Research Profiles

MECHANICAL ENGINEERING
AT MICHIGAN STATE UNIVERSITY

Introduction From The Chair

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I am proud to present this sample of the extraordinary work that goes on every day in our department. Our profile now covers almost every area of modern research in mechanical engineering. As you look through these pages, you will find that our faculty and our students are engaged in state of the art research with an eye toward the future, a global perspective, and an awareness of the importance that our work can have on society.

Research in our department over the last five years has been characterized by a period of rapid growth and the formation of an extensive network of interdisciplinary collaborations. Expertise clusters in our department can be identified around several centers of excellence, most notably in energy and automotive research and in experimental mechanics and composite materials. In addition to research laboratories in the Engineering Building on MSU's central campus, we have extensive facilities dedicated to the Energy & Automotive Research Laboratories and the Composite Vehicle Research Center.

We are preparing our graduates to participate in a global society and to be ready to compete in a world that is changed constantly by new technologies. Graduate studies and research opportunities are available in all modern areas of fundamental and applied research in mechanical engineering: fluid mechanics, combustion, heat transfer, thermodynamics, biomedical engineering, internal combustion engines, turbomachinery, computational fluid dynamics, system dynamics, controls, vibrations, mechatronics, manufacturing, computational design, computational solid mechanics, mechanics and processing of composite materials, experimental mechanics, micromechanics and more.

We are looking towards the future, preparing for new challenges and opportunities made possible by a constantly changing technological environment. Our department is growing with this in mind. Faculty is solving new and exciting research problems, in alternative energy, biofuels, biomedicine, computational materials science, advanced manufacturing, MEMS, robotics, sensors and more. In these pages we can only give you a glimpse at the contributions we are making in these fields. Hopefully this will encourage you to want to learn more about our work. We are excited about our work and look forward to sharing it with you.

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Nanomaterials Synthesis & Processing

Aerosol-only methods for controlling the properties of nanocrystals

Rebecca Anthony's research has focused on using plasmas as tools for materials synthesis and processing. Low-pressure plasmas are elegant tools for making nanomaterials in the gas phase, starting with vapor or gaseous precursors and resulting in nanocrystals with tunable physical properties. These nanocrystals are then incorporated into light-emitting devices, solar photovoltaics, and other applications.

Even though the plasma is basically a room-temperature processing tool, gas-phase reactions at nanoparticle surfaces lead to heating of the materials. This heating allows formation of high-quality crystals even from materials with high crystallization temperatures, such as silicon. One of Dr. Anthony's current projects examines how to use additional plasmas and other gas-phase schemes to modify nanocrystal surfaces with additional atoms or molecules for diverse functionalities, such as enabling water-dispersability and enhancing electronic transport between nanocrystals. Other projects include synthesis of compound materials using plasmas, and exploring the abilities of the plasma for controlling crystal structure and nanocrystal morphology. Throughout, these experiments involve quantitative measurements of plasma properties such as optical emission and plasma species densities, so that these plasma characteristics are linked to the resulting materials properties.

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Multi-Disciplinary Design Optimization

Discovering better designs through mathematical modeling and exploration

In many industries, numerical design optimization has become a key enabler to a more rational and more efficient design process. Rather than manually iterating on design parameters in the hope of finding a design that meets a given set of requirements, an automated numerical optimization approach can yield much better designs in much less time. In the face of ever-increasing pressure to improve performance, mass, quality, and cost, numerical optimization can help manage design complexity to provide greater understanding of design trade-offs and guide the decision making process.

Ron Averill conducts research on the development and application of novel mathematical algorithms for searching complex design spaces. Combining the best attributes of evolutionary methods and local search techniques has led to the discovery of new hybrid search strategies that have significant advantages over classical optimization methods. Algorithms developed by Dr. Averill and his colleagues are now used worldwide within commercial design optimization software packages.

Dr. Averill also develops multi-level optimization methods for solving very large and complex design problems. Often there is not enough time or computing resources to solve these problems directly, so they remain unsolved. But the use of new convergent multi-level optimization techniques allows many of these problems to be solved between 10 to 1,000 times faster than direct approaches. Applications in several different fields have demonstrated the significant potential of these new methods to yield optimized designs that might not be found using direct search techniques.

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Cardiovascular and Tissue Mechanics

Towards patient-specific modeling of abdominal aortic aneurysms

Abdominal aortic aneurysms are the focal enlargement of the aorta in the abdomen and are the 3rd leading cause of sudden death among men older than 65 years in US. More in-depth understanding of the pathophysiology of the disease and patient-specific risk assessment are critically important in reducing aneurism-related mortality.

Research in Seungik Baek's Cardiovascular and Tissue Mechanics Laboratory involves the development of theoretical and computational tools to characterize material behavior of biological soft tissues and synthetic biomaterials and on the computational modeling of growth and remodeling of vascular tissues.

Dr. Baek's research integrates medical imaging data from patients with computational methods to help doctors with the clinical management and surgical treatment of vascular diseases. The computational model of vascular growth and remodeling is implemented on a geometry constructed from medical images and patient specific data.

The new computational framework is being used to account for coupling

> ‘ development of theoretical and computational tools to characterize material behavior of biological soft tissues

between hemodynamic loads on the vessel wall and long-term evolution of the aneurysmal wall during the progression.

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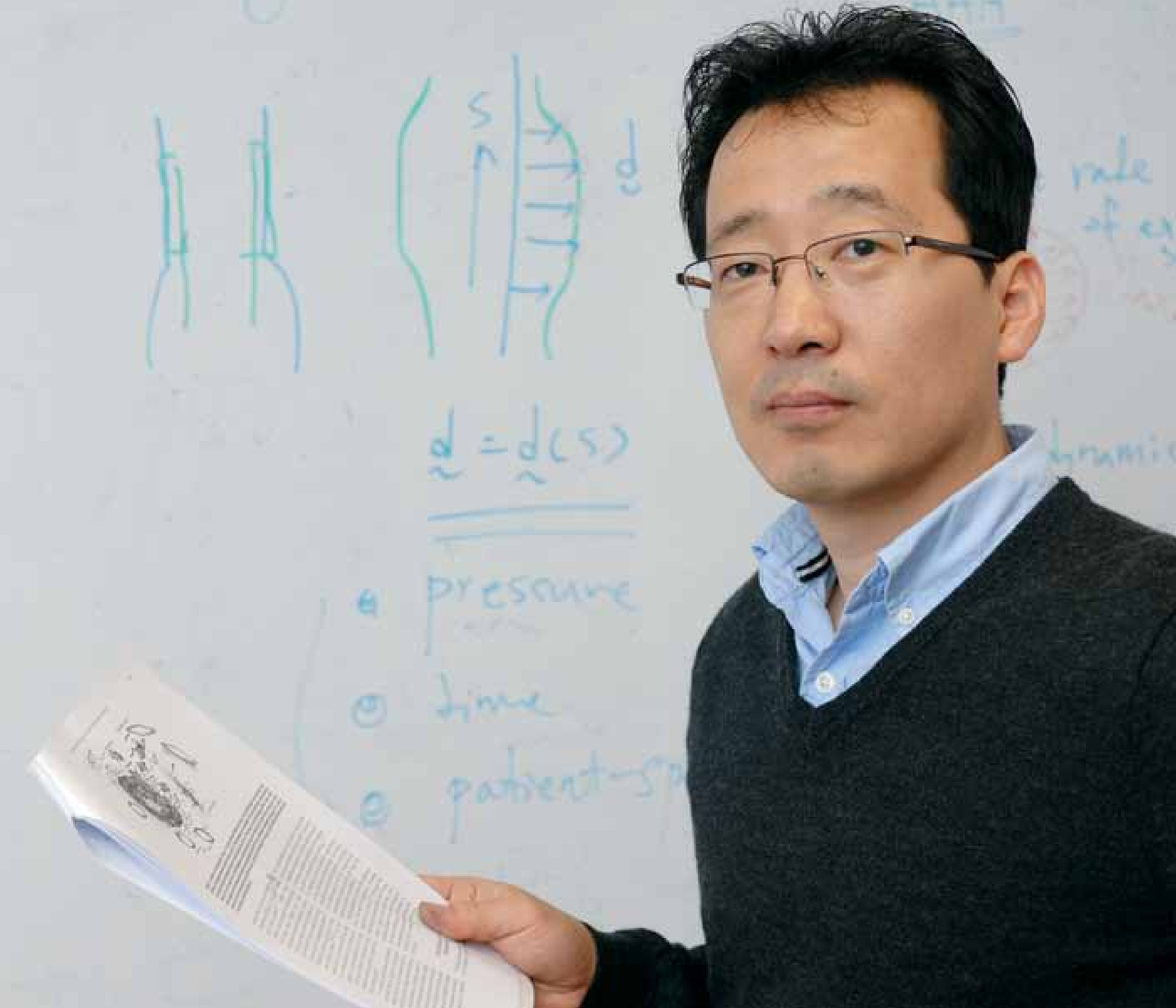

Multiphase Flows and Energy

Studying multiphase systems for a sustainable energy future

Multiphase flows are commonly found in a variety of natural and industrial systems. Catastrophic events such as the Deepwater Horizon oil spill exemplify the importance of understanding such flows. Multiphase problems are diverse and involve, for example, the cleanup of contaminated water, electrochemical systems, or the orientation of nanoparticles by fluid flows.

Andre Benard's research involves multiphase problems related to energy production and manufacturing. A recent research area related to multiphase flows involves the cleanup of water contaminated with oil using filters and membranes. The development of systems for treating water extracted with the production of oil and gas presents challenging environmental problems. New devices and filtration systems are being designed for the cleanup of these waters. Numerical methods and optimization and the development of new turbulence models are often part of Dr. Benard's work.

Fluids incorporating suspensions of macromolecules, nanoparticles, and fibers are also studied by Dr. Benard. Such multiphase fluids are found in products with unique chemical, electrical, and mechanical properties and include structural composites, electronic displays, protective and barrier coatings, circuit materials, and optical devices. Research efforts by Dr. Benard are spent in modeling the microstructure evolution of such materials to understand their properties. In addition, recent efforts toward modeling electrochemical devices such as fuel cells and batteries, which have multiple components and phases, target the identification of the microstructure that will maximize the performance of such systems.

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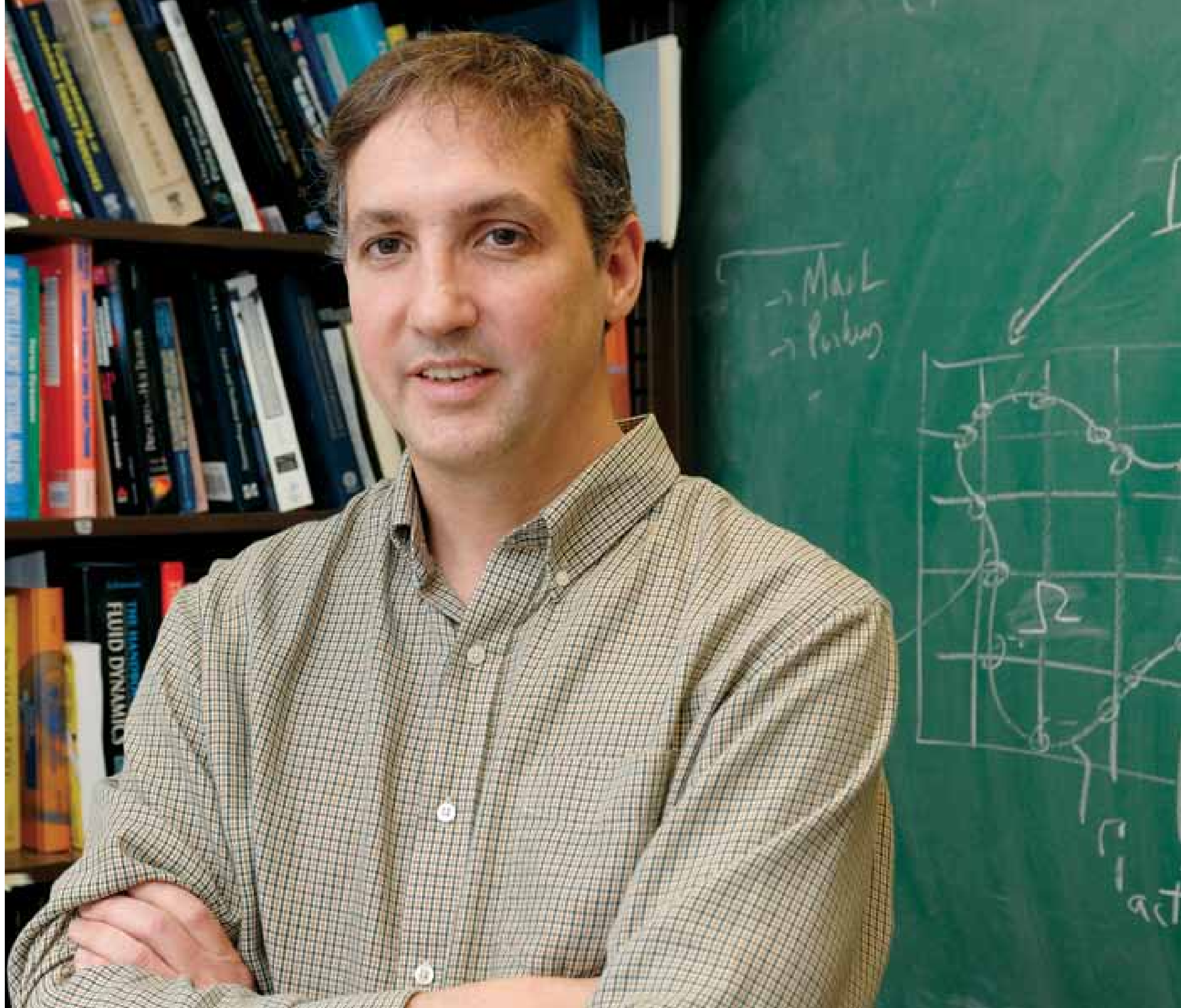

Biofuel Sprays

Measuring and modeling the behavior of biofuel droplets

As energy demands of the US grow, we continue to seek secure, reliable sources of energy-dense fuels for transportation and power generation. Biofuels are one class of potential contributors to our future energy supply, both as pure fuels and as additives to fuels derived from other sources. These fuels are typically injected or sprayed into the combustion chambers of engines where they mix and evaporate in air at high temperatures and pressures before undergoing combustion. The efficiency of the combustion process and its propensity to produce pollutants depend on the uniformity of the air-fuel mixture to be burned which, in turn, depend on the evaporation and mixing of fuel droplets in fuel sprays.

