# MEnews Summer 2014

Stanford | ENGINEERING
Mechanical Engineering

DEPARTMENT OF MECHANICAL ENGINEERING | STANFORD UNIVERSITY


Dear Alumni and Friends,

Welcome! It is my privilege to be serving as the new department chair and to have this opportunity to share with you the latest exciting developments. I know that you all join me in expressing warm thanks to my predecessor, Professor Fritz Prinz, for his years of service and great leadership as department chair. I learned much from Fritz during my five years of service with him as vice chair.

Our hiring activities over the past several years have set us on track for continued international leadership. We have appointed many faculty in core disciplinary areas from robotics to combustion, launched new areas with additional recruits, and substantially improved our gender and age demographics. In addition, during this time, eight of our untenured assistant professors have achieved tenure and are charting new and compelling research directions. This past year our hiring efforts continued with a search in Product Design, with a very promising outcome that we can communicate soon.

Our department has a remarkable history—and an impressive roster of current faculty talent—in theory and simulations. Some of these faculty have just led a major new, successful, proposal effort to the NNSA Predictive Science Academic Alliance Program II (PSAAP II). This issue features an article about the new program, which involves simulations at the forefront of solar conversion technology. This activity will set a new bar with its highly challenging set of multiphysics simulations for heat and fluid transport.

Mechanical Engineering faculty and students are leading a campus movement towards "hands on" learning and creative discovery. This movement, which is closely linked with the "maker" culture in society, offers a healthy balance with the surging popularity of computer science and the growth of online learning. The ME Product Realization Laboratory (PRL) has been leading this special educational activity in our department for decades, and has seen enormous growth in student participation over the past several years. You can read a feature article on the PRL in this issue.

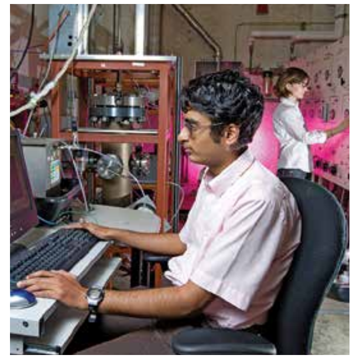
This Spring, we opened half of the renovated Building 524, which will serve as a new home for many of the department's faculty and students and will include much needed departmental teaching laboratories (see article inside). The new space offers dramatically improved natural lighting and vaulted ceilings that are both modern and consistent with the traditional architecture of the campus. This renovation is a key step in the revitalization of the ME buildings, which lie at the heart of Stanford.

*Kenneth E. Goodson*
*Davies Family Provostial Professor and Robert Bosch Chair*

I am delighted to announce that three of our senior faculty were elected to the National Academy of Engineering (NAE) in 2013: C. Thomas Bowman, Charbel Farhat, and Eric Shaqfeh. The NAE is a service institution that provides engineering leadership to the nation, and elected membership is among the highest honors that are awarded to engineers. We currently have 7 total faculty in the NAE—nearly 20% of our total number—and this is a great mark of distinction.

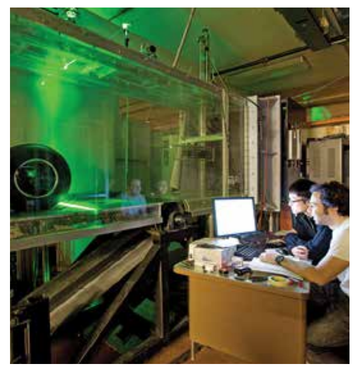
I hope that you will enjoy reading the fascinating articles submitted on several of these topics for ME News. As always, we invite you to visit our website at http://me.stanford.edu to learn about other innovative research endeavors of our faculty and students.

THERMOSCIENCES



DESIGN

FLOW PHYSICS & COMPUTATIONAL ENGINEERING



BIOMECHANICAL ENGINEERING

MECHANICS & COMPUTATION

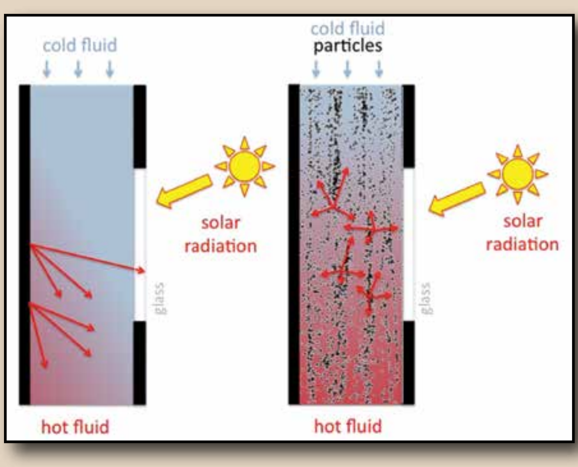
# Exascale Computing @ Stanford

Gianluca Iaccarino and Ali Mani

In 2013, the National Nuclear Security Administration (NNSA) selected Stanford University as one of the **new centers of excellence in predictive science**. Stanford was named as one of three Multidisciplinary Simulation Centers, together with the University of Utah and the University of Illinois at Urbana-Champaign, which will each receive $20 million for the next five years under NNSA's Predictive Science Academic Alliance Program II (PSAAP II). As of March 2014, the project has officially started!

