NEWS 2014

THE OHIO STATE UNIVERSITY

Department of Mechanical & Aerospace Engineering

CONTENTS

MESSAGE FROM THE CHAIR

As I reflect on the past year as department chair, it has been gratifying to continually observe the impact of our distinguished faculty on our students, the engineering profession and the broader society.

At the Department of Mechanical and Aerospace Engineering (MAE), we have created a vibrant learning environment that engages our students, faculty, and government and industry partners. Our talented scholars continue to attract the best and brightest students. Their insights and research keep us at the leading edge of innovation and discovery, sought after by industry and government agencies. We are truly proud of our 469 brilliant graduates with 317 BS degrees, 122 MS degrees and 30 PhD degrees.

It is a privilege to acknowledge Professors Datta Gaitonde and Levent Guvenc, elected to Fellow status of the American Society of Mechanical Engineers (ASME). We also congratulate James Gregory, associate professor, selected as a 2014-15 Fulbright Scholar; Carlos Castro, assistant professor, who earned a National Science Foundation (NSF) Early CAREER Development Award; Associate Professor Rob Siston, presented with one of the Ohio State University's 2014 Alumni Awards for Distinguished Teaching; and Professor Bharat Bhushan, who received the 2014 International Award from the Society of Tribologists and Lubrication Engineers (STLE). Such prestigious recognition speaks to the distinct strengths of our exceptional faculty, making a difference in the profession and around the world. From uncovering new restorative techniques in dentistry, to the development of more accurate nonlinear dynamic models and improved vibration behavior of mechanical components, to assessing neutron sensors through unique neutron beams and advancing the manufacture of smart structures through Ultrasonic Additive Manufacturing, their established scholarship is well respected.

Our faculty's collaborations with industry and government agencies have far-reaching impact into the future. Our Center for Automotive Research (CAR) has worked on system fault diagnosis and prognosis through programs funded by the National Science Foundation (NSF), the U.S. Department of Energy (DOE) and automotive industry partners.

Investigations of micro-hot-embossing have biomedical applications in areas such as cancer research and device design to promote wound healing. Our Movement Lab seeks to understand the basic principles underlying predictive models for human movement and, in collaboration with researchers at Carnegie Mellon University, develop a rational basis for the design of robotic prosthetic devices. Our Aerospace Research Center (ARC) is at the forefront of turbine deposition research, developing new technologies and designs for diagnosing turbine deposition mechanisms and exploring effective design solutions. And, current research on the mechanical systems of the ant neck could lead to micro-sized robots that combine soft and hard components similar to the ant's body.

Looking ahead, the department will continue on its sound trajectory of excellence in education, discovery and dissemination of original knowledge, while preparing the next generation of engineers for success.

AHMET SELAMET, *Professor & Chair*
Department of Mechanical & Aerospace Engineering

FACULTY RESEARCH

UNDERSTANDING THE FAILURE MECHANISMS OF THIN-WALLED CERAMIC CROWNS

BY PROFESSOR NORIKO KATSUBE

In the dental industry today, there is an increased demand for crowns that look like real teeth. Ceramic crowns are more biocompatible and more esthetic than metal-based restorations. However, ceramics are brittle and failure from fracture continues to be a major concern.

Several high strength ceramic materials have become available and are being used in dental practices. Their superior fracture resistance and good esthetics make them suitable for thin-walled monolithic ceramic crown applications similar to metal.

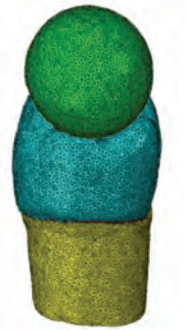
These materials are often introduced into the market without a basic understanding of their clinical performance because long term controlled clinical trials are not required, and are both time consuming and expensive. In collaboration with Professor Robert R. Seghi, College of Dentistry, and Professor Stanislav I. Rokhlin, Materials Science Engineering, Professor **Noriko Katsube** and her research group have developed computational simulation models that can predict survival probability of single ceramic crowns.

It has been clinically observed that most failures initiate from the cement interface for adhesively retained ceramic crowns. Ceramics are known to fatigue as a result of cyclic (mastication) load and oral environment. Life prediction mathematical tools are developed by combining experimentally-determined surface flaw size distribution and slow crack growth parameters of ceramic and finite element stress calculations on the basis of a fracture mechanics-based statistical failure probability model.

With the advent of digitized technology such as computer-aided manufacturing and high resolution scanners, and the availability of image-processing software, mathematical prediction tools are currently extended to structural assessment of actual crowns with complex geometry. In addition to ceramic fatigue, the adhesive cement and bonding conditions are known to deteriorate under cyclic loads in an oral environment.

Fractured ceramic crown

There is a need to understand the sequence of events that lead to ceramic fracture. Under cyclic loading from mastication, the relationship between interface stresses and its influence on ceramic fatigue and bond integrity must be clearly understood in order to optimize the clinical longevity of thin-walled ceramic crowns. Katsube's research indicates that the combination of well-designed experiments and mathematical modeling efforts could be used to help predict long term clinical survival of these new restorative techniques.



Finite element model

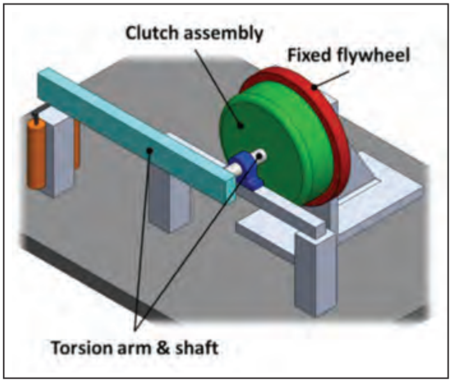
DYNAMICS OF DISCONTINUOUS NONLINEAR SYSTEMS: DEVELOPMENT OF ACCURATE SIMULATION MODELS AND IMPROVED VIBRATION BEHAVIOR OF MECHANICAL COMPONENTS BY DR. RAJENDRA SINGH

Dr. **Rajendra Singh**, a professor in mechanical and aerospace engineering, and director of the Acoustics and Dynamics Laboratory and the National Science Foundation Smart Vehicle Concepts Center, is leading a group of researchers in the study of the dynamics of discontinuous nonlinear systems.

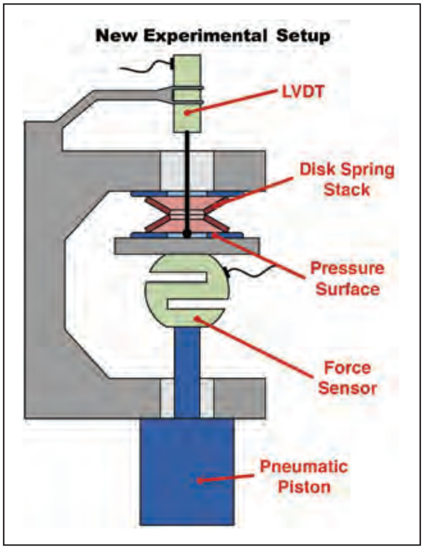
Researchers have been studying the transient dynamics of torsional systems with discontinuous (non-analytical) nonlinearities; many vehicle driveline components contain clearances, multi-staged elastic and dissipative elements. This research is driven by a demand for more accurate vehicle driveline models that can be used for refining and troubleshooting products. The development of such validated simulation codes provides significant economic impact, as they can reduce expensive physical testing and product warranty costs.