Giles Brereton conducts experiments on biofuel sprays in which he processes laser-light signals scattered from many droplets within the spray to deduce the sizes of the droplets and their statistical distribution. In companion studies, Dr. Brereton is developing mathematical models of individual fuel droplets and their evaporation characteristics. With input from experiments of this kind, the authenticity of models of the behavior of biofuel droplets and sprays can be verified. This approach can then be used to describe the behavior of droplets of existing, new, or hypothetical biofuel blends of arbitrary composition. These models can be used to design fuels with prescribed droplet behavior and to describe fuel-droplet behavior in large-scale computer simulations of combustion, which are used to predict pollutant formation and combustion efficiency, and to optimize biofuel combustion-chamber designs.

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Ulcers and Blood Flow

Using mechanics to understand clinically motivated problems

The human body undergoes extreme loading on a daily basis - whether it is from running, jumping rope, or a mundane activity such as shoveling snow off the sidewalk. Most of the time, injury does not result from these activities. However, as a person ages, or if a person's health is compromised through disease, the body cannot respond as efficiently to these daily challenges. One common injury to individuals with reduced mobility - such as the elderly, or those with spinal cord injuries - is a wound that extends from the surface of the skin down to the muscle and sometimes the bone. These wounds are termed pressure ulcers, or pressure sores. Over three million Americans have pressure ulcers, suggesting that current prevention practices are insufficient.

Tamara Reid Bush studies the mechanics of phenomena that occur at the interface with the skin. Forces on the skin, both normal and parallel to the skin's surface, play a strong role in the formation of pressure ulcers. As the loading on the skin is increased, the result is reduced regional blood flow and decreased oxygen and nutrition to the area, leading to death of tissues and ulcer formation.

Dr. Bush studies how various loadings impact blood flow and perfusion to the skin level as well as deep vessel flow. Her work couples experimental aspects with imaging and mechanics modeling. By studying this inter-disciplinary problem from a mechanics viewpoint, Dr. Bush develops tools that allow clinicians to identify events prior to the onset of an ulcer, making prevention techniques more robust and reducing the number of individuals affected by ulcers.

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Environmental Adaptive Sampling

Spatial prediction and coordination algorithms for robotic sensors

Due to recent global climate changes, it is necessary to monitor the changing ecosystems over vast regions on land, in our oceans, and in our lakes. Monitoring and finding peaks in uncertain environmental fields are important issues due to numerous applications of tracking toxins in uncertain environments. Emerging technologies in robotic sensor networks and field prediction algorithms can offer great potential to deal with such issues.

Jongeun Choi's research group is developing a new systematic framework for the synthesis and analysis of distributed learning and cooperative control algorithms for multi-agent systems with applications in environmental sciences. Practical algorithms are being developed and analyzed so that a resource-constrained, multi-agent system can collect spatial measurements of a scalar field in order to self-calibrate the environmental model; recursively learn the unknown field based on the calibrated model; and perform tasks such as the exploration, estimation, prediction, and maximum seeking of the scalar field in a robustly intelligent manner.

Theoretically sound, implementable control laws are being developed and analyzed using concepts such as stochastic approximation theory and kernel regression. The conventional inverse-problem approach based on physical transport models is too computationally costly for resource-constrained, multi-agent systems. In contrast, emphasizing practicality and usefulness, Dr. Choi's research relies extensively on phenomenological and statistical modeling techniques such as Gaussian processes and kernel regression to represent fields undergoing transport phenomena.

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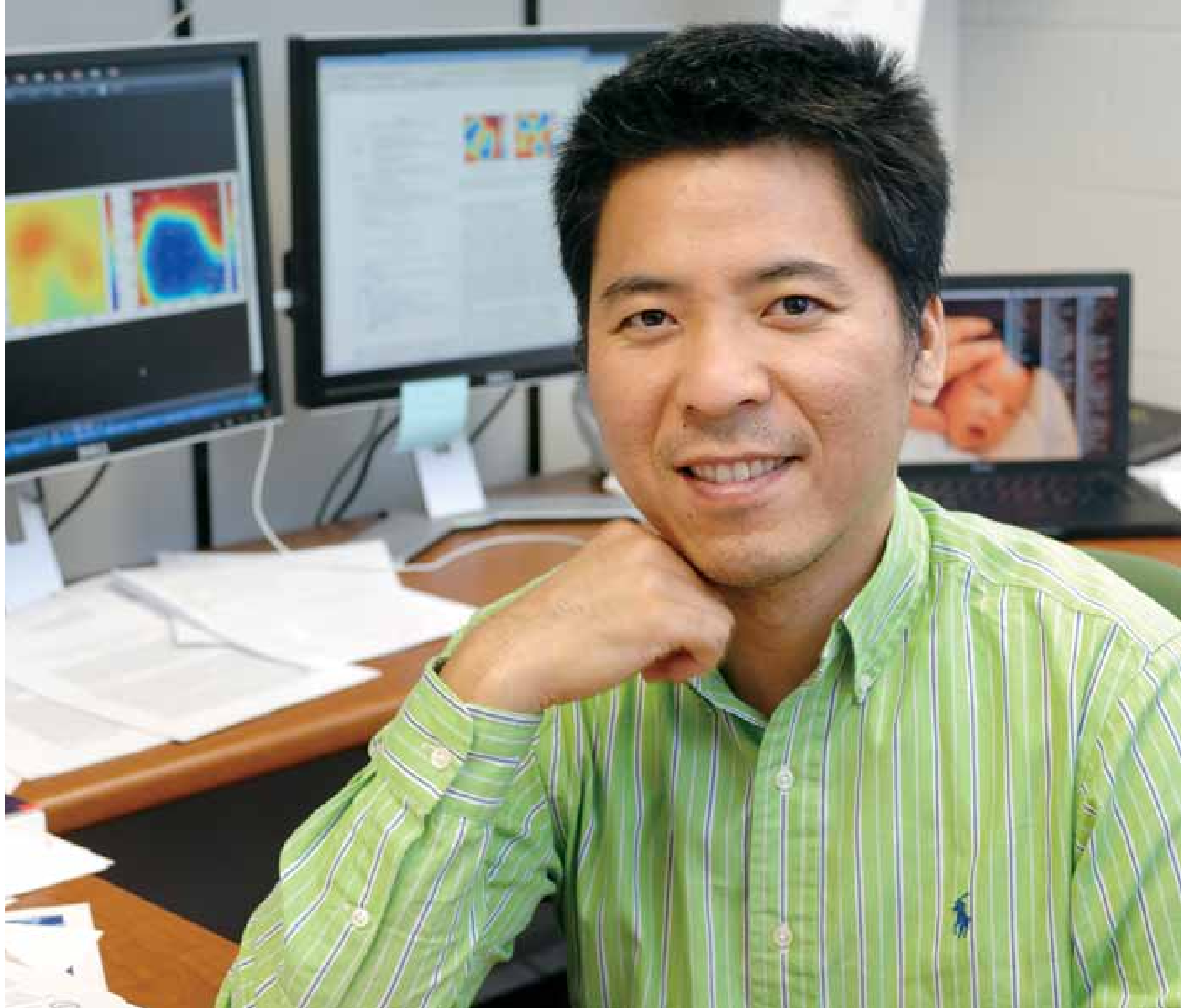

Experimental Mechanics

Applied mechanics is the science that studies the responses of objects to loads. It is the foundation of engineering design. This field of science is divided into two broad disciplines, analytic mechanics and experimental mechanics, which usually are undertaken simultaneously to develop validated solutions to design problems. Experimental mechanics, as the name implies, measures the response (e.g., motion, displacement, strain, fracture, and fatigue of bodies or structures such as bridges, human bodies, autos, airplanes) to expected and unexpected service loads (e.g., gravity, impact, vehicles, hard landings, and thermal gradients).

Gary Cloud's research concentrates on three distinct but related areas:
1) Development and improvement of methods, particularly digital laser speckle methods, for measurement of displacement, strain, motion, and crack length on the surface and in the interior of 3-dimensional objects. 2) Investigations of the mechanics of mechanical fastening of thick composite sections for static and dynamic loading of heavy-duty vehicles. Experiments using optical techniques and fiber-optic gages yield data to validate and update finite element models. Parameters investigated include fastener size, arrays, clearance, interference, preload, washers, hole shape, and bushings. 3) Development of improved techniques for nondestructive inspection including the use of digital optical techniques and a console approach wherein nondestructive inspection methods are combined into a systematic hierarchy to facilitate decision-making at low cost. Structural health monitoring for vehicles is another thrust of this research

Techniques at hand for experimental mechanics investigations include geometric moire, moire interferometry, photoelasticity, digital speckle pattern interferometry, holographic interferometry, moire interferometry, digital shearography, resistance and fiber-optic strain gages, laser Doppler velocimetry, and accelerometers.

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Optimization of Engineered Materials

Looking for extraordinary performance across multiple scales

Advances in materials science and manufacturing have given engineers considerable control over material properties. When combined with enhanced capabilities in computer simulations, these advances have resulted in opportunities for exploration and optimization of completely new design concepts. The decisions required to optimize a design involve many variables, often defined across multiple scales and multiple physics, complicated analysis, and complex simulations. It is no longer possible to synthesize competitive designs based solely on intuition or on modifications of existing concepts. The design space associated with complex engineering systems is complicated and its exploration requires a framework for search and optimization that is fully integrated with analysis and simulations.

Alejandro Diaz works on topology optimization problems in engineering design optimization. In the topology optimization approach to material design, a material with desirable, often extraordinary properties is synthesized by carefully designing the micro-geometry of mixtures of two or more constituents. Adding a topology optimization framework to the material design process often leads to radically new designs, capable of meeting functional specifications not met by any available design, such as metamaterials with negative permeability in electromagnetics, or materials with negative Poisson's ratio in elasticity. Dr. Diaz has applied topology optimization in many engineering fields, including structural design, heat conduction, vibrations, phononics, and electromagnetics. His most recent work has been applied to design of fuel cell design, miniaturization of antennas and sensors, control of large, flexible structures, and synthesis of engineered materials for vibration suppression.

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Radial Turbomachinery

Flow analysis and design

Turbomachinery in mechanical engineering describes machines that transfer energy between a rotor and a fluid. Many turbomachines are categorized according to the type of flow they encounter. When the flow is perpendicular to the axis of rotation, they are referred to as radial (or centrifugal) flow machines.

Radial turbomachinery is vital to many industries. Abraham Engeda's research emphasis is on the experimental and theoretical flow analysis and design of all types of turbomachinery, in particular, radial turbomachinery. His work includes testing gas turbine model combustors and the properties of biogas and other alternative fuels for power generation.

Dr. Engeda also develops design procedures for volutes and impellers used in turbomachinery. His techniques allow both easy geometry generation using Bezier curves and surfaces and theoretical model building for selected impeller/ diffuser/ volute/ conic geometry with associated topology. The design process is conducted with minimum intervention of a CAD technician, while providing an efficient interface to standard CAD environments. This iterative design process is flexible enough to generate and assemble impeller and volute models for computational simulation and to include numerical post processing evaluation in a fraction of the time of current industrial practice.

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Understanding and Using Vibration

Vibration analysis in the man-made and natural world

The majority of current vibration research can be classified as the enhancement of good vibrations or the reduction of bad vibrations. Good vibrations are desired in musical instruments, sensors, and energy harvesters. Unwanted vibrations include those that lead to vehicle noise and harshness, structural fatigue and damage, and harmful human-machine interfaces.

Brian Feeny studies linear and nonlinear vibration systems to achieve improved performance of machines and structures. His projects involve reducing vibrations, harnessing vibrations and waves, and quantifying vibration properties.

Vibration reduction occurs on several fronts, beginning with centrifugal pendulum vibration absorbers for automotive applications that enable strategies for improved efficiency of engines. Dr. Feeny's research also involves the role of vibrations in wind turbine failures. As wind turbines continue to increase in size, failures in bearings, gears, blades, and towers become more prevalent. Wind turbines undergo a variety of cyclic and vibration inducing loads, prompting the study of vibrations in potential failures.

Dr. Feeny's research on vibration modal analysis is being developed for broad classes of oscillations and waves, and applied to structural components such as beams, shafts and cables, as well as mobile entities such as crawling nematode worms, swimming fish, and human walking. He is seeking ways to use nonlinearity to manage vibrations and waves for applications in energy transfer, event detection, and vibration isolation.

