review and analyze videotaped records of people interacting with systems and with other people in the workplace. Video analysis is time-consuming work, and if it is performed without a conceptual framework the quality of results suffers accordingly. We have developed a conceptual framework for video analysis called exploratory sequential data analysis (ESDA) that is supported by a widely used software tool (MacSHAPA). In this project, we are engaged in further development of the ESDA framework and the MacSHAPA software so that researchers can more effectively extract meaning from video data.

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.

Manufacturing Systems

Collaborative Research: Virtual Machine Tool
R. E. DeVor,* S. G. Kapoor,* P. Bless
National Science Foundation, DMI-00-04226

The objective of this project is to build a flexible, easily reconfigurable, and interactive software development environment that supports the large and growing body of software tools for computer-aided manufacturing (CAM). The envisioned virtual machine tool (VMT) environment will be based on a systemization of the CAM component domain, an agent-based communication framework, and a set of algorithmic strategies to develop a flexible environment for the simulation of manufacturing processes in terms of workpiece attributes and process capabilities.

Testing of Machinable Austempered Ductile Iron (MADI)
R. E. DeVor,* S. G. Kapoor,* O. Bhattacharyya, M. Glowik, A. Balasubramanian
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. 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. Recently, Intermet has developed a machinable austempered ductile iron (MADI).
Study of Low Degree-of-Freedom Parallel Kinematics for Multiscale Manufacturing
P. M. Ferreira,* J. Stori, 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. A. Stori,* J. Dong
National Science Foundation, DMI-99-84214, 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.

Modeling and Analysis of Internal Thread Forming Process
S. G. Kapoor,* R. E. DeVor,* C. Warrington
National Science Foundation Industry/University Cooperative Research Center for Machine Tool Systems Research

Many applications in industry rely on threaded holes as a means of joining components. The most popular way to create the threads is via cutting. However, another method, thread forming, has recently seen increasing interest. The mechanism behind thread forming is plastic deformation of the material, which also causes work hardening; thus, threads are able to withstand greater loads. The project aims to investigate thread quality, in particular, the formation of split crests. Through both experiments and numerical modeling the impact of tap design and process parameters, a split crest formation is being studied.

Noise Reduction for High-Speed Milling Process
S. G. Kapoor,* R. E. DeVor,* S. Marathe, K. Sampath
National Science Foundation Industry/University Cooperative Research Center for Machine Tool Systems Research

Machining at very high rotational speeds (range of 20,000–30,000 revolutions per minute) often causes a great amount of noise. The noise levels to which operators are exposed usually exceed the total allowable worker noise dose (90–95 db). The goal of this project is to gain an understanding of the fundamental sources of noise generation in machining and to develop effective techniques to mitigate the noise in the machining process and in machine tool systems.

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.

*Denotes principal investigator.
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 techniques, feature-based cost modeling, and mathematical models to convert feature 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.

Decision Support Systems for Electronics Manufacturing
J. Stori,* P. 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.

Development of a Native AP210 Package Modeler
J. A. Stori,* P. M. Ferreira, T. Dong, D. Mukhaphadyay, A. Seth
National Institute of Standards and Technology

The objective of this project is to develop an electrical component modeler native to STEP AP 210. This component modeler will provide an easy-to-use GUI that allows users to quickly define the many geometric constructs (such as leads, contacts, seating planes, dimensions, tolerances, etc.) and the many functional capabilities of features (e.g., wire, microwave waveguide, optical waveguide, electrical, thermal, mounting, orientation) that are called for in the standard. By providing a “parametric” capability based on package technology, it will allow for the rapid generation of “library” objects that can be used to facilitate the population of a component library of AP 210 packaged parts.

Process Characterization of Vibrostrengthening and Application to Fatigue Enhancement of Aluminum and Titanium Components
J. A. Stori,* 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.

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 have 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.

*Denotes principal investigator.
Mechanism-based Theories of Strengthening and Hardening for Alloy Design and Processing
Y. Huang*

We use the theory of Mechanism-based Strain Gradient (MSG) plasticity to investigate the size effect in alloys.

