Mechanical Science and Engineering

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Building upon the longstanding strengths of programs in mechanical engineering and in mechanics, the University of Illinois Department of Mechanical Science and Engineering (MechSE) is taking a bold, new approach to research and education that will enable it to address some of the most pressing problems facing the nation and the world. Integrating biology, chemistry, applied mathematics, and applied physics with mechanical engineering and engineering mechanics disciplines, MechSE engages in leading-edge research that serves some of society’s greatest needs: for clean, affordable and reliable sources of energy; for better methods of disease detection; for more effective identification of threats to national security; for cost-effective and nonpolluting modes of transportation; and for manufacturing solutions that will facilitate the transition of nanoscale discoveries from the laboratory to the public.

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

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

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

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

With its new approach to education and research, MechSE offers its students and faculty outstanding opportunities to make significant contributions in the high technology, research, and policy arenas. Explore the website to learn more about MechSE.

Faculty and Their Interests

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Automotive systems, control systems
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engineering mechanics, fluid dynamics, nano-, micro-, and  
meso-technology

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Bioengineering, computational science and engineering, human factors and ergonomics

Automotive Systems

Integrated Vehicle Dynamics  
A. G. Alleyne*  
* Denotes principal investigator.

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 Conventional Fuels and Biofuels  
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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, Fraunhofer Diffraction, and Particle Image Velocimetry. Distributions of liquid fuel and fuel vapor are measured with laser-induced fluorescence techniques. 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, C. H. Wu
*University of Illinois at Urbana-Champaign; Argonne National Laboratory*

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

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

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

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

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

**Effects of Biodiesel and Paraffinic Fuel on Particle Size Distribution in the Exhaust of Diesel Engines**
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Biodiesels as alternative fuels have been widely investigated in conventional diesel engines, but the particle size distribution emitted from heavy-duty diesel engines fueled with palm-biodiesel and paraffinic fuel blends has seldom been addressed. For health and environmental reasons, particle size distribution emitted from diesel engines fueled with biodiesel should be investigated. Various test fuel blends including diesel, palm-biodiesel, and paraffinic fuel were used in this study. Preliminary experimental results indicated that palm-biodiesel could be blended with diesel to improve combustion efficiency in diesel engines, but pure palm-biodiesel would cause incomplete combustion in the diesel engine. Moreover, adding palm-biodiesel to diesel would cause more fine particle emission. It was also found that the soot particle size, THC, and CO emissions are very sensitive to the blends.

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

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

Investigation of Biodiesel Fueled Engines under Low-Temperature Combustion Strategies
C. F. Lee,* A. C. Hansen,* V. L. Stringer, J. P. McCrady, J. R. Beasley
U.S. Department of Energy, DE-FG26-05NT42634

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

* Denotes principal investigator.
Modeling Droplet Breakup Processes in Biofuel Diesel Engines under Microexplosion Conditions
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Microexplosion affects both vaporization and atomization of biofuel 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). Microexplosion is believed to have positive effects on engine performance since they tend to produce smaller droplets compared to conventional breakup mechanisms. The theory and model for the breakup due to microexplosion for biofuels will be developed and verified. This study has a special focus on microexplosion for multicomponent droplets in biodiesel engines.

Modeling of Blow-By, Ignition, Combustion, and Emissions of a High-Speed Diesel Engine
C. F. Lee,* J. X. Zhao
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
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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.

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

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

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

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

* Denotes principal investigator.
System Analysis of a Biodiesel Engine Using GT-Power Engine Simulation
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Agricultural fat and oils, in raw or chemically modified forms, have the potential to supplant a significant proportion of petroleum-based fuels. Biodiesel is of particular interest to the automobile industry because it significantly reduces particulate matter, hydrocarbon, and carbon monoxide emissions. In addition to its benefits to regulated exhaust emissions, biodiesel contributes less to global warming than fossil fuels due to its closed carbon cycle. There is almost no net increase of carbon dioxide emission from biodiesel combustion. However, effects of biodiesel on the system of high-performance, high-speed, direct-injection engines are not well known. In this study, the commercial code, GT-Power, will be modified and used to study the biodiesel effects on intake, engine combustion, exhaust, and after treatment.

Tripot Constant Velocity (CV) Joint Internal Friction Characterization
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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.

Bioengineering

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

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

Bone Fluid Flow
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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.

Microcirculation Simulation
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Tools are being developed to faithfully represent the dynamics of large numbers of blood cells flowing in the microcirculation. The cells are modeled as massless shells.

* Denotes principal investigator.
and a fast $O(N \log N)$ method has been implemented to discretize a boundary integral formulation of Stokes flow. We have applied this method to study the transport of leukocytes (white blood cells), particularly their tendency to move toward the vessel walls, which they do as part of the physiologic inflammation response. We show that it is the many-body hydrodynamic interactions with the red cells that promote this margination and demonstrate that it is lubrication forces that lead to the observed decrease in margination observed in vivo at higher flow rates.

**Renal Tissue Damage in Shock-Wave Lithotripsy**
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Extracorporeal shock-wave lithotripsy has become a common treatment for kidney stones and other renal calculi. But since its invention in the early 1980s, it has become clear that more injury to renal tissue occurs than initially thought, and long-term studies are suggesting some chronic conditions correlate with treatments. We are investigating the mechanics of the tissue injury and have conducted simulations that suggest that shock-induced shear might accumulate with the 1000+ shocks of a typical treatment, breaking vessels, and precipitating more extensive spreading cavitation-driven damage.

**Simulation of Incompressible Flow-Structure Systems with Large Solid Deformations**
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U.S. Department of Energy, Center for Simulation of Advanced Rockets

Many biological systems involve flow interacting with relatively soft tissues. Often cited examples include heart valves and other cardiovascular components, flowing and deforming blood cells, and swimming animals. We have designed a novel algorithm for such systems. It discretized the momentum equation on a fixed Eulerian mesh, as is usually done in simulating fluid flow. This mesh is overlaid with a moving Lagrangian mesh for tracking the reference condition of the solid to compute its elastic stresses. We demonstrated the method on several flows, including the swimming of a model jellyfish.

**Bio-Inspired Active Membranes and Transepidermal Water and Ion Transport**
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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.

* Denotes principal investigator.
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.

Effect of SCBA Bottle Configuration on Gait and Balance Performance among Firefighters
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As first responders to emergency situations, firefighters play a crucial role in homeland security. Therefore, providing support to these first responders by examining human factors issues to improve their health and safety is of critical national importance. Falls and loss of balance on the fireground are one of the leading causes of traumatic injuries among firefighters, resulting in ~11K injuries per year (i.e., over 1/4 of all annual fireground injuries). Many of these events are potentially preventable; however, research examining the underlying mechanisms leading to these events and efforts to develop intervention programs to prevent falls have been limited. Along with the Illinois Fire Service Institute (IFSI) at the University of Illinois, we are developing a research program to explore how firefighting equipment and environment affect balance, locomotion, and slip, trip, or fall (STF) risk. The overarching goal of this program will be to improve firefighter safety by reducing preventable STFs and provide knowledge that will aid in the choice and design of better firefighting gear. Specifically, we are examining how the addition of personal protective equipment (PPE), which consists of coat, pants, gloves, boots, helmet, hood, and self-contained breathing apparatus (SCBA), affects STF risk through modification of gait and balance performance.

Effect of Tai Chi on Balance and Movement Strategies
E. T. Hsiao-Wecksler,* K. S. Rosengren
University of Illinois at Urbana-Champaign

Tai Chi has been promoted to older adults as an exercise to improve physical and mental fitness. It has also been found to reduce the likelihood of falling in senior citizens. This project explores how Tai Chi experience may modify postural control mechanisms and movement strategies specifically during unexpected external perturbations to balance and while walking over level ground and obstacles. We are also investigating new techniques for assessing Tai Chi skill proficiency. Dynamic systems modeling, control theory, and movement analysis are used to examine these issues. We are conducting both cross-sectional studies on individuals with long-term Tai Chi experience (greater than 2 years) and longitudinal studies on older adults who are receiving Tai Chi training for 5 months.

Fluid Power Assistive Orthoses
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National Science Foundation

In the United States alone, there are over 800,000 individuals affected by gait disabilities caused by weakness of muscle groups below the knee. This project, which is a testbed project for the NSF funded Engineering Research Center for Compact and Efficient Fluid Power, will design novel ankle foot orthoses (AFOs) with embedded fluid power control and actuation that assist a person's functional gait. Each design iteration will address progressively more complex gait pathologies, thus allowing for an evolution of advanced fluid power concepts, such as power harvesting and fast-response sensing. Initial designs will utilize fluid-controlled (adaptive-passive) systems to correct for toe drop and foot slap, helping to lift the foot during swing and initial foot contact during walking. Later advanced designs will use fluid-powered (active) systems to provide torque assistance during the propulsive late-stance phase of the gait cycle. The testbed will demonstrate and integrate compact, efficient, and effective fluid power concepts in a challenging, untethered, human-scale device. The long-term goal is to develop and test a series of prototype devices that will incorporate current thrust area projects, as well as drive new enabling and systems technologies within the center. These technologies will follow an evolutionary roadmap addressing the highest priority aspects of the overall testbed first, and then integrating developments from other center projects as they come available over the lifetime of the center. This testbed will culminate with prototypes supplied to health care professionals and patients for testing and evaluation.

* Denotes principal investigator.
Gait Analysis of Labrador Retrievers with Cranial Cruciate Ligament Deficiency
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University of Illinois at Urbana-Champaign: American Veterinary Medical Association

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

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

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

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

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

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

Acute lower limb injury may lead to chronic gait problems or even disability due to asymmetry between the injured and uninjured limb. Current clinical gait analysis techniques used for diagnosis and rehabilitation are qualitative in nature and do not quantitatively assess recovery. The overall goal of this project is to develop quantitative techniques to assist in the treatment and monitoring of lower limb injury and asymmetry. Gait is a

* Denotes principal investigator.
dynamic behavior with considerable changes in joint and body positions throughout the gait cycle. We are developing a novel technique, integrated multivariate gait analysis (IMGA), to distinguish asymmetry in gait and identify the source of asymmetry. IMGA uses geometric shape analysis (generalized procrustes analysis) with multivariate statistical techniques (principal components analysis and parallel factor analysis) to capture the dynamic nature of walking behavior that current univariate measures cannot capture.

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

Much of the research related to falls in older adults has used retrospective self-reports of falls over the previous 6 months or year. We are developing a prospective slips, trips, and falls survey (STAF inventory) to better establish the incident rate of falls and fall-related behaviors. This survey evaluates the number of fall-related incidents as well as the environmental conditions, individual factors, and whether any injuries have occurred over a given study period. Falls and fall-related events are being tracked for a period of 30 days. The STAF inventory is being administered to college-aged, middle-aged, and older adults.

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

Pregnant women anecdotally state that balance changes as pregnancy progresses and the circumference of the trunk and body weight increase. However, no studies have examined how balance, and postural control that moderates balance, may vary throughout pregnancy and the subsequent postpartum period. This study will assess how balance and postural control may vary as a consequence of pregnancy by examining how a subject’s postural sway varies over the 9-month pregnancy and a following 6-month postpartum period.

Characterization and Modeling of Trabecular Bone
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We study bone as a hierarchical material and predict its local fields and constitutive responses at different structural scales in healthy and disease states. More specifically, we characterize the hierarchical structure of normal and osteoporotic bone at several structural levels from nano to macro scales, identify failure and fracture mechanisms in bone at different structural scales, measure in vitro and in vivo bone’s properties at different scales, develop micromechanics models to predict local fields and constitutive responses of bone from nano to macro scales, and use an automatic learning program combining analytical and experimental outputs from different structural scales and outputs from clinical databases to predict bone properties.

Mechanics of Helices
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Research was focused on the derivation of effective responses of helices with substructure. The first area of study was homogenization of multiphase, microperiodic helices with perfect or imperfect interfaces, with phases characterized by parabolic or hyperbolic heat conduction. Effective equations of motion, along with effective constitutive coefficients, were determined via an asymptotic homogenization method. The results are valid in the case of wavelengths much longer than the length of the unit cell. Formulas for shorter wavelengths can be derived by admitting higher order terms in the expansion. The second area of study focused on a helical strand made of a viscoelastic material governed by a constitutive relation with fractional-order (i.e., not integer-order) derivatives. Overall, it was found that the resulting fractional-order differential equation of the helix is more complex (i.e., it involves higher derivatives) than the constitutive equation governing the material per se, which, in turn, has consequences for models of chiral media. These two topics also provide a stepping-stone to a new study of transient dynamics of head trauma.

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

* Denotes principal investigator.
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.

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

T. A. Saif,* S. Yang  
*National Science Foundation, ECS 0524675*

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

**Mechano-Stimulation and Transduction 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.

**Stochastic Models of Cell Cycle Regulation in Eukaryotes**

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The cycle of cell growth, DNA synthesis, mitosis, and cell division is the fundamental process by which cells (and all living organisms) grow, develop, and reproduce. The control system is so complex that mathematical and computational methods are needed to reliably track the interactions of dozens of genes, mRNAs, proteins, and multiprotein complexes. The goal of the proposed project is to create a realistic and accurate stochastic model of cell-cycle control in budding yeast. Success in modeling growth and division will translate into better understanding of the roles of cell division in basic biological processes of significant relevance to human health, e.g., embryonic development, tissue regeneration, wound healing, and carcinogenesis.

**Mechanical Behavior of Bone Scaffolds with Multiscale Porosity: Effects of Ingrown Tissue and In Vivo Degradation**

A. J. Wagoner Johnson,* R. Jamison, M. Wheeler, S. Clark  
*University of Illinois Research Board*

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

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

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

Bioengineering Approaches to Map Stress Propagation in the Cytoskeleton
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One of the central questions in cell biology is how mechanical signals are propagated and distributed inside the cytoplasm of living cells. Previously Prof. Wang’s lab showed that locally applied stresses were propagated to remote sites in the cytoplasm, a finding that contradicts conventional model predictions. Recently Prof. Wang’s lab demonstrated that force propagation in the cytoplasm is regulated by the cytoskeletal prestress. Prof. Wang’s lab also shows that, surprisingly, at a fixed level of prestress, the extent of stress propagation exhibits biphasic behavior with loading frequency. These results suggest mechanical signaling is controlled by prestress and loading frequency.

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
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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.

Generating Extreme Speed and Force from Small, Simple Materials: Biologically Inspired Models from Striking Ability in Trap-Jaw Ants
X. Zhang,* A. Suarez (Entomol.), A. Vakis
Beckman Institute for Advanced Science and Technology

This collaborative research initiative seeks to study the extreme force and motion production abilities of trap-jaw ants and to understand and model the underlying principles. These principles are intended to inspire the design of novel mechanisms or devices that can generate, store, and release large amounts of force with relatively small, simple materials or organisms.

Combustion and Propulsion

Aluminum Agglomeration in Solid Propellant Combustion
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Agglomeration of aluminum at the burning surface of composite solid propellants is an important phenomenon that influences performance of the rocket. Observations of

* Denotes principal investigator.
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.

Radiative Properties of Burning Aluminum Droplets
M. Q. Brewster,* J. Harrison
U.S. Department of Energy Center for Simulation of Advanced Rockets, B341494

Burning aluminum droplets are a significant source of thermal radiation in aluminized solid rocket motors for transferring heat to the burning solid propellant surface and inert surfaces such as insulators. As part of large-scale, integrated simulations of internal flows in solid rocket motors, it is important to be able to simulate thermal radiation heat transfer. Yet there is no proven, reliable understanding of the radiative properties of these burning aluminum droplets. The goal of this project is to develop a better understanding and model of burning aluminum droplet thermal radiation using experiments and modeling.

Flow Control in Hypersonic Vehicles using Laser and Microwave Discharges
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Hypersonic vehicle flow control systems will require response times that are shorter than the times over which conventional mechanical flaps can respond. This project investigates the use of radiation-based methods—visible light lasers and microwave sources—to create discharges that can generate pressure disturbances and control flows to mitigate instabilities. The experimental project includes both characterization of the discharges, as well as the effect of such discharges on relevant high speed flows.

Aluminum Water Combustion for Unmanned Underwater Vehicles
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Unmanned underwater vehicles (UUVs) can exhibit a tenfold increase in range over conventional battery powered systems if the fuel is powdered metal burning in the ambient seawater. Numerous challenges with such a system need to be overcome, not the least of which is the understanding of fine aluminum combustion in water vapor under relevant conditions. This study aims to develop a combustion rate correlation for fine metal particles in a water vapor ambient relevant to UUVs.

Research in Metal Combustion for Thermobaric Weapons
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Defense Threat Reduction Agency

Thermobaric weapons are a critical element in the war on terrorism. This project utilizes the University of Illinois at Urbana-Champaign heterogeneous shock tube to test advanced thermobaric candidate materials and to establish baseline data against which advanced computational thermobaric weapons models can be compared.

Combustion of Aluminum and Aluminum Hydride
H. Krier,* N. Glumac, P. Lynch
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.

Reactive Metals in Shaped Charge Applications
H. Krier,* N. Glumac,* R. Bill, B. Fant
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

* Denotes principal investigator.
study uses the shock tube to investigate fundamental reaction rates of metal in water, as well as a powder gun facility with a 1.3 km/s capability.