Dr. Feeny also works with industry to understand strategies for reduced vibration at the interface between humans and machines, tools, and sporting equipment.

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Turbulent Shear Flows

Fluid mechanics takes center stage in energy research

Turbulent shear flows are ubiquitous in nature and in technological devices; they have gained proportionate attention from experimentalists, computationalists and theoreticians. They are inhomogeneneous flows with mean gradients that develop in the absence of boundaries, usually occurring in natural or engineering environments. Studies of turbulent shear flows can range from the wakes that occur behind moving bodies to the exhausts from jet engines. Concerns with energy consumption make the study of turbulent flows critical because most combustion processes involve turbulent shear flows.

> "Concerns with energy consumption make the study of turbulent flows critical.

John Foss has a long history of experimentally investigating these turbulent shear flows. A common theme of his research is the execution of "analytical experimentation," whereby the fundamental mechanics of a given flow field can be identified and possibly manipulated. One important area of research involves the Rotating Controlled-Diffusion Airfoil, which serves as an archetypical fan blade shape. In this work, basic studies of axial fan flows using advanced flow diagnostic techniques are combined with a wide range of investigations, from basic to applied research and development.

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Biomechanics of Sports Injuries

Lower extremity injuries - strategies for prevention of chronic disease

Musculoskeletal injuries and joint disorders due to sports, recreation and exercise (SRE) have reached epidemic proportions as our society attempts to develop a healthy lifestyle. It is generally accepted that participation in SRE carries a significant risk of musculoskeletal injury. These injuries often increase the risk of long term, chronic diseases, such as post-traumatic osteoarthritis. This painful and debilitating disease currently affects approximately 14% of men and 23% of women aged 45 years and older. Recent studies have shown that the risk factor for developing a chronic disease in a joint increases 3-fold with soft tissue (ligamentous) injury in the knee or ankle.

Roger Haut's Orthopaedic Biomechanics Laboratories conduct primarily research on lower extremity injuries to the ankle and knee. These studies may involve human subjects or isolated joint tissues, animal subjects, and computational models. In his laboratories, located in the College of Osteopathic Medicine, he uses biochemical, histological and biomechanical tools to study injury mechanisms and intervention strategies. In association with his colleagues in the Department of Radiology, Division of Sports Medicine at MSU, Dr. Haut's research involves the use of high resolution magnetic resonance and computed tomography imaging techniques. Dr. Haut studies mechanisms of musculoskeletal injuries resulting from SRE, where he investigates potential intervention strategies to help limit or mitigate injury severity and the potential for developing chronic disease, such as post-traumatic osteoarthritis, in the afflicted joint.

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Advanced CFD Modeling

Large-scale simulations of high speed turbulent combustion

Computational fluid dynamic (CFD) models are playing an increasingly important role in the development of advanced engineering systems involving fluid flow, heat transfer, and chemical reaction. They are particularly useful for the design of high-speed air vehicles and their propulsion systems. However, despite significant progress that has been made in compressible flow and combustion modeling, CFD models are still unreliable when applied to turbulent combustion, especially at very high speeds.

Farhad Jaberi is developing a new class of high fidelity models based on the large eddy simulation concept that can capture the complex interactions between the flow turbulence, shock waves, and combustion and can be used for computations of supersonic turbulent combustion. These computations are conducted on high-performance parallel computers at MSU for conditions where a laboratory experiment is not possible or is very difficult to conduct. In support of the modeling efforts, detailed, large-scale data are being generated for several fundamental high speed flows by model-free or direct numerical simulation of the basic fluid flow and chemical reaction equations. The numerical data are being used for better understanding of the flow physics and for a systematic assessment and improvement of turbulance and combustion models.

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Experimental Fluid Dynamics

Turbulent mixing and unsteady aerodynamics

Manoochehr Koochesfahani concentrates on fundamental experimental studies of several classes of fluid flows. They include turbulent mixing, unsteady fluid mechanics and aerodynamics, vortex flows and, more recently, micro- and nano-flows. Dr. Koochesfahani is also well known for developing advanced optical techniques for imaging fluid flows and mixing fields. One of the early developments is the digital laser induced fluorescence (LIF) method for the quantitative imaging of scalar mixing field and molecular mixing in liquids. A hallmark of his group's efforts at MSU is the development of molecule-based methods for imaging the velocity and temperature fields in a flow. Among them are the techniques of molecular tagging velocimetry (MTV) and molecular tagging thermometry (MTT). More recently, his lab has introduced the method of quantum dot (QD) imaging for mapping flows with nanometer resolution.

> ‘ A hallmark of his group's efforts at MSU is the development of molecule-based methods for imaging the velocity and temperature fields in a flow.

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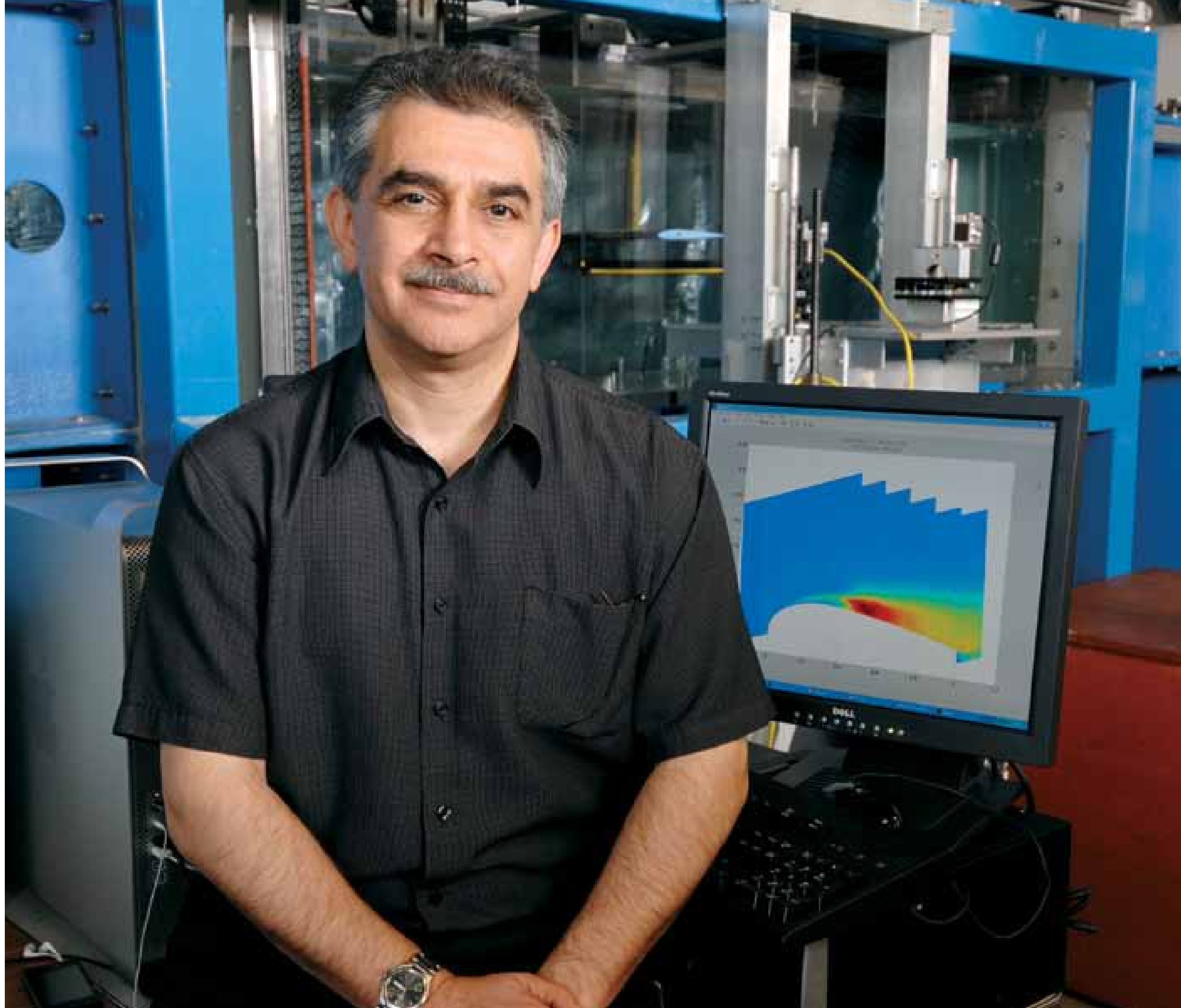

Cutting Tools and Perspirable Skin

Multifunctional materials for extremely high temperature applications

Cutting tools are the essential, consumable components of many manufacturing processes. They are typically made of tungsten carbide in a cobalt matrix with or without layer(s) of coatings such as TiAlN and Al2O3, more expensive cubic boron nitride, or even more expensive polycrystalline diamond. The multifuntionality of cutting tools comes from the fact that they must withstand extremely intense thermomechanical loadings in addition to the extreme tribological condition, all of which depend on the material and process conditions. Recently, generalized dissolution wear has been proposed where tool material dissociates, dissolves, and eventually diffuses into a work material. This theory explains the wear observed in practice. To prove this theory, Patrick Kwon is now conducting machining experiments with various work materials and measuring the progress of wear through confocal microscope.

Perspirable skin is a new concept for autonomous self-cooling multi-functional material for re-entry or supersonic vehicles. The basic configuration of the perspirable skin is a peg-and-hole arrangement of two materials with distinct coefficients of thermal expansion (CTEs), whose interference fit is designed to open at high temperature. This allows compressed air to be expelled through the interference to eliminate the frictional heating. The design and fabrication of perspirable skin are being considered with materials having negative CTEs and a designed gradiency. A completely different approach is also being explored using thermal buckling. A set of high-temperature ceramic tiles is being designed to buckle under intense thermal loading, and extensive research is underway to gain an understanding of the compaction and sintering behaviors of these ceramic powers.

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Microfluidic Systems

Microfluidic platforms for biodetection and point-of-care diagnosis

The detection of biological species, toxins, and chemical compounds is essential for a broad range of real world applications including clinical diagnosis, food/water safety, environmental monitoring, and homeland security. Current laboratory-based detection technologies generally require specialized facilities and equipment, highly trained personnel, and processes that are time consuming and laborious, which hinders their applicability. New technologies are needed that are compact, inexpensive, and simple to use for improved usability and accessibility, especially in resource limited settings and the developing world.

Peter Lillehoj's laboratory is developing state-of-the-art, point-of-care biomedical devices for current and emerging applications in clinical diagnosis, biodetection, and bioprocessing. These platforms combine cutting edge principles of micro- and nanotechnology with contemporary techniques of molecular and cell biology. Microfluidics enables the manipulation, processing, and analysis of particles and liquids in small dimensions (nano - to micrometers) and volumes (micro - to picoliters). When combined with MEMS-based biosensors, these systems are capable of rapid analysis, enhanced detection sensitivity and minimal reagent consumption.
Dr. Lillehoj is also investigating the use of mobile communication devices (i.e. cell phones, tablets) for biodetection, which is a new and extremely promising direction of research. These systems use microfluidic chips that integrate sample processing components and sensors onto single-use, disposable platforms. This technology is currently being developed for the detection of malaria, one of the deadliest infectious diseases in the world, and aims to improve the convenience and accessibility of diagnostic testing worldwide.

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Computational Cardiovascular Modeling

Applying mechanical principles to understand heart diseases

Approximately 6 million people in the United States have been diagnosed with congestive heart failure and 550,000 new cases occur annually. In order to make critical advancement in treating heart failure, a detailed understanding on the mechanisms of cardiovascular diseases is necessary. After recent advancements in computing power and medical imaging techniques, it has become possible to do this in silico.

Lik Chuan Lee's research focuses on developing theoretical and patient-specific computational models to understand cardiovascular diseases. Although the heart is a complex biological system, its primary function is still the same as a mechanical pump and obeys the fundamental principles of mechanics. Nevertheless, a multi-physics and multi-disciplinary approach is essential to construct realistic and predictive heart models. To this end, Dr. Lee is working on developing computational heart models that couple cardiac electrophysiology and cardiac mechanics, the two main branches of physics describing the heart. In parallel, he is also working on using growth and remodeling theories to develop models that predict the chronic progression of cardiovascular diseases and its treatments. When integrated with geometrical, structural, deformation, and hemodynamics data derived from medical images and experiments, these computer models allow one to gain a better understanding of the mechanisms behind cardiovascular diseases.

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The Rise of Composite Materials

Lightweight composite materials with high survivability

Designing 3D composite materials with lightweight constituents and high mechanical properties has been the center of many strategies to achieve low weight and high survivability in harsh environments involving blast, impact and crash loading. Fiber-reinforced polymer-matrix composite materials have been identified as good candidate materials with lightweight and high mechanical properties.

Dahsin Liu's research focuses on an innovative quasi-3D (Q3D) weaving technique developed for manufacturing lightweight composite materials. The Q3D composite materials have been found to have an excellent capability of confining damage propagation, compared to conventional laminated composite materials. In characterizing the performance of the Q3D composites, Dr. Liu has developed a unique Laboratory Blast Simulator (LBS). The LBS can create a pressure wave with a pressure of 250 MPa, a temperature of 1500° C, and a wave speed of 6 Mach. The wave can be used for many survivability simulations including blast, impact, and crash tests. Advanced measuring techniques, such as fringe sensor and fringe projection, have also been implemented in the dynamic tests for deformation characterizations.