A combination of analytical, numerical and experimental methods is utilized to develop component and systems-level simulation tools. To validate models, a novel laboratory experiment has been developed to yield benchmark vibro-impact measurements in time domain. The accuracy and reliability of such driveline simulation tools require an enhanced understanding of the transient dynamics of discontinuous nonlinear torsional systems, which provides fertile ground for fundamental work for graduate students.

In a related study, compact disk stacks are being tested because they have a unique tuning capability, with strong implications for use as vibration isolators, sensors and preload devices. However, they are highly nonlinear structural elements. Latest experimental results exhibit both continuous and discontinuous nonlinear behavior (and accompanying hysteretic effect due to friction at the edges or interfaces) over a wide operating load range. Such piecewise discontinuous nonlinearities and transitional stiffness regimes cannot be explained using existing mathematical formulations. New characterization experiments should lead to the development of more accurate nonlinear dynamic models and improved vibration isolation concepts. Insights gained from ongoing doctoral research could also be used to investigate potential interfacial sensor and possible energy harvesting applications.

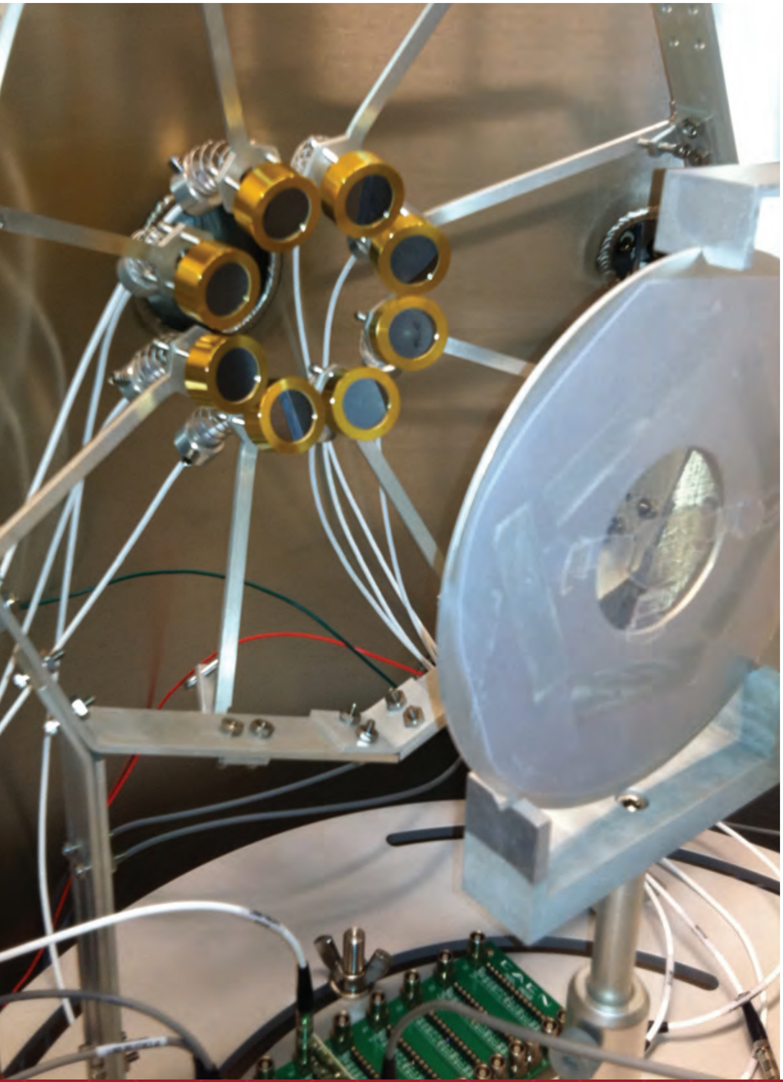


^ *New torsional experiment to measure nonlinear dynamic behavior*



IMAGING AND QUANTIFYING LITHIUM IN A "LIVING" LI-ION BATTERY WITH NEUTRON BEAM

BY ASSISTANT PROFESSOR LEI R. CAO



Many *in situ* tools have been developed to aid in the advancement of a lithium-ion (Li-ion) battery for efficient and safe energy storage. The common limitation shared by all current technologies is the inability to directly observe phenomenon associated with lithium-ion transportation, which may account for the unresolved challenging problems related to short battery cycle life times and safety concerns.

Assistant Professor **Lei R. Cao** and his research group have built a neutron beam facility at The Ohio State University Research Reactor (OSURR), which will deliver a well-thermalized, pencil-sized neutron beam to a working bench where various instrumentation can be set up for materials characterization, such as a Li-ion battery.

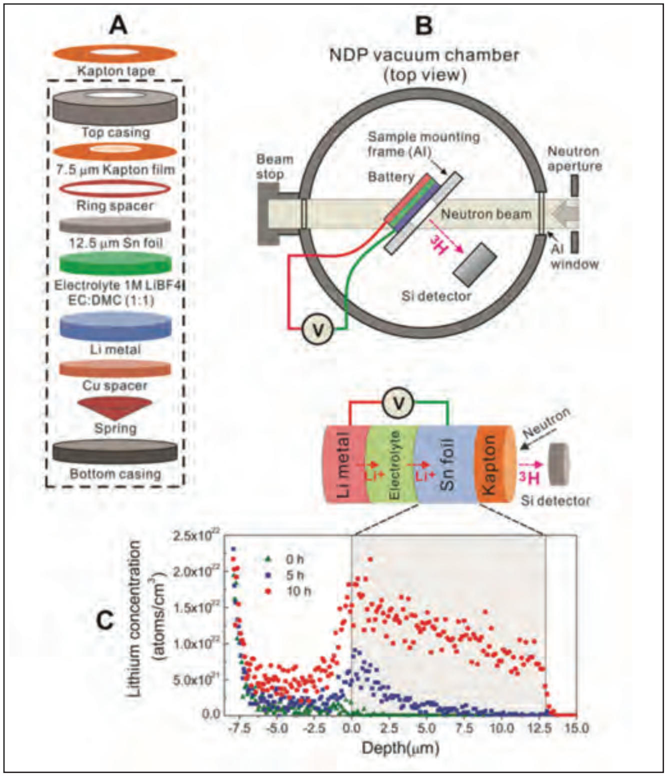
In operation since 2012, OSURR is one of very few facilities of its type available in the U.S., providing an indispensable tool for multidisciplinary investigations of advanced materials across regions and campus. One of the significant successful applications is the development of a neutron-based analytical technology termed as neutron depth profiling (NDP) for imaging the flow of Li-ion in batteries. Neutron technique stands out from many probing particles for its high penetration power and highly probable nuclear reactions, with a few rare light elements (e.g., Li, B, He). Given a proper nuclear instrument setup, the selective nature of the nuclear reaction between a neutron and a ^{6}Li atom results in a spectrum that tracks and counts lithium atoms directly.