Stanford's PSAAP II Center will involve six faculty in the Mechanical Engineering Department (Eric Darve, John Eaton, Gianluca Iaccarino, Sanjiva Lele, Ali Mani and Parviz Moin) and several colleagues in the Aeronautics and Astronautics, Computer Science, and Mathematics Departments on campus, as well as a partnership with the University of Michigan, the University of Minnesota, the University of Colorado at Boulder, the University of Texas at Austin and the State University of New York at Stony Brook.

The project, Predictive Simulations of Particle-laden Turbulence in a Radiation Environment, will investigate the effect of **radiation on particle motion in an air-turbulent environment**. This is a poorly understood physical process that can open new opportunities for efficiency gains in solar thermal receivers with applications in energy conversion and chemical splitting of components in chemical plants. The objective in such systems is to achieve high temperatures with minimal thermal losses to the environment. Conventional solar-receivers collect focused sunlight primarily via a solid surface, which then conducts heat to the target fluid. One main drawback is that achieving high mean temperature in the fluid requires local heating of the solid surface to even higher temperatures, which can result in significant radiation losses.




Particle-based receivers present potential remedies to this issue by allowing more uniform and volumetric absorption of radiation by the working fluid. Since most fluids are transparent to radiation, absorbing particles are needed to intercept high-energy solar rays, allowing local transfer to the fluid mixture. However, the three-way coupled physics of particle transport, fluid dynamics, and radiation presents additional engineering challenges which are mostly unexplored. For example, fluid motion in such systems naturally involves turbulence, and while turbulence helps global mixing of mass and heat, it induces preferential concentration of particles: local turbulent vortices can centrifuge out particles to zones of local shear, and lead to heating non-uniformities and reduction of the overall efficiency. Additionally, temperature inhomogeneity leads to local fluid expansion, altering the turbulence structures. Insights into design and optimization of such systems require careful investigation of the physical interactions between particles, radiation transport and fluid turbulence.

The Center will focus on simulations at an unprecedented level of fidelity by accessing the largest supercomputers in the U.S. This will help develop and, ultimately, demonstrate predictive science simulations on next-generation **exascale systems**—computers that can perform a trillion floating-point operations per second—expected to become available in 2020. The current trend in supercomputer systems is to increase the number of computing cores which, consequently, leads to data movement across extensive networks. Moreover, diverse and specialized computing units (CPUs, GPUs and other accelerators) and multiple memory banks with different levels of performance will coexist, creating a truly complex hardware and network system. Achieving high performance requires new programming models that will enable computational scientists to develop algorithms and software tools without intimate knowledge of the underlying architecture details. A key feature of the Stanford PSAAP II Center is a strong partnership between computational and computer scientists. Domain Specific Languages (DSLs), such as Stanford-developed Liszt, are the key ingredients enabling computer programs to identify and recover from faults while providing flexibility in data management and efficiency in mapping algorithms on the most appropriate computing units.

The project will also concentrate on **uncertainty analysis**, allowing researchers to quantify errors and uncertainties in the simulations and, therefore, determine how much confidence can be placed in the results. A dedicated **experimental campaign** will be undertaken alongside the computational work to help understand and identify these uncertainties and provide overall validation data to assess the predictive ability of the physical models and software tools developed within the project.

In addition to the research effort, new graduate-level classes on computational science, multiphase flows and radiation modeling, and high-performance computing will be introduced at Stanford. Workshops on uncertainty analysis, multiphysics and exascale challenges will also be organized to expose the broader community to the research efforts at the Center.

The agreement continues a 15-year history of strong collaboration between NNSA laboratories and Stanford, including the Advanced Simulation and Computing (ASC) and PSAAP programs.

For more information on Stanford's PSAAP II project, please visit the Center's website at http://exascale.stanford.edu.