**Solid Rocket Motor Aluminum Burning Models**

H. Krier*

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

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

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

D. C. Kyritsis,* K. Bijjula

*National Science Foundation; University of Illinois Research Board*

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

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

D. C. Kyritsis,* S. A. Smyth, M. S. Agathou, C. J. Evans

*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.

* Denotes principal investigator.
Effects of Oxygenate in Diesel Fuel on Spray Structure, Combustion, and Emissions
C. F. Lee,* Y. Xu
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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 NO\textsubscript{x} 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 NO\textsubscript{x} and PM levels.

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

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

Reducing NO\textsubscript{x} Emission from the Combustion of Biodiesel Blends Using Low-Temperature Combustion Engines
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Biodiesel used as alternative fuel in diesel engines can reduce total hydrocarbons, carbon monoxide, carbon dioxide, sulfur dioxide, particulate matter, and polycyclic aromatic hydrocarbons emissions, and slightly increase the brake specific fuel consumption and NO\textsubscript{x} emission. Thus, the strategies for reducing exhaust emissions from biodiesel combustion in low-temperature combustion engines were investigated in this study. The preliminary results show that, although NO\textsubscript{x} emission increases with percentage of biodiesel contents for conventional and late injection strategies, NO\textsubscript{x} emissions of B20, B50, and B100 in low-temperature combustion strategy were all lower than that of B0 in conventional strategy.

Two-Photon Fluorescence Detection of Nitric Oxide
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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. Subsequently, this technique will be applied to diesel engine combustion measurements.

A Continuous Thermodynamics Formulation for the Vaporization of Liquid Fuel Mixtures
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Continuous thermodynamics, describing the fuel composition by a probability distribution function, is an efficient mean for transport calculation in complex liquid mixtures such as fuels. Variation in liquid compositions and properties can be known by tracking the mean and variance of the probability distributions, instead of solving the large numbers of differential equations. However, a single probability distribution function is used in most

* Denotes principal investigator.
studies. This might be inadequate for a liquid mixture composed of groups of species with significantly different properties. An extension of the previous model using continuous thermodynamics that would accommodate multiple probability distribution functions is proposed.

**Computational Aerodynamics Applied to Solid Rocket Motor Modeling**

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_U.S. Department of Energy Center for Simulation of Advanced Rockets, B341494_

The burnback of a solid rocket motor propellant grain is simulated using methods from computational aerodynamics to accelerate convergence to quasi-steady solid rocket motor ballistic flows.

**Computational Science and Engineering**

**Adaptive Space-Time Meshing for Discontinuous Galerkin Finite Elements**


*National Science Foundation Center for Process Simulation and Design, DMR 01-21695*

This project supports numerical research in the Center for Process Simulation and Design at the University of Illinois at Urbana-Champaign. The objective is to develop algorithms for space-time mesh generation and adaptive refinement that are responsive to the special requirements of discontinuous Galerkin methods as applied to problems with evolving geometries. Specific topics include unstructured space-time meshing subject to nonlinear causality constraints, dynamic h-adaptive space-time meshing, and discontinuity tracking for problems with shocks, growing cracks, and evolving inter-phase boundaries.

**Transport and Phase Behavior of Binary Fluids in Porous Media**

J. G. Georgiadis,* A. Kalinichev (Geol.), D. C. Karampinos

*NSF Center of Advanced Materials for the Purification of Water with Systems (CAMPWS), CTS-0120978*

As an integral part of the computational activity under the auspices of the Center of Advanced Materials for the Purification of Water with Systems (CAMPWS), a National Science Foundation Science and Technology Center, the project combines expertise in _ab initio_, Monte Carlo, molecular dynamics, and Lattice-Boltzmann methods. The common objective is to investigate hydrogen bonding in aqueous solutions, solute hydration and diffusion, ion cluster formation, phase separation, absorption, and electrokinesis in water-gas-salt systems in the bulk or near separation membranes or functionalized solid substrates.

**Discontinuous Galerkin Method for Thermomechanical Response Using Hyperbolic Conduction Models**

R. B. Haber,* S. Miller, R. Abedi

*National Science Foundation Center for Process Simulation and Design, DMR 01-21695; National Science Foundation Material Computation Center, DMR 03-25939*

The standard, parabolic Fourier conduction model is inappropriate for applications that exhibit very small length and time scales, such as pulsed lasers impinging on thin films. In such cases, conduction models with finite propagation speeds, such as the Maxwell-Cattaneo-Vernotte (MCV) model, are more appropriate. This project implements the MCV model within a space-time discontinuous Galerkin finite element scheme; a purely thermal and a coupled thermoelastodynamic model have been tested. We are investigating possible adaptive schemes that would approximate the Fourier model within the hyperbolic framework or adaptively switch between
the Fourier and MCV conduction rules in multiscale problems.

**Improved Time Marching Schemes for Molecular Dynamics**

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National Science Foundation Center for Process Simulation and Design, DMR 01-21695; National Science Foundation Materials Computation Center, DMR 03-25939

This project involves new time integration algorithms for molecular dynamics based on time-discontinuous Galerkin methods. An implicit method with exact energy and momentum balance (to within machine precision) has been realized. However, this scheme is impractical for the very large collections of atoms required in many applications. We are developing iterative solution schemes and semiexplicit methods to address this issue.

**Multiscale Models for Microstructure Simulation and Process Design**

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National Science Foundation, DMR 01-21695

This research initiative establishes new collaborations among materials scientists, physicists, mechanicians, mathematicians, and computer scientists to enable multiscale simulations of complex material response. Specifically, the investigators are developing numerical models for microstructure evolution in manufacturing processes (e.g., dendritic growth in casting processes) and new methods for coupling atomistic and continuum simulation models. Information technology is an important component of the research, where development of discontinuous Galerkin finite element methods, space-time meshing and visualization algorithms, variable-topology geometry models, and parallel/adaptive analysis techniques support the scientific goals of the project.

**Space-Time Discontinuous Galerkin Framework for Cohesive Damage Models**

R. B. Haber,* R. Abedi, M. Hawker; K. Matous (Center for Simulation of Advanced Rockets)

National Science Foundation Center for Process Simulation and Design, DMR 01-21695

This project involves an implementation of cohesive damage models using an elastodynamic space-time discontinuous Galerkin (SDG) method. Cohesive models can be used to simulate fracture and particle dewetting in composite materials. The SDG implementation localizes the cohesive nonlinearities and achieves exact momentum balance on every space-time element. Adaptive procedures ensure an accurate solution for the bulk response while maintaining the fidelity of the cohesive traction-separation relation. Our high-resolution simulations led to the discovery of unexpected singular velocity response in dynamic cohesive fracture; we are studying the dependence of the singular zone size on various material parameters.

**Space-Time Finite Elements for Nonlinear Conservation Laws**

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National Science Foundation Center for Process Simulation and Design, DMR 01-21695

This project involves a new class of O(N) solvers for systems of nonlinear conservation laws using space-time discontinuous Galerkin finite element methods. Our formulation features exact conservation on every space-time cell and compact, order-independent stencils. An object-oriented software framework supports dynamic adaptive generation of unstructured space-time meshes, parallel execution, and GPU-based visualization. Any system of conservation laws can be treated by specifying appropriate spatial fluxes. The Euler equations for inviscid gas dynamics comprise an important application where we are investigating hp-adaptivity, shock capturing, and discontinuity tracking.

**Parallel Implementations of Space-Time Discontinuous Galerkin Methods**

R. B. Haber,* L. Kale,* A. Becker, S. Chakravorty,
H. Govind, M. Hills, T. Wilmarth (Comput. Sci.)

National Science Foundation Center for Process Simulation and Design, DMR 01-21695

This project supports numerical research in the Center for Process Simulation and Design at the University of Illinois at Urbana-Champaign. The objective is to develop highly
asynchronous parallel implementations of the adaptive Tent Pitcher algorithm used in space-time discontinuous Galerkin (SDG) methods. Our implementation is built on the ParFUM framework, which is in turn based on the Charm++ runtime system. ParFUM manages distributed data structures needed for parallel execution, including support for asynchronous local adaptive operations. Maintaining good parallel performance for hp-adaptive space–time finite elements is of particular interest. Excellent speed-ups have been obtained.

**Domain Decomposition Algorithm for Large Scale Transient Simulations**
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**U.S. Department of Energy Accelerated Strategic Computing Initiative**
We are developing a domain decomposition algorithm for large scale transient simulations. Using this algorithm, one divides a domain into a number of smaller subdomains and over each system time step resolves the individual subdomains in parallel and then couples their solutions. The algorithm enables arbitrary numeric time integrators and subcycling strategies to be used in each subdomain. Our initial studies of a nonlinear transient conduction system will give way to coupled fluid-combustion-solid systems that arise in the simulation of solid propellant rockets.

**Computational Modeling of Supersonic Disk-Gap-Band Parachutes**
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**NASA; Jet Propulsion Laboratory**
The development of new entry-descent-landing sequences for planned heavy payloads to be sent to Mars requires the use of new supersonic parachutes. Our understanding of the performance of these supersonic disk-gap-band (DGB) parachutes is limited. We propose to use high-performance three-dimensional coupled large-eddy and finite-deformation structural dynamics simulation to aid in the development of these new systems. The objective is to improve our understanding of the multiple stability domains and performance parameters, drag, lateral forces, and structural loading, of the parachute-payload system during the entry, descent, and landing sequences of Mars missions.

**Large-Scale Parallel Computing to Design Advanced and Miniaturized Explosive and Propellant Systems**
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**U.S. Air Force Office of Scientific Research; Apple Computer; University of Illinois at Urbana-Champaign**
A 256-processor parallel supercomputer with approximately 1 - Terabyte of memory has been obtained to carry out simulation of advanced and miniaturized explosive and propellant systems. These systems have heterogeneous character or geometric complexity with multiscale physics. The system supports the Air Force-sponsored research of the Stewart and the Buckmaster/ Jackson research groups as well as other Air Force-relevant science and engineers. The housing and maintenance of the system is in collaboration with the College of Engineering and Computational Science and Engineering program.

**Tools for Understanding Transients in Explosive Systems**
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**U.S. Air Force Research Laboratory, Munitions Directorate, Eglin Air Force Base, Florida**
This research is focused on the development of advanced simulation tools for characterization of unsteady effects regarding condensed explosive systems, especially related to miniaturization and granular porous explosives. Critical energies are being calculated from asymptotic theory and compared with simulation and experiment.

**Control Systems**

**Advanced Dynamic Modeling and Control of Air Conditioning and Refrigeration Systems**
A. Alleyne,* N. Jain, B. Li, T. McKinley
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.

* Denotes principal investigator.
Control of Fluid Power Systems
A. G. Alleyne,* S. Manwaring, S. Tyson
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.

Dynamic Simulation of Transport Refrigeration: Baseline Model
A. Alleyne,* N. Jain
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Ingersoll Rand

This project develops a dynamic simulation-modeling environment that is suitable for closed loop control of mobile a/c and refrigeration systems. The project consists of developing baseline dynamic models to be tested against data from our industrial partners. Additionally, real-time systems will be developed to enable hardware in the loop setups to test OEM controller hardware.

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

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

Nano-CEMMS Systems Integration Testbeds for the Micro- and Macroscale
A. G. Alleyne,* P. M. Ferreira, D. Mukhopadhyay, K. Barton, R. Khanapure, B. Helfrich, X. Xiao
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). 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 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.

A Dynamic Simulation Model for the Environmental Control Systems (ECS) on Combat Vehicles
A. Alleyne,* T. McKinley
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General Dynamics Land Systems

This project develops a dynamic simulation-modeling environment that is specifically targeted for high performance military cooling applications.

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

The research project deals with issues arising in controlling geographically distributed complex real-time systems over a heterogeneous communication network. It is aimed at developing the foundations of network-based control, from theory to applications. The overall objectives are the following: the design, analysis, implementation, and performance characterization of hierarchical and heterogeneous distributed control algorithms and middleware that are affected through hierarchical heterogeneous networks comprised of wired and wireless subnets; and specification and implementation of network services and support required for the development and 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,* 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. D. Kelly, C. Liu, Q.-D. Kim
National Science Foundation, CMS-032463; ECS 05-01407

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

Control of Uncertain Time-Varying Systems Based on Robust Predictive Control Technique and Localized Time-Frequency Concepts
J. Bentsman,* K. Zheng, J. Kim
National Science Foundation, CMS-0000458

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

Control-Oriented Modeling, Identification, and Controller Synthesis for Electrical Motors and Nonsmooth Electromechanical Systems
J. Bentsman,* K. Zhang
Grainger Center for Electromechanics; National Science Foundation, CMS-03-24630; University of Illinois Research Board

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

**Discrete-Time Polynomial Controller Synthesis**  
J. Bentsman,* K. Zheng  
*National Science Foundation, CMS-0324630; Electric Power Research Institute, EP-P9362/C4722 and EP-P15596/C7752*

A novel polynomial analytical and computational technique is being created that permits minimal order numerically efficient $H_2$ and $H_\infty$ controller synthesis using direct Diophantine equation decomposition.

**Modeling and Identification of EMF-Induced Transitions in Lipids**  
J. Bentsman,* I. Dardynskaia, O. Shadyro, P. G. Glushonok  
*National Science Foundation, CMS-0324630*

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.

**Mold Oscillation Control**  
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*NUCOR*

The project aims at providing precise control of position and velocity profiles of oscillating mold in continuous steel casting under resonance constraints.

**Robust Controller Design for Power Plant and Its Implementation on the Actual Boiler/Turbine Unit**  
J. Bentsman,* K. Zheng  
Electric Power Research Institute, EP-P93624722, EP-P15596/C7752

The goal of this project is to design an H-infinity controller for a coal-fired power plant, test it on an EPRI simulator, and compare its performance with existing control laws.

**Self-Tuning Robust Control of Multi-Input/Multi-Output Nonlinear Processes**  
J. Bentsman,* K. Zheng  
Electric Power Research Institute, EP-P93624722, EP-P15596/C7752

This project is focused on combining recently developed $H_\infty$ predictive control techniques with the $H_\infty$ 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.

**Suppression of Catastrophic Loss of Stability of Low-Velocity Impacting Motions**  
H. Dankowicz*  
Royal Institute of Technology, Sweden

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

**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.

* Denotes principal investigator.
Architectures for Secure and Robust Distributed Infrastructures
S. Lall* (Stanford Univ.); C. Beck (Indus. & Enter. Syst. 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 (Indus. & Enter. Syst. Engr.); C. Tomlin (Stanford Univ.); G. Verghese (MIT); V. Vladimerou, D. King
U.S. Air Force Office of Scientific Research,
F49620-01-1-0365

The major barrier constraining the successful management and design of large-scale distributed infrastructures is the conspicuous lack of knowledge about their dynamical features and behaviors. Until very recently, analysis of systems has primarily relied on the use of nondynamical models. These traditional approaches have enjoyed considerable success while systems are run in 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.

Fundamental Limitations in Control of Nonlinear Dynamics
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This project aims to develop theoretical foundations and computational tools for control of nonlinear systems. A theme in our research is the introduction of ergodic theoretic and Markovian methods for control of nonequilibrium behavior. Recent papers have focused on the use of stochastic duality arguments for stability and control of nonequilibrium dynamics and on the analysis of fundamental limitations in control of nonlinear systems. The research is aimed at identifying aspects of nonlinear dynamics that detrimentally affect closed-loop stabilization and performance objectives in a fundamental (controller-independent) fashion.

Modeling, Estimation, and Control in Building Systems
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National Science Foundation; United Technologies Research Center

This project aims to develop and demonstrate, computationally, a network-centric framework to impact modeling, estimation, and control in integrated building systems of the future. The basic idea is to recast the complex large-dimensional models as dynamics, Markov chains, on graphs. Recent papers have focused on using these constructions to demonstrate multiscale complexity reduction approaches to the problem of modeling and estimating people evacuation dynamics in a large building. The applied work is closely tied with our industrial partners, United Technologies Research Center. The theoretical work on complexity mitigation of dynamic models can also potentially impact a wide array of other application areas.

Nonequilibrium Analysis and Design of Communication Networks
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The broad goal of the research is to build a scientific foundation for networks that will address the critical dynamic issues arising in communication and other network applications. A theme in our research is the introduction of a Markovian modeling framework to capture complex and nonequilibrium dynamics even in deterministic network models. Recent papers have focused on Markovian analysis of nonequilibrium dynamics and network control design using Markov Decision Processes and game theoretic formulations. The results, also demonstrated using network simulations, provide the first such theoretical justification for certain probabilistic control algorithms used in communication networks.

Quantized Control Problem
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National Science Foundation

This project seeks a quantization scheme for a dynamic system, that is, a partition of the state space and the allocation of control values to each cell in the partition so that a cost function that reflects a relaxed notion of quadratic stability is minimized. A probability distribution function is defined on the space of quantizers that has the maximum entropy for a given average (expected) value of
the cost function. The control values are calculated by finding the most probable values under this distribution. The resulting quantizer is logarithmic and explicitly gives the partition of the state space.

**GOALI: Online Dynamic Control of Cooling in Continuous Casting of Thin Steel Slabs**
B. G. Thomas,* J. Bentsman,* S. Vapalahti, K. Zheng, B. Petrus, H. Li, A. Behera
Continuous Casting Consortium; National Science Foundation GOALI DMI 05-00453

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 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.