Quantum Confinement in Nanostructured GaN
H. T. Johnson*

Gallium nitride and other group III-nitride materials are desirable for many important applications in telecommunications and microelectronics due to favorable operating wavelengths and high temperature/power characteristics. However, large lattice mismatch between these materials and the available substrate layers leads to tremendous stresses and high dislocation densities. Thus, the coupling of thin film mechanics and electronic/optical properties is a central issue in fabricating new devices. In this project, two types of nanostructured GaN and III-nitride systems are investigated. One class of material is nanostructured through spontaneous composition segregation occurring during growth; the other class is a deliberately template-grown form of GaN with length scales on the order of 20nm. The work will be done in close collaboration with investigators at the University of Michigan and General Electric Global Research, who have recently fabricated and characterized GaN nanostructures. The work in this project relies on computational methods developed previously in the PI’s group for understanding the connection between mechanical and optoelectronic properties in realistic systems with disorder and defects in other materials.

Biaxial Nonproportional Testing of Aircraft Alloys
P. Kurath*

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*

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*

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

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.
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,* A. J. Wagoner Johnson,* 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 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.

**Parameter Estimation of Plasticity Models via the Finite-Element Method and Inverse Analysis**

D. A. Tortorelli,* D. Bammann* (Sandia Natl. Lab.), D. Pattillo  
*Sandia National Laboratories*

Various plasticity models, which include both temperature and strain rate effects, are being implemented in a small strain plasticity finite-element code. Parameter estimation will be performed via an inverse analysis. Novel to this work is the computation of the parameter distributions.

**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

Development of a Two-Phase Model for the Hot Deformation of Highly Alloyed Aluminum
U.S. Department of Energy; Alcoa Aluminum

This research is developing a fundamental understanding of deformation of wrought alloys with emphasis on the upper temperatures bounding the hot working regime. Traditional constitutive models consider the alloy as a single-phase system. This research is developing a two-phase (grain interior and boundary) mathematical description. The focus on hot rolling provides a computation platform for optimization of the thermomechanical processing window (TPW) within industrial capabilities of temperature and deformation rate. This research will provide the computational tools to allow “faster and cooler” processing of highly alloyed aluminum.

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.

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.

Simulation of Epitaxial Growth of Elastic Thin Films
E. Fried* (Washington Univ.), D. A. Tortorelli,* D. Kulkarni
National Science Foundation; ITR

We employ our domain-decomposition-based, finite-element approach to simulate epitaxial growth in thin films. A continuum theory based on configurational forces is employed. The dynamical theory accounts for both stress and diffusion within the epitaxial surface.

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.

Development of a Process to Continuously Melt, Refine, and Cast High-Quality Steel
B. G. Thomas,* L. Zhang, J. Aoki
U.S. Department of Energy; University of Missouri–Rolla; Continuous Casting Consortium (Algoma Steel, Canada; Corus Strip Products, The Netherlands; ISG Riverdale Steel, Illinois; LWB Refractories, Pennsylvania; Nucor Steel, Alabama; POSTECH, South Korea; Swedish Institute for Metals Research, Sweden)

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 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.
Flow Dynamics and Inclusion Transport in Continuous Casting of Steel
B. G. Thomas,* S. P. Vanka,* L. Zhang, Q. Yuan, B. Zhao
National Science Foundation, GOALI No. DMI-0115486; Continuous Casting Consortium (Algoma Steel, Canada; Corus Strip Products, The Netherlands; ISG Riverdale Steel, Illinois; LWB Refractories, Pennsylvania; Nucor Steel, Alabama; POSTECH, South Korea; Swedish Institute for Metals Research, Sweden)

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 the steel companies that are cosponsoring this research.

