Dear Alumni and Friends,

Stanford’s Mechanical Engineering Department thrives on the new research ideas we create and the anticipation of how these ideas might change society in the future. We will share a few of these research ideas with you in this issue of ME News.

For the future of efficient energy conversion, diagnostic tools that monitor combustion will be very important. Ron Hanson’s lab continues to be a leader in pioneering laser diagnostic tools used in fundamental studies of combustion science. Currently, one of his research groups is working on sensors which characterize and control combustion efficiency and pollutant emissions. One particular diagnostic concept, called tunable diode laser absorption (TDLAS), is utilized to monitor and control several combustion and propulsion systems, including pulse detonation engines, scramjets, coal-fired combustors and gasifiers, and internal combustion engines. In addition, these sensors play a key role in Stanford investigations of fuel chemistry aimed at understanding the ability of oxygenated fuels to reduce soot formation in engines.

Our research in fuel cells technology is entering the process of transitioning to industry. Juan G. Santiago’s group is working with a major automotive corporation to incorporate his group’s advanced water management methods to improve the performance of automotive fuel cells. This work is currently being evaluated by the company’s production group in a series of demonstration and feasibility experiments.

Featured Articles

Under Parviz Moin’s leadership, our department has attracted a new center called the Predictive Science Academic Alliance Program (PSAAP), one of five centers selected by the U.S. Department of Energy. Parviz has written an article for this issue of the newsletter introducing the research expectation for this program and explaining how the “predictive science” process will be applied to the simulation of air-breathing hypersonic vehicles.

This issue also features the research work of three of our newest faculty members. Gianluca Iaccarino is developing an innovative approach to computational engineering predictions which account for error and uncertainty, using improved physical models and performing realistic simulations on massively parallel computers. He shares highlights of his analysis of the dispersion of biological agents in the atmosphere and their potential impact on air quality in urban areas. Xiaolin Zheng’s interest in the interface among nanomaterials, energy conversion and biology is evident in three of her current projects: building solar cells with nanowires; fluid optimization for nanoscale sensing; and, flame synthesis of nanomaterials for energy conversion systems. Finally, Marc Levenston’s research in biomechanics, mechanobiology and tissue engineering seeks to understand soft tissue physiology and function, and then apply that knowledge in the development of replacement tissues.

I hope this issue of ME News is of interest to you and serves to communicate the exciting future of our department, as well as the exceptional quality of our faculty, students and staff. Please feel free to contact me or other members of our faculty for further information on any of our programs.
Predictive Computations Aim at Changing Engineering Practice

Gianluca Iaccarino

“Prediction is very difficult, especially if it is about the future.”
N. Bohr, Nobel Laureate in Physics

The last three decades have seen the rise of computer-aided engineering in almost every industrial sector. Today, many aspects of product development, design, optimization, performance analysis and certification, rely heavily on numerical simulations.

In spite of their wide use, computer predictions of real-life phenomena remain challenging and it is very difficult to evaluate their accuracy rigorously. Specifically, a generic computational model is built upon physical laws and transformed into a mathematical model; then, a numerical algorithm is used to fast-forward the model from an initial (known) state towards the future. Each of these steps is subject to error, making predictions using computers problematic. To complicate matters, we must account for potential uncertainty (lack of knowledge) about the system we want to predict. Namely, unexpected operating conditions or manufacturing tolerances may introduce differences between the intended design and the actual components.

My interest is fluid dynamics and heat/mass transfer in complex systems for a variety of applications. My research aims at developing genuine computational engineering prediction methods which objectively account for errors and uncertainties. In my research lab, we focus on the introduction of improved physical models and innovative numerical algorithms to perform realistic simulations on massively parallel computers. In addition, we develop efficient probabilistic approaches to quantify the impact of uncertainties on the simulation results. The combination of these activities results in a truly interdisciplinary research program with collaborations across several departments at Stanford: Mechanical and Chemical Engineering, Computer Science, Mathematics, and the Institute for Computational and Mathematical Engineering (ICME).

One of my current projects involves analysis of the dispersion of biological agents in the atmosphere and their potential impact on air quality in urban areas. The ability to simulate the mass transport and diffusion processes of a variety of agents ranging from long molecular chains to rod-shaped viruses is challenging because it involves a variety of physical scales. We are developing constitutive models to characterize different classes of agents.