An *in situ* measurement of an electrochemical cell was demonstrated by Cao, in collaboration with Marcello Canova, assistant professor of mechanical and aerospace engineering, and Anne Co, assistant professor of chemistry and biochemistry, to investigate lithium transport phenomena in

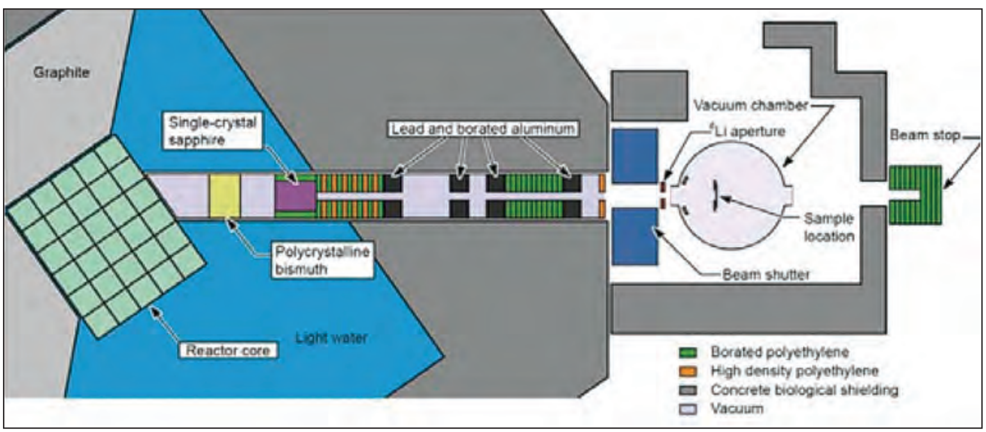
< *Multi-detector setup at OSURR for acquiring Li-ion battery data*

normal, working batteries during charging and discharging. This work is published in the September 1, 2014 issue of the journal *Angewandte Chemie International Edition*, and is recognized as a Very Important Paper (VIP) by the publisher. While this work has visualized and quantified the lithium atoms' transportation in a Sn electrode during battery charging and discharging, the developed *in situ* technique is also applicable to Li-ion batteries with thicker electrodes and to study SEI dynamics. Findings suggest that NDP could one day help explain why rechargeable batteries lose capacity over time, or sometimes even catch fire. For this study, the research team developed their methodology at OSURR, and acquired the final data at the National Institute of Standards and Technology's Center for Neutron Research (NCNR) in Gaithersburg, Maryland.

The high-intensity, size-adjustable neutron beam provided by the OSURR is also ideal for testing and evaluation of neutron sensors. Researchers from universities and national laboratories have come to Cao for solving their problems in developing neutron sensors, and for exploring new research opportunities.



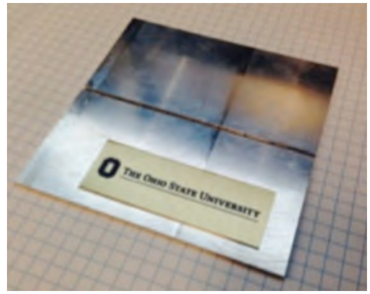
(A) A schematic representation of the battery components; (B) Illustration of the NDP chamber at NCNR; and (C) Snapshot of the in situ NDP spectra showing Li transport during charging/discharging a battery



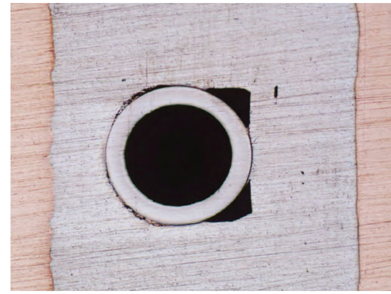
Layout of neutron beam facility built by Dr. Cao at OSURR for performing Li-ion battery characterization and neutron sensor studies

ADVANCING THE MANUFACTURE OF SMART STRUCTURES THROUGH ULTRASONIC ADDITIVE MANUFACTURING

BY PROFESSOR MARCELO DAPINO



Aluminum hinge actuated by shape memory (NiTi) wires



Cross section of a build including copper, stainless steel, and a cooling channel

The Center for Ultrasonic Additive Manufacturing (UAM) in the Department of Mechanical and Aerospace Engineering conducts basic and applied research on ultrasonic additive manufacturing, including modeling of processes and composite materials, fabrication of metal-matrix composites and structures, and characterization of process-property relationships in UAM parts.

Ideally, an adaptive or “smart” system has its sensors, actuators and control electronics embedded in the host structure. Such configuration allows for more precise measurement of internal structural dynamics, finer control of local and global responses, and protection of delicate components against environmental factors like corrosion, wear or radiation. **Marcelo Dapino,** professor and Honda R&D Americas Designated Chair in Engineering, and his research team in the UAM Center seek to achieve smart structures with seamlessly integrated components.

UAM, a freeform fabrication process based on ultrasonic metal welding, makes it possible to produce fully-dense, gapless 3D structures composed of dissimilar metals (including hard and soft alloys), smart materials (including polymers, metal alloys and ceramics), heat management devices and electronic components.

As a solid-state manufacturing process, UAM combines additive joining of thin metal tapes with subtractive milling operations to generate near net-shape metallic parts without melting of the constituent materials.

The UAM system recently installed at The Ohio State University utilizes 9 kW of ultrasonic power, approximately an order of magnitude beyond previous systems. The increased power improves the ability of the process to achieve quality joints, involving a wide range of dissimilar metals.

Dapino’s group is engaged with GE Aviation in a research contract focused on the manufacture of aircraft engine components based on aluminum alloys, 3D printed with the UAM process. They have also received a research grant from the Government of Israel to study use of the UAM process to make 3D printed steel parts, a collaboration that also involves Columbus, Ohio-based Fabrisonic and researchers at the University of Tennessee.

Although UAM was originally developed to weld together dissimilar metals, Dapino’s group has successfully demonstrated that the UAM process can be used to seamlessly integrate metals and organic polymers. This development is important as the automobile industry seeks to design lightweight structures from dissimilar materials in order to meet fuel economy targets. A collaboration with the Air Force Institute of Technology, Wright-Patterson Air Force Base, is focused on developing components for civil infrastructures that one day may be manufactured and deployed in the field. Working collaboratively with researchers at MIT Lincoln Laboratory, Dapino’s team has shown that embedding shape memory materials into aluminum leads to structures with reduced coefficient of thermal expansion. At one-third the density of invar, these thermally stable alloys are attractive for mounting sensitive equipment, such as optical metering components, in satellites.

< *New 9 kW UAM system enables joining of dissimilar metals along with embedded sensors, actuators, and electronic components*

RESEARCH IN SYSTEM FAULT DIAGNOSIS AND PROGNOSIS – A TIMELY SUBJECT BY PROFESSOR GIORGIO RIZZONI

The presence of electrical/electronic (E/E) components and related software systems in automobiles has increased dramatically. In addition to enabling information, comfort and entertainment systems, embedded control systems make it possible for automobile makers to meet stringent regulations governing fuel economy, tailpipe emissions and safety in today's vehicles. The complexity of today's software and E/E systems, and their critical role in guaranteeing safety, reliability and regulatory compliance, presents significant challenges.

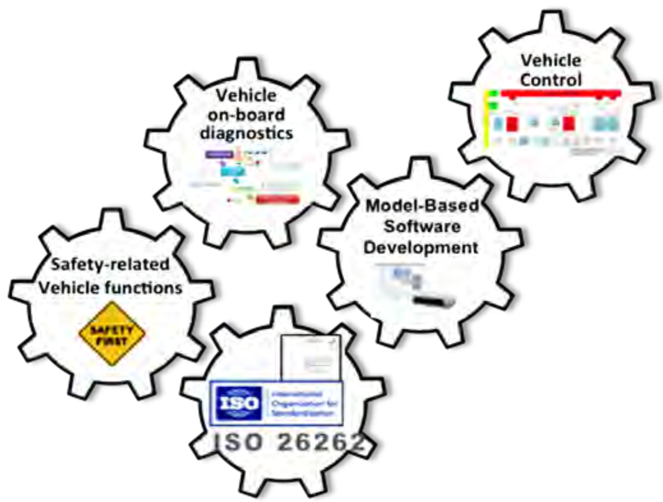
Professor **Giorgio Rizzoni**, director of the Center for Automotive Research (CAR) and Ford Motor Company Chair, and his team at CAR have worked on related problems for a quarter century through sponsored programs funded by the National Science Foundation (NSF), the U.S. Department of Energy (DOE) and automotive industry partners.