Fluid Flow, Heat Transfer, and Interfacial Phenomena in Nozzle Refractories
B. G. Thomas,* Z. Hashisho, F. Harvengt, J. Nuttin
Continuous Casting Consortium (Algoma Steel, Canada; Corus Strip Products, The Netherlands; ISG Riverdale Steel, Illinois; LWB Refractories, Pennsylvania; Nucor Steel, Alabama; POSTECH, South Korea; Swedish Institute for Metals Research, Sweden)

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 (Algoma Steel, Canada; Corus Strip Products, The Netherlands; ISG Riverdale Steel, Illinois; LWB Refractories, Pennsylvania; Nucor Steel, Alabama; POSTECH, South Korea; Swedish Institute for Metals Research, Sweden)

The first few seconds of solidification at the meniscus create the final cast product surface. Defects, such as deep oscillation marks, surface depressions, and subsurface hooks in the microstructure may occur if conditions are not optimal. In-house computational 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. 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.

Interface Heat Transfer and Friction in Continuous Casting
B. G. Thomas,* Y. Meng
Continuous Casting Consortium (Algoma Steel, Canada; Corus Strip Products, The Netherlands; ISG Riverdale Steel, Illinois; LWB Refractories, Pennsylvania; Nucor Steel, Alabama; POSTECH, South Korea; Swedish Institute for Metals Research, Sweden)

Heat transfer in continuous casting molds is controlled primarily by heat conduction across the interface between the solidifying steel shell and the water-cooled copper mold. A comprehensive model, CON1D, has been developed to predict this heat transfer, including mass and momentum balances on the interfacial powder layers, superheat delivery from the turbulent liquid pool, gap formation, and friction between the shell and the mold walls. Plant and lab experiments are being conducted to measure interfacial heat transfer in the continuous casting mold. These are needed to obtain fundamental interfacial property data, so that the model can become a fully predictive tool to solve quality problems and interpret mold thermocouple and friction signals.
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 being developed and 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 the composition, morphology, and distribution of inclusions, refractory wear, and other relevant phenomena are being conducted for additional insight and model validation.

Online Dynamic Control of Cooling in Continuous Casting of Thin Steel Slabs
B. G. Thomas,* J. Bentsman,* Y. Meng, K. Zheng, D. Li
Continuous Casting Consortium (Algoma Steel, Canada; Corus Strip Products, The Netherlands; ISG Riverdale Steel, Illinois; LWB Refractories, Pennsylvania; Nucor Steel, Alabama; POSTECH, South Korea; Swedish Institute for Metals Research, Sweden)

Temperature variations during cooling cause quality problems such as cracks, especially under transient conditions such as 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 computer 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 model-based predictive control, incorporating both online measurements of mold heat removal and a high-speed finite-difference model of heat conduction and solidification during the process.

Thermal Stress Analysis of Solidifying Steel Shells
B. G. Thomas,* C. Li, S. Koric, K. Xu
Continuous Casting Consortium (Algoma Steel, Canada; Corus Strip Products, The Netherlands; ISG Riverdale Steel, Illinois; LWB Refractories, Pennsylvania; Nucor Steel, Alabama; POSTECH, South Korea; Swedish Institute for Metals Research, Sweden); Columbus Stainless; Hatch Associates

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.

Computational Tools for Analysis of Chaotic Mixing
C. L. Tucker,* J. Phelps, M. Wilhelm
University of Illinois Research Board

Chaotic fluid motions, in which the velocity field is known exactly but particle positions are ultimately unpredictable, 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 low 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.

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

*Denotes principal investigator.
influence on the properties of the bulk material. We are developing theoretical models for how this microstructure arises during processing, from the deformation during mixing. We are also testing the model with carefully controlled experiments on droplet deformation and writing 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 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 microelectrofluidicmechanical systems.

Mixed-Domain Simulations, Reduced-Order Models and Circuits for Bio-MEMS
N. R. Aluru*
National Science Foundation

The objective of this research is to develop analysis and design tools for device, reduced-order, and circuit modeling of biological electromechnanical systems (bio-MEMS) for structured design of bio-MEMS. The objectives of device modeling are to develop mathematical models to include all significant microscopic effects in bio-MEMS, develop fast and efficient scattered point and mixed-regime techniques for mixed-domain analysis of biofluidic devices. The objective of reduced-order modeling is to represent the device by a low-order model that can capture the functional behavior. Low-order models based on a weighted snapshot approach will be developed to capture multiple time scales encountered in bio-MEMS. By identifying several bio-fluidic components, which could form the basic building blocks for complex bio-MEMS on a chip, and developing reduced-order models for these building blocks, circuit models will be developed to design large-scale, biointegrated circuits on a chip.