**Design Methodology and Tribology**

**Reliability-Based Topology Optimization**
J. Norato (Caterpillar); M. F. Silva, D. A. Tortorelli*
Caterpillar, Inc.

We are combining reliability and material distribution topology design methods to optimize linear elastic structures subject to random loadings. In the usual topology optimization problem a domain containing loading surfaces, body load regions, regions with fixed displacement, and regions that must contain holes for shafts, etc. is initially defined along with the load values and the material properties, e.g., for steel. An optimization follows in which a given amount of material is distributed to maximize the stiffness. In this problem, the stiffness is evaluated assuming the loads are deterministic; i.e., they are assumed to be precisely known. However, this knowledge is seldom the case, so we will represent the loads as random variables with known statistics. We will then resolve the optimization problem; however, rather than maximizing the deterministic stiffness value, we will minimize the probability that the stiffness is less than a given failure value.

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

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

**Tribology of Coatings for Oil-Less Compressors**
A. A. Polycarpou,* T. Solzak, N. G. Demas
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.

* Denotes principal investigator.
Dynamic Systems

Floor and Facility Vibration Mitigation Using Passive and Hybrid Nonlinear Energy Sinks
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National Science Foundation, NSF CMS 03-24433

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

Minimum-Contact Tapping-Mode Atomic Force Microscopy for Nondestructive Characterization of Soft Nanostructures
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The invention of the atomic force microscope has paved the way for direct measurements of intermolecular forces and atomic-precision topographical mapping in a wide array of materials including semiconductors, polymers, carbon nanotubes, and biological cells. Of the different imaging modalities, intermittent-contact (TappingModeTM), the invention of the atomic force microscope has paved the way for direct measurements of intermolecular forces and atomic-precision topographical mapping in a wide array of materials including semiconductors, polymers, carbon nanotubes, and biological cells. Of the different imaging modalities, intermittent-contact (TappingModeTM) atomic-force microscopy greatly reduces the effects of adhesion and friction on the probe tip. Here, however, the destabilizing influence of the intermittency of contact may result in probe-tip oscillations with high contact velocity and destructive, nonrepeatable, and unreliable characterization of the nanostructure. This research effort aims to develop and experimentally demonstrate the feasibility of innovative design and control strategies for minimum-contact, tapping-mode atomic force microscopy to successfully and nonintrusively characterize soft physical structures at the nanoscale. Successful application of the proposed control strategies is expected to dramatically improve the repeatability of structure scans and to provide a more faithful representation of surface properties while significantly reducing damage to the measured structure.

* Denotes principal investigator.
A direct link to industry-relevant problem formulations and a channel for long-term commercialization is provided through a formalized collaboration with Veeco Instruments Inc., a leading provider of nanoscale metrology equipment. This research effort is also integrated with educational and outreach activities of the investigators, through the inclusion of modules on principles of nanoscale characterization in the senior-level undergraduate and first-year graduate-level course "Modeling MEMS and NEMS" and through the creation of a promotional brochure on nanoscale science aimed at local and regional high schools.

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

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

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

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

Energy Systems and Thermodynamics

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

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

Including Material Cost and Strength Constraints in Heat Exchanger Design
C. W. Bullard,* I. Davidson
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

* Denotes principal investigator.
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.

**Integrating HVAC Equipment with Other Building Subsystems**

C. W. Bullard,* B. Yannayon
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29 Company Consortium: Air Conditioning and Refrigeration Center

This project addresses the following question: are today’s split/unitary system designs easily adaptable for space conditioning in buildings that have extremely low thermal loads, or will a radically different conceptual approach be required to integrate them into prefabricated components of residential and small commercial buildings? Fundamental questions underlie the qualitatively different tradeoffs between centralized versus decentralized systems; simultaneous versus independent handling of sensible and latent loads; integration of space and water heating; and the role of thermal capacitance. The need for the project is based on several assumptions: heat pumps driven by natural gas-generated electricity are more efficient than direct-fired gas furnaces and water heaters and are, therefore, likely to displace them; stabilizing atmospheric carbon dioxide concentrations will require 60% reductions in carbon emissions; and heat pumping equipment efficiencies are nearing the point of diminishing returns so the largest reductions must come from reducing building loads. Hence, there is a need to fundamentally re-evaluate the HVAC systems that have evolved to serve them.

**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 caputures. By focusing on the way mass flow requirements relate to other system states, and analyzing the way in which component designs and charge management can alter those states, results can be generalized to many kinds of a/c and refrigeration systems.

**University of Illinois Solar Decathlon 2007**

P. Chapman, M. McCulley, D. Schejbal, W. Sullivan, T. A. Newell*
http://www.solardecathlon.uiuc.edu

U.S. Dept. of Energy: multiple sponsors

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

**Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems**

P. M. Ferreira,* and 21 other investigators

National Science Foundation Nano-Chemical-Electrical-Mechanical Manufacturing Systems

The objective of this research is to create a revolutionary new way to manufacture at the nanoscale, based on the newly invented molecular gate developed in the Biological Intelligent Processor project, and to develop the human resources needed to create the nanomanufacturing workforce of the next century. Students from chemistry, chemical engineering, electrical, material science, and mechanical and industrial engineering are being brought together to work as a team on this exciting new paradigm in manufacturing. The goal of this research is to create ultrahigh density arrays of nanoscale elements that can direct the chemical assembly of a diverse group of molecules on substrates and sense both position and composition of the nanoscale structures being created.

**Mesoscopic Thermomechanical (MTM) Desalination**

J. G. Georgiadis,* M. A. Shannon,* L. G. Raguin, M. Nsumuna

NSF Center of Advanced Materials for the Purification of Water with Systems (CAMPWS), CTS-0120978

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

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

Charge Minimization in Components and Refrigeration Systems
P. S. Hrnjak,* K. Traeger
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.

Development of Transcritical CO\(_2\) Systems for ECU Applications
P. S. Hrnjak,* X. Li, S. Elbel
U.S. Army; Modine
Natural fluids are not only ecologically attractive but also offer an advantage in logistics. The main issue is operation in extremely hot, ambient conditions.

Development of Transcritical CO\(_2\) Systems for Mobile Applications
P. S. Hrnjak,* S. Peuker
U.S. Army; Modine
Two-evaporator application for HMMWV is a difficult challenge for transcritical CO\(_2\) systems because of stability in the control system.

Effect of Oil on Evaporation of R744 in Round Smooth and Enhanced Tubes
P. S. Hrnjak,* C. Y. Park
29 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation
R744 (CO\(_2\)) has very good heat transfer characteristics but the reduction when oil is present seems to be also dramatic. What is the mechanism? Can we reduce these detrimental effects?

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

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

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

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

Improving Transcritical CO\(_2\) 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.

* Denotes principal investigator.
Opportunities for Microchannel Heat Exchangers in High Efficiency Air Conditioning Systems
P. S. Hrnjak,* M. Dschda, M. Johnson
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Daikin Industries

The leader in efficient air conditioning systems is exploring options for further improvement.

Opportunities in Transcritical CO\textsubscript{2} Systems with Two-Stage Compressor
P. S. Hrnjak,* S. Elbel, J. Mott
Sanyo

Various options, including multistage expansion, mechanical subcooling, internal heat exchange and work recovery options, are considered and elaborated in the project.

Improving the Energy Efficiency of a Clothes Washing Machine
A. M. Jacobi,* J.-S. Park
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Arcelik S. A. Istanbul, Turkey

In this project we demonstrate the effectiveness of pumping heat from the ambient to the water used in a clothes washing machine. We also attempt to recover waste heat from the machine in an attempt to improve the energy efficiency of the washing machine. The study is focused on a particular machine; however, the methods under study might be extended to improve the energy efficiency of other domestic and commercial appliances.

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.

Porous Silicon Fuel Cells for Micro Power Generation
R. I. Masel,* M. A. Shannon*
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Defense Advanced Research Projects Agency

There is a critical need to create sub-millimeter power sources for cognitive arthropods, subdermal drug delivery systems, and other applications. The objective of this proposal is to create a millimeter-sized fuel cell system that delivers enough energy and peak power for such devices. The approach is to combine a small, silicon-based hydrogen generator with a porous silicon fuel cell. The entire device will be built with silicon fab. Microfabricated anode and cathode layers are used so that the millimeter scale device is more efficient than a conventional scale device. At the end of this program, we expect to create millimeter-sized fuel cells with a peak power of greater than 1000 W/l, an energy density above 1000 W-hr/l, and a shelf life over a year.

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

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

Active Nanopore Membranes
M. A. Shannon*
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National Science Foundation, Center of Advanced Materials for the Purification of Water with Systems (WaterCAMPWS)

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 nanopore membranes. The goal is 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.

* Denotes principal investigator.
Characterization of Transport and Detection of Toxins in Single Nanopores
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National Science Foundation, Center of Advanced Materials for the Purification of Water with Systems (WaterCAMPWS)

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. A goal is 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 m-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. The detection of the macromolecules within these channels, such as toxins in water, is also a critical need. To do so, we are developing a multicompartment, multimembrane biofluidic device with characteristic linear dimensions of nanometers and volumes ranging from tens of attoliters and up, specifically designed to manipulate species which must be handled at extremely low masses. Electrical-Impedance Spectroscopy (EIS as above) is being investigated for integration into these systems.

DNA Amplification and Detection Chip
M. A. Shannon*
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Akonni, Inc.

The objective of this research is to develop a new, rapid method of amplifying DNA using polymerase chain reactions (PCR). The PCR chip uses a new micronanofluidic device based on the molecular gate, in which multiple types of gates are integrated with PCR reaction chambers to enhance amplification rates, as well as a separation system with electronics and optical systems for detection of completed DNA structures. The device and approach include on-chip heating and cooling, incorporating advances in biomolecular tagging and recognizing a multiplicity of compounds, making on-chip analysis of the wide range of biological warfare agents a practical reality.

Heavy Metal Sensor for Water
M. A. Shannon,* D. Cropek, Y. Lu, P. W. Bohn, J. Sweedler
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Strategic Environmental Research and Development Program

Heavy metals are a ubiquitous and troublesome class of pollutants, and lead occupies a prominent position as a contaminant requiring constant attention. Despite the recognized adverse effects of lead on aquatic and terrestrial biota, its presence is not actively monitored, in large part due to the lack of a field product that meets all requirements for in situ measurement of lead in ground water, i.e. rugged, reliable, sensitive, selective, and remotely operable. We are creating a highly selective and sensitive miniature sensor for lead by combining two recent advances: catalytic DNA that is reactive only to lead and which can be tagged to produce fluorescence only in the presence of the metal, and nanoscale fluidic molecular gates that can manipulate fluid flows and perform molecular separations on tiny volumes of material. We are developing the chemistry and engineering needed to create a microfluidic device for separating, sensing, and quantifying lead in a complex matrix. This work will also manipulate this sensor platform for separation and detection of other heavy metals.

Mass Gas Analyzer
M. A. Shannon,* R. I. Masel,* K. Cadwallader, M. Strong
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Defense Advanced Research Projects Agency

The objective of this research is to create a revolutionary new way to sense molecules in gases, in particular toxic poisons, in air. The project is based on a new type of micro-preconcentrator, micro-GC column, and three types of detectors operating in parallel at the end of the column to reduce the number of false positives and negatives. The detectors employ nanoscale structures and devices in order to enhance the signal-to-noise ratio, as well as detect highly mass-limited samples. The total sensing time is designed to be in the seconds, with a sensitivity gain of greater than 1000 times. The system includes both sampling pumps, ultrafast microvalves, new molecules and methods for coating structures with them for adsorption and desorption, and integrated power to drive a remote system.

* Denotes principal investigator.
Mesoscopic Thermo-Mechanical (MTM) Water Purification System
M. A. Shannon,* J. G. Georgiadis*
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* Denotes principal investigator.

In this project, we are developing the concept of ice distillation to purify water and concentrate soluble compounds, in particular to create an energy efficient means to minimize residuals for inland desalination. The MTM employs freezing, fractionation, and filtering to separate ions and particles from an aqueous solution. This method is any type of tradition freeze purification. Ice is only used as a driving potential for creating a density gradient. The method in theory can be as energy efficient as reverse osmosis (RO), but unlike RO is relatively insensitive to the salt concentration. Therefore, the MTM method is being focused on residual minimization of salt water waste, in particular for inland desalination applications. To date, we have demonstrated the fundamental concepts. Experimental apparatus is being constructed and characterized.

Micro-Electrolytic Conductivity Sensors with Temperature Compensation
M. A. Shannon*
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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

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.

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.

Analysis and Solving of Convolution Integral Equations
S. M. Salapaka,* C. Lee, G. Mohan
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Air Force Office of Scientific Research

This project develops an algorithm for inverting large matrices (of sizes a million by million and more) corresponding to convolution integral equations defined on arbitrary domains. New schemes are being developed that study the robustness of these algorithms to the uncertainty in structure assumed in the matrices. This research has led to some control tools that give new perspective to root solving algorithms, such as standard Newton descent method and its variants. In fact, this methodology gives a generalization to descent methods and a new set of root solvers that accommodate problem specific constraints.

Stresses under Contact Loading and Material Ratchetting
H. Sehitoglu,* Y. Jiang, D. Canadine, 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 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

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

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

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

The goal of this project is to facilitate the implementation and evaluation of pollution prevention, health, and safety and regulatory compliance activities at twelve food processing sector companies.

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

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

Science and Technology Center of Advanced Materials for the Purification of Water with Systems (WaterCAMPWS)
J. G. Georgiadis,* M. Shannon,* P. Bohn,* J. Economy, V. Snoeyink;* M. Reinhard (Stanford Univ.)
National Science Foundation

The research component of WaterCAMPWS 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 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
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Illinois Department of Natural Resources, Waste Management and Research Center; University of Illinois at Urbana-Champaign

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.

Database Development for Comparative Analysis of the Performance of Metalworking Fluids in Machining Operations
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Illinois Department of Natural Resources, Waste Management and Research Center

The goal of this research is to develop a second-generation drilling testbed that measures lubricity and cooling of metal working fluids (MWF). The fluids to be tested will come from a cross-section of soluble oils, semi-synthetics, and synthetic MWFs. In addition to lubricity and cooling measurements, the fluids will be evaluated for corrosion resistance, workpiece surface finish, viscosity, and emulsion stability. A performance model will also be developed to study various MWF characteristics.

Unstable Two-Phase Mixtures for Metalworking—A Greener Alternative
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Illinois Department of Natural Resources, Waste Management Resource Center; University of Illinois at Urbana-Champaign

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.

Sustainable Construction and Development
T. Lindsey,* K. Barnes
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U.S. Environmental Protection Agency

The Waste Management and Research Center will work with Illinois contractors, designers, and architects, to develop and implement methods for minimizing, recovering, and recycling construction debris. This will be accomplished through a combination of research, training, and on-site technical assistance.

Randomized Distributed Data Structures for Product Design
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National Science Foundation

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

* Denotes principal investigator.
Fluid Dynamics

Outer-Layer Structure in Wall Turbulence
K. T. Christensen,* Y. Wu, V. K. Natrajan
Oak Ridge Associated Universities (ORAU); University of Illinois at Urbana-Champaign; U.S. Air Force Office of Scientific Research, FA9550-05-1-0043 and FA9550-05-1-0246

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

Polymer-Induced Turbulence Modifications in Impinging Jets
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University of Illinois at Urbana-Champaign

The turbulence modifications imposed in impinging jets via the addition of a minute amount of polymer to the flow are studied experimentally. In particular, we focus on any alterations of the complex vortex interactions that are observed in the impingement zone of Newtonian impinging jets as well as any convective heat-transfer enhancement that can be attained in this region through the addition of polymer. These goals are accomplished via detailed PIV experiments of the flow within the impingement zone at low and high Reynolds numbers, various nozzle-to-plate spacings and multiple polymer concentrations. Simultaneously, a constant heat flux is applied to the impinging surface and instantaneous fluid temperature fields are acquired over the same field of view in the impingement zone using laser-induced fluorescence (LIF) techniques.

Realistic Roughness Effects in Wall Turbulence
K. T. Christensen,* Y. Wu, A. Rosenbaum, B. Johnson

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

Simulation of Advanced Rockets
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U.S. Department of Energy

We have designed, developed, and implemented advanced high-accuracy numerical methods without artificial dissipation to make fundamental investigations into the mechanics of flows in solid rocket motors. Current focus is on the driving mechanisms of acoustic instabilities. These can cause failure in full-scale rockets but are not well understood. Our model simulations are testing hypothesis concerning the driving mechanisms.

Atomic Detail of Evaporating Menisci
J. B. Freund,* A. Willis
National Science Foundation

The microscopic region where the liquid-vapor interface of a vapor bubble contacts a hot surface, whether it is in a MEMS actuator or in a large-scale boiling application, is important for the dynamics and thermal transport of the overall system. However, this region is challenging to diagnose in experiments, since the liquid film is only nanometers thick in places. We use atomistic simulations to test continuum asymptotic models that couple viscous flow, evaporation kinetics, surface tension, and thermal transport in this atomically thin region of the liquid film.