Rizzoni's team has explored the diagnosis, prognosis, and fault-tolerant control of engines and hybrid powertrains, vehicle electrical systems, and vehicle steer- and brake-by-wire systems. For the past few years, Rizzoni's research has been funded by DOE China-USA Clean Energy Research Center (CERC) – Clean Vehicles Consortium, a select committee of the DOE and various automobile manufacturers and suppliers.

The focus of this research is on designing methods that guarantee functional safety and fault-tolerance of electric and hybrid vehicles, with special emphasis on torque security (no unintended torque delivery) and on battery state of health diagnosis, life prognosis and safety. The project includes a demonstration of the implementation of a functional safety design process consistent with the ISO 26262, standard in The Ohio State University's EcoCAR 2 plug-in hybrid electric vehicle prototype.

Today, functional safety, or the ability to guarantee correct and safe operation of all safety-critical subsystems in the automobile by design, is the next frontier in the integration of E/E systems in modern automobiles. Recent events related to vehicle unintended acceleration and other safety-critical faults leading to extensive product recalls in the industry have attracted significant attention, emphasizing the importance of a systematic approach to designing diagnostic functions and fault tolerance into embedded control systems.

Tomorrow's car will have ever-increasing autonomy in governing the operation of its powertrain and vehicle functions. Self-optimizing hybrid powertrains that learn from their environment to minimize energy use, as well as autonomous vehicle functions, already exist. These advances have greatly benefitted from the use of model-based control design methods that accelerate system integration and control design. Professor Rizzoni's team is extending these advances by developing methods and processes to implement model-based functional safety in the control design process.



Vehicle performance, availability, reliability and safety

Ohio State's EcoCAR 2 – A Demonstration Program

Ohio State's EcoCAR 2 is fully operational and is used as a test bed for the CERC project. The vehicle, a Parallel-Series Plug-in Hybrid Electric Vehicle capable of 50 miles of all-electric range, features a 18.9-kWh lithium-ion battery pack with range extending operation in both series and parallel modes, made possible by an 1.8-L ethanol (E85) engine and 6-speed automated manual transmission. The front axle is powered by a 1.8L Honda engine clutched directly to a 6-speed automated manual transmission that drives the front wheels. A 90 kW electric machine is connected via belt to the transmission input shaft. The rear axle is powered by a 148 kW electric machine, connected to a single speed gearbox which drives the rear wheels. In addition, the vehicle has an onboard DC-DC converter to supply 12-V loads and an AC-DC charger allowing the vehicle to charge through a 208-V or 110-V outlet.

Educating Students – Preparing for Tomorrow's Technology

Ohio State is a leader in educating the next generation of system integration engineers for the automotive industry. A graduate course on the subject of system fault diagnosis and prognosis, taught by Rizzoni for more than 20 years, has attracted a wide variety of engineering students. The course, which focuses on model-based methods for diagnosis and prognosis, presents a mix of theoretical content and applications motivated by automotive industry needs, and culminates in the completion of a functional safety design project for a subsystem. Project examples include diagnosis and fault tolerance of steer- and brake-by-wire systems, and diagnosis of battery and electric drive systems in hybrid-electric vehicles.

STUDYING THE GROWTH AND MIGRATION OF CELLS USING MICRO-HOT-EMBOSSED POLYMER SURFACES

BY PROFESSOR REBECCA DUPAIX

Micro-hot-embossing, the subject of Professor **Rebecca Dupaix**'s research, has biomedical applications in areas such as cancer research and device design to promote wound healing. Hot embossing is a polymer processing technique that replicates a variety of micron and nano-scale surface features, such as microchannels, pyramids and wells, at a high level of accuracy. The resulting topographies can then be used to study the motion and growth of cells. Currently, hot embossing design relies largely on trial-and-error experimentation to establish processing windows that will create the desired microfeatures. However, optimizing this process through experimentation alone can be costly and time consuming.

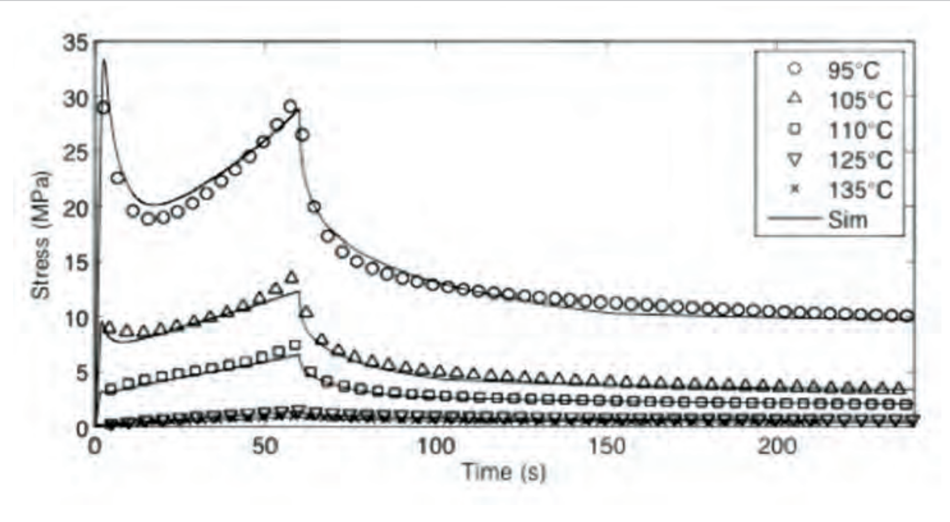
According to Dupaix, it is more practical to model hot embossing using finite element analysis, but to do so requires a constitutive model that can capture the material's highly temperature-dependent mechanical behavior around the glass transition temperature. In hot embossing, the molding process is performed at temperatures above the glass transition, where the polymer can easily flow and fill the fine features of the mold. The polymer substrate is then held while being cooled below the glass transition, such that the polymer hardens and maintains the relief shape of the die after removal. During die removal a variety of factors compromise feature replication, such as spring-back and adhesion, yet current finite element models of embossing are unable to simulate these important parts of the process.

The goal of this work is to model micro-hot-embossing of poly (methyl methacrylate) (PMMA) through 3D multi-scale finite element simulations utilizing a new constitutive model that captures the large-strain, temperature-dependent stress relaxation behavior of PMMA. PMMA is of particular interest due to its biocompatibility.

Dupaix's group has recently developed a new constitutive model that is able to capture both the stress-strain as well as stress relaxation behavior of PMMA at temperatures that span the glass transition and at very large levels of deformation. This model is a huge advance over previous polymer constitutive models that were much more limited. The model is currently being used in multi-scale finite element simulations to predict the final shape of microchannels, because of the significant difference in scale between the substrate (mm) and feature size (nm-µm).