At low concentrations, aerosolized particles can be treated as passively transported by the underlying wind field, whereas at large concentrations they directly affect air motion and the flow must be treated as a non-Newtonian solution. This difference is important only in the region immediately close to the release location, but the resulting cloud might evolve in different ways. Figure 1 illustrates two different release scenarios in downtown Chicago. Each picture shows iso-concentration clouds 10 minutes after the initial release. The location of the release was changed by less than 200ft, but it resulted in a cloud evolution that is considerably different because of the high wind above the Chicago River. The quantification of the uncertainty in the location of the release, its initial concentration and interaction with the underlying air motion and, finally, the effect of atmospheric conditions are all goals of our current research. In addition, the ability to perform the simulation using an actual, detailed building layout rather than an idealized environment provides increased confidence in the predictions. This was accomplished by using a fast grid-generation technique we have developed, using topographical maps as the input to the computational procedure.

Another example of the usefulness of our predictive computational tools is the design of turbines in modern jet engines. Until now, detailed numerical simulations of the external aerodynamics, the internal passages and the heat transfer across the metal structure have been beyond the capability of the computational tools used in blade design. In addition, uncertainties associated with the manufacturing process – for the internal passages and the cooling holes, for example – resulted in wide tolerances and potentially large safety margins. The numerical tools we are developing in my lab will enable probabilistic analysis of the flow and heat transfer in turbine blades, thus leading to a revolution in the design of such components.

Other current projects in my group include the aerodynamic analysis of Formula 1 tires and the design of thermal protection systems for planetary exploration vehicles. In all cases, the goal of our research is to change computational engineering by enabling predictive simulations with objectively quantified confidence. It is an uncertain path, but one worth traveling. Gianluca Iaccarino received his B.S. and M.S. degrees in Aeronautical Engineering from the University of Naples, Italy in 1992 and 1993 respectively. He served as research scientist at the Italian Center for Aerospace Research in Capua, Italy and as Research and Development Engineer at Stanford prior to earning his Ph.D. in Mechanical Engineering from the Politecnico di Bari, Italy in 2005. He has been an Assistant Professor at Stanford’s Mechanical Engineering Department, in the Flow Physics and Computational Engineering group, since January 2007.

Figure 1. Simulated release of a biological agent in downtown Chicago depicting an iso-concentration cloud predicted 10 minutes after the initial release. The cloud on the left is contained by the surrounding buildings. The cloud on the right is captured in the high wind region above the Chicago River and quickly transported downstream.

Naples, Italy in 1992 and 1993 respectively. He served as research scientist at the Italian Center for Aerospace Research in Capua, Italy and as Research and Development Engineer at Stanford prior to earning his Ph.D. in Mechanical Engineering from the Politecnico di Bari, Italy in 2005. He has been an Assistant Professor at Stanford’s Mechanical Engineering Department, in the Flow Physics and Computational Engineering group, since January 2007.
Nanomaterials have ubiquitous electronic, photonic, thermal, mechanical and chemical properties, and are powerful and versatile building blocks for a wide range of nanoscale electronics, optics, mechanical and sensing devices. Nanomaterials have the potential to directly impact important issues we are facing, ranging from energy crisis, to pollution, to healthcare.

My research group is interested in the interface among nanomaterials, energy conversion and biology. Specifically, we focus on

- Synthesis and assembly of functional nanomaterials and understanding the physical and chemical processes involved in the synthesis;
- Characterization and elucidation of the fundamental properties of nanomaterials;
- Applying nanomaterials in energy conversion systems, such as solar cells, fuel cells, and catalytic combustion; and,
- Applying nanomaterials for biosensing applications.

My research labs are located in both the Mechanical Engineering Research Lab and Building 570. My lab is joined by four energetic and entrepreneurial graduate students: Dong Rip Kim, Charles Avila, Pratap Rao and Etosha Cave. Current major projects include:

**Building Solar Cells with Nanowires**

We are developing third generation solar cells using semiconducting nanowires, which represents a promising approach to reduce cost and improve efficiency for photovoltaics. We have successfully shrunk the conventional solar cells onto a single silicon nanowire, which is about 200 times thinner than a human hair. The miniaturized silicon nanowire photovoltaic devices are ideal to power nanoscale gadgets, from consumer devices to bioterrorism monitors and in-body diagnostics. When the nanowire devices are scaled up vertically, they have great potential to improve the carrier collection and the overall efficiency.

