

Rensselaer Department of Mechanical, Aerospace, and Nuclear Engineering

LOW CEILING

ANNUAL REPORT 2015



FACTS & FIGURES DEPARTMENT OF MECHANICAL, AEROSPACE, AND NUCLEAR ENGINEERING

STUDENTS

1,115

126 GRADUATE

95% of current full-time doctoral students received financial assistance

DEGREES OFFERED

Aeronautical Engineering (B.S., M.Eng., M.S., Ph.D.) Engineering Physics (M.S., Ph.D.) Mechanical Engineering (B.S., M.Eng., M.S., Ph.D.) Nuclear Engineering (B.S., M.Eng., MS) Nuclear Engineering & Science (Ph.D.)

DEGREES AWARDED (AY) 2014



249 BACHELORS

27 MASTERS

26 PH.D.'S

RESEARCH

6

AFFLIATED RESEARCH CENTERS

- Center for Automation Technologies and Systems cats.rpi.edu
- Center for Flow Physics and Control www.scer.rpi.edu/cefpac
- Center for Modeling, Simulation and Imaging in Medicine www.scer.rpi.edu/cemsim
- Computational Center for Nanotechnology Innovations ccni.rpi.edu
- Center for Engineering-based Patient Modeling cepm.rpi.edu
- ► Scientific Computation Research Center | scorec.rpi.edu

RESEARCH AREAS

AEROSPACE SCIENCE AND ENGINEERING

- Fluid Dynamics/ Aerodynamics
 Advanced Structure
- Advanced Structures/ Materials
- Optimization
- Space
- Combustion/Propulsion

MECHANICAL SCIENCE AND ENGINEERING

- Mechanics and Materials
- Thermal and Fluids Engineering
- Design and Manufacturing
- Dynamics and Controls

NUCLEAR SCIENCE AND ENGINEERING

- ► Nuclear Power Systems
- Applied Radiation Technologies
- Radiation Protection, Medical and Industrial Uses of Radiation
- Nuclear Materials

CROSS-CUTTING RESEARCH AREAS

- Energy Science and Engineering
- Materials, Materials
 Processing and Controls
- Human Health and Safety

INSIDE 06 03 08 18 **MESSAGE FROM THE ALUMNI SPOTLIGHT FEATURE RESEARCH FEATURE** MARK JENKS LOW WALLS **DEPARTMENT HEAD** THE BATTERY NO CEILING THAT LASTS DR. SUVRANU DE

2 | Mechanical, Aerospace, and Nuclear Engineering

MESSAGE FROM THE DEPARTMENT HEAD

The theme of this year's MANE annual report is Collaborations. Diversity is at the core of the uniqueness of our department and we derive our strength from the collaborations that arise from low boundaries and no ceilings.



Dr. Suvranu De, Professor and Head

exceptional individuals as colleagues.

Congratulations to Professor Zvi Rusak for being elected Fellow of the ASME. Professor Rusak also won the Jerome Fishbach '38 Faculty Travel Award in 2015. Congratulations are also due to Professor Michael Podowsky for winning the Arthur Holly Compton Award from the American Nuclear Society and the Faculty Travel Award in 2014. Professor Farhan Gandhi has won a bronze award from the Royal Aeronautical Society for his paper published in The Aeronautical Journal.

Our faculty have also been very successful in winning Rensselaer awards. Professors **Dan Walczyk** and **Catalin Picu** have received the Excellence in Assessment and Continual Improvement and the Research Excellence awards from the School of Engineering, respectively. The 2014 Outstanding Team Award went to a research team comprising Professors Mark Shephard,



Dr. Kurt Anderson Dr. Dan



Dr. Matthew Dehlschlaeger



Dr. Diana Borca-Tasciuc

r. Jie Lian



John Tichy



Michael



Catalin Picu

r Mark Shapard

The past three years of my service to the department has led me through an extraordinary journey of discovery of how three programs, with their apparent disparity in themes and thoughts could coalesce and reinforce each other in unprecedented ways to evolve into an organic entity which is so much more than the sum of its parts. In this issue, we share some of my experience with you.

First, I would like to share some highlights from the past academic year. Thanks to our collaborative effort and superb guidance from Associate Dean Kurt Anderson, who is also a MANE colleague, all three programs sailed through the ABET accreditation process with flying colors. Special thanks are due to Professors Dan Walczyk, Matt Oehlschlaeger and George Xu who served as our ABET directors for the Mechanical, Aeronautical and Nuclear Engineering programs, respectively. Leading us through two ABET cycles, George and Dan have passed on the baton to Professors Jie Lian and Diana Borca-Tasciuc as out next ABET directors in Nuclear and Mechanical, respectively.