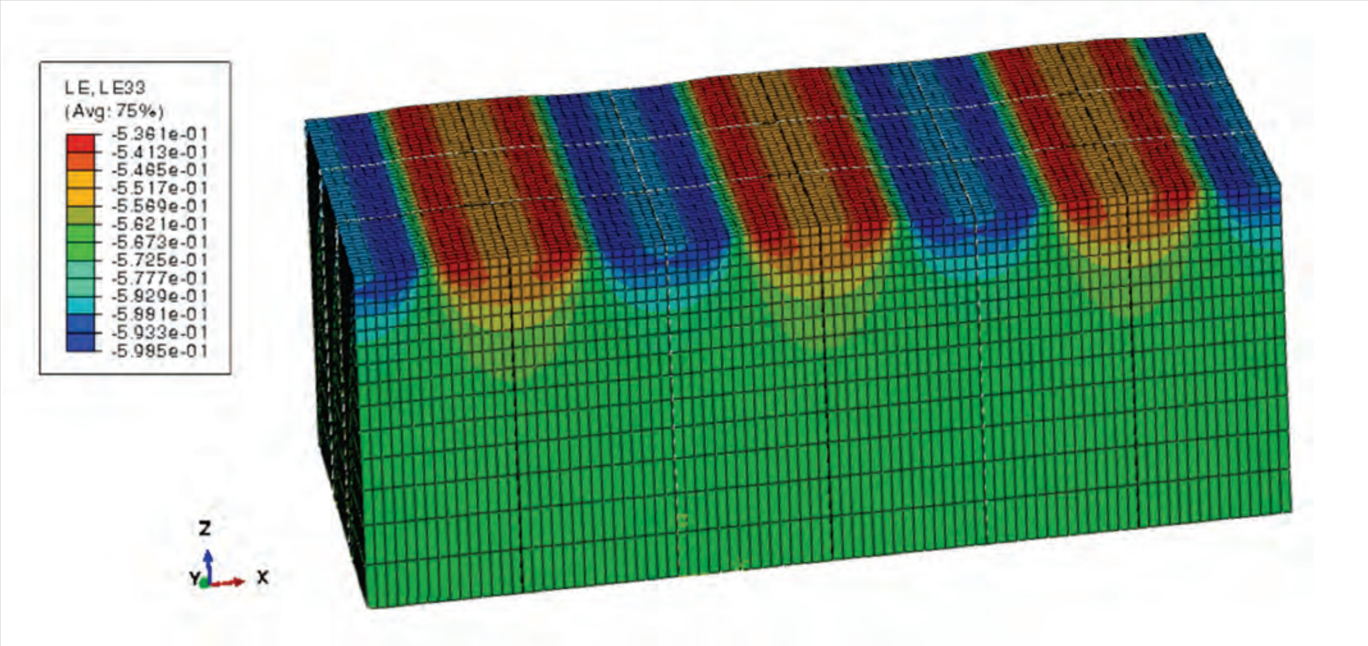
Dupaix's research team is also working on experiments to support the modeling effort. Collaborating with Professor Allen Yi (integrated systems engineering), they are able to conduct embossing experiments where molding and release temperatures can be varied to measure their effect on feature replication. The embossed parts are then used in directed cell growth studies, in collaboration with Professor Jessica Winter (chemical and biomolecular engineering).

This work has introduced a promising method of predicting micro-hot-embossing of PMMA. First, by capturing the key deformation mode of stress relaxation with the new constitutive model, spring-back trends can be predicted. Then, through 3D multi-scale finite element simulations, channel height can be predicted.



< Stress relaxation behavior, comparing experiments (symbols) to model prediction (line) at a held strain of -1.0 and temperatures spanning from Tg-10˚C to Tg+30˚C

v Strain in Z with reflected and repeated geometry to show 3 embossed channels (blue region is valley of channel, red region is peak of channel), 145˚C, 20lbf, Y-direction is along length of channel, X-direction is across the width of channel, Z-dirction is the height on the channel



CHALLENGES TO GLOBAL AVIATION BY PROFESSOR JEFFREY BONS

As the primary means of propulsion for civilian and military aircraft, gas turbines play a pivotal role in determining the future growth and viability of the aircraft industry. Gas turbines (jet engines) are continuous flow propulsion devices and require enormous quantities of uninhibited airflow to function properly.

The large fan and compressor at the front end of the jet engine can be thought of as an enormously powerful vacuum cleaner. At take-off condition, a modern high-bypass turbofan like the GE90 will pull in the equivalent of a football field of air (one meter deep) every two seconds. With such a huge volume of air entering the fan, it's prohibitive to install a filtration device to protect the engine components from foreign object damage (FOD). Fortunately, airport runways are generally kept clear of debris and bird strikes are rare events, so the number of engines damaged by FOD is very small. More damaging in the long term, however, is the cumulative effect of imperceptibly small (micron sized) particulate, continuously ingested by the rotating turbomachinery inside engines. Fine particulate matter from human-generated (smog) or natural (volcanic ash) sources scrapes against metal surfaces causing erosion and compromising the integrity of crucial seals inside the compressor. This reduces the efficiency of the compressor, translating directly to higher fuel use for the same distance travelled.

As airborne particles make their way back to the hot section of the engine (combustor and turbine), they soften and can thus deposit on metal surfaces, clogging crucial cooling paths and damaging fuel nozzles. Over the past 40 years, numerous disastrous aircraft encounters with volcanic ash plumes have chronicled the hazards of flying in densely particle-laden airstreams. The 2010 Eyjafjallajökull, a volcanic eruption in Iceland, underscored the general sense of caution and uncertainty in the airline industry with regard to airborne contamination of engines in flight.

Fortunately, volcanic ash eruptions into the tropopause (where most aircraft fly) are rare events. However, the cumulative effect of more dilute suspensions of particles can be just as damaging over time as a concentrated plume of volcanic ash.

While the first century of aviation saw growth in air travel primarily among the developed economies of North America, Europe and the Pacific Rim, the 21st century growth markets are in Asia and the Middle East. Clearly, a new era has dawned for assessing the effect of long-term exposure to fine particulate, as the growth markets (and particularly mainland China) have particulate concentrations five to 10 times that of traditional markets. This has piqued the interest of engine operators and manufacturers as the required maintenance and overhaul frequency for engines operating in these "dirty" environments has increased sharply.

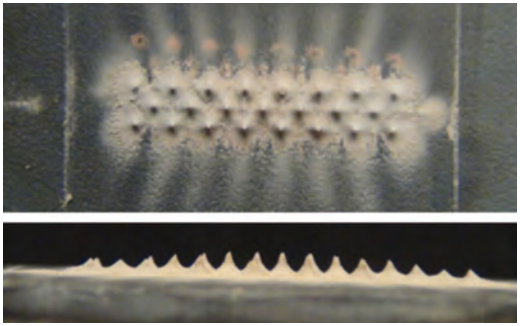
At the same time, engine manufacturers are scrambling to both understand the phenomenon and develop new technologies and designs that are more robust to particulate erosion and deposition. The Gas Turbine Deposition Research Facility (GTDRF) at The Ohio State University has figured prominently in government and industry efforts to tackle this challenging design problem. With funding from both the public and private sectors, the GTDRF, under the direction of Professor **Jeffrey Bons**, has developed state-of-the-art facilities for diagnosing turbine deposition mechanisms, as well as vetting effective design solutions. These facilities are part of the Aerospace Research Center (ARC) located near Ohio State's Don Scott Airport in Columbus, Ohio.