Optimal Control of Jet Noise
J. B. Freund,* R. Kleinman

Noise levels affect the attractiveness of new aircraft on the market and limit their usable lifetime, with billions of dollars at stake in the aerospace industry. Jet noise remains a significant component of overall aircraft noise, especially at takeoff. Given this, it is somewhat surprising that most improvements in aircraft noise are accomplished by trial and error iterations in expensive-to-operate facilities. We have developed simulation tools for modeling jets and are studying jet noise control by a novel adjoint-based optimization procedure. Our approach circumvents the complexity of the flow and allows us to study the mechanics of jet noise control directly. For the first, time

* Denotes principal investigator.
we have been able to compare a baseline, loud flow with a perturbed, much quieter flow to illuminate mechanisms.

**Super-Resonances in Engine Altitude Test Cells**
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U.S. Air Force Office of Scientific Research

Jet engines are often ground tested in facilities that simulate conditions at altitude. Under certain conditions, strong (170dB) resonances have been observed in such facilities as Arnold Engineering Development Center (AEDC) and elsewhere. We are designing simulation tools to predict resonances in the complex geometries of the actual facilities. We are also doing more focused simulation and analysis using Wiener-Hoff to study the details of mechanisms to aid mitigation of the resonances.

**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.

**Statistical Mechanics of Turbulence**
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ggioia@uiuc.edu
National Science Foundation, DMR-0604435

This project is an unprecedented attempt at construing turbulence on rough and smooth surfaces as expressions of a single critical phenomenon. Our research will clarify the analogy between turbulence and critical phenomena; evince the connections between large-scale turbulent phenomena and small-scale statistics (and, in particular, the striking connection between the turbulent friction and the phenomenological spectrum); provide direct evidence that the phenomenological theory applies under much more general conditions than usually thought; and furnish a theoretical understanding of the complete range of turbulence states in shear flows, from the transition to turbulence to fully developed turbulence. To attain these objectives, we will perform closely related experimental, theoretical, and computational work.

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

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

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

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

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

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

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

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

* Denotes principal investigator.
the one corresponding to a homogeneous mixture of the local equivalence ratio of mixture compositions close to the lean flammability limit. Also a significant extension of the lean flammability limit was observed. It was established that the local spatial gradient of the equivalence ratio was not sufficient to describe the departure of stratified combustion from quasi-homogeneity. Instead, an appropriately defined integral parameter that depended on the history of flame propagation has been shown to determine when the flame could not be treated as a series of premixed flamelets propagation at the local adiabatic flame speed.

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

Development of Exciplex Fluorescence Planar Droplet Sizing Technique
C. F. Lee,* J. W. Powell
National Science Foundation, CTS 01-1671; University of Illinois at Urbana-Champaign
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.

Effects of Ultrasonic Excitation on the Atomization of Sprays
C. F. Lee,* J. W. Powell
TECAT Engineeering, Inc.
The atomization of sprays under ultrasonic excitation was investigated. An 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

* Denotes principal investigator.
velocimeter (LDV) and a phase Doppler particle analyzer (PDPA) will be used in the experiment.

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

**Study of Implicit Time Integration in Adaptive Mesh-Refinement Compressible Large-Eddy Simulation**
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California Institute of Technology

This research activity studies the use of implicit time integration within the context of the adaptive mesh-refinement framework that is part of the Virtual Test Facility (VTF) of the ASC Alliance Center supported by the Department of Energy at Caltech. Specifically, we will investigate the efficacy of implicit time integration methods for the compressible large-eddy simulation solver that is part of the VTF. This research is pursued to alleviate the stringent time steps (too small) that must be taken to integrate the Navier-Stokes equations when the level of compressibility is low and the time integration is explicit, as is current practice. This research will investigate the use of factorizable approximate Newton methods with multigrid acceleration for the pressure-wave equation that results as part of the compressible equations.

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

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

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

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

**Numerical Simulation of Shock Wave/Turbulent Boundary Layer Interactions Controlled via Micro-Ramps**
A. Shinn, S. P. Vanka*
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Boeing Company

Computational fluid dynamics will be used to study the flow physics of controlling shock wave/turbulent boundary layer interactions in aerodynamic channel (inlet) flow; the study will investigate both oblique and normal shock waves. The cases will be studied using unstructured grids with a finite-volume unsteady Reynolds Averaged Navier-Stokes (URANS) solver in an attempt to resolve the flow features in a time accurate manner.

**Advanced Theory and Simulation of Compressible Reactive Flow**
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Work was carried out to develop asymptotic theory for motion of detonations, their stability, ignition transition, and their relation to the general theory of hyperbolic PDEs. Work is being carried out to develop advanced simulation strategies that track shocks. New work has started to simulate complex particle-laden explosive materials.

**Investigations on Detonation Shock Dynamics**
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U.S. Department of Energy, Los Alamos National Laboratory; University of Illinois at Urbana-Champaign

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

Development of a High-Performance LES Computational Tool for Complex Geometries
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We are developing a robust LES solver for complex geometries using a Cartesian grid and immersed boundary technique. The LES equations are solved with an implicit solver using a coupled Gauss-Seidel solver, accelerated by a multigrid method. The code is being used for isothermal and reacting flows.

Non-Nested Multigrid Algorithm for Fluid Flows in Complex Domains
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The objective of this research is to develop and demonstrate a fast computational procedure to perform accurate simulations of thermal transport in complex domains. The algorithm will be based on a non-nested multigrid method for unstructured grids. The flow domain will be discretized using unstructured tetrahedral/hexahedral/prismatic grids. These grid elements will then be coarsened by a novel algorithm to automatically generate coarser grids without human intervention. A consistent multigrid procedure for solution of the Navier-Stokes and energy equations will be developed and applied to several industrially significant flows. Here we advocate an approach that uses multiple, non-nested grids, which are generated automatically from a given fine grid. The solver will be applicable to three-dimensional turbulent and natural convection flows.

Thermophoretic Capture of Nanoparticles in Wavy Channels
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Thermophoresis is one of the main forces acting on particles when a transverse temperature gradient exists in the flow field whereby particles migrate against the temperature gradient. The present effort focuses on understanding the particle capture characteristics in one class of passages that have been previously demonstrated to provide enhanced heat transfer rates in compact heat exchangers. A wavy (corrugated) channel has been shown to have rich flow physics, which can be exploited to mix the core fluid with the boundary layers and provide increased concentration and temperature gradients over a straight channel with fully-developed boundary layer profiles. A comprehensive computational model with solution of the multidimensional unsteady Navier-Stokes equations and particle transport will be constructed and validated using results of an experimental study.

Heat Transfer

Radiation Heat Transfer Modeling with CFD in Solid Rocket Motors
M. Q. Brewster,* J. Y. Jung, K. C. Tang
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 this 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 Transfer in Absorbing and Scattering Media
R. O. Buckius,* J. He
University of Illinois at Urbana-Champaign

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

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

This research program consists of a combined analytical and experimental investigation of the scattering from realistic interfaces and films, including those with surface

* Denotes principal investigator.
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.

Tectonics and Heat Transport in a Frigid Enceladus
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University of Illinois at Urbana-Champaign

Cassini-mission observations of Enceladus, the 500-km icy moon of Saturn, have revealed a polar region with a distinct array of tectonic features, intense heat radiation, and geyser-like plumes. We are developing the first integrated model of the mechanics and thermodynamics of Enceladus to give a unified explanation of the salient tectonics and heat transport from a depth of tens of kilometers to the surface. Ours is a frigid, stiff, thoroughly solid Enceladus with neither solid-state convection nor liquid water. It is unlikely to harbor life, but it is consistent with all the major observations, and perhaps more compatible than other models with what might be surmised of a tiny, icy moon.

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

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

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

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

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

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

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

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Advanced Heat Transfer

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

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

Novel Materials for Heat Exchangers
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Air-conditioning and Refrigeration Institute

In this broad-based exploration of heat exchanger materials, we will identify new materials that hold promise for application in heat exchanger systems; the properties of new materials will be estimated; the potential for adopting these materials in air-to-air, refrigerant-to-air, and secondary-fluid heat exchangers will be explored; a comparison of predicted thermal-hydraulic performance, mechanical and chemical stability, safety, cost, and manufacturability will be conducted. The study is conducted in collaboration with engineers from industry and recognized leaders in the manufacture of heat exchangers. While the study relies on the technical literature for material properties and suggested applications, it also includes the generation of new designs to exploit the properties of emerging materials, and the modeling of overall system response to the new designs.

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.

Ultra-Hydrophobic Surfaces for Heat Exchangers in Air-Conditioning Systems
A. M. Jacobi,* Y. Xia
29 Company Consortium: Air Conditioning and Refrigeration Center

In air-conditioning systems, the evaporator usually operates with its surface temperature below the dewpoint of conditioned air. As a result, moisture from the air stream condenses and accumulates on the surface of the heat exchanger. Condensate retained on the air-side surface of the heat exchanger has a profound impact on its performance and on the air quality. Recent developments in materials processing have produced surfaces with

* Denotes principal investigator.
extremely high contact angles, called ultra-hydrophobic surfaces (UHS), showing strong water-repelling characteristics. We propose to investigate condensate retention and thermal-hydraulic performance for the new surfaces. We will provide test data for the performance of UHS-based heat exchangers, compared to conventional coils, and for transient condensate retention over a range of operating conditions. We will expand our retention model to predict the amount of condensate on UHSs and, in particular, we will account for condensate bridges.

Using Mesoscale Devices to Integrate Fans and Heat Exchangers: Beehives for Heat Transfer
A. M. Jacobi,* A. Dubas
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29 Company Consortium: Air Conditioning and Refrigeration Center

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

Using Microscale Morphology to Create Anisotropic, Patterned Wettability for Condensate Management in Air-Side Heat Transfer
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29 Company Consortium; Air Conditioning and Refrigeration Center

We have obtained preliminary data demonstrating that anisotropic (i.e., directional) wettability can dramatically alter the contact angle, spreading behavior, and critical droplet size on aluminum surfaces. Moreover, we have created such surfaces in our laboratory using microscale morphology alone. If patterned wettability can be achieved through simple surface modification of aluminum fin stock, it is likely that mass production methods can be developed, and the impact on air-cooling applications could be profound. However, several questions must be answered before this new method of condensate management can be effectively exploited: What is the optimal depth and channel spacing for maximizing the hydrophobic properties of the surface? What is the critical droplet size for water on these surfaces? Are there differences in behavior associated with how the water is placed on the surface (by injection, condensation, or melting of frost)? What changes are needed to existing models to provide predictions of critical droplet behavior on these functionalized surfaces? The overarching objective of the proposed research is to develop methods for creating controlled microscale, anisotropic topological features on aluminum surfaces, and to quantify the effects of these surface features on wetting and droplet retention.

Wings and Winglets Deployed as Arrays to Enhance Air-Side Heat Transfer
A. M. Jacobi*
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29 Company Consortium; Air Conditioning and Refrigeration Center

We propose the deployment of delta-wing and winglet vortex-generator arrays to create strong coherent vortices at low wing Reynolds numbers, and in this way to generate stronger vortices in a confined space than is possible in prior single-winglet vortex-enhancement strategies. Through this research we hope to demonstrate that vortex-generator arrays may be designed for constructive interference, and to develop design guidelines for optimal array design. We will deploy a near-optimal array in a developing channel flow (as a model of a plain-fin heat exchanger) and quantify the heat transfer enhancement and pressure-drop penalty associated with the vortex generator array in a scale model, plain-fin configuration. Using data from the scale model, we will predict the performance impact in application, where the presence of tubes and end effects may be important.

A Literature Review of Alternate Materials for Heat Exchangers in HVAC&R Systems
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29 Company Consortium; Air Conditioning and Refrigeration Center

Recent material advances, particularly in plastics, have stimulated interest in the use of materials other than conventional copper and aluminum for the construction of heat exchangers. The purpose of this one-year project is to critically evaluate materials currently used for heat exchangers in HVAC&R applications. We will review the technical literature to assess the current state of the art with respect to nonmetallic materials for heat exchangers, with a focus on the advantages and disadvantages associated with plastic heat exchangers. We will identify applications
where plastic might be promising, and suggest how implementation might be achieved. We will also consider hybrid plastic-metal constructions, and perform a preliminary cost comparison of alternate-material to conventional heat exchanger construction.

**Visualization of the Flow inside a Thermostatic Expansion Valve**

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The role of a thermostatic expansion valve (TXV) is to meter liquid refrigerant to the evaporator to control the cooling load. However, if the TXV passes too much liquid to the evaporator, it can overshoot the desired operating point. If the valve then starves the evaporator in an attempt to compensate, valve hunting can occur, causing compressor wear. If the TXV does not atomize the liquid well, it can also lead to poor distribution in the header, another cause of excessive valve hunting. We plan to place the poppet/seat from a stock TXV in a visualization chamber in order to measure the flow produced by a real valve and quantitatively measure the droplet size distributions with a phase-Doppler anemometer (PDA). Then we will use the equations that govern liquid sheet breakup in hollow-cone spray applications, and make changes to that geometry to improve atomization and see if the equations are applicable to this spray as well. From there, we will modify the valve components in an attempt to improve atomization and enhance liquid breakup over the entire range of valve lift for different qualities and mass flow rates.

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

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

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

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

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

T. J. Mackin*

*Calphalon Corporation*

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

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

T. J. Mackin,* J. Lesniak

*National Science Foundation*

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

* Denotes principal investigator.
Manufacturing Systems

Burr Formation in Drilling Machinable Austempered Ductile Iron (MADI)
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Intermet Corporation; University of Illinois Manufacturing Research Center

The use of machinable austempered ductile iron (MADI) 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 objective of this research is to understand the process of burr formation as a result of drilling intersecting holes in MADITM with worn tools. The effect of tool wear and exit surface curvature on burr dimensions will also be investigated in order to determine their effects on burr formation.

Development of a Microscale Machine Tool System Testbed
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Center for Nano-Chemical-Electrical-Mechanical Manufacturing Systems; National Science Foundation, Nanoscale: Science and Engineering Center

The ultimate realization of Nano-CEMMS will require the existence of concepts and methods that will enable the integration of nanoscale devices and subsystems into mission-oriented engineered systems, requiring manufacturing capabilities that include high relative accuracies and precision, complex three-dimensional feature generation, and excellent surface quality. To this end, this project proposes to design and construct a piezoelectrically-driven XY-stage with submicron positioning accuracy and integrate XY-stage into microscale Machine Tool (mMTs) to increase their accuracy from 1-3μm to <200nm. The manufacturing capability of the device will be proven by manufacturing a wide range of micro-, and nanoscale parts, including 3-D nanowire deposition, microchannel array systems, and assemblies to be integrated into nanoscale devices.

Decision Support Systems for Electronics Manufacturing
P. M. Ferreira,* 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.

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

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

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

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

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

* Denotes principal investigator.
An Investigation of a Combined Drilling and Thread Milling Process: Thread Milling
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University of Illinois Manufacturing Research Center

A new thread making process called thrilling, which performs both drilling and thread milling with one tool is being investigated. A simplified linear thread milling operation will be performed to understand the forces associated with thread milling and number of engaged threads. Thrilling experiments will be conducted to examine the process and associated forces. The effects of both drilling and thread milling and their interaction on the thread quality will also be investigated.

CAD-Integrated Cost Model for Sand Casting
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aPriori, Inc.

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

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

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

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

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

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

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

* Denotes principal investigator.
Materials Behavior

Modeling of Delamination Fracture in Advanced Aluminum-Lithium Alloys
A. J. Beaudoin,* R. H. Dodds, P. Kurath,* R. J. McDonald
National Aeronautics and Space Administration

Strength, toughness, and weight design requirements for the next generation metallic cryotankage has promoted development of aluminum-lithium alloys. This work combines characterization of microstructure, experimental studies of fracture and fatigue, and multiscale modeling of "delamination" cracking. A parallel computer code combines models for metal plasticity with cohesive zone elements for study of fracture at grain boundaries.

Imperfections and Defect Tolerance of Aircraft Shells and Structures
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The randomness of the microstructure in Functionally Graded Materials (FGM) brings a statistical nature to the material response that must be characterized when designing structures with FGMs. Utilizing the latest image analysis techniques, we obtain the morphology statistics of a particular FGM. In a Monte Carlo study, we then generate finite element models of statistically equivalent microstructure specimens and perform finite element analyses to obtain the statistical nature of the FGM material response. Our results depend on the size of the specimen. The large randomness observed for small specimens diminishes as the specimen size approaches that of the representative volume element (RVE). We suspect the RVE size is greater than the length scale of the FGMs used in the structures and of the finite element size used in the numerical discretization. For this reason classical homogenization methods must give way to stochastic analyses, which require the material response statistics obtained through our Monte Carlo studies.

Fracture Mechanics with the Topological Derivative
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In this fracture mechanics research, we use the topological derivative to determine the location at which a crack will nucleate and the direction of its propagation. Our proposed method offers significant computational advantages over current finite-element-based methods. Indeed, our method requires a single analysis whereas the others require a distinct analysis for each location—propagation direction combination. Our preliminary studies address linear elastic fracture mechanics of two-dimensional domains.