# Welcoming the Future in the Product Realization Lab

Dave Beach

**Engaging More, and More Diverse, Students**

The Product Realization Lab (PRL) continues to attract an increasing number of students. During the 2013-2014 academic year, 1700 students produced amazing work in the PRL. Of those students, 50% were women. Students engaged with the Lab at various stages of their academic and professional development: 50% were undergraduates and 50% were graduate students. In the past, the great majority of PRL student makers came from the School of Engineering. This year, 60% were engineers and the remainder came from disciplines in the School of Humanities and Sciences, the Graduate School of Business and the Medical School. This increasingly diverse population of students provides fresh perspectives and a broad array of domain expertise that enrich the PRL learning environment and improve outcomes for all students.

**Pioneering Curriculum for Rapidly Changing World**

Product Realization Lab faculty and lecturers have developed seven new courses allowing students the freedom to explore their intellectual and personal passions, including the Introductory Seminar Product Realization: Making Is Thinking, Flexible Part Design, MechaPHONEics, Design for Exploration, Mystery of Manufacturing, Advanced Design Studies in Product Realization, and Deliverables: A Mechanical Engineering Design Practicum.

**New Students and New Curriculum Yield MAKING MAGIC!**

Each quarter, at the Meet the Makers Expo, more than 100 Product Realization Lab students show their culminating projects, which range from sports equipment to medical devices to fine furniture and much, much more. These events draw a crowd of several hundred aficionados who yearn to understand the realization process—how pathbreaking products are conceived and then made—and want to celebrate the brilliance and tenacity of the Product Realization Lab students.

**Taking the Design/ Manufacturing Conversation Beyond Stanford**

The Product Realization Lab has extended the conversation about the inextricable link between designing and making well beyond the University's boundaries. At its public lecture series, Meet the Makers Expert Sessions, more than 300 audience members—students, faculty and staff, and members of the local community—met Stanford engineering alumni who are transforming our world. Speakers included Peter Dreissigacker (BS ME '73), founder and CEO of Concept2 Oars and Ergometers; Michael Topolovac (BS Product Design '92), founder of Crave and Light & Motion; Kirk Hawkins (MS ME '95, MBA '05), founder and CEO of ICON Aircraft; and Chris Haughey (BS ME '02), co-founder at Tegu Toys. The series culminated in a panel of recent grads who have launched successful startups: Anne Fletcher (MS ME '07, Orta Kitchen Gardens), Mark Frykman (BS ME '12, BOOSTED Longboards), Bret Kugelmass (MS ME '11, Airphrame unmanned aerial vehicles), and Hans-Georg Liemke (MS MSME '95, ELHA Machinenbau Machine Tools).

*Students created battling robots for their final class project in Introduction to Mechatronics (ME 210), taught by Tom Kenny and Matt Ohline.*

*Students designed aluminum kitchen gear in Computer-Aided Product Creation (ME 318), taught by Craig Milroy.*

In summary, the Product Realization Lab has seen tremendous growth in the number and diversity of students, responded with a broadened and deepened curriculum, and nurtured the engagement between its students and alumni with the world beyond Stanford. These transformations will ensure that the next generation of global leaders will gain the skills necessary to create and produce the world-changing innovations that solve the greatest challenges of our time.

To watch a brief video about the Product Realization Lab, please visit the following website: https://vimeo.com/97360300.

# Building 524 Renovation Update

Lester Su

The dust and cacophony of construction that have lately enveloped the intersection of Panama and Duena Streets, just behind the Memorial Church, will soon subside as the Mechanical Engineering Department moves into the renovated Building 524. This will house a variety of teaching facilities, including the D'Arbeloff laboratory, thermosciences labs including dedicated spaces for subsonic and supersonic wind tunnels, student meeting areas, and offices. The renovation of Building 524 expresses the commitment of the department, and the School of Engineering, to the kind of hands-on, experiential education that we have provided to generations of students.

Throughout higher education, the development and proliferation of computer and communications technology is upending traditional pedagogical models. In recent years, we have seen the emergence of on-line lectures, automated assignments and quizzes, "flipped" classrooms, and, arguably the culmination of such technologies, massive open on-line courses ("MOOC"s). While the jury is still out on the optimal ways to incorporate these tools into teaching, the clear advantages of on-line delivery methods in cost, efficiency and convenience virtually ensure that they are here to stay in one form or another. However, the technological trend with which we, as mechanical engineers, most resonate is the "maker" movement. Our natural realm encompasses tangible objects, problem-solving through physical systems, and the optimization of our physical environment. Our students will, as such, continue to need a curriculum that offers immersion into the methods of design and fabrication, and exposes them to testing and measurement through physical laboratory assignments.