The past year has been very successful, with several of our faculty and students winning external and internal awards. I will start with two lifetime achievement awards to two of our senior and most celebrated faculty. Professor John Tichy won the Mayo D. Hersey award from the American Society of Mechanical Engineers (ASME). This is the highest honor bestowed on an individual for lifetime contributions to the field of tribology. Professor George Xu has won the Randal S. Caswell Award for **Distinguished Achievements** by the Council of Ionizing Radiation Measurements and Standards (CIRMS). Professor Xu has recently been honored with the Edward E. Hood Ir. Endowed Chair in Engineering for his pioneering work in radiation dosimetry. We are most honored to have these

mane.rpi.edu | 3





Dr Assad Ob

Onkar Sahni





Dr. Antoinette Maniatty



Dr. Jason Hicksma

Onkar Sahni, Assad Oberai, Catalin Picu and Antoinette Maniatty for "Development and Delivery of Advanced high Performance Computing Technologies". The Class of 1951 Outstanding Teaching Award was awarded to Professor Johnson Samuel.

Two MANE faculty, Professors Onkar Sahni and Johnson Samuel, have won the prestigious Faculty Early Career Development Award (CAREER) from the National Science Foundation (NSF) and Professor Jason Hicken has won the Young Investigator Award from the Air Force Office of Scientific Research (AFOSR). Professor Sahni is a computational fluid dynamics expert who will use the grant to develop software abstractions for stochastic embedding in predictive simulations in extreme-scale

NEW FACULTY



Dr. Kristen Mills, Assistant Professor

PROMOTIONS



Dr. Matthew Oehlschlaeger

Professor Matt Oehlschlaeger has been promoted to the rank of Full Professor in MANE, following which he joined as Associate Dean of Academic Affairs.



We would like to extend a

Kristen Mills who joined

Assistant Professor from

the Max Planck Institute

where she was engaged in

pursuing her postdoctoral

studies with a prestigious

Alexander von Humboldt

Research Fellowship.

for Intelligent Systems

in Stuttgart, Germany

MANE in Fall 2014 as

warm welcome to Professor

Dr. Theodorian Borca-Tasciuc

Professor Theodorian Borca-Tasciuc has been appointed to the position of Associate Head of Graduate Affairs and Director of the Mechanical Engineering Program.



Dr. Farhan Gandhi

Professor Farhan Gandhi has assumed the role of Director of the Aeronautical Engineering programs.



Kristen is a Mechanical

Engineer by training, but

of applying principles of

mechanics to the exciting

area of cancer cell biology.

One of her most fascinating

elastic modulus of the tumor

findings is that the ratio of

the elastic moduli of the

surrounding gel and the

determines the shape of

tumor growth.

her research is in the area

Dr. Yaron Danon

Professor Yaron Danon has assumed the role of Director of the Nuclear Engineering program.

computing. Professor Samuel is a precision machining expert who will investigate the fundamental effect of bone microstructural components on its machining responses. Professor Jason Hicken is an expert in computational optimization, particularly as they apply to complex aerospace systems. His AFOSR project, titled "Optimization of Complex Systems using Imperfect Data from Large-scale Simulations," aims to help engineers address challenging design problems, especially

those governed by uncertain, chaotic dynamics that can defy intuition. Jason has also won the inaugural Howard Rosenbrock Prize for his paper published in the journal Optimization and Engineering (OPTE) in 2014. MANE students continue to excel in academics and research.

A group of seven Aero graduate students competed in the American Helicopter Society (AHS) Student Design Competition, and placed third in the graduate category. Three of our students have received the Dorothy M and Earl S. Hoffman Scholarship from the Society for Women Engineers and nine have received the Founders Award. Two Aero students - George Jacobellis and Robert Niemiec - have won the highly selective Vertical Flight Foundation Scholarships from the American Helicopter Society. Incidentally, George and Robert have also won the prestigious SMART and NDSEG fellowships form

New MANE Industrial Affiliates Program We are proud to welcome:

- Boeing
- ► General Electric
- ► Corning
- United Technologies
- ► Navarro Research

the Department of Defense, respectively to continue their graduate studies in MANE.

We have continued to host highly successful alumni events. In the Spring of 2014 the Emerging Frontiers in Mechanical Engineering @ Rensselaer was organized to honor graduates of Rensselaer's mechanical engineering program and to build a vibrant community of alumni, faculty and students to foster engagement, support and a rich exchange of ideas and expertise. Honors were conferred on the late Dr. Lois Graham '46, the first woman to graduate from our Mechanical Engineering program and Dr. Bob Scaringe '74, President and CEO of Mainstream Engineering. A Reconnect to MANE! event was organized coinciding with the Homecoming and Reunion weekend in October. If you are an alum reading this message, we will be thrilled to have you join us next year!