Foam Models for Occupant-Seat Interaction Engineering
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National Science Foundation, CMMI-0092849

The objective is to develop and calibrate a model of polyether polyurethane solid foams for the computational simulation of occupant-seat interaction in automotive engineering. The project involves theoretical, experimental, and computational components. Because foams are governed by nonconvex potentials, even a simple uniaxial foam model involves a vast phenomenological universe, including large deformations, lack of uniqueness, multiple-phase, multiple-length-scale fields, and metastable states. Our model will rely on a detailed description of the nonlinear behavior of the individual open cells of the microstructure of the foam. A tensorial stress-stretch constitutive relation will be based on the homogenization of periodic cell structures.

Mechanics of Cohesive Powder Compaction
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We research the particle rearrangement process that dominates the first 30% to 45% of the compaction stroke during the densification of cohesive powders. The research is relevant to such applications as forming of ceramic components and pharmaceutical tablets. We have shown both experimentally and computationally that particle rearrangement occurs in the form of a phase transformation. We are studying the energetics associated with this phenomenon, by means of theory and computations. Experiments using X-ray tomography are being performed by collaborators in the Frederick Seitz Materials Research Laboratory.

The Relation between Similarity Fields and Invariant Path Integrals in Nonlinear Fracture Mechanics
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Computational simulations indicate that the plastic-zone fields of growing cracks depend on the stress intensity

* Denotes principal investigator.
factor K and the t-stress T through a single similarity variable, implying that we can ascertain the type of fracture (brittle or ductile) associated with any combination of K and T by performing experiments over a range of values of a single variable. Here we will trace the cause of these similarity fields to the existence of invariant path integrals. We will relate the similarity variable to the crack-tip energy flux, viscosity, cohesion, and triaxiality. For several failure criteria, we will construct diagrams identifying the ductile, transitional, and brittle regions in K-T space. We will also study separable crack-tip similarity fields and establish their connection with critical phenomena. Lastly, we will study the case of stationary cracks, where the fields are not similarity fields but there exists an invariant path integral.

**Mechanism-Based Theories of Strengthening and Hardening for Alloy Design and Processing**

Y. Huang*

*National Science Foundation, CMS-0084980; ALCOA*

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

**Biaxial Nonproportional Testing of Aircraft Alloys**

P. Kurath*

*General Electric, 00-2711 RFA*

An age of many service aircraft invokes questions of safety and remaining useful service life. Most baseline fatigue data are uniaxial and inherently proportional. However, several major service events are nonproportional. Current efforts attempt to quantify the effect of these loadings on the service life at several temperatures.

**Multiaxial High-Cycle Fatigue**

P. Kurath*

*Dayton Research Institute, RSC00011*

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

**Residual Stress Simulations for Welded Structures**

P. Kurath*

*John Deere Company*

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

**Durability of Advanced Materials**


*Fracture Control Program*

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

**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.

* Denotes principal investigator.
Three topics were studied. The first focus was assessment of the size of representative volume element (RVE) in plasticity, classical and finite (thermo)elasticity, and Darcy-type permeability and conductivity of random composites. Overall, it was found that the scaling trend to RVE decreases in the following order: linear elasticity, plasticity, linear thermoelasticity, nonlinear elasticity, and permeability. The second focus was stochastic dynamics of acceleration wavefronts in a wide class of random media, modeled by two random fields: the dissipation and elastic nonlinearity. The wavefront's thickness is generally smaller than the RVE size. In effect, the wavefront is more appropriately analyzed as a statistical volume element, and therefore is treated via a stochastic rather than a deterministic dynamical system. The third topic was quasi-particle modeling of dynamic fragmentation, with applications to comminution processes. A model has been validated on experiments involving epoxy plates, containing nonuniformly distributed circular holes. Contrary to intuition, microscale perturbations in material stiffness were found to have a stronger effect on deviations from the dominant crack pattern than microscale perturbations in tensile strength. These three topics provide a stepping-stone to a new study of transient dynamics of head trauma.

**Determining the Mechanical Constitutive Properties of Metals as a Function of Strain Rate and Temperature: A Combined Experimental and Modeling Approach**


**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.

* Denotes principal investigator.

**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**

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**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.
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.

Linking Rail Surface Yield Strength, Microstructure, and Wear
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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, CMS 04-28428

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
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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.

Hydrogen Effects on Ductile Crack Growth
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Finite element analysis is used to study the hydrogen effect on ductile crack propagation in metals and alloys by linking effects at the microscale (i.e., void growth and coalescence) to effects at the macroscale (i.e., bulk material deformation around a macroscopic crack). The purpose is to devise a mechanics methodology to simulate the conditions under which hydrogen enhanced plasticity induces fracture that macroscopically appears to be brittle. Crack propagation is modeled by cohesive elements whose traction separation law is determined through void cell calculations that address the hydrogen effect on void growth and coalescence. Numerical results for the A533B pressure vessel steel indicate that hydrogen, by accelerating void growth and coalescence, promotes crack propagation by linking simultaneously a finite number of voids with the crack tip. This “multiple-void” fracture mechanism knocks down the initiation fracture toughness of the material and diminishes the tearing resistance to crack propagation.

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Hydrogen Embrittlement of Pipeline Steels: Causes and Remediation
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Hydrogen is a ubiquitous element that enters materials from many different sources. It almost always has a deleterious effect on material properties. The goal of the proposed program is to develop and verify a lifetime prediction methodology for failure of materials used in pipeline systems and welds exposed to high-pressure gaseous environments. Our approach integrates mechanical property testing at the microscale, microstructural analyses and transmission electron microscopy observations of the deformation processes of materials at the micro- and nanoscale, first-principle calculations of interfacial cohesion at the atomic scale, and finite element modeling and simulation at the micro- and macro-level.

Hydrogen Interactions with Material Elastoplasticity
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The constitutive response of materials is investigated in the presence of hydrogen solute impurities using a solid mechanics approach and finite element methodology. The approach accounts for the deformation mechanisms acting at the microscale and have been observed and quantified experimentally.Interstitial hydrogen expands the lattice and softens the elastic moduli. As a result, hydrogen forms atmospheres around microstructural defects and changes the dislocation mobility. A thermodynamics framework is used to account for these interactions in an effort to devise constitutive laws capable of describing macroscopic phenomena such as shear localization triggered by hydrogen interstitials. In the case of the IN-903 material system, it was found that the mean free path between carbides is the microstructural length scale that controls the fracture mechanism in the presence of hydrogen.

Micromechanics of Damage in Solid Propellants
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A numerical simulation approach is used to understand the major issues of deformation and fracture in solid propellant materials. Solid propellants are composite materials with complex microstructures. In a generic form, the material consists of polymeric binder, ceramic oxidizer, and fuel particles. Damage induced by severe stress and extreme temperatures is manifested in decohesion along particle/binder interfaces followed by void formation and opening. Rigorous homogenization theory for nonlinear composite materials is used to devise a macroscopic constitutive model that accounts for continuous void nucleation and growth upon straining. The constitutive law is used to simulate hot spot generation under dynamic impact.

Study of the Hydrogen/Tritium Interactions with Material Microstructure in Stainless Austenitic Steels
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The purpose of this program is to study the interaction between tritium solute atoms and helium bubbles in austenitic stainless steels. Solid mechanics methodology and advanced finite element analysis are used to simulate the development of the tritium atmosphere around a helium bubble both in the absence and presence of macroscopic loads. The calculations account for the interaction between neighboring bubbles and involve modeling the tritium decay and expansion of the helium bubble. Parametric studies on the applied load triaxiality are conducted. In particular, the magnitude of the hydrostatic stress around a bubble is studied to account for relaxation from dislocation-loop punching and from interactions with the stress fields of neighboring bubbles.

A Dislocation Mechanics Approach to the Study of Void Growth in Stressed Solids
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Dislocation-mechanics methodology and finite element analysis is used to study the micromechanics of void growth in metal systems under high strain rates. Despite intense investigation over the past 30 years, this

* Denotes principal investigator.
phenomenon is still very poorly understood from a micromechanical perspective as a number of related issues (e.g., macroscopic shear stress effect on void growth) require a dislocation-based approach in order to be elucidated. In particular, the research focuses on the interaction of interstitial dislocation loops in the neighborhood of a void with the void surface and the energetics of loop emission by including surface energy effects for nano-sized voids.

**The Mechanics of Hydrogen Embrittlement**

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*National Science Foundation, DMR-0302470*

*In cooperation with the Frederick Seitz Materials Research Laboratory*

Hydrogen embrittlement is a severe form of environmental degradation of materials. Introduction of hydrogen in metallic systems generally has a deleterious effect on the mechanical properties, and particularly the fracture resistance of the materials. This project’s goal is to develop a fracture criterion for hydrogen-induced intergranular fracture. Experiments and finite element simulations are carried out concurrently and the loads to fracture, the hydrogen population distributions at fracture, and the modes of fracture are determined. On the basis of the HRR stress and deformation fields and field solutions from direct finite element simulations ahead of a crack tip, a statistical model for cleavage fracture in the presence of hydrogen in equilibrium with local hydrostatic stress and plastic strain has been developed.

**Stochastic Crystal Plasticity**

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*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.

**Predicting Wear Rates for Metal Fiber Brushes in Homopolar Machines**

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*Naval Surface Warfare Center, N65540-06-M-5122*

DC homopolar motors and generators are being designed for high-efficiency ship propulsion. Large electric currents flow through metal-fiber brushes in the presence of strong magnetic fields so that electromagnetic body forces dominate the large deformations of the metal fibers. Successful designs depend on the accurate prediction of the rates of wear of fiber tips that slide on the rotor surface. Wear rates depend on the normal force, the local temperature, and anode-cathode effects in the oxide film.

**Materials Processing**

**Hot Working and DRX of Steel**

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*Caterpillar*

This research is focused on the hot working of steel and prediction of dynamic recrystallization (DRX) using a mesoscale modeling approach.

**Hot Rolling of 7XXX-Al Alloys**

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We model the evolution of texture and damage during hot rolling of Al-Mg-Zn alloys.

* Denotes principal investigator.
Phase Field Crystal Modeling of Microstructure Development
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National Science Foundation

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

Hot Rolling Scrap Reduction through Edge Cracking and Surface Defects Control
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In a collaborative effort with Alcoa, the Ohio State University and Lawrence Livermore National Laboratory (LLNL), the reduction of scrap in the hot rolling of aluminum alloys is addressed through simulation of the rolling process. The coupling of modeling with experiments provides insight into the fundamental mechanisms of localization. Detailed 3-D modeling of the rolling process is conducted through collaboration with researchers at LLNL.

Diffusion Effects in Photopolymerization
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University of Illinois at Urbana-Champaign

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

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

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

Entrapment of Bubbles and Inclusions during Flow in the Mold
B. G. Thomas,* S. H. Kim, S. Mahmood, G. Lee
Continuous Casting Consortium

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

Flow Dynamics and Electromagnetic Effects in Continuous Casting of Steel
B. G. Thomas,* K. Cukierski, R. Chaudhary
Continuous Casting Consortium

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. The important effects of electromagnetic forces to slow down and control the flow pattern are being incorporated. Process parameters, such as nozzle geometry and gas injection rate, which are easy to change and yet profoundly influence both flow and product quality, are being optimized. Models to compute the transport and entrapment of inclusion particles are being tested through water model experiments, steel plant trials, and metallographic measurements at several steel companies that are cosponsoring this research.
Fluid Flow, Heat Transfer and Interfacial Phenomena in Nozzle Refractories
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Continuous Casting Consortium

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
B. G. Thomas,* C. Ojeda
Continuous Casting Consortium

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

Modeling of Clogging and Erosion of Nozzle Refractories in Steel Casting
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Depending on their composition relative to the inclusions in the steel, the walls of nozzle refractories can clog or erode, leading to severe quality problems in cast products. These phenomena have rarely been subjected to fundamental modeling, and never to computational modeling involving the several coupled phenomena that govern it: the turbulent flow of molten steel through the nozzle, contacting of solid inclusions in the steel with the nozzle wall, heat transfer in the wall and steel, the diffusion of compounds such as Al2O3 and CaO through the nozzle wall, and the thermodynamics of the chemical reactions that form solid precipitates, or liquefy the inclusions, allowing them to erode from the walls. With the support of numerous experimental measurements that have been made for this project, computational models will be developed to increase understanding of this important, yet complex problem.

SIRG/Collaborative Research: Distributed Subwavelength Photonic Sensors for In-situ High Spatial and Temporal Resolution Monitoring in Manufacturing Environments
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National Science Foundation SIRG DMI 05-28668; Continuous Casting Consortium

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

Thermal Stress Analysis of Solidifying Steel Shells
B. G. Thomas,* S. Koric, K. Xu, C. Ojeda, L. Hibbeler
Continuous Casting Consortium

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

* Denotes principal investigator.
dynamic effect of solidification shrinkage on heat transfer across the interfacial gap between the mold and the shell. The model is being applied to simulate the early stages of solidification, ideal taper for different steel grades, maximum casting speed to avoid excessive bulging, and understanding crack formation. Finally, the model is being extended to simulate behavior in complex shapes, including ideal taper of beam blank molds, and crack formation in thin slabs cast in funnel molds, using full three dimensional simulations.

**Thermal Stress and Surface Crack Formation in Continuous Casting**

B. G. Thomas,* K. Xu

*Continuous Casting Consortium*

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

**Computational Tools for Analysis of Chaotic Mixing**

C. L. Tucker,* J. Phelps, M. Wilhelm

*University of Illinois at Urbana-Champaign*

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 flow protocols that are globally chaotic. Another characterizes the distributive mixing properties of a globally chaotic flow. These tools are applicable to polymer processing as well as to microfluidics.

**Fiber Orientation in Injection Molded Composites**

C. L. Tucker,* J. Wang

*Delphi Automotive Systems*

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

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

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

**Flow-Enhanced Crystallization in Injection Molding**

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*National Science Foundation, Center for Advanced Engineering of Fibers and Films, EEC-973160*

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

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* Denotes principal investigator.
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.

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

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

Statistical and Structural Similarities Between Micro- and Macro-Scale Wall Turbulence
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Microscopic particle-image velocimetry is utilized to study the statistical and structural characteristics of turbulence in 500-micron glass capillaries. High-resolution, instantaneous velocity measurements are made in the streamwise-wall-normal plane of the capillary at Re = 4500 and the single-point statistics are quantitatively compared to those of a direct numerical simulation of turbulent pipe flow at Re = 5300. This comparison establishes the efficacy of microscopic PIV in resolving the relatively small instantaneous velocity fluctuations that exist in such flows. In addition, the structural characteristics of turbulence in the microscale capillary are found to be remarkably consistent with the character of turbulent channel flow at the macroscale.

The Character of Transition to Turbulence in Microscale Capillaries
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Microscopic particle-image velocimetry is utilized to study the character of transition to turbulence in 500-micron glass capillaries. High-resolution, instantaneous velocity measurements are made in the streamwise-wall-normal plane of the capillary over a broad Reynolds number range (1800 < Re < 4500) and these datasets reveal that transition to turbulence at the microscale occurs at a Reynolds number (Re~2000) consistent with past macroscale observations. In addition, patches of disordered motion bounded upstream and downstream by nominally laminar flow are observed in the instantaneous velocity realizations and the occurrence of disordered motion is found to steadily increase with Reynolds number until a fully-turbulent state is attained at Re~3400. These characteristics are entirely consistent with the observations of intermittent turbulent spots in the transition of wall-bounded flows at the macroscale.

Atomistic-Based Continuum Models of Micro- and Nanoscale Engineered Systems/Processes
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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.

* Denotes principal investigator.
Development of Micro- and Mesoscale Machine Tool Technology
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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.

Low Cost Precision Micromachining Using Microscale Machine Tools (mMTs)
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National Center for Defense Manufacturing and Machining (NCDMM)

The objective of this project is to provide a demonstration and quantitative assessment of the use of recently developed micromachining technology for applications to a variety of small precision parts. In particular, we will develop a microscale hard-turning capability to machine small but high-precision parts. For improved process planning of micromachining operations, a machinability database will also be developed.

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

Nonfouling Heat Exchanger Surfaces by Controllable Anodization and Etching
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29 Company Consortium: Air Conditioning and Refrigeration Center

Micro- and nanostructured coatings have been proposed to modify the surface wettability, and they have proven to be successful in antifouling windows and mirrors. The fundamental principle behind the manipulation of surface hydrophobicity and hydrophilicity are established as Wenzel effect or Cassie-Baxter effect, that is, a significant portion of the microscopic area remain unwetted, resulting in multiple fluid-air-surface interfaces leading to apparently large or low contact angles at the macroscale. Inspired by this principle, we propose to utilize a well established and cost effective process—aluminum anodization and etching—to achieve the effect with highly ordered and controllable surface textures. The original concept in our proposal is to design and optimize the surface profile such as tip spacing and tip angles according to the Cassie-Baxter model, and on the other hand, to establish the anodic process parameters (such as forming voltage and etchant concentration) based on nanoscopic mass transport and growth kinetics.

Optical Negative Index Material for Imaging and Information Processing
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Defense Advanced Research Projects Agency

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

* Denotes principal investigator.
Solid State Electrochemical Nanomanufacturing
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This project proposes a revolutionary approach, based on room-temperature solid state ionic (superionic) conductors that enable the fast and reversible growth and dissolution of metallic (specifically silver and copper) nanoclusters, to achieve active and reprogrammable nanopatterning. It offers a highly competitive approach, both as a stand-alone process and as a complement of other nanofabrication techniques, in fabricating chemical sensors, photonic and plasmonic structures, and electronic interconnects.