Dr. Liu models the response of the innovative Q3D composites under dynamic loading. An advanced numerical method, the peridynamic method, has been formulated due to its objectivity in modeling damage initiation. Based on an integration form of a governing equation, instead of the conventional differential form, the peridynamic method is capable of modeling matrix cracking, fiber breakage, and delamination in composite materials. The formulation and programming of the numerical code is much simpler than that of state-of-the-art FEM.

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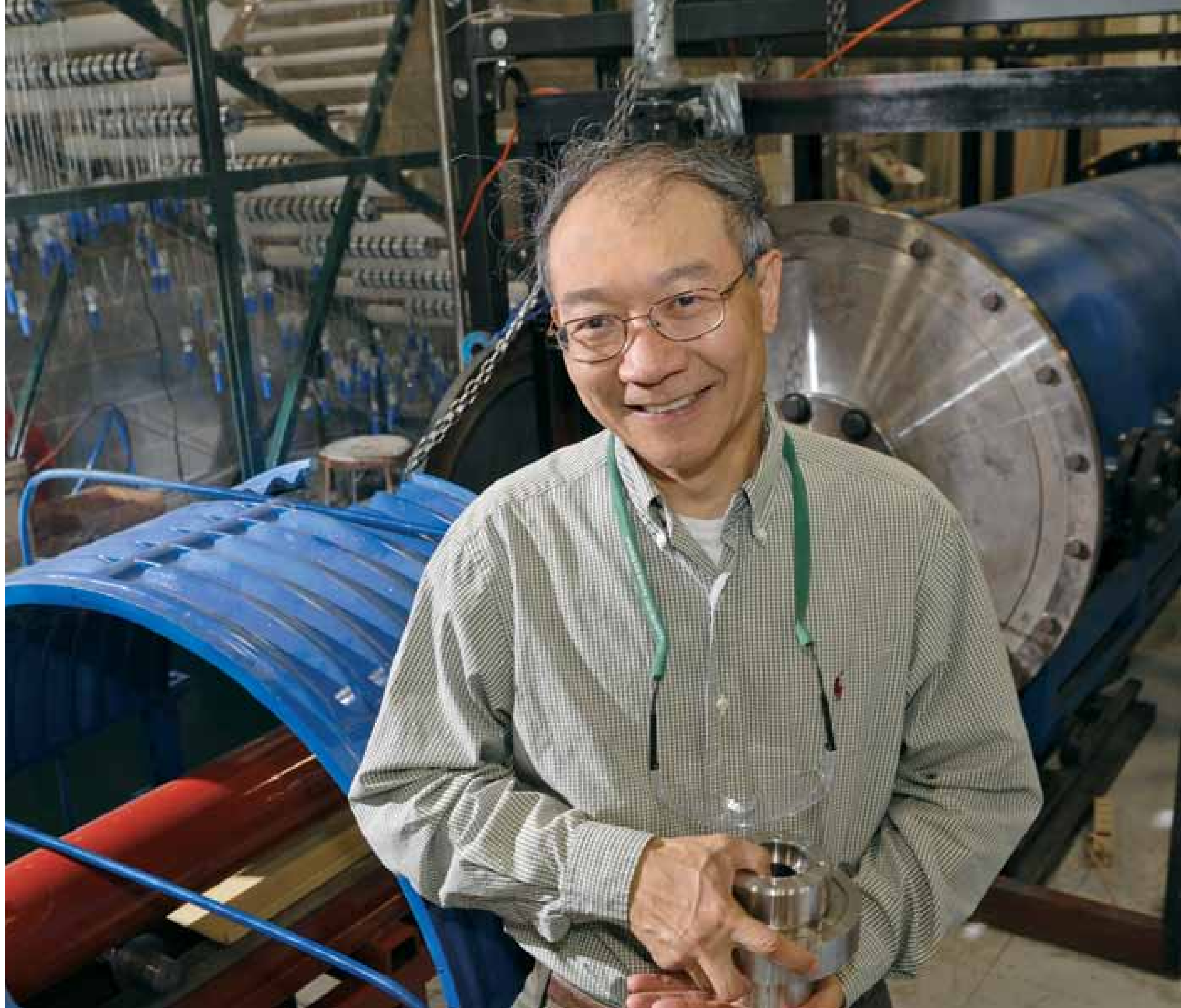

Low cost Composite Manufacturing

Modeling the vacuum assisted resin transfer molding process

Composite materials offer performance characteristics that are superior to those of conventional materials. Advanced composites, composed of fibrous reinforcements embedded in polymer matrices, have been attractive materials for high-performance aerospace applications due to their high strength, stiffness, and light weight. However, use of these materials in commercial aircraft and automotive, marine and other industries has been limited due to high manufacturing costs. Composite manufacturers recognize that new fabrication techniques that reduce material and assembly labor costs will lead to wider composite material utilization.

The activities of Al Loos within the Composite Vehicle Research Center focus on the processing science of polymeric-based composites. Analytical models; which consider thermal and fluid transport, polymer chemistry, and mechanics; are being developed to investigate new manufacturing methods, optimize the processing cycle, and relate processing to mechanical performance. The models are solved by finite element techniques and can be readily changed to simulate composite structures with different geometries.

Dr. Loos' activities include the development and verification of simulation models of vacuum assisted resin transfer molding, advanced fiber placement, and rapid consolidation composites manufacturing processes. Dr. Loos is also investigating a paper-making technique to produce fibrous mats from biofibers and biobased polymers and consolidation techniques for molding the mats into complex shaped structures. Studies have recently been initiated on the effects of nanoreinforcements on the processing characteristics and mechanical performance of composites manufactured by liquid molding techniques.

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Turbomachines in Energy Conversion

The future of wave disk engines

Turbomachines are the most widely used machines in energy conversion. While turbomachines are often seen as steady-state flow machines in which unsteady and supersonic flow phenomena are avoided, disk engines are based on these principles and utilize shock waves for energy conversion.

The Humphrey Cycle combines the confined combustion of the internal combustion engine with the complete expansion of the gas turbine in a turbomachine to obtain higher efficiency. Norbert Mueller designs turbomachines that use shock waves as a pre-compression mechanism for the wave disk engine in order to realize the Humphrey Cycle. The resulting wave disk engine can be a more efficient engine. Dr. Mueller's research highlights the wave disk engine's very simple geometry, ease to manufacture, lower cost and lighter weight, and the actual potential of higher efficiency.

The wave disk design eliminates many of the components of a conventional IC engine; there are no valves, pistons, or crankshaft. The engine also requires no cooling system, transmission, or fluids, meaning that maintenance costs are greatly reduced. The design is about the size of a large cooking pot - much smaller and lighter than an existing engine. With fewer parts, the wave disk engine would be much less expensive to produce than a traditional internal combustion engine, and it could be made to run on a variety of fuels. Dr. Mueller is working on increasing the power and efficiency of the wave disk engine to supply back up and mobile power and to power small households.

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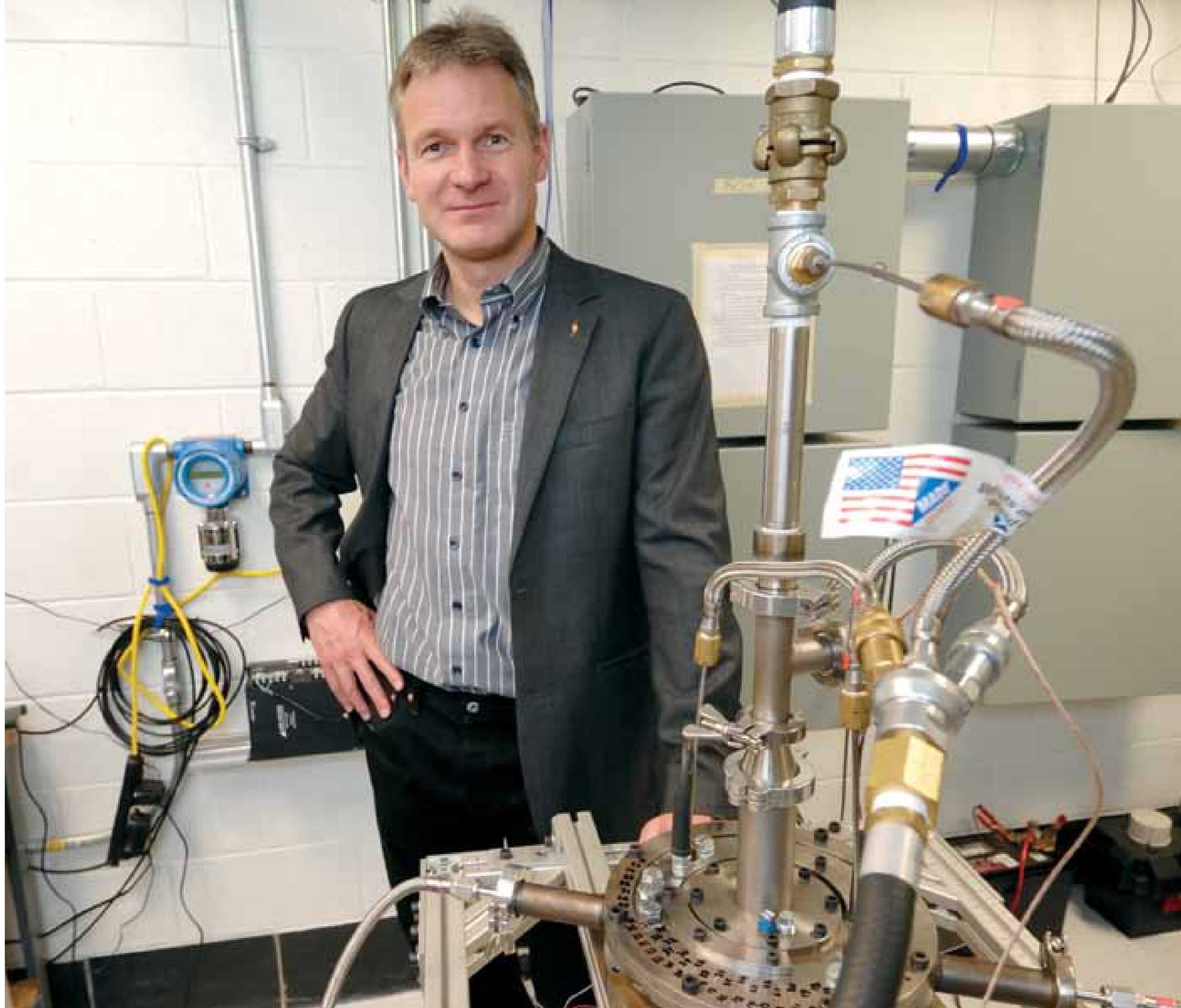

Underactuated Dynamical Systems

Problems in sensing and control

Underactuated dynamical systems have fewer generalized forces than their degrees of freedom and control of such systems pose unique challenges. Ranjan Mukherjee's research on underactuated systems has focused on systems with passive degrees-of-freedom as well as nonholonomic systems with kinematic or dynamic constraints. His research includes the development of mathematical models, motion-planning algorithms, and feedback stabilization strategies for underactuated systems ranging from space robots to underwater vehicles. This has led to improved understanding of their behavior and controllability. The experimental component of his research provides verification of theoretical results and, importantly, illustrates the potential benefits of introducing underactuation through the design and development of novel platforms.

For systems with passive degrees-of-freedom, Dr. Mukherjee is developing new control methods using impulsive inputs. In experimental work, he is involved in the development of biped platforms, hopping robots, a synergistically propelled underwater robot, and miniature wall-climbing robots. In addition to these mobile robots, he has also been involved in the development of a haptic interface for minimally invasive surgical training and collaboration.

Dr. Mukherjee's research on underactuated systems has branched into the parallel domain of sensing. Some noteworthy research in this direction includes bias-current excitation in magnetic bearings for synchronous disturbance cancellation through observability enhancement, shared-sensing in reversible transducers, and enhancement of both controllability and observability in dynamical systems through switching.

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Flow Control

Towards taming turbulence near surfaces

Turbulence may be thought of as the chaotic state that most fluid flows attain in practice. To an engineer, turbulent flows are frequently undesirable as they, for example, increase the air resistance to the movement of vehicles, decreasing fuel economy and increasing costs of operation. In many instances, turbulence is generated in the fluid layer immediately adjacent to the surface of the moving object, known as the boundary layer.

In a multi-university, cross-disciplinary, international effort, Ahmed Naguib is developing methods for adaptive control of boundary layers. Though the focus thus far has been on impeding the inherent tendency of near-wall flows to become turbulent, the control methodology could also provide the foundation of the more challenging task of controlling near-wall turbulence directly. Dr. Naguib embeds sensor arrays in surfaces to detect extremely small disturbances within the boundary layer and accordingly activate devices, known as plasma actuators, to produce "counter disturbances" to oppose the naturally growing disturbances and prevent, or delay, the transition to a turbulent state. Questions regarding where, when, and how much actuation should be exercised, and how does a natural disturbance differ from that caused by actuation, are just a handful of many questions being answered in Dr. Naguib's research. The goal is to arrive at complete autonomous systems that can be embedded in the surface of vehicles to mitigate, or weaken near-wall turbulence.

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Extremely Deformable Materials

Activated swelling and programmable shape change in porous, elastic materials

Materials that give structural support while at the same time undergoing complicated shape changing rearrangement in the structures themselves hold significant promise for robotics and biomedical applications. These materials include gels capable of swelling and deswelling over a large range of volume. Designing with these materials is challenging because the mechanical properties exhibit great change as the material rearranges at the microscale.