Last year we also rolled out our MANE Industrial Affiliates Program to develop mutually beneficial relationships with industry based on enhanced student recruitment opportunities with the potential for

- Newport News
 Shipbuilding and
- Knolls Atomic Power Lab among the inaugural class of members.

vigorous exchange of ideas and exploration of research collaborations. Through this program, member companies receive premium access to MANE students and faculty to become informed about the department's research priorities and to facilitate effective hiring decisions based on the quality and accomplishments of individual graduate and undergraduate students. We are proud to welcome Boeing, General Electric, Corning, United Technologies, Navarro Research, Newport News Shipbuilding and Knolls Atomic Power Lab among the inaugural class of members. Details of this program may be found on our website (mane.rpi.edu).

As we celebrate the success of our students and faculty, we recall with pain and sorrow the recent passing of our beloved colleague Professor **Burt Swersey**. In summary, we've had a terrific year and I am both humbled and honored to present this annual report to you. I hope you enjoy reading this.

Suram De

Suvranu De Professor and Head



IN MEMORIAM: PROFESSOR BURT SWERSEY

Burt was a visionary, a dreamer and an innovator who had inspired generations of students and faculty, spawning numerous successful companies including Ecovative, whose cofounders Eben Bayer and Gavin McIntyre were featured on Forbes' 30 under 30 list this year. His Inventor's Studio has become an icon of creativity and entrepreneurship education in the country. Recently, Burt had initiated a new course – How to Change the World. As a tribute to Burt's legacy, we have undertaken the MANE.Innovation initiative with three bold ideas: an Innovation Spine to explore a new model of studentcentric technological innovation pedagogy, an Innovation Crucible as a physical space featuring rapid prototyping tools that will enable students to explore innovative ideas and an Innovation Challenge. We are seeking industrial partnership to grow these programs.

"I was lucky enough to meet Professor Burt Swersey on day one of classes. I smiled nearly the entire time he was talking and, by the end of class, my hand was cramping from writing ferociously every time he exclaimed, "write this down!" I knew that I was going to love RPI from the moment that Burt started telling my class that he was going to teach us to learn how to see, to question what exists, to challenge assumptions, and to solve real problems in society—and that as visionary engineers, we'd have the skills to figure out 'how.'"

— Meghan Olson '15

MARK JENKS'S AEROSPACE ADVENTURE

Rensselaer alum has traveled the world, collaborated with astronauts, overcome challenges, and brought success to Boeing's most valuable projects. Like many children his age, Mark Jenks watched every Apollo moon mission and vowed to become an astronaut. He just took it a bit farther than his peers.

"I actually started at Rensselaer on an NROTC scholarship, hoping to become a pilot on my way to entering the astronaut program," Jenks recalled. "Unfortunately, my eyesight didn't cooperate. Even if I couldn't fly into space, though, I was still determined to make a career working on large-scale aerospace projects."

Consider his mission accomplished. Since 1983, Jenks has contributed his skills to nearly every type of product and component developed by Boeing, from helicopter rotors and wing design to the International Space Station. In the process, he helped turn around one of the aerospace giant's most challenging projects.

From Helicopters to Outer Space

Jenks began his Boeing tenure in Philadelphia analyzing the computational fluid dynamics behind advanced helicopter rotors. After earning master's degrees in materials engineering and management, he took over Boeing's Helicopters Division Developmental Center, overseeing all phases of manufacturing the RAH-66 Comanche and the structural testing of the V-22 Osprey. "At its heart, engineering is about solving problems and developing solutions that can positively impact the lives and opportunities of people around the world."

Then came one of the highlights of his career: five years working on Boeing's contribution to the International Space Station (ISS).

"My time on ISS has got to rank right up there with my most challenging and, at the same time, most rewarding assignments," Jenks said. "I had the opportunity to work closely with the astronauts, learn about the technical details of Shuttle operations, be at the Cape to see my hardware launched, and sit in mission control in Houston as it was first put into operation in orbit. For an aerospace engineer who grew up watching the Apollo missions, it just doesn't get much better than that."

While on the ISS project, Jenks took on a variety of responsibilities, from managing the joint U.S./ Russian airlock program to leading the engineering effort for U.S. pressurized elements. His performance must have impressed Boeing leaders, for after five years they assigned him to a position of even higher responsibility: technology integration director for the next generation of Boeing's vaunted aircraft.