To tackle such a complex problem as particle deposition requires a merger of multiple disciplines: thermodynamics, fluid mechanics, heat transfer and structural mechanics to name a few. It also requires a wide array of experimental and computational capabilities. The GTDRF has test facilities with capabilities ranging from the testing of full engine hardware, to sub-assembles and even fundamental particles impacting on flat metal plates. GTDRF researchers are currently working with several industrial sponsors to document deposition phenomenon and aid in developing “deposition-resistant” (or resilient) designs. This includes a substantial effort to develop computational models with predictive capability to someday accurately predict deposition evolution over the life of an engine, and thus prescribe appropriate maintenance cycles to the industry. Students make use of the Ohio Supercomputer Center (OSC) to run complex multi-physics simulations of particle-laden flows in hot gas streams.

As evidence of the demonstrated interest of the industrial community in the capabilities at Ohio State, the State of Ohio has invested $2.2M through the Center for Intelligent Propulsion and Advanced Life Management (CIPALM) in a new turbine deposition facility (TuRFR II) that is under construction at ARC. The new facility will be able to operate at significantly higher temperatures (up to 2700F compared to 2000F for TuRFR), and has many new state-of-the-art diagnostic capabilities. The facility, shown side-by-side with the original TuRFR, (image at right), is expected to be operational in January 2015, and will be open for use by a wide variety of sponsors from both the public and private sectors. It will undoubtedly keep Ohio State at the forefront of turbine deposition research for many years to come.

TuRFR (old) on left and TuRFR II (new) on right located at GTDRF

A



B

< *Deposit generated at GTDRF on (A) turbine nozzle guide vanes and (B) flat plate impingement cooling*

RESEARCH STUDIES MECHANICAL SYSTEMS OF ANTS AND DESIGN APPLICATION OF SOFT-BEARING COMPONENTS AND ROBOTS

BY ASSISTANT PROFESSOR CARLOS CASTRO

Insects have been optimized for form and function over millions of years. Ants in particular have evolved capacity to lift and manipulate extraordinarily heavy and bulky loads relative to their own mass. A team of researchers including Assistant Professor **Carlos Castro**, Associate Professor Blaine Lilly and former student Vienny Nguyen have been studying these tiny mechanical systems to learn how their structural and material design enable such impressive mechanical function.

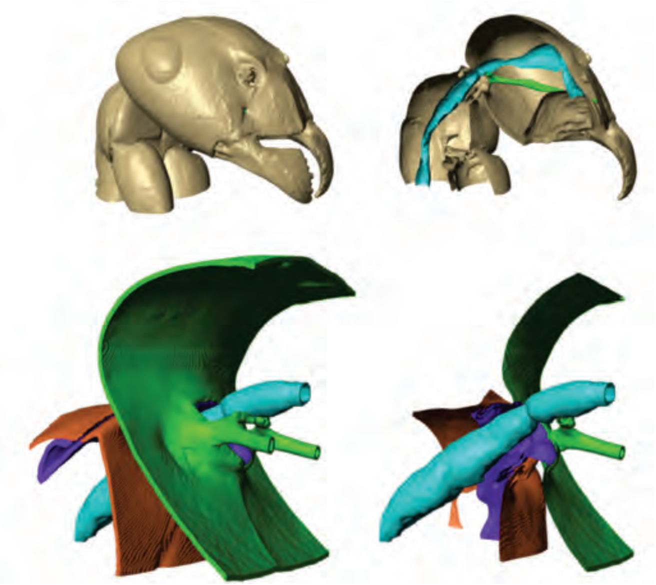
Other researchers, primarily from the field of entomology, have long observed ants carrying hundreds or even a thousand times their own weight, which allows them to cooperatively haul leaves, insects or even small birds. While a few prior studies have investigated the attachment forces of the ant feet, this work has focused on the neck joint as a critical load-bearing component of the ant.

Insect joints are mechanically distinct from those of vertebrates. Where vertebrates employ stiff components connected with physical constraints (i.e. ball and socket) to constrain motion, insect body and limb segments are connected by soft, membranous material of varying geometries. The neck is the one soft material component of the ant that withstands the full weight of the load carried at the mouth. Given the recent interest in lightweight and soft material robotic systems, the research aims to understand design principles of naturally optimized systems to guide design of soft load-bearing components and robots.

Castro and his colleagues developed a framework to reverse engineer the ant neck joint design using a combination of mechanical testing, micro-computed tomography (microCT), scanning electron microscopy imaging, structural modeling and finite element analysis. Initial studies, recently published in the *Journal of Biomechanics*, focused on the Allegheny Mound Ant, which is not particularly known for its load carrying capacity, but is easily found in local fields of central Ohio. Due to the unorthodox sample of interest, the use of traditional mechanical testing equipment was not possible. Therefore, Nguyen and Lilly built a custom centrifuge mechanical testing device to carry out stress-strain tests on ant specimens. Surprisingly, experiments revealed that the neck joint of even a common field ant could withstand upwards of 300 times the body weight of the ant before incurring any damage, and up to 5,000 times the weight of the ant before rupturing.

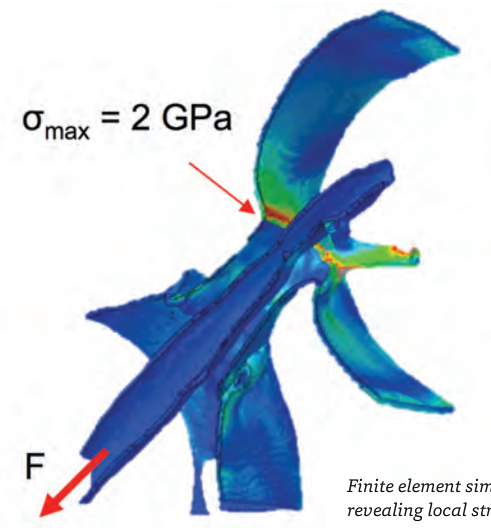
Current research on the project has focused on imaging and testing the interface between hard and soft materials at the head to neck transition. Hiromi Tsuda, a mechanical engineering undergraduate student, has begun using scanning electron microscopy to image dissected specimens in order to quantify the internal microstructure of the interface; a new collaboration with Professor Noriko Katsube has led to the development of a micro-mechanical finite element model of the membrane-exoskeleton interface.

The ultimate goal of this research is to establish a foundation for optimized design of mechanical components and systems based on design principles learned from the ant. With the ongoing advances of additive manufacturing, our ability to mimic complex structures found in nature has expanded. Looking forward, it's possible that this research could lead to micro-sized robots that combine soft and hard components similar to the ant's body.