To meet this challenge, Thomas Pence is creating new engineering analysis procedures in the form of mathematical models for use in engineering design software. This allows the practicing engineer to fully exploit the capabilities of these materials while ensuring that stress levels do not lead to failure in the form of excessive straining, fracture, or buckling.

Dr. Pence studies swellable elastomeric gels and investigates the effect of microstructures containing fine reinforcing filaments in specifically chosen directions. This directionality causes a controllable swelling deformation to exhibit specific fine scale displacement modes - such as bending and torsion - and permit new classes of "soft and wet" actuators. This includes devices employing electroactive polymers that actuate as artificial muscle. The biocompatible nature of these materials leads to the possibility of shape changing biomedical implants that allow easy insertion and retrieval. The material constituents in these gels can be engineered to break down in a safe and controllable fashion. Mathematical models enable the efficient design of resorbent tissue scaffolds with precise stiffness control for the scaffold / tissue complex, as healthy tissue replaces the resorbing scaffold.

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Mechanics of Manufacturing

Multi-scale characterization of engineered materials and modeling of advanced forming processes

To achieve automotive weight targets set to increase fuel efficiency in the United States, it is of paramount importance that engineered materials be used in the construction of future vehicles. Farhang Pourboghrat and his team of graduate students work together to perform fundamental and applied research related to the multi-scale experimental and computational characterization of engineered materials, as well as modeling of advanced forming processes using phenomenological yield functions, crystal plasticity, molecular dynamics, and statistical mechanics.

Dr. Pourboghrat's laboratory houses state-of-the-art 30- and 300-ton sheet thermo-hydroforming, as well as 60-ton tube hydroforming presses equipped with precision position, velocity, force, fluid pressure, and temperature control systems to conduct unique forming experiments at high pressures and elevated temperatures. The material characterization capabilities of the lab include biaxial bulging of sheet and tubular products at elevated temperatures with strain rate control. Dr. Pourboghrat currently studies the characterization of metallic materials, such as niobium, tin, multiphase advanced high strength steel, and aluminum alloy sheets and tubes. In addition, engineered materials such as thermoplastic sheets reinforced with woven glass, carbon, chopped fiber glass, bio-fiber, clay nano-tube, and graphene nano-platelets, and sandwich metal/composite/metal hybrid materials have been formed and characterized in the lab. Computational modeling of forming processes is performed on state-of-the-art multiprocessor PCs and workstations, as well as on high performance parallel computers at MSU.

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Skin Mechanics: Growth & Remodeling

Employing mathematical models to understand the development of melanoma

Malignant melanoma is one of the most common cancers worldwide and the most common cancer in the United States. Over the last five decades, much research has been performed to assess the developmental mechanisms of melanoma. Although in vivo/in vitro studies are crucial to unravel tumor growth processes, it is undeniable that mathematical models are also powerful tools to describe, understand, and predict the development of all living tissues. Mathematical and numerical descriptions and simulations of soft biological tissues and of their ability to grow and adapt have already provided important insights into the development of multiple diseases, including hypertension, aortic aneurysms, and heart failure.

Sara Roccabianca's work focuses on understanding the fundamental mechanisms that correlate the mechanical environment and the biological process of growth in melanoma's early development. Dr. Roccabianca's research goals are to develop a micro-structurally motivated mechanical model of the non-linear elastic behavior of skin, develop a stress-mediated model of skin adaptive response, and understand the mechanisms that correlate the mechanical environment and the biological process of growth in the early development of melanoma. This breakthrough will have an important impact on the field of cancer mechanics, for lead users (biomedical engineers) and end users (medical doctors and surgeons) alike.

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Sustainable Energy Solutions

Transformative automotive technologies:
thermoelectric generator, biofuels and increased efficiencies

Transportation accounts for about two-thirds of oil consumption in the United States and about one-third of all the energy used in the country. The critical need to reduce the nation's dependence on oil imports, combined with today's use of the same efficiency-limiting combustion system that powered the first automobiles more than 100 years ago, presents a significant challenge and opportunity.

MSU is home to one of the most advanced thermoelectric power generation research groups in the world, and part of the university's automotive research involves recovering wasted heat from diesel engines that is then used to extract energy to help power the vehicle. Harold Schock's goal is to improve fuel economy of large trucks by 5 percent in the next few years. Automobile companies are turning to MSU's hybrid vehicles team, which translates research conducted at the university for application to auto components to maximize the efficiency and affordability of hybrid models.

MSU's collaborative automotive and fuels research holds promise to reduce automobile emissions and improve the economic outlook for Michigan. A 20% to 50% efficiency improvement is possible by designing engines to accommodate new biofuels that enhance combustion, taking advantage of enhanced combustion modes enabled by tailored fuels. The MSU group is developing technology that can cost-effectively achieve a 30 percent increase in efficiency for all U.S. personal transportation using today's engines. The potential energy saved, 2.4M bbls/day, is equivalent to an Alaska National Wildlife Refuge discovery every five years or the energy that could be made from 30% of the arable land in the US if it were used to produce ethanol or increasing domestic oil output by about 45 percent. That's nothing short of revolutionary!

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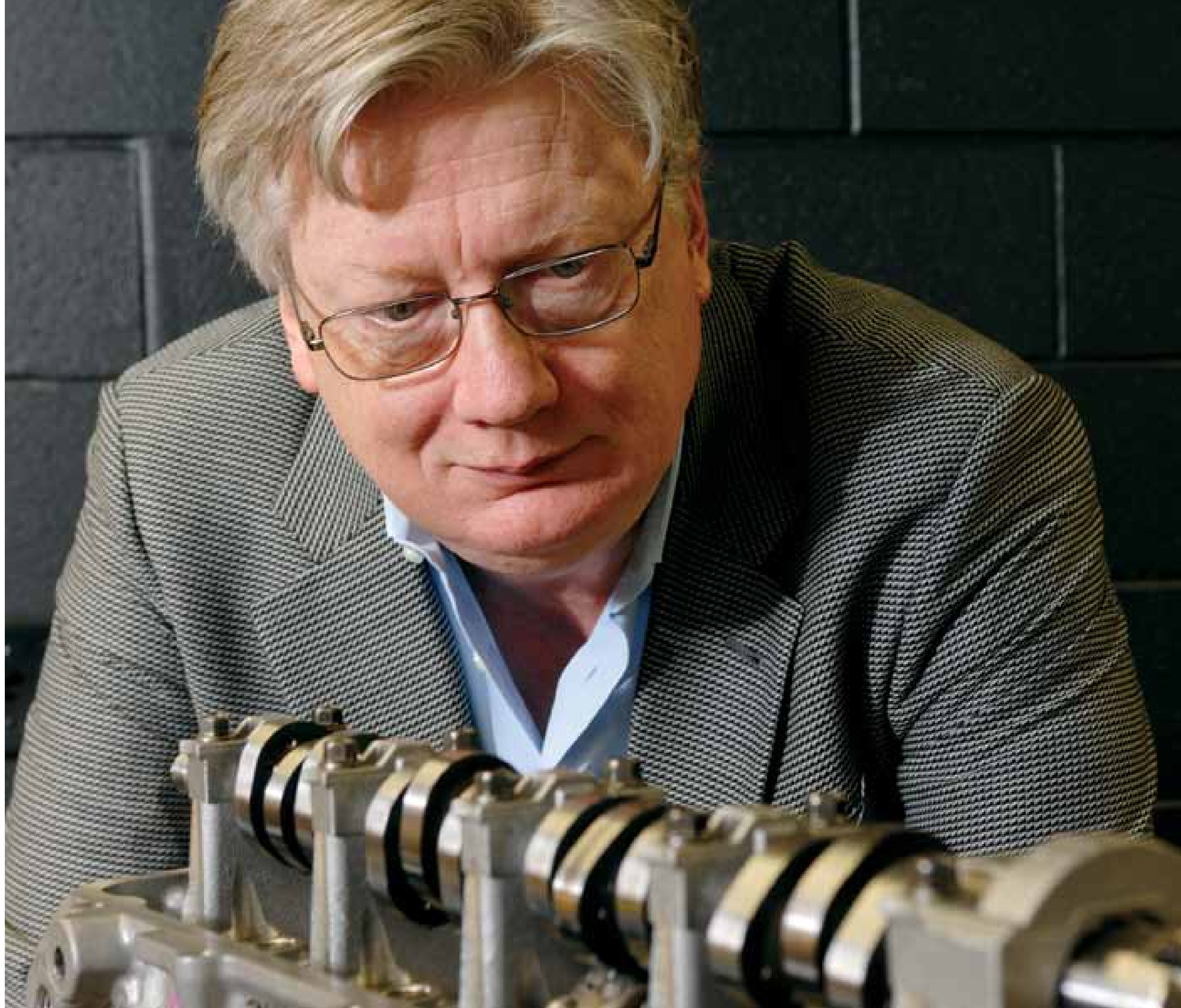


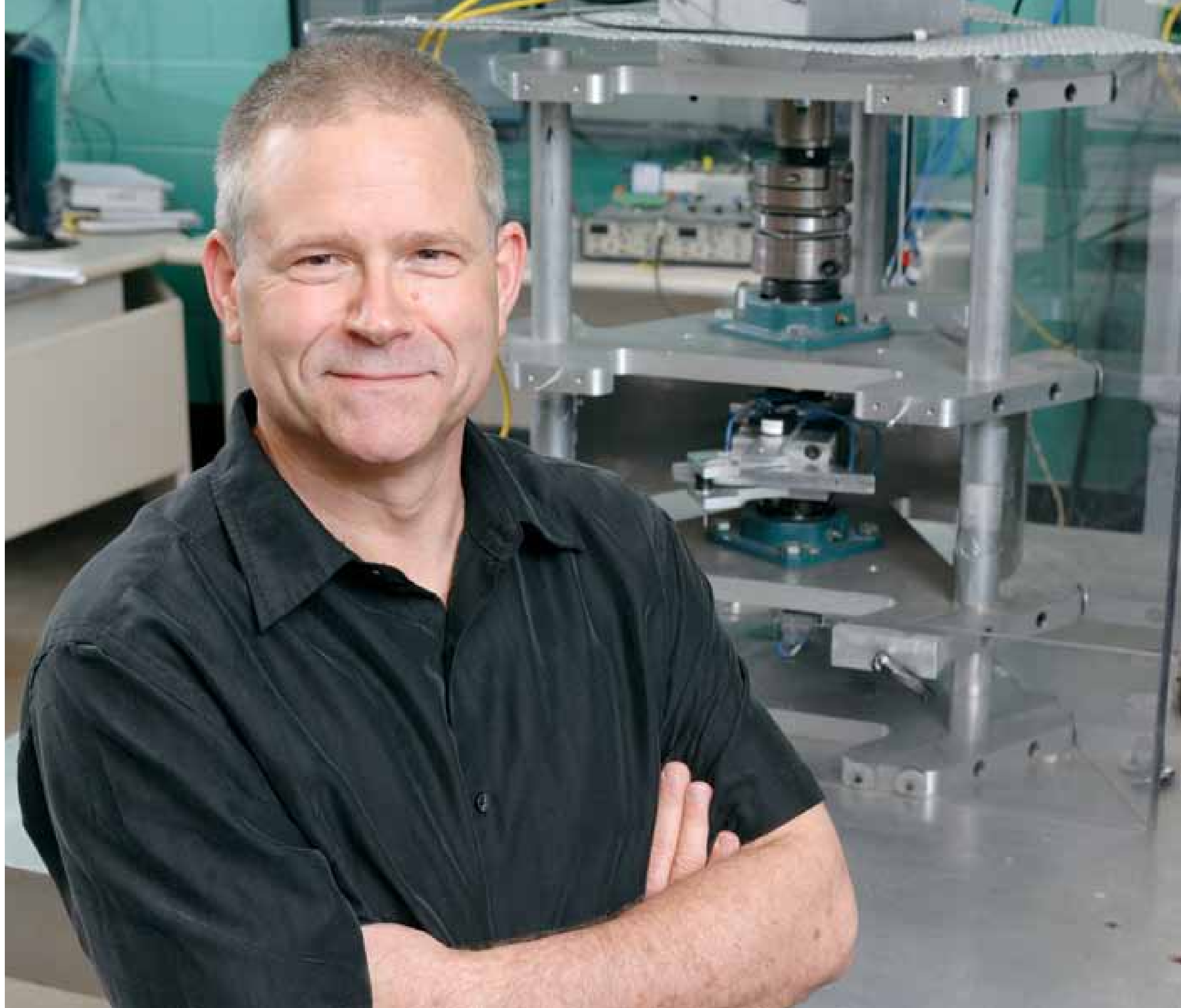
Tailoring Mechanical Vibrations

Vibration management: Improving automotive fuel economy and enhancing micro-system performance

The common theme in Steven Shaw's work is the modeling and tailoring of vibratory behavior of mechanical systems. In many systems vibrations are unwanted, while in others they are necessary for proper function. The development of novel system designs that exploit nonlinear behavior to achieve performance not attainable by more conventional designs allows Dr. Shaw to concentrate on the analysis of mathematical models and verification with controlled experiments.

The design of micro-scale mechanical resonators for use in signal processing and sensing applications is a critical issue in vibrations. These systems benefit from the high efficiency, high quality of resonance, and design flexibility offered by vibrating micro-electro-mechanical systems. The modeling and design of devices allows a great deal of collaboration with experimental groups at other universities for fabrication and testing.