Taking On a Breakthrough Boeing's 787 Dreamliner family of airplanes broke ground in several ways. It features the first-ever airframe made primarily of composites, which delivers several major advantages over traditional aluminum: lighter weight, superior corrosion resistance, very good fatigue performance, and flexibility in wing design. The use of electronics to control the aircraft's systemsdeicing, braking, and cabin pressurization, among others—is more extensive than ever before.

Jenks oversaw the selection of these technologies as part of his leadership position. Later, he led the design team for the Dreamliner's wing and eventually took over as vice president of engineering for the whole effort.

After its launch in 2004, the Dreamliner became the fastest selling twinaisle commercial aircraft in Boeing history. However, its development also ran into well-documented technical problems. "As with any major aerospace project that pushes the boundaries of technology, the 787 development process encountered some significant, and often very public, challenges," Jenks said. "With challenges come intense learnings, and that was certainly the case for me."

As it turned out, Jenks was soon able to put those intense learnings to good use. "I was given the truly unique opportunity to apply all those lessons learned as the program manager for the first derivative of the Dreamliner. the 20-foot stretch called the 787-9." Jenks's team certified and delivered the 787-9 ahead of schedule, with major improvements in capability, reliability, and producibility. His work on the project continues to this day: he currently serves Boeing as vice president of 787-9 development.

Spanning the Globe The Dreamliner's unique

development model—using teams and plants around the world to design and build individual components turned Jenks into a world traveler: his responsibilities took him to Melbourne, Moscow, Naples, Japan, China, Sweden, and numerous other locales. When suppliers from these far-flung regions came to Boeing's headquarters in Everett, Washington, "it was like the United Nations of aerospace design," Jenks remembered. "You could walk down the hall and hear four languages."

The project's international nature fit well with one of Jenks's passions outside of work: adventure travel. In the last few years alone, he and his wife have traveled on safari in the Serengeti, climbed an island volcano in Lake Nicaragua, and explored jungles in Cambodia and Central America.

"There aren't many engineering endeavors that truly harness the unique and diverse capabilities of the world's technology leaders, and the 787 is perhaps the most prominent example," Jenks said. "I'd have to say that it's been the highlight of my career and a real privilege to play a part in that amazing process."

THE RENSSELAER CONNECTION

Jenks credits many aspects of his experience at Rensselaer where he earned his bachelor's and master's degrees in aerospace engineering—for his current success. "Clearly, the technical foundation that I received has served me well, and I've always felt technically prepared to deal with any new engineering challenge," he said. "I also played football for Rensselaer and was a member of TKE fraternity, experiences that taught me a lot about being a part of an effective team." Today he serves on MANE's Strategic Advisory Council—and his work there has given him insight into engineering education. "Rensselaer has always been known for the practical abilities of its graduates, and that's a real attraction for those of us in industry," Jenks said. "At its heart, engineering is about solving problems and developing solutions that can positively impact the lives and opportunities of people around the world. It's that perspective that weneed to continue to bring to the education of the next generation of Rensselaer engineers."



LOW WALLS

E



It's not a metaphor that would work at Rensselaer's School of Architecture. In the School of Engineering, however particularly the Department of Mechanical, Aerospace, and Nuclear Engineering (MANE) – it expresses a profound truth.

When walls are low, collaborations happen. When collaborations happen, there is no ceiling. The sky's the limit.

Low walls are more than a practice within MANE: they are part and parcel of the culture. Mechanical engineering professors team with aerospace engineering professors. Peers collaborate across the hall and around the world. Teams of undergraduates pull from every discipline—and work with technical experts and Fortune 500 companies.

It happens this way because it's how MANE works. But the proof is in the examples. The three stories that follow illustrate how a tradition of low walls places no ceiling on innovation.

WHEN VIRTUAL HUMANS BREATHE

Modeling the act of respiration may resolve a longstanding challenge in radiation treatment



(left) Edward E. Hood Endowed Chair Professor of Engineering, George Xu with Department Head, Professor and Director, CeMSIM, Suvranu De

One problem with radiation treatment involves an inescapable fact: patients have to breathe.

Breathing, of course, expands the lungs, and that lung movement moves (or, in the language of the field, "deforms") all surrounding tissues as well—including tumors. That in turn makes it a stiff challenge to pinpoint the precise location of the tumor at the precise time when the radiation is delivered. Too often, the radiation dose misses the tumor, and the treatment is ineffective. To make matters more difficult, experts in radiation oncology thought that the solution to this problem—involving 4D imaging technology—could be a black box unless we know how such deformation occurs in reality.

So who better to investigate potential breakthroughs in 4D simulation of the respiratory motion than the researcher who pioneered 3D modeling of human anatomy?