Atomistic-Based Continuum Models of Micro- and Nanoscale Engineered Systems/Processes
R. E. DeVor,* S. G. Kapoor,* Y. Huang,* K. 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 mm and producing three-dimensional features.

Development of a Microscale Machine Tool System Testbed
R. E. DeVor,* S. G. Kapoor,* X. Liu, A. Phillip
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

*Denotes principal investigator.
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 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.

**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 toolkit 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; 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.

*Denotes principal investigator.
P. S. Hrnjak,* X. Tu
U.S. Department of Defense Advanced Research Projects Agency

In the second phase of the project, the focus is on heat transfer and pressure drop in refrigerant flow through 100- to 200-micron hydraulic diameter channels.

Heat Transfer in Evaporating CO₂ at Low Temperatures
P. Hrnjak,* C. Y. Park
National Science Foundation; 29 Company Consortium: Air Conditioning and Refrigeration Center

Heat transfer in evaporation at CO₂ with and without oil in channels 1 to 6 mm is studied.

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.

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.

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- to 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.
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.

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,* S. C. Lee, A. Y. Suh
National 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.

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

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,* D. Tewari, 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.

Self-Assembled Nanowires
M. T. A. Saif,* H. Sehitoglu,* B. E. Alaca, 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.

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, 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

*Denotes principal investigator.
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 the 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, Q. Yao
*NSF Nanoscale Science and Engineering Center, DMI-0328162*

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 toolbit-work piece interface of the Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems (Nano-CEMMS). The project will extend to the integration of flexible and scaled-down toolbit interfaces and include the functions for the rapid characterization and evaluation of the performance of individual gated nanopores within the Nano-CEMMS toolbit on a work piece.

**NER: Interplay between Mechanical and Electronic Properties in Carbon Nanotube Structures**
M. F. Yu,* D. Qian
*National Science Foundation, CCF-0404001*

The proposed efforts will aim to understand the fundamental electro-mechanical coupling in CNTs having realistic dimensions for application and provide valuable parameters related to the functionality and reliability of such CNT electromechanical devices.

**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 advance of nanoscale science and technology.
Ultrahigh Sensitivity Parametric Sensing with Nanotube
M. F. Yu*
National Science Foundation

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*
University of Illinois at Urbana-Champaign

The research 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 study, which includes the study of the surface mediated flow on external nanotube surface or the liquid transport through internal nanotube channel. In situ liquid manipulation and characterization techniques developed in this project facilitate the flexible study of various liquids, such as water, polymer, and ionic solution, and the 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, I. Shryayev, H. Kaul
National Science Foundation, DMI-0222597; Department of Mechanical and Industrial Engineering, Program for Exploratory Studies

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 vaccines 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 of any new pediatric combination vaccine products as they enter the market place.

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 neighborhood functions to be combined into a single hybrid heuristic model.

*Denotes principal investigator.
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 card and therefore the proposed models are technologically doable.

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.

Next-Generation Linear Optimization
D. Klabjan*
Sabre, Inc.; National Center for Supercomputing Applications (NCSA)

We will develop a software library for airline crew scheduling. Unique features of the library will be the use of parallel algorithms, portability, independence of the complex crew scheduling rules, and its generality. The design will easily allow the use of the library for

*Denotes principal investigator.
other similar problems such as robust crew scheduling and rostering.

**Dynamic Models for Optimizing Retail Assortments**
U. S. Palekar,* G. Daruka
*Sears; University of Illinois at Urbana-Champaign*

We consider the problem of determining the best set of items to be displayed as well as the amount to be carried in retail stores in a multiperiod scenario. The model considers product interactions, such as substitution, ensembles, contiguities, and dependencies. We analyze the computational complexity of several variants of the problem. We also design and test exact algorithms for the solution of the problem.

**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,* J. A. Stori, T. Dong, H. Shi
*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 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.

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.