Dr. Shaw is also developing centrifugal pendulum vibration absorbers that attenuate torsional vibrations in automotive powertrain components. Reduction of these vibrations will facilitate a number of fuel saving technologies, including enhancements of cylinder deactivation strategies and improved efficiency of torque converters. These absorber designs have several attractive features, including the use of existing inertial components, such as counterweights and flywheels, modified to include absorber elements, so that engine responsiveness is not affected. Dr. Shaw's work in this area includes basic research on system dynamic response, experiments using a rotor system designed specifically to characterize these absorbers, and close interactions with automotive companies.



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Appropriate Technology

Refrigeration and heating with a global perspective

The term appropriate technology applies to technology for energy, water, and health that departs from the conventional technology and is concentrated on the appropriate use of a developing country's resources, so as to not disrupt its culture and environment. Further, the technology should be simple and inexpensive to employ and could lead to the development of cottage industries.

Craig Somerton's research efforts are on global issues relating to the acceptable storage of vaccines and the efficient use of solar energy to effectively cook food. The World Health Organization estimates that 50% of the vaccines in the developing world spoil due to lack of temperature control. Research into the best methods of maintaining temperatures adequate to prevent spoilage are critical in third world countries. The destruction of forests across the globe has also led Dr. Somerton to study economical ways to provide the basic tools of cooking to regions where there is ample solar energy but little in the way of available heating materials.

Using a solar powered refrigeration system with ethanol as the refrigerant based on the adsorption cycle, Dr. Somerton and his student teams have provided villagers in Guatemala with a means to preserve needed vaccines. Maintaining a cold space to a temperature of 4°C, the refrigeration unit is made of materials readily available in the developing world with manufacturing methods that are common in most developing countries. The primary expenditure is a high quality vacuum pump that is used to initially charge the system. It is anticipated that micro-financing could be employed to provide the funds to cottage industries for this capital expenditure.

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Engine Flows and Combustion

Understanding engine flows, fuel-air mixing, and combustion during start-up of an IC engine

The new fuel economy standard of a fleet averaged value of 54.5 mpg by 2025 combined with more restrictive emission standards has renewed the emphasis on developing and understanding new types of combustion processes coupled with the electrification of the automobile. Hybrid powertrains by their very nature require the shut-down and start-up of the internal combustion engine depending on the driver's power demands. Hence, the internal combustion engine is turning on and off frequently thus having the potential of a significant number of transient operation modes. It is during these transients that most of the emissions are emitted from the vehicle.

> understanding of cycle to cycle air-flows, fuel delivery and mixing, and the subsequent combustion of the charge will be critical to reducing cold start and transient emissions.

Rod Tabaczynski's studies the causes of cycle to cycle variability during the initial phase of engine start-up which is critical to meeting the emission standards. An understanding of cycle to cycle air-flows, fuel delivery and mixing, and the subsequent combustion of the charge will be critical to reducing cold start and transient emissions. The goal is to determine operating strategies and engine design features that minimize the cyclic variability. The research can also be extended to determine if unique formulations of biofuels can reduce the observed cyclic variations.

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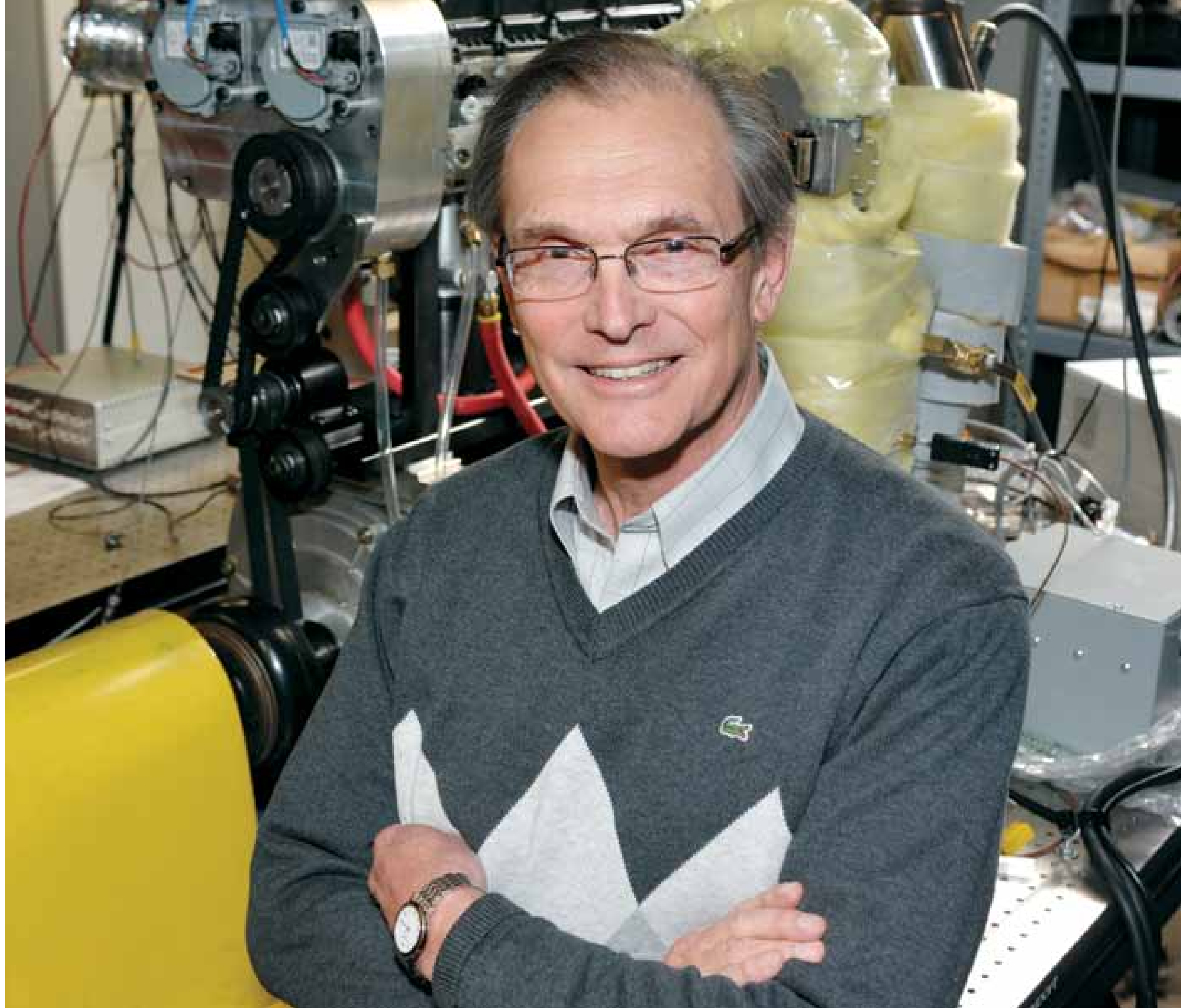

Design of Bio Inspired Materials

Reduced energy consumption by incorporating lightweight multifunctional composites

Transportation accounts for 28% of US energy consumption and 80% of this consumption comes from non-renewable energy sources. This makes it crucial for engineers to develop efficient strategies covering all aspects of design, including material selection, processing, manufacturing, packaging, and recycling. In this context, multi functional composite materials offer important advantages; including being lightweight, having self-sensing capabilities, and providing easy repair mechanisms and longevity. Most natural materials are multifunctional composites that have incorporated best design principles over years of evolution.

Enhancing strength, modulus, and efficient energy transfer capabilities in a light weight composite material is of primary importance to Arjun Tekalur. In this regard, he has been attentive to staggered architectural materials (as observed in seashells or bone), their microstructure-strength correlation, and their suitability as impact resistant materials. Dr. Tekalur uses state of the art experimental techniques to validate his theories and further explore the mechanics of these unique staggered architecture composites. Application of these principles has lead to successful manufacturing of nacre-mimetic composites that offer 45% reduction in weight compared to traditional ceramics and more importantly, more than 200% increase in fracture toughness. He also uses some of the basic mechanics' principles in these materials' designs to understand dynamic failure in mechanical joints (bonded and bolted joints). With increasing use of multi-material systems, joints between them become crucial points where failure might initiate. Successful design and optimization of both materials and their joining will lead to enhanced efficiency and reduced energy consumption.

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A Planet in Dire Need of Engineering

Focusing on the basic needs of people

According to many predictions the world population will increase by 50 percent and explode to 9 billion people before 2050. How will planet Earth sustain all these people? How can we ensure international peace, equality and justice, as the world's population strives to survive despite the inevitable poverty, inequity and hunger?

Currently 70 percent of the world's population lives on less than two dollars a day. How can the powerless, the poor, the marginalized acquire food, potable water, energy, health, air, sanitation and shelter? How can we diffuse education and also appropriate humanitarian aid into this complex inter-disciplinary cauldron called the developing world while simultaneously ensuring that MSU's graduates are authentic global citizens with an aroused empathetic societal conscience? Surely this international situation comprises the very biggest challenge confronting humanity at the beginning of this brand new century.

During the past decade Dr. Thompson has worked in Tanzania and Peru designing, manufacturing, and then diffusing innovative low-cost solar-thermal technologies that address inherent health and societal issues while transforming lives. Educational initiatives have included the organization and delivery of national workshops on solar box ovens in Morogoro for Tanzania's elite, including professors, politicians, teachers, business people, and entrepreneurs. Brian. Thompson has delivered workshops across the globe in the remote Andean communities of Huamachuco and Choquizonguillo, and in remote rural health posts, offering advice on a variety of solar-thermal water heater designs for domestic use, hospitals, and schools, and on solar-thermal dehydrators that preserve horticultural produce.

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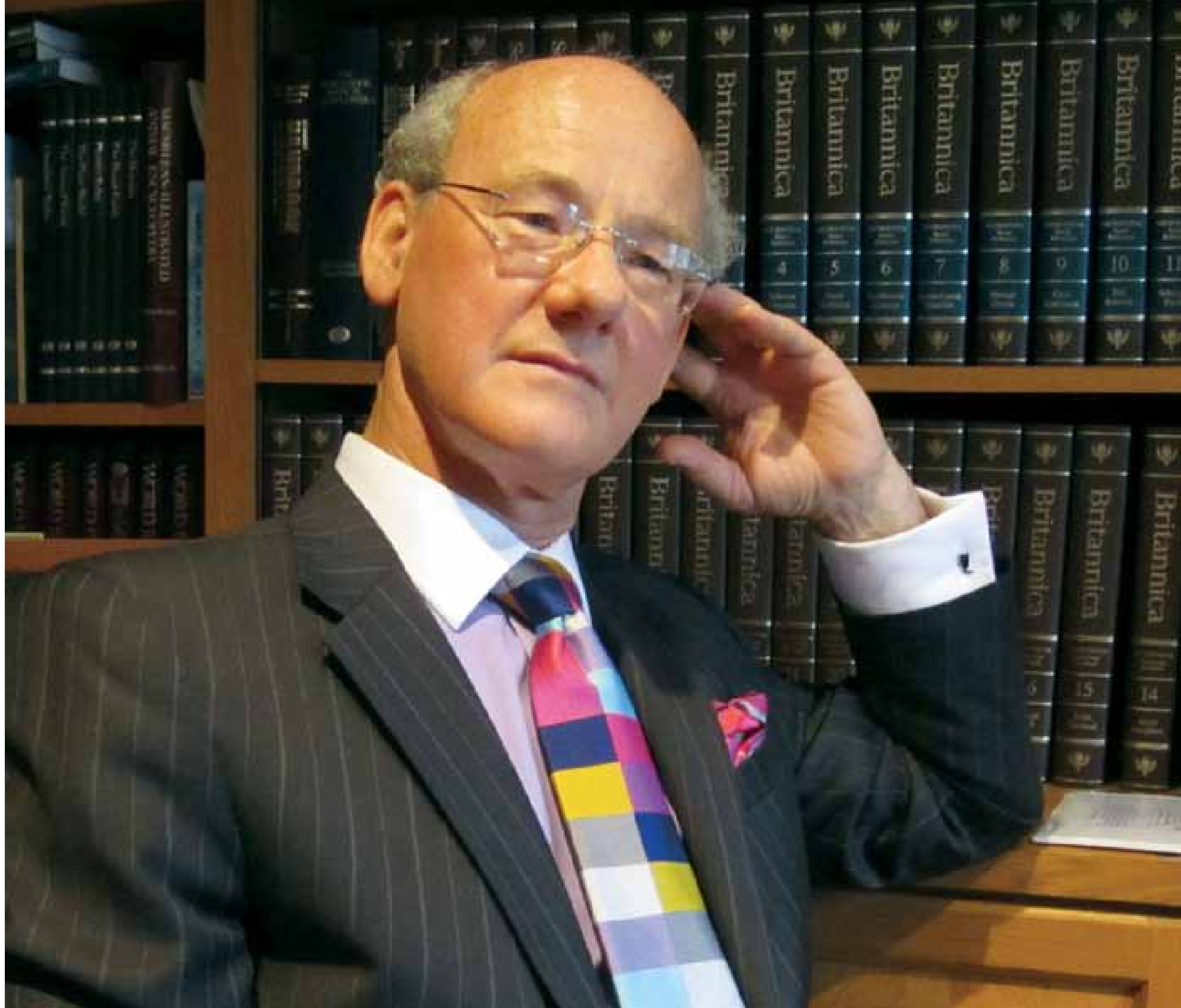

Enhanced Ignition Technologies

Studying chemical kinetics and innovative ignition technologies of combustion

The world is currently dependent on burning non-sustainable fossil fuels to meet its energy needs. Combusting these fuels releases large amounts of greenhouse gases and other pollutants that are affecting our climate and atmosphere. The future will require both improved fuel efficiency and the incorporation of renewable fuels in order to meet energy production and transportation needs. Enhanced ignition technologies may provide one way forward to meeting future emission standards and fuel economy requirements. Additionally, studying the chemical kinetics of the combustion and after-treatment processes can lead to the development of cleaner and more efficient systems.