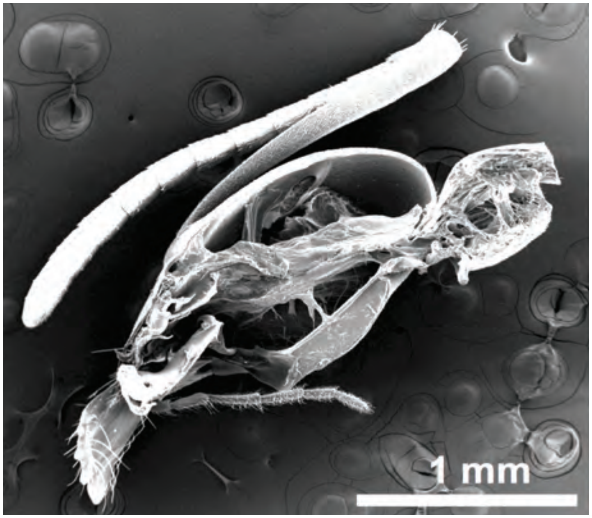


MicroCT-based structural model of the ant head and neck

Castro studies how ants carry a thousand times their own weight as part of research project



Finite element simulations of neck joint revealing local stress concentration



Scanning electron micrograph of internal structure of head and neck

PREDICTIVE MODELS FOR HUMAN MOVEMENT: WHY WE WALK AND RUN THE WAY WE DO

BY ASSISTANT PROFESSOR MANOJ SRINIVASAN

Humans and animals walk, run and perform other movements more stably and robustly, and with less energy cost, than most walking robots.

Assistant Professor **Manoj Srinivasan**'s Movement Lab seeks to understand the basic principles underlying such movement, and to determine how our nervous system accomplishes such tasks. Understanding these principles may inform the building of better walking robots, more natural prosthetic and orthotic devices, and diagnoses and treatment of movement disorders.

Healthy human legs and muscles are capable of much more than normal walking and running, but among all the different possibilities, we walk and run in a stereotypical manner. Srinivasan and his students have contributed to the hypothesis that humans move in a manner that minimizes energy consumption, using a mixture of simple experiments, basic mathematical theory and large-scale computation.

Energy minimization is predictive of human movement. Using mathematical models of a person, ranging from the very simple to complex, Srinivasan and his team have shown numerical optimization of the energy required to move that can explain various features of steady walking and running. More remarkably, recent work by Srinivasan's students has shown that humans seem to minimize energy consumption even in unusual tasks, not only in normal walking and running.

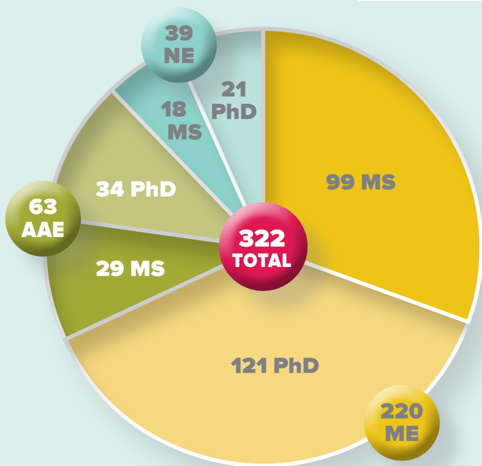
For instance, humans seem to be energy-optimal even in unpracticed movements such as walking sideways. Humans use a mixture of walking and running to reduce energy consumption when constrained by time, and humans seem to use smooth turns as opposed to sharp turns as predicted by energy optimality for walking with turns.

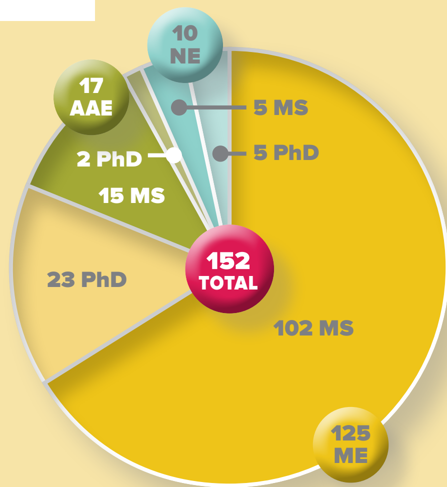
In work supported by a National Science Foundation CAREER Award, Srinivasan and his students are working on expanding the energy optimality theory to be able to predict a vast array of experiments to carefully circumscribe the applicability and limitations of the theory. Current work in the Movement Lab also seeks to characterize the control system that humans use to walk and run stably without falling down and, in collaboration with researchers at Carnegie Mellon University, develop a rational basis for the design of robotic prosthetic devices.

AUTUMN SEMESTER 2014

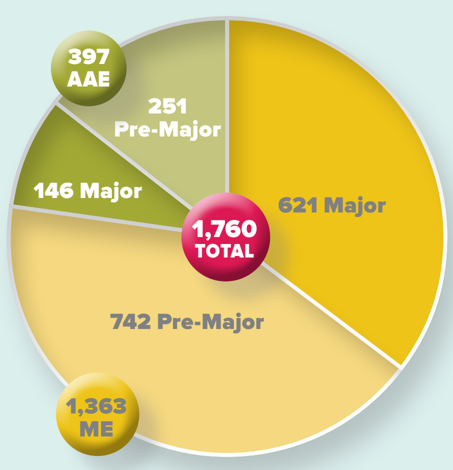
CURRENT STUDENTS | DEGREES GRANTED (SU13–SU14)

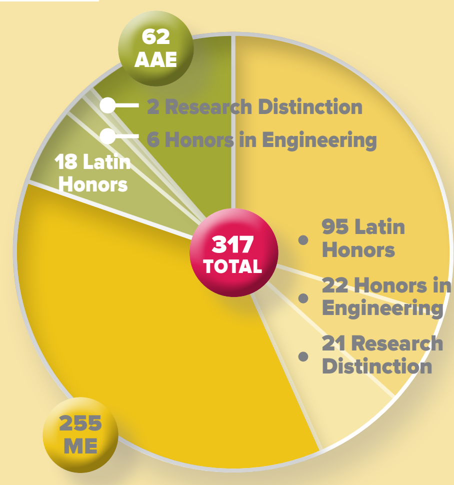
GRADUATE PROGRAM





UNDERGRADUATE PROGRAM





FACULTY RECOGNITION

MAE has an excellent academic reputation among peer programs and within several major industry and government sectors. Research and teaching excellence attract the best and brightest students, providing an unparalleled learning experience. Several MAE faculty were honored in 2014 for their academic achievements:

Datta Gaitonde

Levent Guvenc

Gaitonde and Guvenc Elected to ASME Fellow Status

The Board of Governors of the American Society of Mechanical Engineers (ASME) elected Professors **Datta Gaitonde** and **Levent Guvenc** to ASME Fellow status.

Gaitonde, a member of MAE's aerospace engineering faculty since 2010, is also principal inves gator for the Collabora ve Center for Aeronau cal Science and John Glenn professor at Ohio State. Gaitonde is a world leader in the eld of advanced computa onal methods and their applica on to turbulent ows.

Guvenc joined MAE in 2014 as the newest member at the Center for Automo ve Research. He is recognized for signi cant contribu ons in applied robust control, mechatronics, coopera ve mobility of road vehicles, automo ve control and control applica- ons in Atomic Force Microscopy.

ASME confers the distinction of Fellow grade membership to candidates who have been nominated by their peers and selected by the Fellow Review Committee with final approval of the Committee of Past Presidents. These individuals are recognized for their distinguished career and engineering achievements.

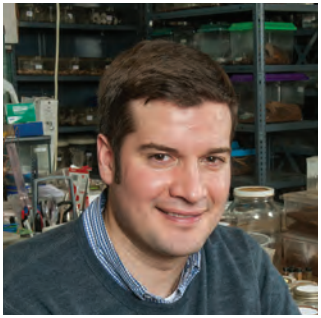
Gregory Named Fulbright Scholar

James Gregory, associate professor in MAE, was selected as a 2014-15 Fulbright Scholar. Grant funding will support Gregory's research at the Technion in Haifa, Israel in the aerodynamics of vertical-axis wind turbines and methods to control the flow to make turbines more efficient. The Technion, a one-of-a-kind facility for modeling dynamic stall for enhanced wind turbine performance, is ranked among the world's top 100 universities. Fulbright Scholar recipients are selected by the Council for International Exchange of Scholars which administers the program for the U.S. Department of State.