Dynamic Pricing for Manufacturer Capacity
W. Zhao*
University of Illinois at Urbana-Champaign

Advances in e-commerce, enterprise information systems, and automated production process control enable manufacturers to sell their processing capacity to more potential customers. We develop models that dynamically determine the price of the capacity in order to maximize the total expected revenue. The prices depend on the demand forecast, existing orders, and due dates.

Journal Articles

Automotive Systems


Bioengineering


Combustion and Propulsion


**Computational Science and Engineering**


**Control Systems**


**Design Methodology and Tribology**


**Dynamic 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**


Yu, N. and Polycarpou, A. A. Use of the focused ion beam technique to produce a sharp spherical diamond indenter for sub-10 nm nanoindentation measurements. Journal of Vacuum Science and Technology B, 22:2, 668-672 (2004).


Operations Research


Book Chapters

Control Systems


Engineering Mechanics


Materials Processing


Books

Nano-, Micro-, and Meso- Technology


Operations Research

Operations Research


Papers Presented at Conferences and Symposia

Automotive Systems


Bioengineering


**Combustion and Propulsion**


Computational Science and Engineering


Control Systems


Design Methodology and Tribology


Energy Systems and Thermodynamics


Malik, T. and Bullard, C. *Air conditioning HEVs while stopped in traffic [Paper 04HX7]*. Annual Congress of the Society of Automotive Engineers (Detroit, MI, Mar. 2004).


Rajan, J. and Bullard, C. W. *Residential space conditioning and water heating with transcritical CO$_2$ refrigeration cycle [Paper R101]*. 10th International Refrigeration and Air Conditioning Conference at Purdue (West Lafayette, IN, Jul. 2004).


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**Engineering Mechanics**


Fluid Dynamics


Heat Transfer


Manufacturing Systems


Materials Behavior


Materials Processing


Nano-, Micro-, and Meso-Technology


Operations Research


**Theses**

**Automotive Systems**


**Bioengineering**


**Combustion and Propulsion**


**Computational Science and Engineering**


**Control Systems**


Design Methodology and Tribology


Dynamic Systems


Energy Systems and Thermodynamics


Engineering Mechanics


Environmental Engineering


Fluid Dynamics


Heat Transfer


Materials Behavior


Materials Processing


Nano-, Micro-, and Meso-Technology


Awards and Honors

Andrew G. Alleyne
Outstanding Graduate Student Instructor Award, 1990-1991
Listed in the Daily Illini “Incomplete List of Teachers Ranked as Excellent by Their Students,” Spring 1995, Fall 2004
Faculty Early Development (CAREER) Award, National Science Foundation, 1996
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 1998, 1999
Xerox Award for Faculty Research, University of Illinois College of Engineering, 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

Narayan R. Aluru
Career 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 Development (CAREER) 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
Fellow, Japan Society for the Promotion of Science
Associate Fellow, American Institute of Aeronautics and Astronautics
ASCE State-of-the-Art in Civil Engineering Award, American Society of Civil Engineers, 1983
Editorial Board, *Journal of Vibration and Control*, 1994-
Associate Editor, *Shock and Vibration Digest*, 1998-
Japan Society for the Promotion of Science (JSPS) Fellowship, 1998
ASCE 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 ICIOSSAR, 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
Committee on Institutional Cooperation Academic Leadership Fellow, 1990
Editorial Advisory Board, Heat Transfer-Japanese Research, 1990-
Who’s Who in Science and Engineering, Marquis Who’s Who in America, 1993
Editorial Advisory Board, Microscale Thermophysical Engineering, 1996-
Editorial Advisory Board, Heat Transfer Research, 1997-
Associate Technical Editor, Journal of Thermophysics and Heat Transfer, 1999-2004
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
Who’s Who in American Education; Who’s Who in Technology Today; Who’s Who in Science; Men of Achievement; American Men and Women of Science; Outstanding Young Men of America, 1980; Who’s Who of Intellectuals; Biography International; Who’s Who in Engineering; Who’s Who in Technology; Who’s Who in the World; Biography Fame International