Over the past 10-plus years, Rensselaer professor and nuclear engineer George Xu has developed a range of "virtual humans"—computational 3D anatomical models that "In this project, the collaboration between nuclear engineers and mechanical engineers was quite easy because we are on the same campus—even in the same department (the Department of Mechanical, Aerospace, and Nuclear Engineering, or MANE, of which De is the head)—and we have a strong tradition of interdisciplinary collaboration."

accurately portray patient anatomy and physiology. Xu's earliest fame is probably VIP-Man (Visible Photographic Man), an advanced computer model from Visible Human images that simulates in 3D how radiation affects the organs and tissues in the human body. His lab has also created such models as RPI Pregnant Women and RPI Adult Male and Female, as well as RPI Obese Patients, many of which won the best paper awards from the journal of Physics in Medicine and Biology which published their works

As much as these models have contributed to radiation dosimetry, they all have one significant limitation: they are rigid, with constant and fixed geometries for the organs and tissues. Yet organs and tissues rarely stay put—most notably when patients breathe.

That did not stop another Rensselaer professor, Suvranu De, from using tools Xu has developed to investigate surgical simulation techniques, which would enable surgeons to practice complex procedures in a virtual environment before performing them on patients. De, a mechanical engineer, used biomechanical models to simulate tissue deformation in a way the 3D images could not.

That brought De and Xu back to the idea of 4D—and the power of collaboration to make it happen. As a result, the two professors were awarded a \$2.2 million grant from the National Institutes of Health (NIH) to create the first 4D virtual human model to simulate breathing and its precise effects on tissue deformation.

The success of the collaboration, from Xu's perspective, came from a culture of collaboration. "In this project, the collaboration between nuclear engineers and mechanical engineers was quite natural because we are on the same campus-even in the same department (the Department of Mechanical, Aerospace, and Nuclear Engineering, or MANE, of which De is the head)—and we have a strong tradition of interdisciplinary collaboration. Actually, the tradition of interdisciplinary collaboration plays a far more important role than physical location. As engineers we are respected for the engineering expertise and

the collaborative problemsolving skills that we bring to a project."

The collaboration quickly spread to other medical centers including The University of Texas at San Antonio, where a team of radiation oncologists collaborated with Xu to demonstrate the concept of predictive 4D treatment planning for lung cancer patients (the state of the art in the field was based a passive 4D method that could suffer from artifacts). In a related NIH grant, Xu and Peter Caracappa, director of the Reactor Critical Facility in MANE, applied the simulation technology to the protection of nuclear workers, resulting in a series of virtual human models to simulate walking, sitting, and obese employees.

The pioneering research has drawn considerable attention. The team has published nine journal papers and 44 conference abstracts during the 4 years when the projects were funded by the National Institutes of Medicine. Xu and De have been invited to describe their research in plenary and keynote presentations around the world. PhD students and postdoctoral researchers worked on th projects have since been recruited by top companies and medical centers.

Since that time, while continuing to study the generation of geometric models, Xu has been investigating general-purpose graphics processing units, or GPUs, to accelerate computation of the large-size medical images that simulate radiation in the human body. In that new NIH-funded project, he is collaborating with colleagues who are parallel computing experts.

Not surprisingly, Xu continues to stress the central role of collaboration within and across Rensselaer's low walls. "For Rensselaer to compete effectively in today's education and research environments, we must continue to foster interdisciplinary approaches on our campus between academic programs," Xu said. "At the same time, we must also reach out to strategic partners who have complementary research resources."

GO SMALLER TO GO FASTER

The future of hypersonic flight may depend on



(left) John A. Clark and Edward T. Crossan Chair Professor, Nikhil Koratkar with Professor and Associate Dean for Academic Affairs School of Engineering, Matthew Oehlschlaeger

What would it take to fly from New York to Los Angeles in less than an hour—or send a cruise missile across oceans in a few minutes?

The aerospace industry has dreamed of hypersonic propulsion (i.e., propulsion at five times the speed of sound or more) for decades. Researchers have devoted whole careers to every aspect of making it possible.

One of those aspects is a fuel with extraordinary energy density and an enhanced ability to absorb heat from the airframe.

"In hypersonic flight, the aircraft undergoes extreme heating due to the compression of air against its surfaces," explained Rensselaer Professor Matt Oehlschlaeger. "That requires fuels that are not only energy-dense but also act as a heat sink for cooling the aircraft."

nanoparticles in fuel-and getting them to behave

In this regard, nanofluid fuels look promising. They consist of stable colloidal suspensions of energy-dense nanoparticles in a base fluid, in this case liquid hydrocarbon fuel. But little is known about how the particles affect the all-important combustion process—and thus whether the nanofluids will, or will not, fulfill their promise.