Elisa Toulson's research in combustion examines enhanced ignition technologies such as turbulent jet ignition, which can improve fuel consumption, reduce emissions, and improve combustion stability in internal combustion engines. These technologies may also enable renewable fuels and fuel blends to be integrated with existing technologies, facilitating their introduction into the marketplace.

Chemical kinetics modeling is another important aspect of renewable fuel combustion that Dr. Toulson is researching. Alternative fuels such as biodiesel are presently receiving attention as potential substitutes for fossil fuels, as they can be renewable and carbon neutral and provide energy security. However, biodiesel oxidation chemistry is complicated to model; and existing surrogate kinetic models are very large, making them computationally expensive. Reduced chemical kinetic models of biofuels are one way to enable simulation of renewable fuel combustion. This type of modeling in conjunction with experimental research allows for an improved understanding of the combustion of new renewable fuels.

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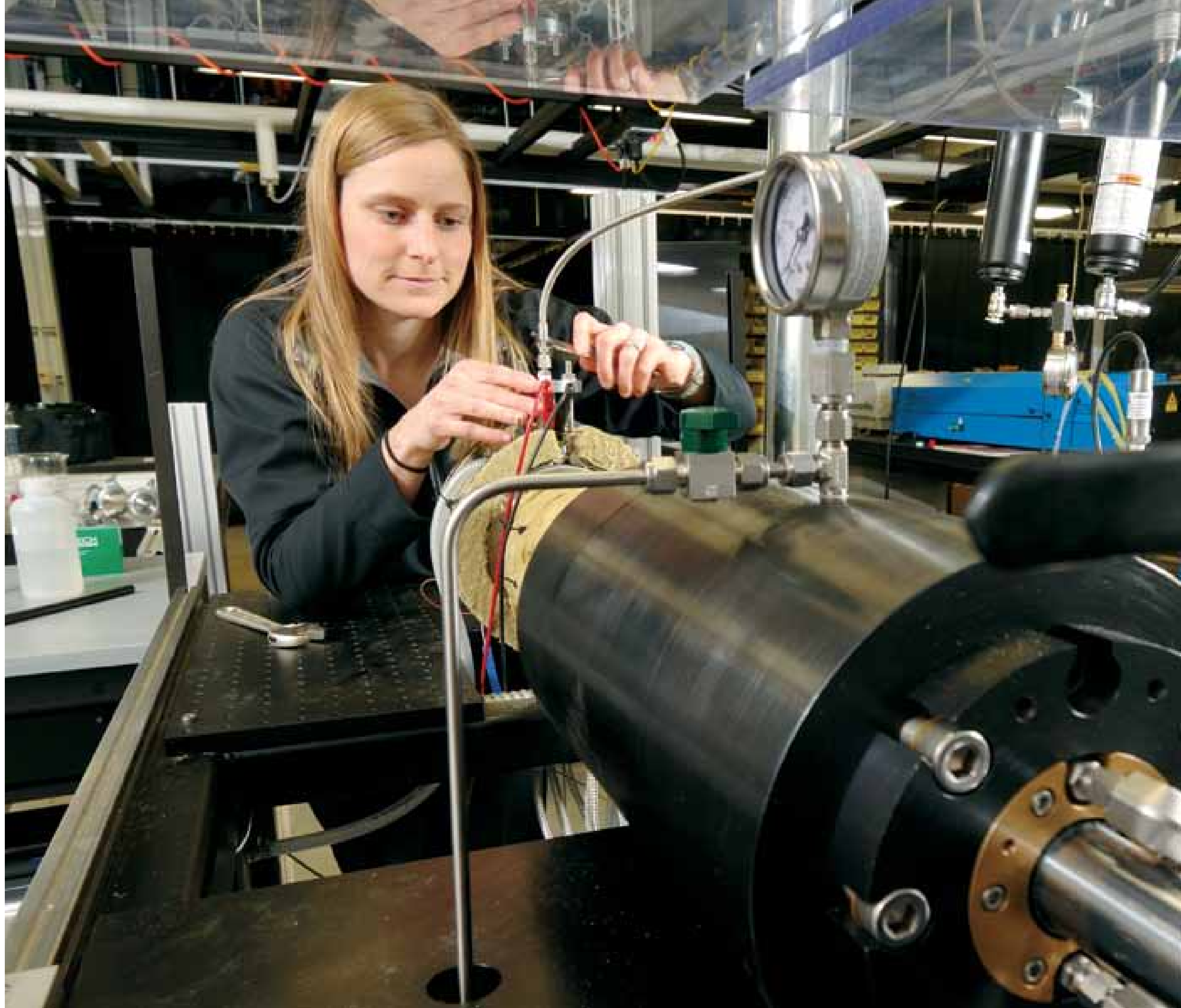

Flame-Surface Interaction

Applications of flame propagation under extreme conditions

The interaction of a flame with a surface is ubiquitous. Rarely does a flame exist isolated, alone, far from any bounding surfaces. Indeed, the "isolated flame" of many model studies is an extreme idealization that is almost never seen in nature. Real flames always interact closely with nearby surfaces. Sometimes - in engines, for example - the surfaces quench and impede the flame. Other times - in the spread of a flame over a matchstick, for example - the surface feeds the flame. Most current problems in combustion involve interacting flames and nearby surrounding surfaces.

Indrek Wichman investigates the flame/surface interaction where material degradation occurs during combustion. Here the interest is in the detailed breakdown of the surface and its interaction with the nearby flame. In companion work, Dr. Wichman is developing and testing a furnace to evaluate material flammability signatures during combustion. If one overarching theme were sought to tie Dr. Wichman's investigations together, it would have to be characterized as flame/surface interaction during combustion.

The far reaching aspects of Dr. Wichman's combustion research involve the development of a Narrow Channel Apparatus that is capable of simulating zero-gravity burn conditions on earth. This apparatus may "fly" in the International Space Station to gather data for subsequent on-earth comparisons. The basic problem of flame/surface interaction stands as a fundamental problem of combustion theory.

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Biothermomechanics

Temperature and deformation in biological systems

The thermomechanical environment has profound effects on biomedical protocols such as cryopreservation and tissue ablation. For example, heating a soft tissue such as a tendon causes it to shrink as the connective proteins that comprise the tissue denature and loose their ordered structure. Stretching the tendon at the same treatment temperature slows the rate of shrinkage. Thus, it is the combined effects of heating and stretching that determine the rate of tissue change. Heating can also damage cells. At temperatures just warmer than 37^{O} C, the cells may express heat shock proteins that protect the cells from damage upon further heating. At still warmer temperatures, cells die, with the rate of death depending on, amongst other things, the cell type and thermal history. Quantitative models of damage to cells and tissues can aid in the design and development of new thermal therapies. These models contain parameters that must be determined from measurements

Neil Wright studies the response of cells and tissues to heating and mechanical load, develops and compares quantitative models of thermally damaged cells and tissues, and develops techniques to measure the model parameters. Dr. Wright studies the difference in rates of injury to tissue and pathogens, such as the fungus responsible for onychomycosis (toenail fungus). He also measures the thermal diffusivity tensor of elastomers and biological soft tissues while the specimens are subject to finite multiaxial deformation. The thermal diffusivity determines the rate of temperature rise in response to heating. Dr. Wright's research also involves measuring the thermal conductivity of superconducting niobium, which is used to make particle accelerators, such as the Facility for Rare Isotope Beams (FRIB) at MSU.

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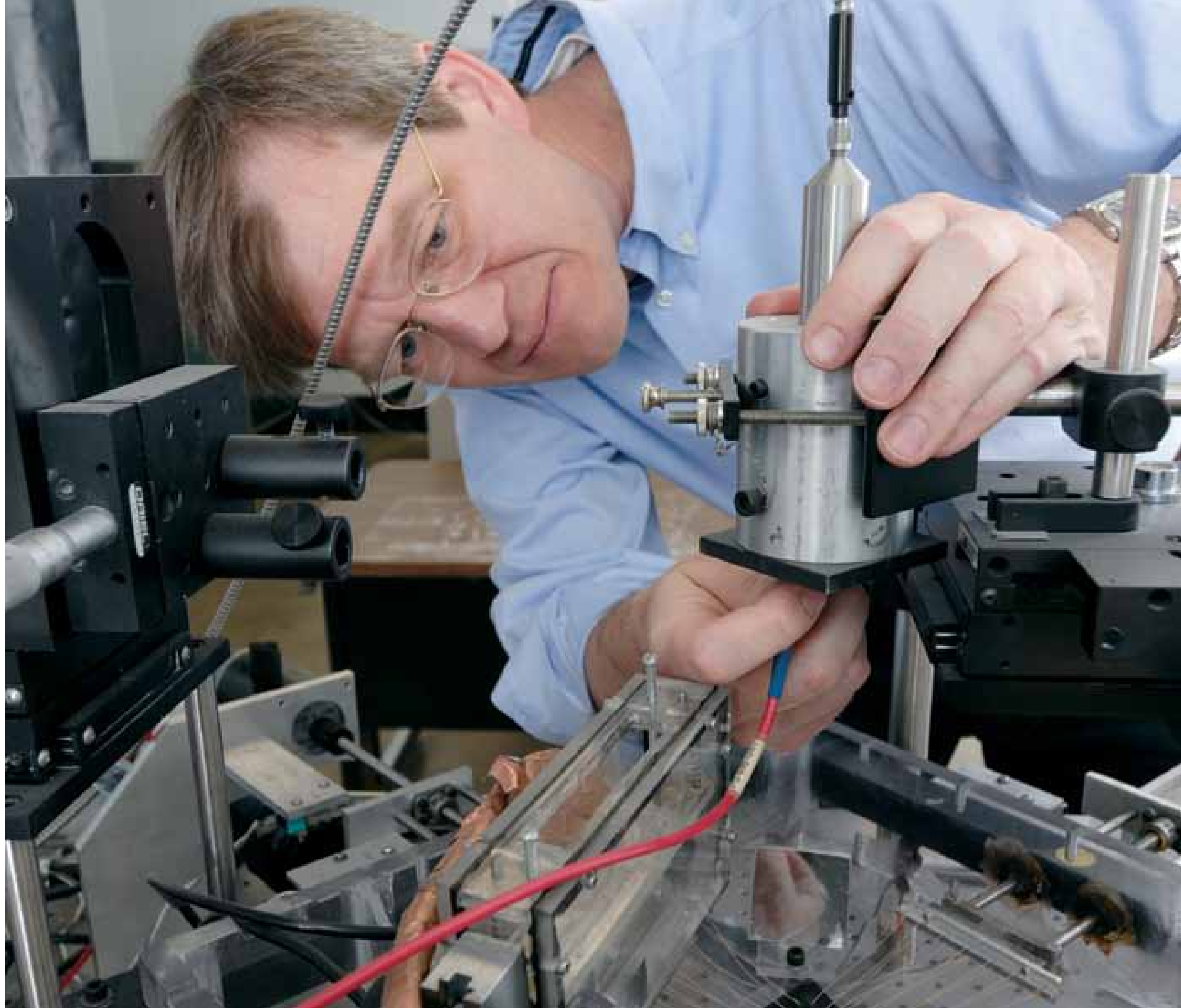

Composite Structures

Prediction of damage and residual strength of composite structures

Structures are subjected to a range of load spectra from static, fatigue, and creep to dynamic impacts. To determine the remaining life of a load bearing structure, one must be able to predict the damage initiation as well as its evolution under further loading.

Xinran Xiao's research is focused on developing models to predict the mechanical behavior of materials under a variety of loading conditions. Dr. Xiao conducts experiments to understand the damage initiation and evolution in materials, develops constitutive models, incorporates the models in finite element codes, and validates the models' predictions of structural performance. Dr. Xiao's group is developing models for crashworthiness, impact, and fatigue life predictions of composite structures. She also works on polymers and metallic materials.

Of special interest is the stress that exists in porous polymeric membranes. Porous membranes are found in a variety of applications including batteries, fuel cells, chemical or cell separations, etc. Currently, Dr. Xiao's work focuses on understanding and predicting the stress in a polymeric separator in a Li-ion battery. The separator enables ionic transport but prevents physical contact between the electrodes. The structural integrity of the separator is crucial to the abuse tolerance of a battery. The stress in a separator in a Li-ion battery is caused by the Li intercalation induced deformation in the electrodes and thermal expansion differential between the battery components. A multi-physics model incorporating battery kinetics, diffusion, and thermal and stress phenomena to reveal the stress is being developed. Dr. Xiao is also measuring the mechanical properties of the separator *in situ* in a battery environment.