Accenture Award for Excellence in Advising, University of Illinois College of Engineering, 2003
F. Paul Anderson Award for Technical Achievement, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2004
J&E Hall Gold Medal, The Institute of Refrigeration, 2005
Distinguished Service Award, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2004

Bei Tse Chao, Emeritus
Member, National Academy of Engineering
Member, Academia Sinica, Republic of China
Life Fellow, American Society of Mechanical Engineers
Fellow, American Association for the Advancement of Science
Life Fellow, American Society for Engineering Education
Boxer Indemnity Scholar, Sino-British Cultural and Educational Foundation, 1945-1948
Blackall Machine Tool and Gage Award, American Society of Mechanical Engineers, 1957
Heat Transfer Memorial Award, American Society of Mechanical Engineers, 1971
Western Electric Fund Award, American Society for Engineering Education, 1973
Russell S. Springer Visiting Professor of Mechanical Engineering, University of California, Berkeley, 1973
Ralph Coats Roe Award (First), American Society for Engineering Education, 1975
Five-Year Effective Teacher Award, University of Illinois, Department of Mechanical and Industrial Engineering Alumni Board, 1978
Southwest Mechanics Lecturer, Southwest Universities Association, 1982
Max Jakob Memorial Award, American Society of Mechanical Engineers and American Institute of Chemical Engineers, 1983
Lamme Medal, American Society for Engineering Education, 1984
Outstanding Achievement Award, American Academy of Higher Education, 1984
Prince Distinguished Lecturer, Arizona State University, 1984
Tau Beta Pi Daniel C. Drucker Eminent Faculty Award (First), University of Illinois College of Engineering, 1985
University Scholar, University of Illinois, 1985-1988
William T. Ennor Manufacturing Technology Award, American Society of Mechanical Engineers, 1992
National Aeronautics and Space Administration Certificate of Recognition for Creative Development, 1993
Centennial Medallion, American Society for Engineering Education, 1993
Centennial Alumnus, National Chiao-Tung University, Taiwan, 1996
Distinguished Alumnus, Shanghai Jiao-Tong University, China, 1996
Honorary Member, American Society of Mechanical Engineers, 2002

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

Thomas F. Conry
Fellow, American Society of Mechanical Engineers

J. Craig Dutton
National Science Foundation Trainee, 1973-1974
Fellow, University of Illinois, 1975-1976

John 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
Member, National Academy of Engineering, 2000
Fellow, American Society of Mechanical Engineers
Fellow, Society of Manufacturing Engineers
Blackall Machine Tool and Gage Award, American Society of Mechanical Engineers, 1983, 1997
William T. Ennor Manufacturing Technology Award, American Society of Mechanical Engineers, 2003
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
Two-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1981, 1989, 1995, 2002
Five-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1981, 1990, 2005
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
Distinguished Professor of Manufacturing, University of Illinois College of Engineering, 2000-2001
Distinguished Emeritus Professor of Manufacturing, University of Illinois College of Engineering, 2001

Geir E. Dullerud
National Sciences and Engineering Research Council of Canada Initiation Grant, 1996
Faculty Early Development (CAREER) 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, 1993-1995
University Scholar, University of Illinois, 1995
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 1997
Invited Guest Professor, Controls Engineering Department, Chalmers University, Gothenberg, Sweden, Summer 1999

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 Development (CAREER) 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

**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, 2004-2005

**Yonggang Huang**
Wakonse Fellow, University of Arizona, 1993
Junior Investigator Award, National Science Foundation, 1995
Alcoa Foundation Faculty Award, 1995, 1996
Motorola Foundation Faculty Award, 1997
Ford Foundation Faculty Award, 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, NCSA, University of Illinois, 2002
Listed in the *Daily Illini* “Incomplete List of Teachers Ranked as Excellent by Their Students,” Spring 2003, Spring 2004, Fall 2004
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
Chang Jiang Chair Professor, Department of Engineering Mechanics, Tsinghua University, Peoples’ Republic of China, 2005-
Regional Editor and Member of the Editorial Board, *International Journal of Fracture*, 2004-
Editorial Board, *International Journal of Multiscale and Interactive Mechanics*, 2004-