Oehlschlaeger, who specializes in the relationship of fuel properties and combustion, sought to explore the nanoparticles' influence on the evaporation rate of fuel droplets, which relates directly to combustion efficiency. As part of that exploration, he needed to understand the nanoparticles themselves—or, rather, find someone who did.

He didn't have to go far.

Professor Nikhil Koratkar, Oehlschlaeger's colleague in MANE, has spent most of his career on the nano level. His research interests lie in the development and characterization of advanced nanostructured materials and devices.

"Nikhil's lab was crucial to helping us characterize materials and understand nanoparticle aggregation, the properties of those aggregates, and the influence on droplet evaporation," Oehlschlaeger said. "His students, using state-of-the-art nanoscale imaging and optical experiments, helped quantify the size and shape of the nanoparticle aggregates."

The aggregation aspect was key. Oehlschlaeger's lab conducted experiments to quantify the influence of added particles and their aggregation on droplet evaporation. As it turned out, raising the percentage of particles in the nanofluids from 1 percent to 3 percent sparked a dramatic decrease in the evaporation rate. Subsequent modeling revealed the cause: the nanoparticles aggregated at the surface of the droplet, "blocking" the fluid molecules from evaporating and thus slowing the energy release required for propulsion.

Follow-on experiments have since confirmed these findings: nanoparticles increase the energy content of liquid fuels but modify the behavior of combusting sprays. Now that the joint team has an idea of the problem, it can aim more effectively at a solution. Next steps include investigating the possibility of coating the nanoparticles to hinder the aggregation process. If the investigation succeeds, it will represent one more step in maximizing the energy benefits of nanofluids while minimizing their drawbacks.

According to Oehlschlaeger, the findings confirm his long-held convictions about the power of experimentation. "My work always starts with experiment," he explained. "Combustion is complicated, so the experiments often yield interesting and unexplained observations. From there, we consider theories, mechanisms, and models to explain the observations. That, we hope, leads to new knowledge that enables the design of new systems and the development of new technologies."

In this case, it might help to make hypersonic propulsion a reality. Stay tuned.

The aerospace industry has dreamed of hypersonic propulsion (i.e., propulsion at five times the speed of sound or more) for decades. FEATURE

BUILD LIKE A MECHANICAL, *think like an Aero*



Design Lab students must not only collaborate across disciplines, but think across them as well If you're going to build for an aerospace engineer, you have to think like an aerospace engineer. That insight may be obvious but it's not innate—which explains why many mechanical engineering students come to campus without it.

"Mechanical engineering students hear terms like fixed wing design and wind tunnel and say, 'We're not aeros," said Scott Miller, a project engineer at Rensselaer's O. T. Swanson Multidisciplinary Design Laboratory, a.k.a. The Design Lab. "I say, 'That's not the point.' Ninety-five percent of an aircraft involves mechanical engineering anyway. So mechanicals need to speak aero."

They certainly needed to speak aero in spring 2013, when Rensselaer's undergraduate subsonic wind tunnel needed an upgrade. Until that time, the tunnel accommodated testing with one degree of freedom: pitch. Aerospace students, however, needed to run experiments with roll and yaw as well. So the Design Lab assigned a team of students to collaborate on the upgrade.

The key word there is collaborate. Since 2001, the Design Lab has assigned cross-disciplinary



"Most engineering school problems are designed to teach one concept," said Mark Steiner, director of the Design Lab. "We address diverse concepts from diverse disciplines in each project, which is why we put interdisciplinary teams together. It's the kind of situation students will find in industry when they graduate."

teams of undergraduates to collaborate on real-world engineering problems supplied by Fortune 100 companies, not-for-profits, and other School of Engineering departments, among others. The goal, on the student side, is to hone skills they will need after graduation—including teamwork.

"Most engineering school problems are designed to teach one concept," said Mark Steiner, director of the Design Lab. "We address diverse concepts from diverse disciplines in each project, which is why we put interdisciplinary teams together. It's the kind of situation students will find in industry when they graduate."

The first student wind-tunnel team spent its semester defining the requirements (for load, speed, and other variables), designing the frame, and building the vertical axis, which would facilitate lift. The fall 2013 team focused on design of the roll and yaw capabilities, while in spring 2014 the students designed the control software. All told, students in mechanical, electrical, and computer/systems engineering collaborated on the upgrade.

As with most Design Lab student projects, learning about collaboration was a work in progress. "Students come in very compartmentalized," Steiner said. "The student selecting the motor for a project says, 'I'll give you all the torque you need and then some.' Meanwhile, the student designing controls says, 'But if you do that, how do I make the control stable and avoid backlash?' That's where they have to work together."