*Showcase of rocket and jet engine*

The renovated Building 524 provides the most up-to-date teaching laboratories for various courses that, until now, have made use of scattered spaces in various buildings on campus. The new facilities will most notably benefit our thermosciences courses, such as E30 (Engineering Thermodynamics), ME70 (Introductory Fluids Engineering), and the ME131A (Heat Transfer)/131B (Compressible Flow and Turbomachinery)/140 (Advanced Thermal Systems) sequence. They will make possible the incorporation of new laboratory apparatus as well as new diagnostic and measurement methods, such as the tools of advanced imaging, or of nanoscale fabrication and measurement. Of course, the new lab spaces will also be flexible enough for use by courses across the department curriculum, and will certainly afford us the ability to explore interdisciplinary connections. We envision offering labs that challenge students to apply design concepts to problems in the thermosciences, or to address issues in bioengineering using the tools and methods of thermosciences and mechanics.

*Lab Space*

*Conference Room*

The design of Building 524 also reflects our understanding that one of the great benefits of a Stanford mechanical engineering education is the opportunity to learn through collaboration with a uniquely creative and capable group of peers. The building provides ample formal meeting space for project groups or study groups, and boasts an open design that encourages impromptu meetings and is easily configurable for informal student gatherings.

Together with the renovation of the Peterson Building (Building 550) several years ago, the Mechanical Engineering Department will soon be able to claim two state-of-the-art buildings that contribute directly to our educational mission, and build on our established strength in encouraging collaboration in both coursework and projects for generations of future students.

*Common Area*

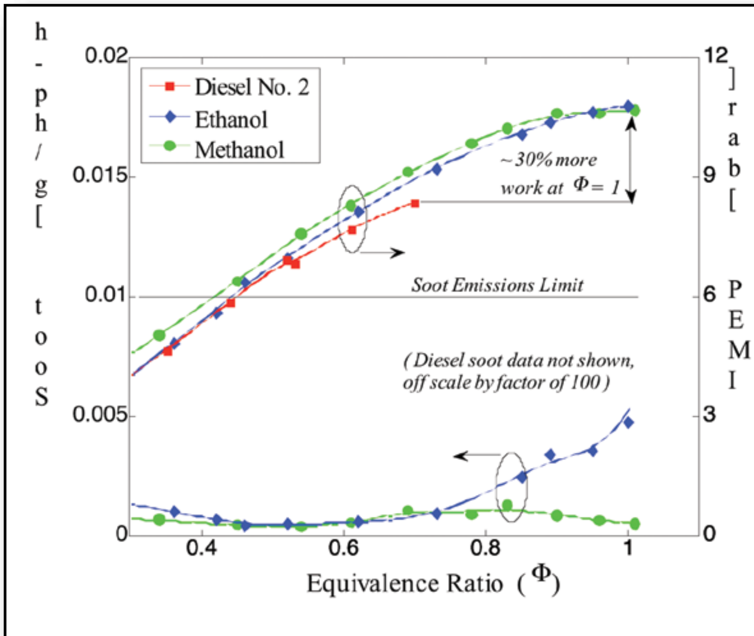
# Advanced Energy Systems Laboratory Demonstrates "Ethanol Diesel" for Heavy-duty Transportation

Chris Edwards

Heavy-duty, long-haul trucking remains a key challenge for carbon-mitigation. Carbon emissions are expected to grow rapidly and, while developments in battery-electric vehicles, hybrids, and alternative fuels have shown promise for light-duty use, none show the same promise for heavy-duty. Switching to natural gas (from Diesel fuel) is being considered on the basis of cost and security, but conversion of Diesel engines to spark-ignited or mixed-fuel operation has significant downsides, including a loss of torque and efficiency.

Graduate student researchers Greg Roberts and BJ Johnson, working with Professor Chris Edwards in the Advanced Energy Systems Laboratory, have demonstrated that not only can neat ethanol (E100) be used in *Diesel-style* combustion, but the result of redesigning the engine to make an "ethanol Diesel" is simultaneous improvement in efficiency, emissions, cost, and even power density (torque).

The results of this research were reported recently at the World Congress of the Society of Automotive Engineers in Detroit (*SAE Paper:* 2014-01-1194). According to Professor Edwards, the basic idea came from two fundamental efforts and one practical observation. The fundamental efforts are Greg and BJ's Ph.D. research projects. Greg is studying how soot emissions might be eliminated when using direct-injection, high-temperature, Diesel-style combustion. BJ is studying how very high efficiency (> 60%) can be achieved in IC engines by eliminating heat loss and improving work extraction. The practical observation was supplied by Craig Brewster of PACCAR (parent company of Kenworth and Freightliner) when he pointed out that as much as 30% of the cost of a new Diesel engine system is emissions aftertreatment—a particulate filter and NOx reduction system—and that the net effect of the aftertreatment is a decrease in both output and efficiency.