Castro Receives NSF CAREER Award

Assistant Professor of Mechanical Engineering **Carlos Castro** earned a National Science Foundation CAREER Award for his research proposal titled, "A Molecular Force Sensor for Single Molecule Studies of Cellular Force Application." The award, which recognizes outstanding junior faculty, provides Castro with funding across five years.

James Gregory



Carlos Castro

Rob Siston

Bharat Bhushan

Castro will develop, calibrate, and implement a nanoscale molecular force sensor that is capable of measuring cellular traction forces of single membrane proteins and protein complexes. Results of his research will shed light on cellular function and guide the design of biomedical devices for applications such as cell sorting or biosensing. The nanoscale molecular force sensor will be constructed using nanotechnology and scaffolded DNA origami (DNA assembled into nanostructures with a pre-determined shape). The device is also intended to provide new insights into antigen detection and 3D fibrous environments by recording the cellular processes of migration.

A portion of grant funding will support the education and outreach mission of Castro's research, intended to increase the pipeline of students from underrepresented populations participating in research at the interface of engineering and biology. Castro, who directs the Nanoengineering and Biodesign Laboratory, will develop a biomolecular design and mechanics workshop to be offered through Ohio State's outreach efforts to middle and high school students.

The research will also be leveraged to develop a lab component for a course developed by Castro, "Mechanics of Biomolecular Systems."

Siston Presented Alumni Award for Distinguished Teaching

Rob Siston, associate professor, was presented one of Ohio State University's 2014 Alumni Awards for Distinguished Teaching.

Siston teaches the department's machine elements course and the neuromuscular biomechanics course. He is also the original developer and teacher of the popular Assistive Devices for Mechanical Engineering Capstone Design course, and was instrumental in "flipping" the machine elements course.

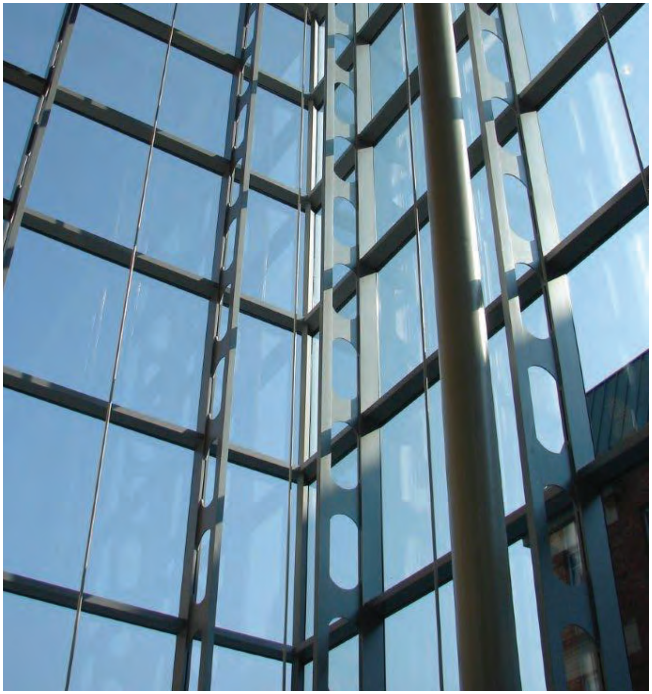
In spring 2013, Siston was presented the College of Engineering's David C. McCarthy Award which recognizes the contributions of junior faculty and staff to create more innovative and effective teaching and learning. That same year, he was also presented the College's Lumley Research Award.

In January 2011, the college presented him with the Ralph L. Boyer Award for Excellence in Teaching Innovation for formulating and implementing a senior capstone design course on designing assistive devices for persons with disabilities, involving teams of mechanical engineering students working with clinicians and occupational therapy students from the Dodd Hall Rehabilitation Hospital.

FACULTY RECOGNITION

In 2010, Siston was selected by the National Academy of Engineering to attend its Frontiers of Engineering Education Symposium, and received the Teaching Excellence Award from the department's Mechanical Engineering External Advisory Board.

Recipients of the University's Alumni Award for Distinguished Teaching are nominated by present and former students and colleagues, and are chosen by a committee of alumni, students and faculty. The recipients will be inducted into the university's Academy of Teaching, which provides leadership for the improvement of teaching at Ohio State.



Bhushan Receives 2014 STLE International Award

Professor **Bharat Bhushan** received the 2014 International Award from the Society of Tribologists and Lubrication Engineers (STLE).

The STLE International Award is the society's highest award and is given to individuals who have made outstanding contributions to the field of tribology and/or its related sciences. Bhushan will also receive lifetime honorary membership in STLE. Bhushan's research focus ranges from automotive, aerospace, hard disk and tape drives, beauty care (hair and skin), nanotechnology, bio/nanotechnology and biomimetics.

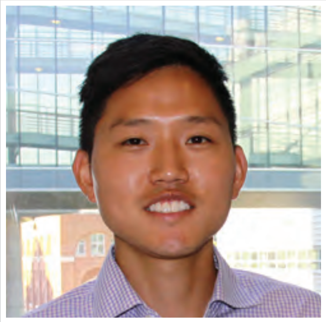
Bhushan is also an Ohio Eminent Scholar and The Howard D. Winbigler Professor, as well as director of the Nanoprobe Laboratory for Bio-& Nanotechnology and Biomimetics at Ohio State. He is also a Fellow of the American Society of Mechanical Engineers, the Society of Tribologists and Lubrication Engineers, and the Institute of Electrical and Electronics Engineers.

STLE is an international society with a membership of 4,000 technical professionals working in industry, academic institutions and government throughout the United States, Canada and around the world. STLE endeavors to bring together managers, engineers, scientists, technicians and craftspeople to learn and share "best practices" associated with the design and operation of modern machinery and equipment.

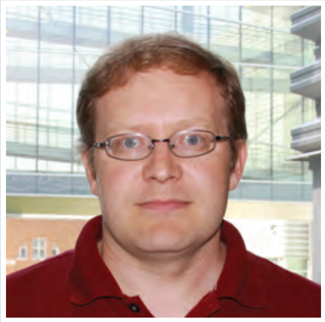
NEW MAE FACULTY

Levent Guvenc

Kiran D'Souza



Jonathan Song



Marat Khafizov

Sandra Metzler

The Department of Mechanical and Aerospace Engineering welcomed five new faculty to its already impressive ranks in 2014.

Professor **Levent Guvenc** joins the department as the newest faculty member at the Center for Automotive Research. **Kiran D'Souza**, assistant professor, works in the Gas Turbine Laboratory of the Aerospace Research Center. **Jonathan Song** is assistant professor and principal investigator of the newly established Microsystems for Mechanobiology and Medicine Laboratory. **Marat Khafizov**, assistant professor, directs the laboratory for Thermal Properties of Materials for Extreme Environments. **Sandra Metzler**, assistant clinical professor, joined MAE in 2014 and currently teaches in the Capstone Design Program.

THE OHIO STATE UNIVERSITY

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

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