In the process, they learn that engineering is not just about the big picture. "The students love this kind of project because they get to build things," Miller said. "They think they can visualize the whole process at the outset, but inevitably they come across unexpected challenges. It's a tremendous lesson in the importance of details."

The redesigned wind tunnel will give aerospace students hands-on experience at a higher level of complexity to complement what they're learning in the classroom. At the same time, the advanced electronics will eliminate the need for cumbersome mechanical changes in setup, allowing students to set up and take down faster and thus have more time for their experiments.

The collaboration on this project, as with many Design Lab projects, went far beyond the students. Design Lab staff, including Miller and technician David DeJulio (who manages wind tunnel operations), provided guidance to the students and worked closely with each other on the project. Boeing provided funding for the materials used in the upgrade, and Simmons Machine Tool Corp. offered its plant equipment to mill certain components.

"When we talk about the low walls at Rensselaer," said Steiner, "we don't just mean between faculty and students. The collaboration is high between faculty and staff, between staff and students, across departments, in many dimensions.

"Most important, we teach all our students collaboration, in every aspect of every project. When they come out of Design Lab, they're far more prepared to be engineers in the real world."

Below, students who worked on the Wind Tunnel Improvements project meet with James McNerney, CEO, Boeing during a recent visit to Rensselaer.





FACULTY PROFILE

TOWARD A KINDER CUT

Patients could enjoy faster recovery if Johnson Samuel's bone-cutting research bears fruit



Assistant Professor, Johnson Samuel

Someday, millions of surgical patients may thank their lucky stars for Johnson Samuel's former departmental secretary.

As a postdoctoral research associate at the University of Illinois at Urbana-Champaign, Samuel often heard her talk about her husband's knee replacements. One was successful; the other was not. The joint never regained full motion.

That sparked not only Samuel's compassion, but his curiosity.

Some might consider that unusual. At first glance, surgery and bone structure seem far afield of Samuel's chief focus: the place where advanced material systems and micro-/nanomanufacturing meet. But Samuel was quick to see the link.

"I think of surgery as a manufacturing operation," said the assistant professor in MANE. "To me, the surgery table is the same as a factory table. So I began to wonder "If we could understand the effect of certain cuts on different bone microstructures, we could make advances in cutting and drilling tools to better suit individual patients which could result in higher success rates and faster recovery times."

whether my knowledge of materials and manufacturing could be useful in this area."

A Gap in the Research While reviewing the literature, Samuel noticed an aspect of the topic that had received little attention. Biomedical engineers had thoroughly investigated the microstructure of bone; doctors focused their interest on surgical results and evaluation of specific tools. Almost no one had connected the two. And that connection was vital.

"When cutting different materials, you get different responses," Samuel explained. "If we could understand the effect of certain cuts on different bone microstructures, we could make advances in cutting and drilling tools to better suit individual patients—which could result in higher success rates and faster recovery times."

Clearly the National Science Foundation (NSF) saw merit in Johnson's thinking: he was honored with the agency's prestigious CAREER Award in 2014 for taking this area in an entirely new direction.

The Right Cut for the Right Bone

Many surgical candidates will see merit in the research too. To take just one procedure, knee replacements in the U.S. number 600,000 per year, and about 10 percent of them do not achieve optimal results. Many other procedures also require the cutting and drilling of bone. Moreover, bone microstructures not only vary from person to person, but also change over time, particularly in their degree of mineralization. As a result, a perfect cut for one patient could be a disaster for another.

At the heart of the CAREER Award research, Samuel's team characterizes and maps the effect of various cuts on age-varying animal bones. Then, using modeling techniques, they develop optimum cutting tool geometries and tool paths for various bone types. If all goes according to plan, the results will lead to a new generation of bone machining tools and surgery planning techniques.

The research may also produce ideas for customizing current tools. "We're not necessarily interested in inventing entirely new tools," Samuel said. "For instance, we could enhance existing saws with different blade geometries for different cutting motions."

The team plans to look into such bone microstructural components as osteon fibers, interstitial matrices, cement lines, and voids.

Of 3D Printers and Lego Machines

According to Samuel, many doctors shy away from considering such patient-specific approaches. Surgery is already a complex, delicate process; tailoring steps to individual patients may introduce too much complexity. Hence the second part of Samuel's research: creating a perfect 3D-printed copy of the surgical site for doctors to practice on before the actual procedure.

"Once we understand the materials aspects of bone properties and microstructures, then we can create the ability to train doctors in patient-specific surgery protocols via 3D printing," Samuel said.