**Anthony M. Jacobi**
Listed in the *Daily Illini* “Incomplete List of Teachers Ranked as Excellent by Their Students,” Spring and Fall 1993; Fall 1995; Spring and Fall 1996, 1997, 1998; Fall 2000; Spring 2003; Spring 2004
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
Associate Technical Editor, *International Journal of HVAC&R Research*, 1998-
Five-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1999
Associate Technical Editor, *Journal of Energy Resources Technology*, 1999-
Editor, *ASME Heat Transfer Division Newsletter*, 2000-
American Society of Heating, Refrigerating, and Air-Conditioning Engineers Distinguished Service Award, 2003
Accenture Award for Excellence in Advising, University of Illinois College of Engineering, 2003
E. K. Campbell Award, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2004
Kritzer Faculty Scholar, Department of Mechanical and Industrial Engineering, 2003-2006
Rose Award for Teaching Excellence, University of Illinois College of Engineering, 2003
E. K. Campbell Award, American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), 2004
Richard W. Kritzer Distinguished Professor, University of Illinois Department of Mechanical and Industrial Engineering, 2004-2009

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, 2002-2005
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 Development (CAREER) 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,” Spring 2004

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

Scott D. Kelly
Listed in the Daily Illini “Incomplete List of Teachers Ranked as Excellent by Their Students,” Spring 2002; Spring 2004, Fall 2004

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 Valicek Medal (joint with graduate student Rivi Sandhu), International Award by the Airline Group of the International Federation of Operational Research Societies (AGIFORS), 2004

Helmut H. Korst, Emeritus
Daniel Guggenheim Medal, ASME, AIAA, and SAE, 1994
Fellow, American Institute of Aeronautics and Astronautics Fellow, American Society of Mechanical Engineers
Senior Postdoctoral Fellow, National Science Foundation, 1957
Dr. Ernest H. Wakefield Award, University of Illinois, 1975
Associate Member, University of Illinois Center for Advanced Studies, 1977-1978
Ebaugh Professor of Mechanical Engineering, University of Florida, 1984
Centennial Medallion, American Society for Engineering Education, 1993
Golden Doctor Diploma, Technical University, Vienna, Austria, 1997
Honorary Member, American Society of Mechanical Engineers, 2001

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 Plasmodynamics and Lasers, American Institute of Aeronautics and Astronautics Conference on Plasmodynamics 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

Dimitrios Kyritsis
Listed in the Daily Illini “Incomplete List of Teachers Ranked as Excellent by Their Students,” Spring 2003, Spring 2004
Faculty Early Development (CAREER) Award, National Science Foundation, 2004

Carl S. Larson, Emeritus
National Science Foundation Summer Teaching Grants, 1957-1963
Teaching Development Award, University of Illinois, 1967
Two-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1974, 1993
Five-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1977
Merit Award, Lincoln Foundation Design Contest, 1981
Honorary Knight of St. Pat, University of Illinois College of Engineering, 1986
Outstanding Faculty Member, Dad’s Association, University of Illinois, 1987

Outstanding Zone Campus Representative Award, American Society for Engineering Education, 1993
Centennial Certificate, American Society for Engineering Education, 1993
Accenture Award for Excellence in Advising, University of Illinois College of Engineering, 2001
Department of Mechanical and Industrial Engineering Alumni Board Award, University of Illinois, 2002-2003

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

Chang Liu
Listed in the Daily Illini “Incomplete List of Teachers Ranked as Excellent by Their Students,” Spring 2001
Faculty Early Development Program (CAREER) Award, National Science Foundation, 2000
Elected Senior Member, Institute of Electrical and Electronics Engineers, 2002

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 Development (CAREER) 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

Norman R. Miller
Listed in the Daily Illini “Incomplete List of Teachers Ranked as Excellent by Their Students,” 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
Listed in the Daily Illini “Incomplete List of Teachers Ranked as Excellent by Their Students,” 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
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