**Flame Synthesis of Nanomaterials for Energy Conversion Systems**

Nanomaterials are attractive candidates for realizing electrodes and catalysts for fuel cells/solar cells due to their large surface to volume ratio. Flame is an attractive environment for material synthesis because of its high temperature, self cleaning environment and scalability. The goal here is to synthesize nanostructured metal oxide materials used in energy conversion devices with controlled physical and chemical properties.

Xiaolin Zheng received her B.S. (2000) in Thermal Power Engineering from Tsinghua University in Beijing, China. She completed both her M.A. (2002) and her Ph.D. (2006) in Mechanical and Aerospace Engineering at Princeton University, and then served as a postdoctoral scholar at Harvard University. In July 2007, she became an Assistant Professor at Stanford in the Thermosciences group of the Mechanical Engineering Department.

**Fluid Optimization for Nanoscale Sensing**

Silicon nanowires have been successfully demonstrated as real-time, label-free, multiplexing and femtomolar level accuracy biosensors in detecting a range of species, including proteins, viruses and DNAs. However, biosensing is frequently carried out inside a microfluidic channel and the transport of the analyte to biosensors limits both the time response and the sensitivity for sensing. The goal of this project is to enhance the analyte transport to the nanoscale biosensors by optimizing the flow pattern inside the microfluidic channel.

**In Memoriam**

A. Louis London (1913-2008)

Professor Emeritus Alexander Louis London died March 18, 2008 in Marin, California following a stroke. He was 94.

Professor London began his Stanford career in 1938 and became a leading authority on heat exchangers. He also helped form Stanford’s geothermal program in 1974 and worked with General Motors on gas turbines for cars. He retired in 1978, although he continued working with graduate students for years afterward.

His engineering research earned him the R. Tom Sawyer Award in 1997, the James Harry Potter Gold Medal in 1980, the Max Jakob Memorial Award in 1984 and induction into the Silicon Valley Engineering Hall of Fame in 1990.

From the Stanford Report
Biomechanics, Mechanobiology and Tissue Engineering

Marc Levenston

My overall research interests focus on understanding and controlling the complex interactions between biophysical and biochemical cues in controlling cell behavior, with a particular emphasis on the function, degeneration and regeneration of articular cartilage and fibrocartilage. Research in my Soft Tissue Biomechanics Laboratory (http://stbl.stanford.edu), located on the second floor of the Mechanical Engineering Research Laboratory building, combines contemporary approaches from a variety of disciplines including experimental and theoretical mechanics, cell and tissue culture, imaging, biochemistry and molecular biology.

Soft Tissue Biomechanics

Articular cartilage forms the bearing surface for articulating joints, and fibrocartilage forms structures such as the knee menisci that experience complex loading patterns and play important structural roles throughout the musculoskeletal system. These tissues have complex, heterogeneous microstructures, and interactions between the various extracellular matrix molecules give rise to highly nonlinear macroscopic mechanical properties that allow the tissues to perform important mechanical roles and enable normal load bearing activities. As we age, degenerative changes in joint tissues lead to compromised mechanical function, greater susceptibility to injury, and altered joint mechanics. These effects are highly interrelated, and play an important role in the initiation and progression of degenerative changes in disorders such as osteoarthritis. Current research in my lab aims to understand how the cells in the knee menisci respond to degenerative stimuli, including both biochemical signals present in early joint disease and mechanical overloads due to overuse. This work aims to build up an understanding of the patterns and mechanisms of cell-mediated degeneration in response to these stimuli, the alterations in tissue microstructure that result, and the resulting changes in tissue level mechanical properties that alter the patterns of load transfer in the knee joint. In the process, this work will identify targets for early diagnosis and treatment that have the greatest impact on mechanical function, improve our understanding of the constitutive behaviors of these tissues, and identify design targets for functional behaviors of “tissue engineered” replacement tissues.