For the educational element of the CAREER Award, Samuel has met a difficult challenge—getting middle and high school students excited about manufacturing—with one of the world's greatest inspirations of childhood creativity: the Lego. Samuel's lab features a variety of common machines built from Lego blocks, and they are having the desired effect.

"Whenever I've had middle schoolers in the lab for a presentation, they couldn't be bothered with the conventional machines, however fancy," Samuel said. "But they go straight for the Lego machines. One of the big challenges facing U.S. manufacturing is that young people aren't interested —so we're hoping that playing with the Lego machines might inspire them to consider a manufacturing career."

This kind of mentoring is second nature to Samuel, thanks in part to a solemn charge from one of his Ph.D. advisors. "Three weeks before he passed away, Professor Richard DeVor said to me, 'Johnson, we trained you. Now you need to train your students," Samuel recalled. "Those were his last spoken words to me. That's the biggest thing that keeps me going."





THE BATTERY THAT LASTS

A strange paradox at the nanoscale may revolutionize the potential of lithium-ion batteries



Associate Professor, Jie Lan

They are the two most dreaded words for any cellphone user. They often appear in airports. They always appear too soon.

Low battery.

Fast battery discharge is more than just a traveler's annoyance. Together with short battery life, it keeps an otherwise promising technology—the lithium-ion battery—from playing a role where it's desperately needed: powering electric cars and other applications that use a lot of power.

Jie Lan and a team of researchers may have found the solution.



Today's batteries are expected to last over a 10 year lifetime—Lian's sphere design batteries nearly double that lifetime at approximately 19 years.

Confronting the Limits In recent years, researchers have focused on materials with high energy density, such as silicon or transition metal oxides, to overcome the intrinsically low capacity of the graphite electrodes in today's lithium-ion batteries. However, these alternative materials face two major challenges of their own: one mechanical, one chemical. On the mechanical side, the charge-discharge cycle causes the anode to expand and contract. Over time, this repeated movement damages the anode, reducing the energy that the battery can hold. Battery performance and life suffer.

As if that weren't enough, the liquid electrolyte in these batteries reacts with the lithium ions and electrons to create a solid-electrolyte interface (SEI) that adheres to the electrode. The SEI impedes the ability of the ions to move about the battery. Moreover, as the anode expands and contracts, the SEI tends to crack; new SEI fills in the cracks and creates ever thicker layers, degrading battery life even more.

Over time, researchers have discovered an electrode material and structure that mitigate these problems: meso- and nanoscale hollow spheres, made of highenergy-density materials like cobalt oxide, with tiny pores scattered across their surfaces. These spheres carry several advantages: shorter lengths for mass and charge transports (adding to battery efficiency), extra surface area to mitigate the anode's expansion and contraction. Even so, the spheres still suffer substantial degradation, particularly at the high charge-discharge rates required for power-hungry applications like vehicles.

That was the state of the research when Lian and the research team began their investigations. No one could have expected what they discovered next.

Death and Reactivation, Nano-Style

What they discovered was a paradox: the process that degrades the hollow spheres can also reactivate them. Specifically, the mechanical degradation of the hollow spheres refined their structure into a "hierarchically mesoporous" configuration that could hold a thin—but stable-SEI. The enlarged empty space of the new structure could withstand the repeated expansion and contraction while allowing for ultrafast charge transport. Meanwhile, the stable SEI greatly enhanced charging efficiency and extended the life of the battery's materials.

In short, these reactivated spheres provided all the advantages of the hollow sphere design while overcoming the disadvantages.

"The reactivated electrode displays an excellent reversible capacity above its theoretical value," according to the team's paper in *Nature* *Communications*, "and an unprecedented cycling stability without capacity fading even after an extremely long cycle at high rates."

Just how important is this discovery? "Today's batteries are expected to last over a 10 year lifetime," Lian explained. "Our reactivated sphere design shows cycling stability, without capacity fading, even after 7,000 cycles—or about 19 years with a daily charge." Moreover, this extraordinary performance takes place at a C rate (a measure of the battery's discharge rate relative to its capacity) of 5.6: well above today's commercial lithiumion batteries (at 0.5 C) and therefore far more suitable for high-power applications.

In the next steps for this research, Lian and colleagues will explore the prospects of reactivation for other materials with high energy density, including silicon and germanium. Potential for commercialization is high.

If it happens, perhaps someday low battery whether in cell phones or electric cars—will be a thing of the past.





Rensselaer

Department of Mechanical, Aerospace, and Nuclear Engineering Rensselaer Polytechnic Institute 110 8th Street Troy, NY USA 12180

Non-Profit Org. U.S. Postage

PAID

Please forward to the appropriate person. We apologize, but we can not accept returns.