Udatta S. Palekar
Listed in the Daily Illini “Incomplete List of Teachers Ranked as Excellent by Their Students,” Spring 1988; Fall 1989, Fall 1993; Spring 1994; Spring 2003; Spring 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
Outstanding Mentoring of Graduate Students (Finalist), University of Illinois, 1997
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

Curtis O. Pedersen, Emeritus
Fellow, American Society of Heating, Refrigerating and Air-Conditioning Engineers
International Member, Doctoral Jury, University of Liege, Belgium, 1981, 1986
Commander’s Award for Distinguished Public Service, U.S. Army Construction Engineering Research Laboratories, 1992

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, 1995-2005
Stanley H. Pierce Award, University of Illinois College of Engineering, 1995
M. Taher A. Saff
Faculty Early Development (CAREER) 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
Listed in the Daily Illini “Incomplete List of Teachers Ranked as Excellent by Their Students” for Spring 2003; Spring 2004
Willett Faculty Scholar Award, College of Engineering, 2003-2006
Associate, Center for Advanced Study, University of Illinois, 2004-2005

Huseyin Sehitoglu
Institution of Mechanical Engineers Award, The City University, London, England, 1979
Listed in the Daily Illini “Incomplete List of Teachers Ranked as Excellent by Their Students,” 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
Editor, Journal of Engineering Materials and Technology, 2002
Best Presentation Award, American Society of Testing Materials, 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-
Peter Seiler
O. Hugo Schuck Award for Best Paper at the 2002 American Control Conference (888 papers were presented), 2003

Mark A. Shannon
Listed in the *Daily Illini* “Incomplete List of Teachers Ranked as Excellent by Their Students,” Fall 1998, Spring 2002; Spring 2004
Faculty Early Development (CAREER) 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

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

Wilbert F. Stoecker, Emeritus
Fellow, American Society of Heating, Refrigerating and Air-Conditioning Engineers
Fellow, American Society of Mechanical Engineers
Honorary Professional Degree in Mechanical Engineering, University of Missouri-Rolla
Honorary Member, APEC Consulting Engineers Association
National Science Foundation Faculty Fellowship, 1960-1961
Foundation Teacher Study Grant, 1961-1962
Danforth Foundation Teacher Study Grant, 1961-1962
Western Electric Award for Effective Teaching University of Illinois/Indiana Section Five-Year Effective Teacher Award, University of Illinois Department of Mechanical and Industrial Engineering Alumni Board, 1966, 1976, 1978, 1985
Two-Year Effective Teacher Award, University of Illinois Department of Mechanical and Industrial Engineering Alumni Board, 1971, 1975, 1975, 1982, 1985
E. K. Campbell Award, ASHRAE, 1973
Award for Best Technical Paper, Annual ASHRAE Meeting Distinguished Service Award, ASHRAE, 1976
F. Paul Anderson Award, Highest Technical Award of ASHRAE, 1978
Halliburton Engineering Education Leadership Award, University of Illinois College of Engineering, 1978
Ralph Coats Roe Award, Mechanical Engineering Division, American Society for Engineering Education, 1980
International Activities Award, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 1985
Hall-Thermotank Gold Medal, British Institute of Refrigeration, 1986
Outstanding Alumnus Award, University of Illinois Department of Mechanical and Industrial Engineering, 1989
Ottesen Memorial Medal, Danish Refrigeration Association, 1991
Life Membership, International Institute of Ammonia Refrigeration, 1992
Distinguished Fifty-Year Member Award, ASHRAE, 2002

James A. Stori
Faculty Early Development (CAREER) 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
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
Rossiter W. Raymond Memorial Award (Best Paper), American Institute of Mining, Metallurgical, and Petroleum Engineers, 1991
John Chipman Award (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 (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 (Best Paper), Iron and Steel Society, 1998
Robert W. Hunt Silver Medal (Best Paper 1998), 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
Included in Marquis Who’s Who in Science and Engineering, 2005-2006

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, Department of Mechanical and Industrial Engineering, 2003-2006

Charles L. Tucker
Listed in the Daily Illini “Incomplete List of Teachers
Fellow, American Society of Mechanical Engineer, 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
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

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W. Grafton 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