Soft Tissue Mechanobiology and Tissue Engineering

Just as cellular activity can alter the mechanical behaviors of tissues by changing the tissue microstructure, the mechanical environment plays an important role in regulating the activities of the cells and guiding normal tissue development and maintenance. Understanding the mechanobiology of soft tissues can provide insights into normal tissue physiology and may also facilitate the development of biological replacement tissues with controlled cell behavior and mechanical properties (tissue engineering). Taking cues from tissue development, ongoing research in my laboratory aims to use coordinated manipulation of the biochemical and biomechanical environment to guide the formation of replacement tissues with appropriate spatial variations in cell behavior, tissue composition and mechanical properties. In recent years, undifferentiated progenitor cells (or adult stem cells) present in bone marrow and adipose tissue (fat) have received substantial attention as potential cell sources for tissue engineering, as they are relatively abundant, fairly easy to obtain, and have the potential to differentiate into various tissue types with appropriate stimuli. My group’s current research explores the coordinated control of biochemical differentiation factors and applied oscillatory mechanical stimuli to modulate the differentiation of mesenchymal progenitor cells from bone marrow and adipose tissue. If successful, combinations of different mechanical stimuli with biochemical factors promoting cartilage or fibrous tissue differentiation will produce a range of cell phenotypes and tissue matrix compositions characteristic of cartilage, fibrocartilage and fibrous tissue. Combined with related work exploring the development of biomaterials that provide specific “cues” to the cells, this research will facilitate the rational design of mechanically functional engineered tissues for the next generation of therapies to repair or replace damaged soft tissues.

Marc Levenston received his B.S. in Mechanical Engineering from the University of Florida, and his M.S. (1990) and Ph.D. (1995) degrees in Mechanical Engineering from Stanford. After postdoctoral training at M.I.T., Marc joined the Mechanical Engineering faculty of the Georgia Institute of Technology in 1998, and was promoted to Associate Professor in 2004. He returned to Stanford as an Associate Professor of Mechanical Engineering in January 2007, as part of the Biomechanical Engineering group.
Predictive Science Academic Alliance Program (PSAAP)

Parviz Moin

Early in March 2008, the U.S. Department of Energy announced the selection of its centers of excellence in computational science. Stanford was named as one of the five universities and will receive 17 million dollars over the next five years to conduct research in broad areas of predictive science. This new DOE initiative is called the Predictive Science Academic Alliance Program (PSAAP) and involves sixteen faculty members from Stanford’s departments of mechanical engineering, computer science, chemical engineering, aeronautics and astronautics, and mathematics. Stanford researchers will collaborate with colleagues at the University of Michigan and the State University of New York at Stony Brook on aspects of the work. The majority of the effort will be in ME’s Flow Physics and Computational Engineering and Thermosciences groups.

The new PSAAP grant follows on a previous DOE Advanced Simulation and Computing (ASC) program at Stanford. In that 10-year, $45 million program, we developed a comprehensive, integrated simulation of a conventional jet engine. In the ASC program, we learned that an overarching problem, as a focal point of the overall effort, acts as an excellent catalyst to promote interdisciplinary research.

The overarching problem for the PSAAP Center is the simulation of air-breathing hypersonic vehicles. Air-breathing hypersonic vehicles are envisioned as a means for reliable low-cost, single stage access to space. These vehicles are highly integrated systems whose performance depends on complex physics and the interactions between all of their components.

Integrated physics of a hypersonic vehicle

Hypersonic flight starts at about Mach 5 (five times the speed of sound in air), beyond which the vehicle is powered by a scramjet (supersonic ramjet) engine. Scramjet powered air breathing vehicles are more efficient than rockets and can carry heavier payloads because they extract oxygen from the air for combustion and need not carry oxygen on board. The first hypersonic flight in 2004 of an aircraft shaped vehicle (with wings, tail, etc.) as opposed to rockets was NASA’s X-43 which successfully obtained thrust from a scramjet engine fueled by liquid hydrogen, (albeit it only lasted 11 seconds).

In Stanford’s PSAAP Center, we will develop a validated and verified simulation environment for unsteady physical phenomena in the hypersonic regime involving extreme speeds and temperatures. To validate the overall predictive capability, a suite of system-level data from previous and planned tests have been identified. World-class experimental facilities in the ME Department’s High Temperature Gasdynamics Laboratory (HTGL) will be used to conduct validation experiments for the key component physics and models. Verification methods will be developed and implemented as an integral part of our effort at both the component and the system levels. We will leverage advanced computer science methods developed at Stanford to ensure scalability (i.e., being able to efficiently run our codes on thousands of computer processors simultaneously), program correctness, and portability to future computer platforms.