A Resonant Photonic Superlattice Sensor with Large Enhancement Factor of Evanescent Waves
N. Fang*
NSF Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems (NanoCEMMS)
To provide the essential embedded sensing capabilities on the center's Micro-Nano toolbit, we propose to design and embed a set of small footprint and transparent photonic superlattice sensors that promise high enhancement of evanescent waves. A set of photonic superlattice sensors optimized at desired working wavelength will be designed and manufactured using standard cleanroom process technologies. We prototyped the initial design of sub-wavelength near-field sensor with surface plasmon controlled beaming. The giant enhancement factor, and thus the sensitivity of chemical species, will be experimentally established and calibrated.

Ab Initio Simulation of Electrokinetic Nanoflows
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NSF Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems, DMI-0328162; NSF Center of Advanced Materials for the Purification of Water with Systems(CAMPWS), CTS-0120978
The role of this project is to develop quantum mechanical (ab initio) models that can combine with "best-practice" molecular dynamics and multiscale approaches in the simulation of electrokinetic nanoflows. These one-of-a-kind simulation tools will be used to understand and characterize the molecular gate technology employed in developing the micro-nano-fluid network toolbit of the Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems (Nano-CEMMS).

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

Analysis of Micro- and Nano-Fluidic Network for Scheduling and Planning of Fluid Delivery
Y. Huang*
National Science Foundation Center for Nanoscale Chemical-Electrical-Mechanical-Manufacturing Systems; University of Illinois at Urbana-Champaign
We are developing multiscale models to study micro- and nano-fluidic networks for scheduling and planning of fluid delivery.

* Denotes principal investigator.
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.

Characterization and Modeling of Polymer Matrix Nanocomposite Materials

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Polymer matrix composites with the same volume fraction of nano and micron size reinforcement are considered in order to assess how the size of reinforcement contributes to the overall mechanical properties. Characterization tools include electron microscopy to assess the arrangement and size distribution of particles. Then, we conduct nanoindentation measurements to determine local properties. These are complemented by the thermogravimetric analysis. Testing focuses on mechanical properties such as elastic modulus, ultimate strength, fracture toughness, and strain to failure, as well as viscoelastic properties. Modeling includes the micromechanics continuum-based analysis and molecular level simulations.

Nanoindentation of Cr$_3$C$_2$-Ni Cermets

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Experimental investigation of chromium carbide based Cr$_3$C$_2$-Ni cermets with different compositions uses several experimental approaches: scanning electron microscopy to obtain microstructure information, EDS to identify special chemical composition, and nanoindentation technique to obtain local mechanical properties. These ceramic-metal composites consist of 80% (by weight) of ceramic Cr$_3$C$_2$ phase and the 20% (by weight) of Ni-based binder phase. The binder phase is either pure nickel or nickel combined with either molybdenum or copper. Local spatially varying elastic modulus and hardness are measured for using the nanoindentation. The collected data can serve as input for modeling of these composites.

Atomistic Origins of Ion Bombardment Nanoscale Surface Instability

H. T. Johnson,* J. B. Freund
National Science Foundation, CMS 05-10624

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

Computational Electromagnetics for Nanophotonic Applications in Soft Materials

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In collaboration with the Frederick Seitz Materials Research Laboratory

Several problems in computational electromagnetics in nanostructured soft materials are studied, with the goal of controlling light intensity distributions for processing and manipulating structures on the scale of the wavelength of visible light. Inverse methods are used to design two-
dimensional phase masks for producing desired periodic intensity patterns in photoresist. Direct calculations are carried out to impose periodic intensity distributions in colloidal photonic crystals, exploiting features of the photonic band structure of the target material. Plasmonic crystal structures are studied for possible sensing applications, whereby small scale material variations can be detected via nonlinear shifts in the transmitted or reflected photonic spectra.

**Deformation and Disorder in Hydrogel Photonic Crystals**

H. T. Johnson*

*Petroleum Research Fund of the American Chemical Society, 42421-AC10*

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

**Determining the Origins of Electronic States in Semiconductor Nanostructures**

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The origins of electronic states in dimensionally confined III-V semiconductor structures are studied via computational analysis, and compared with state-of-the-art experiments, carried out at the University of Michigan. Specifically, the effects of nanostructure size, shape, strain, and interfacial disorder on the electronic band structure and confined states are investigated using real space order(N) semi-empirical tight-binding calculations and compared with scanning tunneling microscopy data. Both techniques yield structural and electronic information with atomic scale resolution. Comparisons between experimental and computational studies will reveal both the origins of the electronic states in semiconductor nanostructures, as well as the validity of the physical assumptions underlying the experimental and computational techniques.

**Optimized Photonic Bandgap Devices with Nanoscale Disorder**

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

* Denotes principal investigator.
yield nanomanufacturable devices, according to known fabrication constraints imposed by state-of-the-art nanomanufacturing tools; improve optimized designs by striving for robustness with respect to typical disorder introduced in nanomanufacturing; and fabricate and test the computationally identified designs as a way to validate the proposed approach.

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

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

**Microscale Cutting Fluid Spraying System**
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The goal is to develop an atomization-based cutting fluid spraying system for micromachining. The effectiveness of the system depends on the ability to control the velocities of the atomized droplets (size 2-10 μm) at different points of travel from the moment of atomization to being sprayed to the cutting zone. Maximum mass flow rate is desired inside the pipe carrying the droplets and a given range of velocities for the droplets is required as the droplets hit the cutting zone. The effect of fluid properties in terms of surface tension and viscosity is also being investigated to improve the overall effectiveness of the cutting fluid application.

**Modeling and Simulation for Process Planning of 5-Axis Micromilling of LCD Backlight**
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The ultimate goal of this research is to better understand the dynamics of the 5-axis micromilling of LCD backlight and achieve form accuracy of 0.5 microns through modeling and understanding of cutting forces, tool/ workpiece, vibrations, and surface finish. A new process for the machining of microgrooves on the LCD backlight panels will be developed. A DEFORM-based numerical model will also be developed to study the three-dimensional microgrooving process.

**A Methodology for Modular and Reconfigurable Microassembly System Design**
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Significant reduction in lead time and enhanced productivity can be achieved with the help of reconfigurable microassembly stations in the manufacturing assembly line. The goals of this project are to: develop a coding and classification system for microassembly; and design and build a modular and reconfigurable microassembly station. A coding system that can link microassembly concepts and technologies to the attributes of the assembly components and their interrelationships can help quickly assemble and disassemble components in a reconfigurable assembly station where different types of grippers, manipulators, vision systems, and force sensing equipment are available.

* Denotes principal investigator.
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.

In-situ TEM and SEM Studies of Fundamental Deformation and Failure Processes of Nanograined FCC Metals Using MEMS Stages
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National Science Foundation, DMR 0237400

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

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

T. A. Saif,* J. Rajagopal  
*National Science Foundation, ECS-0304243*

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

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

T. A. Saif,* J. Han  
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It is widely accepted that materials' behavior, particularly failure characteristics, strongly depends on their size. Uniaxial tensile testing allows direct measurement of materials' stress–strain data without any prior phenomenological model. The objective of this project is to develop a microscale apparatus that allows testing of miniature samples (fabricated separately from the apparatus) under tension and compression at various temperatures (as high as 500 C), and at different strain rates.

**High Precision Positioning with Subnanometer Resolution for Atomic Force Microscopy (AFM)**

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*National Science Foundation*

Typical flexure-based positioning systems in AFM are piezoactuated, which exhibit aggravated nonlinear effects such as hysteresis, creep, and drift, and together with the electronic noise and other noise inherent in the system, make repeatable subnanometer precision positioning a difficult task. This project aims at achieving high resolution by striking an appropriate trade-off between the resolution and the bandwidth. The proposed scheme achieves subnanometer resolution without compromising the scanning/imaging speed by designing a low bandwidth band pass closed-loop system with a high central frequency. This scheme has enabled visualization of subnanometer stick-slip features of Mica, and 96% reduction in tracking error for larger scans.

**Lateral Force Compensation through Cantilever Actuation**

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This project involves modifying the MFP-3-D by adding piezoactuators at the end of the cantilever that will counteract the effect of lateral (friction) forces on the cantilever. Preliminary results show a significant attrition in the lateral force signals after closing the feedback loop. This project, at completion, would yield imaging capability in AFM that is not corrupted by intercoupling between the lateral and the vertical motions of the cantilever. Current work aims at resolving some electronic noise issues with our actuator, after which we can obtain better compensation for the lateral forces.

**Lateral Force Measurement and Calibration in AFM**

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Current methodologies for force-voltage calibration in lateral force atomic force microscopy are based on static evaluations that require very delicate experiments such as atomic-scale stick-slip experiments and/or depend on the hard to ascertain geometrical aspects of the cantilever (such as its length and tip height). We are working on a dynamic (frequency domain), easy-to-implement method based on thermal noise analysis and lateral force curves, which if successful, will provide a mechanism to determine the calibration constant and the lateral stiffness of the
cantilever without doing any delicate experiments or measuring the geometrical aspects of the cantilever.

**Real Time Sample Property Estimation**

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This project develops a design scheme based on modern control theory, which exploits the way the surface properties (stiffness and damping) enter the dynamical model, to obtain a signal that will estimate these properties in real time. In this formulation, the sample profile and compliance effects of the sample enter as disturbance and the proposed scheme will result in a strategy that will give signals that will estimate both the sample profile and the properties in real time. Preliminary designs have shown real-time, high-fidelity sample profile estimations, and preliminary simulations promise property estimations with good signal-to-noise ratios.

**Representation Problem in Drug Discovery**

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This project develops scalable algorithms based on a combinatorial optimization theory that selects sets of drug candidates from a vast database that simultaneously accounts for representativeness, molecular diversity, and constraints on experimental resources. (Current algorithm in literature account only for molecular diversity.) The framework developed in this project uses Maximum Entropy Principle (MEP) to assess scalability (in terms of computational effort) and clustering capability of the algorithms. The algorithms developed are scalable and have selected representative elements from large data test sets where previous existing algorithms failed.

**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 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.

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

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

*National Science Foundation, Nanoscale Science and Engineering Center, DMI-0328162; University of Illinois at Urbana-Champaign*

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

**Mechanics of Damping in Nanostructured Materials**

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*National Science Foundation, CMMI-0600583*

The project is a focused study on the damping properties of nanostructured materials, such as carbon nanotubes (CNT) and CNT reinforce polymer composites. Understanding the origin of damping due to the dramatic reduction in the length scale is essential for many applications. With the dramatic increase in the surface-to-volume ratio at the nanometer length scale, a critical aspect of the research is to study the effects of nanoscale surface and interface. These effects become important as nanostructured materials are integrated with other materials or systems that are of different types and operate at different spatial and temporal scales.

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

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

*National Science Foundation, CCF-0508416*

The goal of this research is to understand the fundamental issues related to the atomic lattice registry related interlayer tunneling in multiwalled carbon nanotube and to explore

* Denotes principal investigator.
the development of novel devices based on this basic understanding. The research will exploit concurrently the unique structural, mechanical, and electronic properties of the carbon nanotube and engineer them for the application of the carbon nanotube in a new field: nanometrology. The research ultimately will lead to the development of a brand new type of nanometrology device, namely an absolute displacement encoder with sub-nanometer resolution, which has rarely been explored, but could find wide application in precision engineering and nanoscale fabrication.

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

M.-F. Yu*

*National Science Foundation, CMS-0324643*

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

**Three-Dimensional Nanofabrication**

M.-F. Yu*

mfyu@uiuc.edu

*National Science Foundation Nanoscale Science and Engineering Center, (DMI-0328162); University of Illinois at Urbana-Champaign*

The project focuses on the development of new technologies for the three-dimensional nanofabrication and heterogeneous integration of structures and components having sub-100 nm feature sizes in free space and in an ambient environment appropriate for large-scale nanomanufacturing. The research aims to explore new concepts for such nanofabrication, expand the material choices for heterogeneous integration, and develop flexible controls for the automated nanoscale construction.

**Ultrahigh Sensitivity Parametric Sensing with Nanotube**

M.-F. Yu*

*National Science Foundation, ECS-0501495*

The objective of the proposed research is to study the resonance sensing behavior of unique nanomaterials and apply the discovery to 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 scanning electron microscope and transmission electron microscope; to prototype parametric resonance sensor integrated with excitation and sensing mechanisms, and to develop a device with microfabrication of parametric resonance sensor incorporating nanotubes.

**Wetting and Liquid Transport in Nanotube**

M.-F. Yu*

*National Science Foundation, Nanoscale Science and Engineering Center, DMI-0328162; University of Illinois at Urbana-Champaign*

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

**Operations Research**

**Pediatric Vaccine Formulary Optimization and Analysis**

S. H. Jacobson,* S. N. Hall, R. Proano

*National Science Foundation, DMI-0457176*

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

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

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

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

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

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

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

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

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

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

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

Optimal Pricing for a Product Assortment with Multiple Market Segments
U. S. Palekar,* G. Daruka
palekar@uiuc.edu
University of Illinois at Urbana-Champaign

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

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

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

Production Management

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

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

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

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

Journal Articles

Automotive Systems


* Denotes principal investigator.


Bioengineering


Combustion and Propulsion


Computational Science and Engineering


Control Systems


Bristow, D. A. and Alleyne, A. G. A high precision motion control system with application to microscale robotic deposition. *Institute of Electrical and Electronics Engineers Transactions on Control Systems Technology*, 14:6, 1008-1020 (Nov. 2006).


Design Methodology and Tribology


Demas, N. G. and Polycarpou, A. A. Ultra high pressure tribometer for testing CO\textsubscript{2} refrigerant at chamber pressures up to 2000 psi to simulate compressor conditions. *Trubology Transactions, 49*:3, 291-296 (Jul.-Sep. 2006).


**Dynamic Systems**


**Energy Systems and Thermodynamics**


Engineering Mechanics


**Fluid Dynamics**


Natrajan, V. K. and Christensen, K. T. The role of coherent structures in subgrid-scale energy transfer within the log layer of wall turbulence [art. no. 065104]. *The Physics of Fluids*, 18:6, 65104 (Jun. 2006).


Heat Transfer


Manufacturing Systems


Honegger, A., Langstaff, G., Phillip, A., VanRavenswaay, T., Kapoor, S. G., and DeVor, R. E.

Jun, M. B. G., DeVor, R. E., and Kapoor, S. G.


Materials Behavior


Mani, S., Saif, T., and Han, J. H. *Effect of annealing on the conductivity of electroless deposited Ni nanowires and films*. Institute of Electrical and Electronics Engineers Transactions on Nanotechnology, 5:2, 138-141 (Mar. 2006).


**Materials Processing**


Thomas, B. G. **Modeling of continuous-casting defects related to mold fluid flow.** *Association for Iron and Steel Technology Transactions, 3:5*, 1-18 (Jul. 2006).


Nano-, Micro-, and Meso-Technology


Lee, K. M., Yeo, C. D., and Polycarpou, A. A.  **Mechanical property measurements of thin-film carbon overcoat on recording media towards 1 Tbit/in(2) [art. no. 08G906].** *Journal of Applied Physics, 99*:8, 08G906 (Apr. 2006).


Mukherjee, S. and Aluru, N. R.  **Applications in micro- and nanoelectromechanical systems.** *Engineering Analysis with Boundary Elements, 30*:11, 909 (Nov. 2006).


Tayebi, N. and Polycarpou, A. A. Adhesion and contact modeling and experiments in microelectromechanical systems including roughness effects. Microsystem Technologies, 12:9, 854-869 (Aug. 2006).


**Operations Research**


**Book Chapters**

**Bioengineering**


**Control Systems**


**Energy Systems and Thermodynamics**

Materials Processing


Nano-, Micro-, and Meso-Technology


Papers Presented at Conferences and Symposia


Automotive Systems


**Bioengineering**


Hsiao-Wecksler, E. T. and Jang, J. **Effect of pregnancy on balance throughout nine months of pregnancy and six months post-partum.** Fifth World Congress of Biomechanics (Munich, Germany, Jul.-Aug. 2006).
Hsiao-Wecksler, E. T., Jang, J., Ramachandran, A. K., Yang, Y., and Rosengren, K. S. **Gait and obstacle crossing behaviors of older adults during five months of Tai Chi training.** Fifth World Congress of Biomechanics (Munich, Germany, Jul.-Aug. 2006).


Combustion and Propulsion


Control Systems


Kim, J. Y. and Bentsman, J. **Multiresolution finite-dimensional adaptive control of distributed parameter systems.** 45th Institute of Electrical and Electronics Engineers Conference on Decision and Control (San Diego, CA, Dec. 2006). Proceedings of the 45th Institute of Electrical and Electronics Engineers Conference on Decision and Control 2801-2806 (2006).


Miller, B. M. and Bentsman, J. **Representation of motion of controlled dynamic systems with unilateral constraints.** 45th Institute of Electrical and Electronics Engineers Conference on Decision and Control (San Diego, CA, Dec. 2006). Proceedings of the 45th Institute of Electrical and Electronics Engineers Conference on Decision and Control 4787-4792 (2006).


Salapaka, S. **Combinatorial optimization approach to coarse control quantization.** 45th Institute of Electrical and Electronics Engineers Conference on Decision and Control (San Diego, CA, Dec. 2006). Proceedings of the 45th Institute of Electrical and Electronics Engineers Conference on Decision and Control 6 (2006).