*Measured soot emissions and work output (IMEP) of methanol, ethanol, and Diesel fuels using high-temperature, low-heat rejection combustion. The soot emissions from Diesel fuel are not shown since they exceed the scale of the figure by a factor of ~100.*

The response from Greg and BJ was to combine their efforts to show that it is possible to eliminate the need for a particulate filter by using *Diesel-style* combustion but with an oxygenated fuel—either ethanol or methanol—in place of Diesel. That this might be possible was not surprising based on prior research. What was surprising is that, by using very high temperature combustion, an ethanol Diesel can operate at the chemically correct (stoichiometric) air-fuel ratio without a significant loss of combustion efficiency. This means that instead of an expensive NOx reduction system, a relatively inexpensive three-way catalyst can be used to control all the emissions from the engine. This provides a cost reduction of ~25% while work output increases by ~30% over using Diesel fuel—a direct result of being able to achieve sootless, stoichiometric combustion.

Recent developments in cellulosic ethanol—particularly the construction of the first full-scale plant by DuPont in Nevada, Iowa—have shown that it is possible for the U.S. to move beyond corn ethanol to produce a viable low-carbon fuel. Similarly, production of methanol from natural gas is already routine, economical, and efficient, and may provide an alternative to direct use of high-pressure or liquefied natural gas in transportation.


*Graduate student researchers Greg Roberts (left) and BJ Johnson (right) shown next to a PACCAR MX Diesel engine in the Advanced Energy Systems Lab.*

*This research was sponsored by the Global Climate and Energy Project (GCEP) as part of its Advanced Combustion research program.*

# ME *faculty achievements*

**Thomas P. Andriacchi**
The Anterior Cruciate Ligament (ACL) Study Group Traveling Scientist Award, 2014-2016.

Lifetime Achievement Award, International Society for Technology in Arthroplasty (ISTA), 2013.

Distinguished Lecturer, Cardiff University, Wales, UK, 2013.

**Wei Cai**
Thomas J.R. Hughes Young Investigator Award, American Society of Mechanical Engineers (ASME), 2013.

**Mark R. Cutkosky**
Fellow, American Society of Mechanical Engineers (ASME), 2013.

**Scott L. Delp**
Appointed Deputy Director of Neuroscience Institute, Stanford University, 2013.

**John K. Eaton**
Senior Award, International Conference on Multiphase Flow, 2014.

**Charbel Farhat**
Gauss-Newton Medal, International Association for Computational Mechanics (IACM), 2014.

**Kenneth E. Goodson**
Davies Family Provostial Professor, Stanford University, 2014.

Heat Transfer Memorial Award, American Society of Mechanical Engineers (ASME), 2014.

Technical Excellence Award, Semiconductor Research Corporation, 2014.

Fellow, American Association of the Advancement of Science (AAAS), 2013.

**Ronald K. Hanson**
Clean Combustion Research Center Plenary Lecture, King Abdullah University, 2014.

Honorary Professor, Xi'an Jiaotong University, 2014.

Outstanding Paper Award, Measurement Science and Technology, 2013.

**David M. Kelley**
Honorary Doctorate of Science Degree, Dartmouth College, 2014.

Robert Fletcher Award, Dartmouth College, 2014.

**David Lentink**
Top 40 under 40, World Economic Forum Young Scientist, 2013.

**Parviz Moin**
Elected Chair, Engineering Sciences Section, National Academy of Sciences, 2014-2017.

Elected to the Royal Academy of Engineering, Spain, 2014.

**Beth L. Pruitt**
Senior Member, Institute of Electrical and Electronics Engineers (IEEE), 2014.

Vice Provost for Undergraduate Education Faculty Scholar, Stanford University, 2013-2014.

**Sheri D. Sheppard**
President's Individual Award for Excellence through Diversity, Stanford University, 2014.

Inducted into the Minerva Academy, Minerva Institute for Research and Scholarship, 2014.

**Sindy K. Y. Tang**
3M Nontenured Faculty Award, 2014.

**Xiaolin Zheng**
Emerging Explorer Award, *National Geographic*, 2014.

Innovator on the 100 Leading Global Thinkers list, *Foreign Policy Magazine*, 2013.

Pioneer on the TR35 Global list, *MIT Technology Review*, 2013.

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