The core of the proposed work concerns the high-speed flow around the vehicle and through its supersonic combustion propulsion system (scramjet), as well as the prediction of unsteady thermal loads on the vehicle structure and fuel (which is also used for cooling the vehicle’s structure). Moreover, the environment associated with hypersonic flight makes the prediction of the vehicle performance quite sensitive to disturbances and uncertainties and one must ensure robustness to unknowns, such as those associated with modeling errors. A fundamental characteristic of our integrated simulation environment will be the ability to control the numerical error present in the highly integrated computations. Research in uncertainty quantification in numerical simulations is an emerging field in computational science and is central to Stanford’s PSAAP effort.

Moving forward beyond the five-year duration of this program, next-generation supercomputers will be based on multi-core and streaming chip architectures for which the current message passing protocols may not be suitable. Accordingly, in collaboration with our colleagues in the Computer Science Department, the PSAAP Center will support a computer science research and educational effort on next generation programming environments and compiler developments for scientific computing.

Parviz Moin is the Franklin and Caroline Johnson Professor of Mechanical Engineering and Director of the Center for Turbulence Research and the Stanford PSAAP Center.
Thomas P. Andriacchi  
Distinguished Lecturer, BME Skalak Lecture, Columbia University, April 18, 2008

David W. Beach  
Sugden Family University Fellow, The Bass University Fellows in Undergraduate Education Program, Stanford University

Mark R. Cutkosky  
Professor Cutkosky and his gecko-inspired robot, Stickybot, were featured in the April 2008 issue of National Geographic and on ABC News (March 28, 2008)

Scott L. Delp  
Van C. Mow Medal (Bioengineering), American Society of Mechanical Engineers (ASME)  
Elected as Fellow of the ASME

Christopher F. Edwards  
John Henry Samter University Fellow, The Bass University Fellows in Undergraduate Education Program, Stanford University  
The Walter J. Gores Award for Excellence in Teaching, Stanford University, June 2008

J. Christian Gerdes  
Professor Gerdes and Kirstin Talvala (one of his Ph.D. students) received the Arch T. Colwell Merit Award from SAE International together with Sven Beiker and Karl-Heinz Gaubatz of BMW for their paper “GPS-Augmented Vehicle Dynamics Control”

Kenneth E. Goodson  
Editor-in-chief, Nanoscale and Microscale Thermophysical Engineering  
Associate Editor, ASME Journal of Heat Transfer

Ronald K. Hanson  
T. A. Wilson Lecture, Iowa State University, 2008

Kosuke Ishii  
Ruth and Joel Spira Outstanding Design Educator Award, ASME, 2008

Marc E. Levenston  
Stanford Tau Beta Pi Award for Excellence in Undergraduate Teaching, conferred June 2007

Adrian J. Lew  
NSF Career Award  
ONR Young Investigator Award  
Ferdinand Beer & Russell Johnston, Jr., Outstanding New Mechanics Educator Award, American Society of Engineering Education

Reginald E. Mitchell  
Dr. St. Claire Drake Award, The Black Community Services Center, Stanford University, May 2008

Parviz Moin  
Outstanding Achievement Award, University of Minnesota, April 2008

Heinz G. Pitsch  
NSF Career Award

Friedrich B. Prinz  
Elected as a Fellow of the American Association for the Advancement of Science, February 2008

Bernard Roth  
Honorary Ph.D., University of Paris (Pierre and Marie Curie), November 2007

Juan G. Santiago  
Outstanding Alumnus Award, Mechanical Engineering Department, University of Florida, April 2008

Sheri D. Sheppard  
Burton J. and Deedee McMurtry University Fellow, The Bass University Fellows in Undergraduate Education Program, Stanford University

Thomas C. T. Ting (Consulting Professor in Mechanics and Computation)  
Daniel C. Drucker Medal, ASME, 2008

Xiaolin Zheng  
DARPA Young Faculty Award  
ONR Young Investigator Award