Design Methodology and Tribology


Demas, N. G. and Polycarpou, A. A. Ultra high pressure tribometer for testing CO2 refrigerant at chamber pressures up to 2000 psi (13.8 MPa) to simulate compressor conditions. 61st Society of Tribologists and Lubrication Engineers Annual Meeting and Exhibition (Calgary, AL, Canada, May 2006). Proceedings of the 61st Society of Tribologists and Lubrication Engineers Annual Meeting and Exhibition CD-ROM (2006).


Energy Systems and Thermodynamics


Elbel, S. W. and Hrnjak, P. S.  **A thermodynamic property chart as a visual aid to illustrate the interference between expansion work recovery and internal heat exchange.**  11th International Refrigeration and Air Conditioning Conference at Purdue (West Lafayette, IN, Jul. 2006). Proceedings of the 11th International Refrigeration and Air Conditioning Conference at Purdue (2006).


Han, J. H., Yang, S., and Shannon, M. A.  **Peeling mode capacitive pressure sensor for low-pressure (few hundred Pascals full range) measurements.**  American Society of Mechanical Engineers International Mechanical Engineering Congress and Exposition (Chicago, IL, Nov. 2006).


Engineering Mechanics


Fluid Dynamics


Heat Transfer


Manufacturing Systems


Han, J., Gonzalez, H., Li, X., and Klabjan, D. 


**Materials Behavior**


Materials Processing


Nano-, Micro-, and Meso-Technology


Flexible carbon nanotube devices using nanomaterial transfer imprint lithography.  

Chaturvedi, P. and Fang, N. X.  
Molecular scale imaging with a multilayer superlens.  

Dankowicz, H.  
Teaching advanced modeling of multibody mechanisms to non-traditional engineering students.  

De, S. K. and Aluru, N. R.  
Effect of the nonlinear electrostatic actuation force on thermoelastic damping/quality factor in micro-electromechanical systems (MEMS).  

Du, X., Jasiuk, I., and Hussainova, I.  
Nanoindentation of Cr3C2-Ni cermets.  

Nanoimprint lithography for high throughput cell substrates having both microscale and nanoscale topography.  

Georgiadis, J. G. and Raguin, L. G.  
Particle segregation in oscillatory Taylor-Couette-Poiseuille flow.  

King, W. P.  
Thermal processing-based nanomanufacturing.  
The Future of Nanoplastics Workshop (San Antonio, TX, Feb. 2006).

King, W. P.  
Understanding polymer flow during nanoembossing.  

King, W. P.  
Writing nanoelectronics with a heated probe tip.  

Lee, J., Beecham, T., Park, K., Zhang, Z. M., Graham, S., and King, W. P.  
Thermal and mechanical characterization of heated microcantilevers.  

Li, X., Wong, C. W., Dornfeld, D., and Thomas, B. G.  
Research on subwavelength microphotonic sensors for in-situ monitoring with high spatial and temporal resolution in manufacturing environments, contacting and solidification in casting-by-design.  

Park, K., Zhang, Z. M., King, W. P., and Marchenkov, A.  
Electrical and thermal characteristics of heated atomic force microscope cantilevers at low temperatures.  
American Society of Mechanical Engineers International Mechanical Engineering Congress and Exposition (Chicago, IL, Nov. 2006).

Raghunathan, A. V. and Aluru, N. R.  
A molecular understanding of osmosis in semi-permeable membranes.  
Raghunathan, A. V. and Aluru, N. R.  


Raguin, L. G., Karampinos, D. C., Honecker, S., and Georgiadis, J. G.  

Raguin, L. G., Karampinos, D., Georgiadis, J. G., and Ciobanu, L.  

Rowland, H. D., King, W. P., Cross, G. L. W., O’Connell, B. S., and Pethica, J. B.  

Suh, A. Y. and Polycarpou, A. A.  

Tang, Z. and Aluru, N. R.  

Tang, Z., Zhao, H., Li, G., and Aluru, N. R.  

Won, C. Y. and Aluru, N. R.  


Yin, L. and Fang, N.  


**Theses**

**Automotive Systems**


**Bioengineering**


Combustion and Propulsion


Design Methodology and Tribology


Energy Systems and Thermodynamics


**Fluid Dynamics**


**Heat Transfer**


**Manufacturing Systems**


**Materials Behavior**


**Materials Processing**


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


**Operations Research**


Awards and Honors

Andrew G. Alleyne
Outstanding Graduate Student Instructor Award, 1990-1991
Incomplete List of Teachers Ranked as Excellent by Their Students, University of Illinois, Spring 1995; Fall 2004, 2006
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 1996
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 1998, 1999
Honorable Mention for paper (one of five finalist papers) at the Fourteenth International Federation of Automatic Control Congress, Beijing, Peoples' Republic of China, 1999
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2000
Best Paper Award, American Society of Mechanical Engineers International Mechanical Engineering Congress and Exposition, Fluid Power Systems and Technology Division, 2000
Who’s Who Among America’s Teachers, 2000
Accenture Award for Excellence in Advising, University of Illinois College of Engineering, 2001, 2003
Fulbright Fellowship, 2002-2003
Key Reader, Metallurgical and Materials Transactions, 1999-
Invited Participant, National Academy of Engineering 19th Annual Symposium on Frontiers of Engineering, 2004
College of Engineers Advisors List, 2002
Willett Faculty Scholar Award, University of Illinois College of Engineering, 2003-2006
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2000
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
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 1999
Fellow, American Society of Mechanical Engineers, 2005
Honorable Mention, Campus Award for Innovation in Undergraduate Instruction, University of Illinois, 2005
Honorable Mention, Campus Award for Excellence in Graduate and Professional Teaching, University of Illinois, 2006

Armand J. Beaudoin
Invited Participant, National Academy of Engineering 19th Annual Symposium on Frontiers of Engineering, 2004
Fellow, American Society of Mechanical Engineers, 2005
Honorable Mention, Campus Award for Innovation in Undergraduate Instruction, University of Illinois, 2005
Honorable Mention, Campus Award for Excellence in Graduate and Professional Teaching, University of Illinois, 2006

Editorial Board, Modeling and Simulation in Materials Science and Engineering, 1998-
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 1999
Key Reader, Metallurgical and Materials Transactions, 1999-
Willett Faculty Scholar Award, University of Illinois College of Engineering, 2003-2006
Listed in the Daily Illini "Incomplete List of Teachers Ranked as Excellent by Their Students," Fall 2000, 2001; Spring 2002, 2006
College of Engineers Advisors List, 2002
Xerox Award for Faculty Research, University of Illinois, 2003
Accenture Award for Excellence in Advising, University of Illinois College of Engineering, 2003
Joseph Bentsman
Presidential Young Investigator Award, National Science Foundation, 1989
Andersen Consulting Award for Excellence in Advising, University of Illinois College of Engineering, 1990
Member, Editorial Board, Nonlinear Phenomena in Complex Systems, An Interdisciplinary Journal, 1999-

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

M. Quinn Brewster
Japanese Ministry of Education Scholarship, Kyoto University, Japan, 1981-1982
National Science Foundation Presidential Young Investigator Award, 1984
Outstanding Poster Presentation Award, Eighth International Heat Transfer Conference, 1986
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
Young Investigator Award, Office of Naval Research, 1987
Listed in American Men and Women in Science, 1992

Richard O. Buckius
Fellow, American Society of Mechanical Engineers, 1988
Associate Fellow, American Institute of Aeronautics and Astronautics, 1996
Dow Outstanding Young Faculty, Illinois-Indiana Section, American Society for Engineering Education, 1978
Stanley H. Pierce Faculty Award, University of Illinois College of Engineering, 1979
Everitt Award for Excellence in Undergraduate Teaching, University of Illinois College of Engineering, 1980
Two-Year Effective Teaching Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1980, 1987, 1994, 2000
Campus Award for Excellence in Undergraduate Teaching, University of Illinois, 1980
Western Electric Fund Award, American Society for Engineering Education, 1981
Five-Year Effective Teaching Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1982, 1989
Halliburton Engineering Education Leadership Award, University of Illinois College of Engineering, 1987
Beckman Associate, University of Illinois Center for Advanced Study, 1989
Centennial Memorial Fund, Tokyo Institute of Technology, 1990
Fellow, Committee on Institutional Cooperation Academic Leadership, 1990
Editorial Advisory Board, Heat Transfer-Japanese Research, 1990-
Editorial Advisory Board, *Microscale Thermophysical Engineering*, 1996-
Editorial Advisory Board, *Heat Transfer Research*, 1997-
Ralph Coats Roe Award, American Society for Engineering Education, 2003
Potter Gold Medal, American Society of Mechanical Engineers, 2006

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

Sahraoui Chaieb
Young Scientist Fellowship, Direction des Recherches et Etudes Techniques de la Delegation Generale a l'Armement, Ministry of Defense, 1994
Collins Scholar Award, University of Illinois College of Engineering, 2001
Image of the Week, Image Technology Group, Beckman Institute, University of Illinois, Feb. 2001, Sept. 2001
*Strathamore's Who's Who, 2002*
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 2003
Grainger Foundation Gift for Emerging Technologies, University of Illinois College of Engineering, 2003
Fellow, Center for Advanced Studies and Beckman Fellow, University of Illinois, 2005-2006
*Who's Who in Engineering Education, 2005*

John C. Chato, Emeritus
Fellow, American Society of Mechanical Engineers, 1975
Fellow, American Institute for Medical and Biological Engineering, 1993
Postdoctoral Fellow, National Science Foundation, 1961
Distinguished Engineering Alumnus Award, University of Cincinnati, 1972
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

Kenneth T. Christensen
Ford Foundation Predoctoral Fellowship (declined), 1995
National Science Foundation Graduate Fellowship, 1995-1998
Clark B. Milliken Fellowship and Special Institute Fellowship, Caltech, 1995
SURGE Fellowship, University of Illinois College of Engineering, 1996-2000
Larson Graduate Fellowship, Theoretical and Applied Mechanics Department, University of Illinois at Urbana-Champaign, 2000
Stanley J. Weiss Outstanding Thesis Award, University of Illinois Theoretical and Applied Mechanics Department, 2001
Academy for Excellence in Engineering Education (AE3) Scholar, University of Illinois, 2004
Ralph Powe Junior Faculty Enhancement Award, Oak Ridge Associated Universities, 2003
Air Force Office of Scientific Research Young Investigator Award, 2006
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Spring 2006
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 2007

Harry Dankowicz
Cannon Faculty Scholar, 2005-2008

Jonathan A. Dantzig
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 Paper (Oral), Fifth Engineering Foundation Conference on Modeling of Casting and Advanced Solidification, 1990

Subject Editor, Modeling, Encyclopedia of Materials: Science and Technology, 1998-2000
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, The Minerals, Metals & Materials Society (TMS), 2005
Keynote Speaker, Modeling of Casting Welding and Advanced Solidification Processes, Opio, France, 2006

Richard E. DeVor, Research Professor
Fellow, Society of Manufacturing Engineers
Fellow, American Society of Mechanical Engineers
Five-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1981, 1990, 2005
Two-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1981, 1989, 1995, 2002
Blackall Machine Tool and Gage Award, American Society of Mechanical Engineers, 1983, 1997
Everitt Award for Excellence in Undergraduate Teaching, University of Illinois College of Engineering, 1985
Campus Award for Excellence in Undergraduate Teaching, University of Illinois, 1987
Halliburton Engineering Education Leadership Award, University of Illinois College of Engineering, 1989
Society of Manufacturing Engineers Education Award, 1993
Grayce Wicall Gauthier Chair Professorship, University of Illinois Department of Mechanical and Industrial Engineering, 1995-2000
Distinguished Service Award, University of Wisconsin-Madison College of Engineering, 1997
Member, National Academy of Engineering, 2000
Distinguished Professor of Manufacturing, University of Illinois College of Engineering, 2000-2001
Distinguished Emeritus Professor of Manufacturing, University of Illinois College of Engineering, 2001
William T. Ennor Manufacturing Technology Award, American Society of Mechanical Engineers, 2003
Geir E. Dullerud
National Sciences and Engineering Research Council of Canada Initiation Grant, 1996
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 1999
Willett Faculty Scholar Award, University of Illinois College of Engineering, 2002-2008
Listed in the Daily Illini "Incomplete List of Teachers Ranked as Excellent by Their Students," Fall 2004
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2005

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

Nicholas X. Fang
Participant (1 of 14), 2006 U.S.-Japan Young Researcher Exchange Program for Nanotechnology and Nanomanufacturing, National Science Foundation, 2006
Pi-Tau-Sigma Gold Medal, American Society of Mechanical Engineers, 2006

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-
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

Jonathan B. Freund
Mechanical and Industrial Engineering Departmental Fellowship, 1991
Franklin P. and Caroline M. Johnson Graduate Fellowship, 1995
Winner, American Physical Society (APS) Division of Fluid Dynamics Gallery of Fluid Motion, 2000
17th Annual Picture Gallery of Fluid Motion Exhibit, APS Division of Fluid Dynamics, 2000

John G. Georgiadis
Engineering Research Initiation Award, Engineering Foundation and 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

Gustavo Gioia
Merit Award, Rutgers University, 1998
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 2001
Short List of Excellent Reviewers, *Journal of Geophysical Research (Planets)*, 2004
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2006

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

**Robert B. Haber**
Beckman Associate, University of Illinois Center for Advanced Study, 1982
Corning Glass Instructional Assistance Award, 1984
Invited Lecturer, NATO Advanced Study Institute on Computer-Aided Optimal Design, Troia, Portugal, 1986
Faculty Visitor, Mathematical Sciences Institute, Cornell University, 1987
Project Director, RIVERS Project, National Center for Supercomputing Applications, 1987-1990
Keynote Speaker, NSF Workshop on Massive Data Sets in Combustion and Heat Transfer, Livermore, Cal., 1988
Cray University Research Affiliate, 1985-1993
Keynote Speaker, Spring Conference of the National Society for Computer Applications in Engineering, Planning and Architecture (CEPA), Chicago, Ill., 1988
Keynote Speaker, ALLUS 1989, Boston, Maine, 1989
Visiting Professor, Danmarks Tekniske Hojskole, Lyngby, Denmark, 1990
Keynote Speaker, Heldagsmode om Optimering af Konstruktioner, Danmarks Tekniske Hojskole, Lyngby, Denmark, 1990
Keynote Speaker, Nordic Visualization Workshop, Umea, Sweden, 1990
Keynote Speaker, International Conference on Computational Structures Technology, Edinburgh, United Kingdom, 1991
Project Leader, Visualization and Application Steering Environments (VASE) Project, Center for Supercomputing Research and Development, University of Illinois at Urbana-Champaign, 1991-1993
Keynote Speaker, SERC Data in Visualization Workshop, University of Manchester, United Kingdom, 1992
Visiting Professor, Danmarks Tekniske Hojskole, Lyngby, Denmark, 1992

"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Spring 1995
Keynote Speaker, Fourth World Congress on Computational Mechanics, Buenos Aires, Argentina, 1998
Director, Center for Process Simulation and Design, 1998-
Otto Mensted Guest Professor, Technical University of Denmark, Lyngby, Denmark, 2000
Editorial Board, *Journal of Computational and Applied Mathematics*, 2001-
Fellow, International Association for Computational Mechanics, 2002
Distinguished Lecture Series on Computational Materials Science and Engineering, Cornell Theory Center, Cornell University, Ithaca, New York, 2002
Plenary Lecturer, Euro Conference: Numerical Methods and Computational Mechanics, Miskolc, Hungary, 2002
Keynote Speaker, DARPA/NSF OPAAL Workshop, Arlington, Virginia, 2002
Editorial Board, *Journal of Multiscale Computational Engineering*, 2002-
Fellow, U.S. Association for Computational Mechanics, 2003
Keynote Speaker, Sixth World Congress on Computational Mechanics, Beijing, China, 2004
Keynote Speaker, Eighth U.S. National Congress on Computational Mechanics, USACM, Austin, Texas, 2005
Member-at-Large, Executive Committee, U.S. Association for Computational Mechanics, 2007

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

Engineering Council Award for Excellence in Advising, University of Illinois, 2002, 2004


Elizabeth Hsiao-Wecksler

Biology of Aging Research Scholar, American Federation for Aging Research and Glenn Foundation, 1998

New Investigator Recognition Award, Orthopaedic Research Society and American Geriatrics Society, 1999

Fellow, Center for Advanced Study, University of Illinois, 2004-2005

Campus Award for Excellence in Guiding Undergraduate Research, Honorable Mention, University of Illinois, 2005

"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Fall 2006

Yonggang Huang

Wakonse Fellow, University of Arizona, 1993

Junior Investigator Award, National Science Foundation, 1995

Faculty Award, Alcoa Foundation, 1995, 1996

Faculty Award, Motorola Foundation, 1997

Faculty Award, Ford Foundation, 1998

Outstanding Young Investigator Award, National Science Foundation of China, 2000

Research Award for U.S. Scientists and Scholars, Alexander von Humboldt Foundation, 2001

Editorial Advisory Board, International Journal of Plasticity, 2002-

Beckman Associate, University of Illinois Center for Advanced Studies, 2002

Faculty Fellow, National Center for Supercomputing Applications, University of Illinois, 2002