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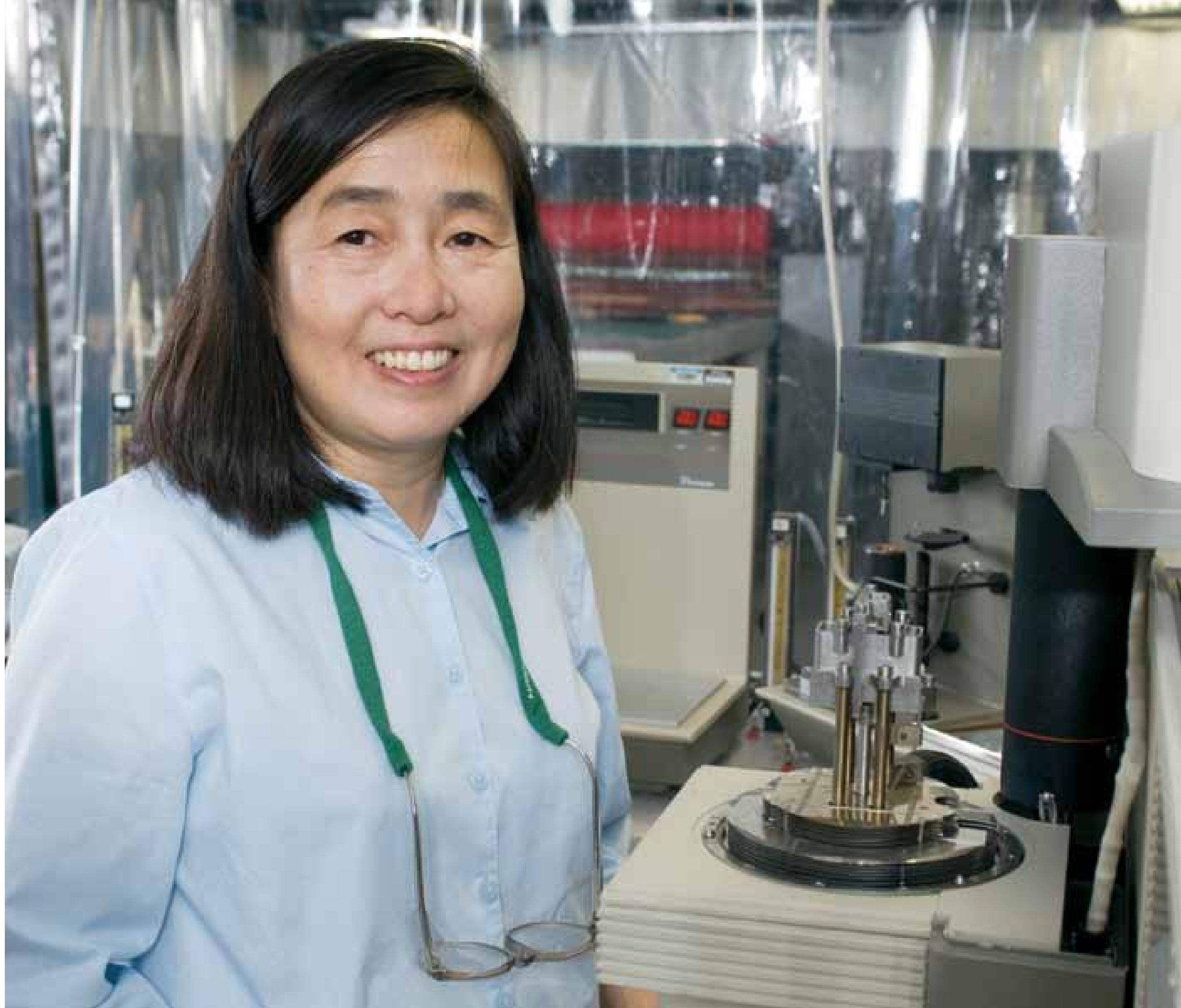

Nanomaterials & Nanomanufacturing

Nanotechnology-enabled solutions to energy and environment

Junghoon Yeom's research focuses on the areas of micro- and nano-manufacturing, functional nanomaterials, and device design and fabrication for micro/nanosystems. Nanomaterials exhibit superior electronic, mechanical, and optical properties compared to their bulk counterpart, but when assembled into a device or system, their salient features are often compromised due to the lack of a suitable fabrication process. A research focus in Dr. Yeom's group is to develop a scalable nanomanufacturing technology to place nanomaterials, especially 1D nanomaterials (e.g. nanotubes and nanowires), into desired locations with high precision and alignment and without sacrificing their intrinsic properties. Dr. Yeom is also interested in developing low-cost, large-area fabrication technology for a periodic array of nanodots and vertically-aligned nanowires directed integrated onto substrates. To achieve these goals, he employs hybrid approaches using top-down and bottom-up methods.

With assembled nanomaterials as building blocks and using scalable nanomanufacturing technologies, Dr. Yeom is looking to construct multifunctional devices and systems with efficient energy conversion, chemical/biological separation and detection, and environmental monitoring. Specific examples of these devices include (i) highly sensitive and selective gas sensor systems for explosives, toxic industrial compounds, volatile organics, and breath biomarkers, (ii) small-scale energy harvesting and storage devices, (iii) separation systems for gases and water, and (iv) opto-electronic devices.

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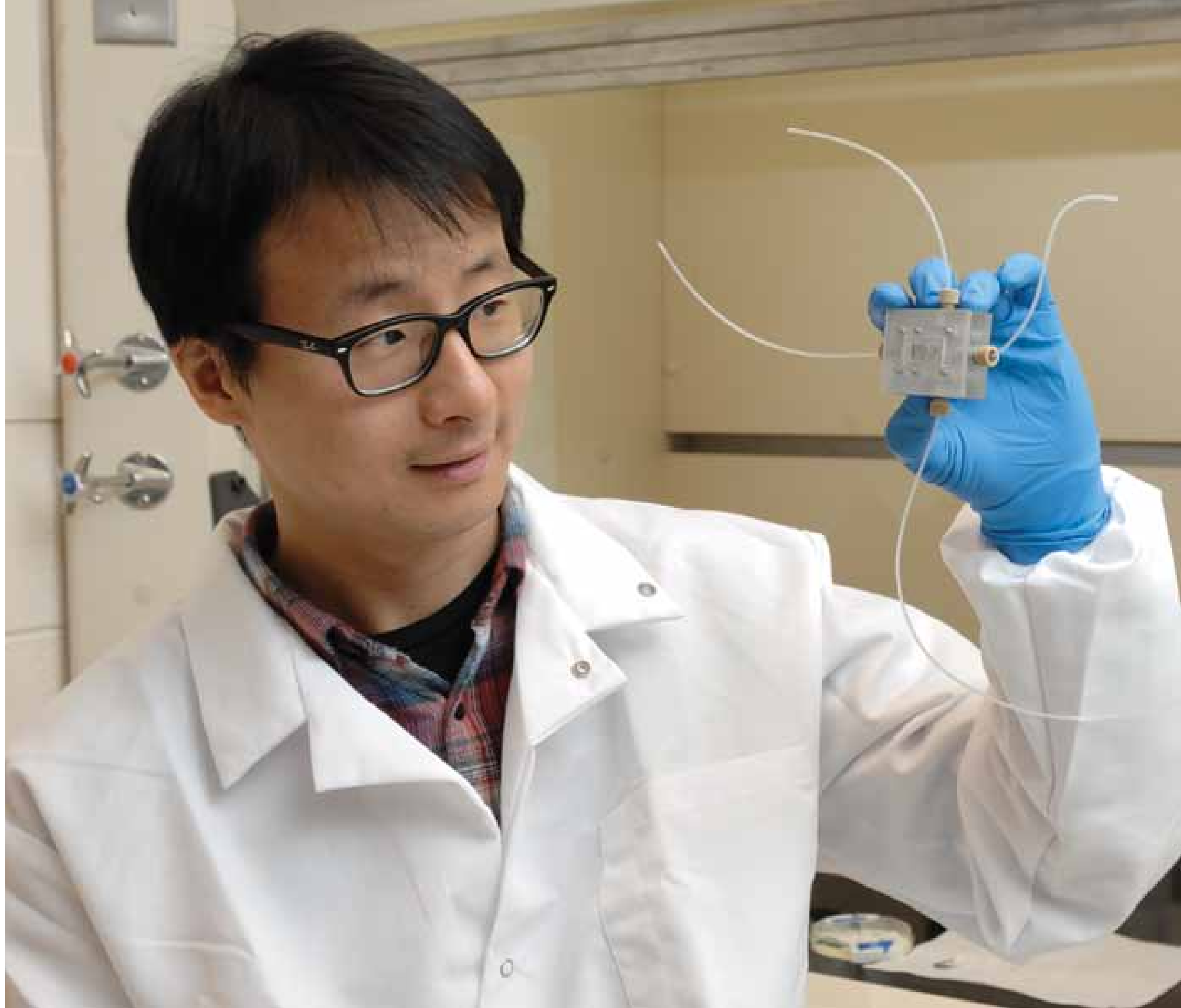

Advanced Engine Control

Improving fuel economy with reduced emissions using in-the-loop advanced control

Increasing concerns about global climate change and ever increasing demands on fossil fuel capacity call for improved fuel economy of automotive engines with reduced emissions. With many biofuel applications on the near horizon, the next generation of automotive engines will be required to operate with multiple fuels. The engine combustion process will have to be optimized to maximize combustion efficiency with improved emissions under different fuel blends and combustion modes. To meet this challenge, advanced engine control will be needed to automatically adapt to the fuel blend and combustion mode.

The research conducted at Guoming (George) Zhu's automotive control lab uses model-based control techniques to accurately control engine fuel injection timing and mass, charge mixture temperature and composition, and to control the valvetrain and other engine subsystems. Control-oriented engine models are being developed and implemented in the lab in a hardware-in-the-loop simulation environment to support model-based control development and validation.

Dr. Zhu is also conducting research in areas of integrated identification and control of automotive systems, optimal control of hybrid powertrain systems, combustion mode transition control, TEG (thermo-electric generator) system management, and applications of smart materials to automotive systems. Active control of the automotive engine and its subsystems is an essential foundation needed to make new engine technologies possible. Research at MSU ranges from new control concept development to validation and demonstration.

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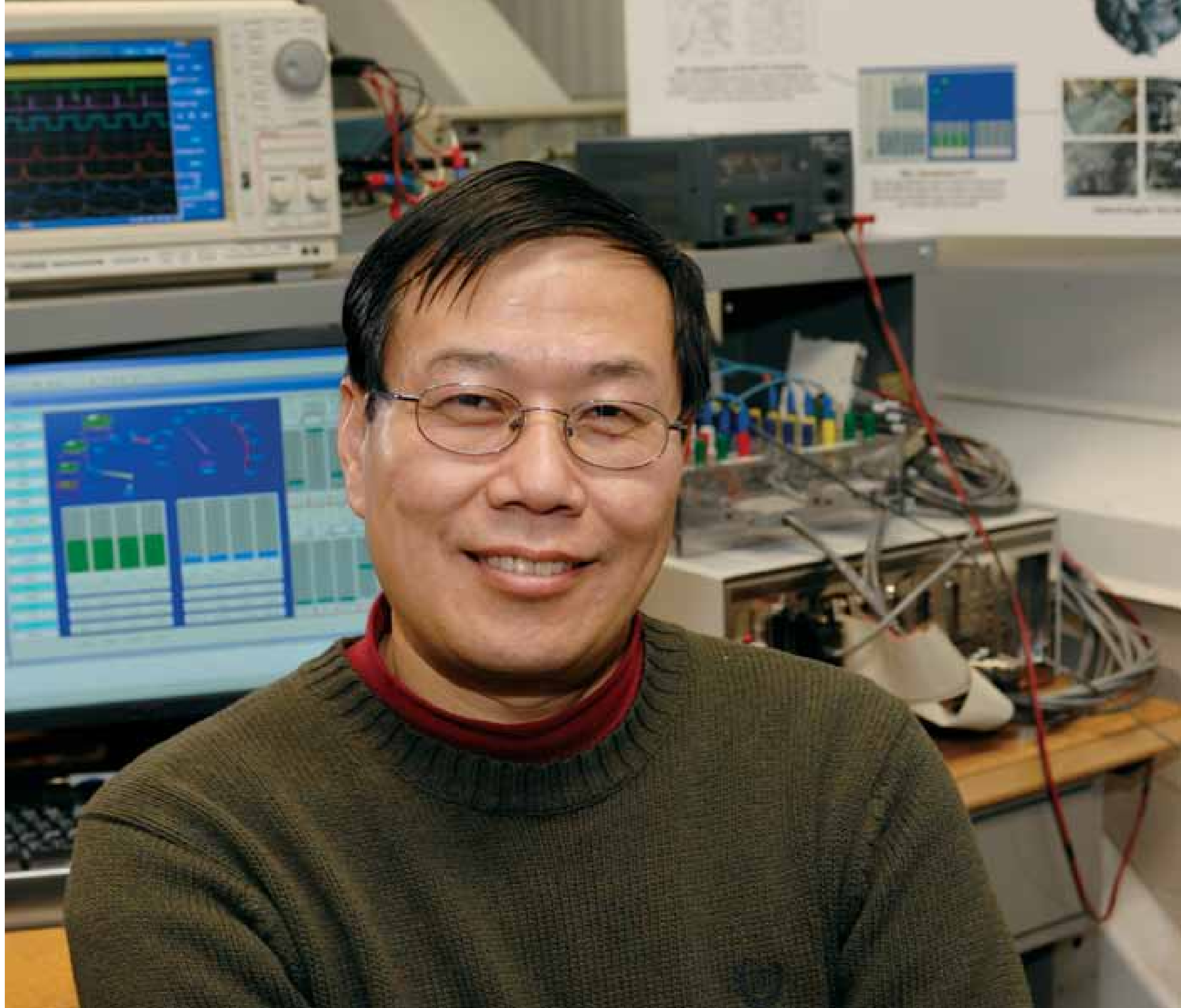

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