"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Spring 2003, 2005; Spring and 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

Regional Editor, Editorial Board Member, International Journal of Fracture, 2004-

Editorial Board, International Journal of Multiscale and Interactive Mechanics, 2004-

Chang Jiang Chair Professor, Department of Engineering Mechanics, Tsinghua University, Peoples’ Republic of China, 2005-

Lecturer, Southwest Mechanics Lecture Series, 2005

SES Young Investigator Medal, Society of Engineering Science (for high impact of research work in engineering science within 15 years of terminal degree), 2006

Outstanding Overseas Investigator Award, Chinese Academy of Science, 2006

Selected for one of “10 Technologies That Will Change of the World,” by MIT’s Technology Review Magazine for stretchable silicon, 2006

Visiting Professor, Royal Society Kan Tong Po, 2006-2007

Anthony M. Jacobi


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, 2006

Associate Technical Editor, Journal of Energy Resources Technology, 1999-
Editor, American Society of Mechanical Engineers 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

Iwona Jasiuk
Guest Editor, Special Issue of Applied Mechanics Reviews, 1994
Listed in Marquis Who’s Who in Science and Engineering (2nd & 3rd Editions), 1996
Member, Board of Editors International Journal of Solids and Structures, 1996-2005
Guest Editor, Applied Mechanics in the Americas Vols. 6, 7, 8, Proceedings of the 6th Pan-American Congress of Applied Mechanics and 8th International Conference on Dynamic Problems in Mechanics, Rio de Janeiro, Brazil, 1999
Keynote Speaker, ME ’00, The 2000 International Mechanical Engineering Congress and Exposition, Orlando, Florida, 2000
Member, Board of Directors, Society of Engineering Science, 2000-2006
“Most Helpful Professor” Teaching Award, Georgia Technical University, 2002
Fellow, American Society of Mechanical Engineers, 2003
Vice-Chair, Applied Mechanics Division Composites Committee, American Society of Mechanical Engineers, 2003

Harley Johnson
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 2001
Cannon Faculty Scholar, Department of Mechanical and Industrial Engineering, 2003-2006
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Spring 2004, 2005
Cannon Faculty Scholar, Department of Mechanical Science and Engineering, 2006-2009
Junior Oberwolfach Fellow Travel Award, National Science Foundation, 2006

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

Member, Board of Editors International Journal of Multiscale Computational Engineering, 2003-
Guest Editor, Special Issue of Mechanics of Materials, 2003
Member, Editorial Board of International Journal of Damage Mechanics, 2003-
Guest Editor, Special Issue of Mechanics of Materials, 2004
Chair, Applied Mechanics Division Composites Committee, American Society of Mechanical Engineers, 2004
Member, Board of Editors Journal of Mechanics of Materials and Structures, 2005-
Member, Board of Directors, Vice-President, Society of Engineering Science, 2005
Member, Board of Directors, President, Society of Engineering Science, 2006
Engineering License: Professional Engineers of Ontario, Canada, 2006-
Representative, U.S. National Committee on Theoretical and Applied Mechanics, Society of Engineering Science, 2007-2010
GM-CAM Professor, University of Illinois Department of Mechanical and Industrial Engineering and College of Engineering, 1997-2000
Outstanding Service Award, American Society of Mechanical Engineers (Manufacturing Engineering Division), 1998
Dedicated Service Award, American Society of Mechanical Engineers, 1999
James W. Bayne Professor, University of Illinois Department of Mechanical and Industrial Engineering, 2000-2005
Scientific Committee Chair, Transactions of the North American Manufacturing Research Institution, Society of Manufacturing Engineers, 1998-2000
President, North American Manufacturing Research Institution, Society of Manufacturing Engineers, 2003-2004
William T. Ennor Manufacturing Technology Award, American Society of Mechanical Engineers, 2003
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Fall 2004
Grayce Wicall Gauthier Chair in Mechanical and Industrial Engineering, University of Illinois College of Engineering, 2005-2010
Engineers Education Award, Society of Manufacturing, 2005
Distinguished Professor, Indian Institute of Technology, Kanpur, India, 2005-2008

Richard D. Keane
Best Paper Award, Institute of Physics Measurement Science and Technology, 1995

Scott D. Kelly
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Spring 2002, 2005, 2006; Spring and Fall 2004

William Paul King
Teaching Fellow, Georgia Institute of Technology Class of 1969, 2005-2006
IBM Graduate Research Fellow, 2000-2002
Faculty Early Career Development CAREER Program Award, National Science Foundation, 2003-2008
Outstanding Alumni Award, University of Dayton School of Engineering, 2004
Invited Participant, National Academy of Sciences Keck Futures Conference on Nanobiotechnology, 2004
Department of Energy Defense Program Early Career Award for Scientists and Engineers, 2005-2010
Presidential Early Career Award for Scientists and Engineers, PECASE, 2005-2010

International Branimir F. von Turkovich Outstanding Young Manufacturing Engineer Award, Society of Manufacturing Engineers, 2006
TR35–List of the Most Innovative People under the Age of 35, Technology Review, 2006
Young Investigator Award, Office of Naval Research, 2007-2010

Diego Klabjan
Fellowship for Exceptionally Talented Students, University of Ljubljana, Ljubljana, Slovenia, 1989-94
Preserener'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

Herman Krier
Fellow, American Institute of Aeronautics and Astronautics
Two-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1985
Five-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1988
Best Paper Award in Plasmadynamics and Lasers, American Institute of Aeronautics and Astronautics Conference on Plasmadynamics and Lasers, 1997
American Institute of Aeronautics and Astronautics Wyld Award, 1998
Richard W. Kritzer Distinguished Professor, University of Illinois Department of Mechanical and Industrial Engineering, 1998-2004
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 2000
Plenary Lecture, 4th International Conference on Internal Ballistics and Combustion Process in Solid Propulsion Systems and Guns, Russian Academy of Sciences, Moscow, Russia, 2002
Honorable Mention, Excellence in Guiding Undergraduate Research Award, 2006
Propellants and Combustion Award, American Institute of Aeronautics and Astronautics, 2005
Sustained Service Award, American Institute of Aeronautics and Astronautics, 2007

Dimitrios Kyritsis
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Spring 2003, 2004, 2006; Spring and Fall 2005
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 2004
Fellow, Center for Advanced Study, University of Illinois, 2007-2008

Chia-Fon Lee
GE Scholar, University of Illinois, 1997
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 1998
Ralph R. Teetor Educational Award, Society of Automotive Engineers, 2000
Fellow, University of Illinois Center for Advanced Study, 2000
Listed in the Daily Illini "Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Fall 2001
Editorial Board Member, Atomization and Sprays, 2004-2005
W. Robert Marshall Award (Best Paper), Institute for Liquid Atomization and Spray Systems, 2004

Tyler Newell
W. Robert Marshall Award (Best Paper), Institute for Liquid Atomization and Spray Systems, 2004

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

Norman R. Miller, Emeritus
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
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, 1999
Fulbright Scholarship, Universidad Nacional de Salta, Argentina, Summer 1992
Commander's Award for Distinguished Public Service, U.S. Army Construction Engineering Research Laboratory, 1992
Invited Lectureship, Ain Shams University/Egyptian Government, 1993
Everitt Award for Excellence in Undergraduate Teaching, University of Illinois College of Engineering, 1995
Five-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1995, 2001, 2002, 2003, 2004
College of Engineering Award for Teaching Excellence, University of Illinois, 1997
Campus Award for Excellence in Undergraduate Teaching, University of Illinois, 2000
Alumni Association Educator’s Award, University of Illinois Alumni Association, 2000
BP Amoco Award for Innovation in Undergraduate Instruction, University of Illinois College of Engineering, 2003
Rose Award for Teaching Excellence, University of Illinois College of Engineering, 2005
Senior Design Team First Place, Parker Hannifin "Chainless Challenge" Hydraulic Bike Competition (co-advisor with Prof. H. T. Johnson), 2005
Honorary Knight of St. Patrick, University of Illinois College of Engineering, 2006

Martin Ostoja-Starzewski
Postgraduate Fellowship, Natural Sciences and Engineering Research Council of Canada (Ottawa), 1980-1982
Research Initiation Award, National Science Foundation, 1987-1989
Guest Editor, Special Issue of Applied Mechanics Reviews, 1995
Guest Editor, Two Special Issues of Engineering Fracture Mechanics, 1997
Guest Editor, Special Issue of Engineering Fracture Mechanics, 1997
Guest Editor, Special Issue of International Journal of Solids and Structures, 1998
Guest Editor, Special Issue of Mechanics of Materials, 1999

Keynote Speaker, Minisymposium Heterogeneous Materials and Homogenization, ECCM-2001: Second European Conference on Computational Mechanics, Cracow, Poland, 2001
Canada Research Chair in Mechanics of Materials (Tier I), 2001-2005
Fellow, American Society of Mechanical Engineers, 2001
Fellow, World Innovation Foundation, 2001
Member, Editorial Board, Journal of Thermal Stresses, 2003-
Member, Editorial Board, Probabilistic Engineering Mechanics, 2003-
Member, International Society for the Interaction of Mechanics and Mathematics (ISIMM), 2004
Keynote Speaker, International Conference on Heterogeneous Material Mechanics, Peoples’ Republic of China, 2004
Guest Editor, Special Issue of International Journal of Solids and Structures, 2005
Associate Fellow, American Institute of Aeronautics and Astronautics, 2005
Keynote Speaker, Symposium "Homogenization and Effective Characteristics," Eighth U.S. National Congress on Computational Mechanics, Austin, Texas, 2005
Member, Editorial Board, Actual Problems of Aviation and Aerospace Systems, 2006-
Associate Editor, Journal of Applied Mechanics, Transactions of the American Society of Mechanical Engineers, 2006-
Member, Editorial Board, Modern Mechanics and Mathematics Series (Chapman and Hall/CRC/Taylor and Francis), 2006-
Keynote Speaker, Symposium "Multi-Scale Mechanical Modelling of Materials and Engineering Applications," THERMEC 2006, Vancouver, Canada, 2006
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Fall 2006
Keynote Speaker, Seventh International Congress on Thermal Stresses, Taipei, Taiwan, 2007

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

James W. Phillips
Listed in American Men and Women of Science, 1972
Listed in Who's Who in the Midwest, 1974
Listed in Who's Who in Engineering, 1976
Listed in International Who's Who in Engineering, 1980
Listed in Who's Who in Frontier Science and Technology, 1982
Experimental Techniques Award, Society for Experimental Mechanics, 1987
Certificate of Merit, Plastic Surgery Educational Foundation, 1998
Special Citation, International Union of Theoretical and Applied Mechanics, 2000
Robert E. Miller Award for Excellence in Teaching, 2005

Michael L. Philpott
Senior Fulbright Scholarship, 1988
Initiation Award, National Science Foundation, 1991
CIM LEAD Award, 1993-1994
Five-Year Effective Teacher Award, Department of Mechanical and Industrial Engineering Alumni Board, University of Illinois, 1996

Andreas A. Polycarpou
Fellowship, Israel Council for Higher Education on Tribology, Haifa, Israel, 1995, 1996
Reviewer of the Year Award, Journal of Tribology, 1997
Burt L. Newkirk Award, American Society of Mechanical Engineers, 2001
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Fall 2001, Spring 2005
Who's Who in Engineering Education, 2002
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 2003
Kritzer Faculty Scholar, Department of Mechanical Science Engineering, 2003-2006; 2006-2009
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2005, 2007
Edmond E. Bisson Award, Society of Tribologists and Lubrication Engineers (STLE), 2007
Fulbright Scholar, The J. William Fulbright Foreign Scholarship Board, Cyprus, 2007

M. Taher A. Saif
Honors in B.S. with rank (1/209; one of only two students to receive annual honors), Bangladesh University of Engineering and Technology, 1984
Invited Member, Honor Society of Phi Kappa Phi, Cornell University Chapter, 1992
Executive Board Member, International Students Programming Board, Cornell University, 1990-1991
Ralph Bolgiano, Sr., Outstanding Teaching Assistant Award, Sibley School of Mechanical and Aerospace Engineering, Cornell University, 1991
Teaching Assistant Fellow, College of Engineering, Cornell University, 1991-1992
Faculty Early Career Development (CAREER) Program Award, National Science Foundation, 1998
GE Scholar, University of Illinois, 1998
Strathmore’s Who’s Who, 2002-2005
Who’s Who in Engineering Education, 2002
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2003, 2006
"Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Spring 2003, 2004; Fall 2006
Willett Faculty Scholar Award, College of Engineering, 2003-2008
Associate, Center for Advanced Study, University of Illinois, 2004-2005
Effective Teaching Award (by alumni graduated during 2004), 2006

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

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

Best Presentation Award, American Society of Testing Materials, 2003
Fellow, American Society of Mechanical Engineers, 2003
C. J. Gauthier Professor, University of Illinois Department of Mechanical and Industrial Engineering, 2004-2009
Interim Head, Department of Mechanical and Industrial Engineering, University of Illinois, 2004-2005
Nadai Medal for Outstanding Contributions to a Greater Understanding of Mechanical Behavior of Metals through the Integration of Mechanics and Materials Science, 2007

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

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

**Petros Sofronis**
National Science Foundation Research Initiation Award, 1991
Ford Motor Company Fund in Support of Research Funded by National Science Foundation, 1992
Fellow, Japan Society for the Promotion of Science, Kyushu University, Fukuoka, Japan, Jun. 2006

**D. Scott Stewart**
Fellow, American Physical Society, Division of Fluid Dynamics, 1998
Outstanding Advisor Award, University of Illinois College of Engineering, 1999, 2006
Fellow, Institute of Physics, 1999
Associate Fellow, American Institute of Aeronautics and Astronautics, 2004
Phi Kappa Phi, University of Illinois, 2004
Engineering Council Award in Excellence in Advising, 2006
Senior Research Award, National Academy Fellow, 2007

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

**Brian G. Thomas**
Presidential Young Investigator Award, National Science Foundation, 1989
Included in Marquis *Who's Who in America*, 1990
Outstanding Young Manufacturing Engineer Award, Society of Manufacturing Engineers, 1990
Xerox Award for Faculty Research, University of Illinois College of Engineering, 1991
Roslter W. Raymond Memorial Award for 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
Engineering Council 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
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, Iron and Steel Society, 1999
Best Paper Award, Metallurgical Society of the Canadian Institute of Mining and Metallurgy, 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

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

**Brian G. Thomas**
Presidential Young Investigator Award, National Science Foundation, 1989
Included in Marquis *Who's Who in America*, 1990
Outstanding Young Manufacturing Engineer Award, Society of Manufacturing Engineers, 1990
Xerox Award for Faculty Research, University of Illinois College of Engineering, 1991
Roslter W. Raymond Memorial Award for 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
Engineering Council 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
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, Iron and Steel Society, 1999
Best Paper Award, Metallurgical Society of the Canadian Institute of Mining and Metallurgy, 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

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

**Brian G. Thomas**
Presidential Young Investigator Award, National Science Foundation, 1989
Included in Marquis *Who's Who in America*, 1990
Outstanding Young Manufacturing Engineer Award, Society of Manufacturing Engineers, 1990
Xerox Award for Faculty Research, University of Illinois College of Engineering, 1991
Roslter W. Raymond Memorial Award for 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
Engineering Council 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
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, Iron and Steel Society, 1999
Best Paper Award, Metallurgical Society of the Canadian Institute of Mining and Metallurgy, 1999, 2000
Dr. J. Keith Brimacombe Lecturer, Electric Furnace Conference, Iron and Steel Society, 2001
W. Grafton and Lillian B. Wilkins Professor of Mechanical and Industrial Engineering, University of Illinois, 2003-2008
Robert W. Hunt Silver Medal (Best Paper, jointly with Q. Yuan and P. Vanka), Association for Iron and Steel Technology, 2004
Adjunct Professor, Graduate Institute of Ferrous Technology, Pohang University of Science and Technology, Pohang, South Korea, 2005
Baosteel Honorary Professor, Shanghai, Peoples' Republic of China, 2006-2010

**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
Young Investigator Award, National Science Foundation, 1993
Associate Editor, *Mechanics of Structures and Machines*, 1997-
Editorial Board Member, *Structural Optimization*, 1999-
Treasurer, Executive Committee, International Society of Structural and Multidisciplinary Optimization, 2000-
Schaller Faculty Scholar, University of Illinois Department of Mechanical and Industrial Engineering, 2003-2006
Associate Editor, *Journal of Mechanism and Machine Theory*, 2005

**Charles L. Tucker**

Fellow, American Society of Mechanical Engineers, 1996
Ralph R. Tector Educational Award, Society of Automotive Engineers, 1980
Everitt Award for Excellence in Undergraduate Teaching, University of Illinois College of Engineering, 1981

**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
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

Amy Wagoner-Johnson
Scholarship, Society of Women Engineers/Central Intelligence Agency, 1993-1994
Fontana Scholarship, The Ohio State University Department of Materials Science and Engineering, 1993-1994
Scholar, American Society for Materials (ASM), 1995

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

Ning Wang
Alumni Scholarship, Harvard School of Public Health, 1988-1989
Scholander Award, American Physiological Society, 1991
Caroline tum Suden Professional Opportunity Award, American Physiological Society, 1991

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