Mechanical Engineering

Momentum

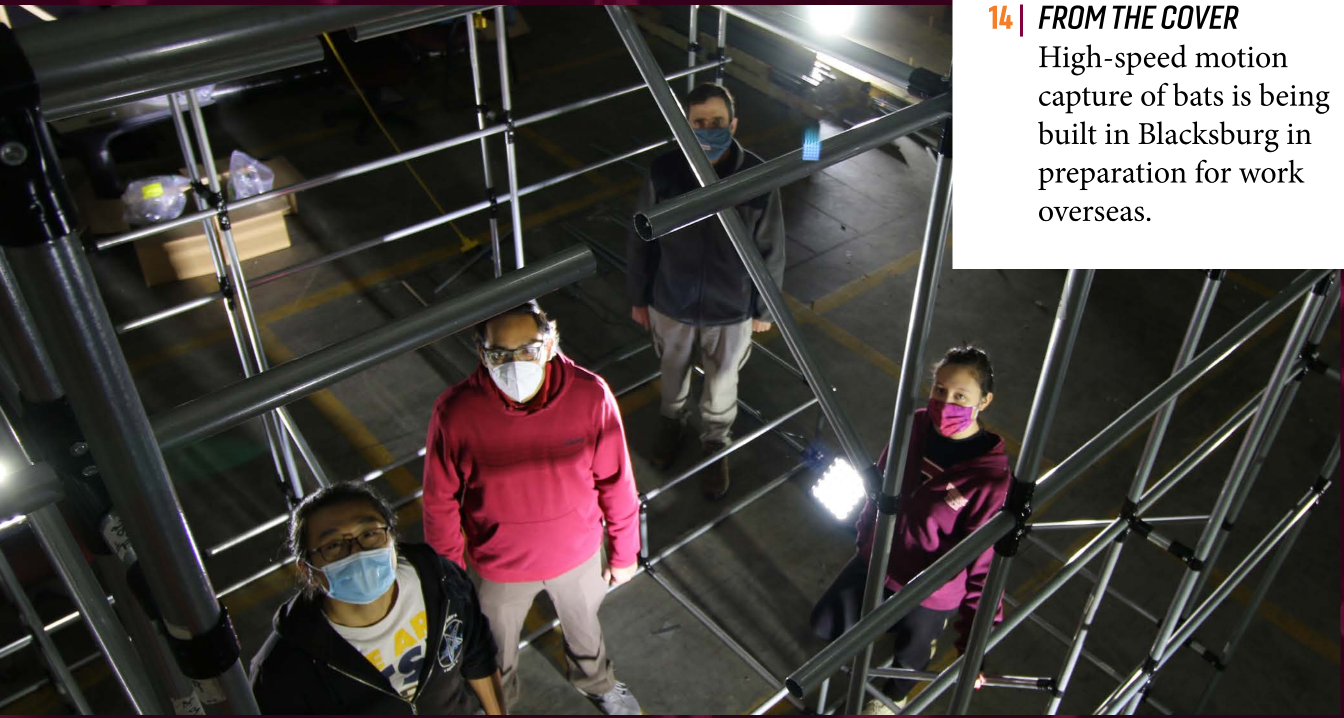
Winter 2021

TO THE BAT CAVE

Researchers prepare high-speed bat photography tunnel for deployment

COLLEGE OF ENGINEERING
MECHANICAL ENGINEERING
VIRGINIA TECH.

INSIDE



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MECHANICAL ENGINEERING
VIRGINIA TECH

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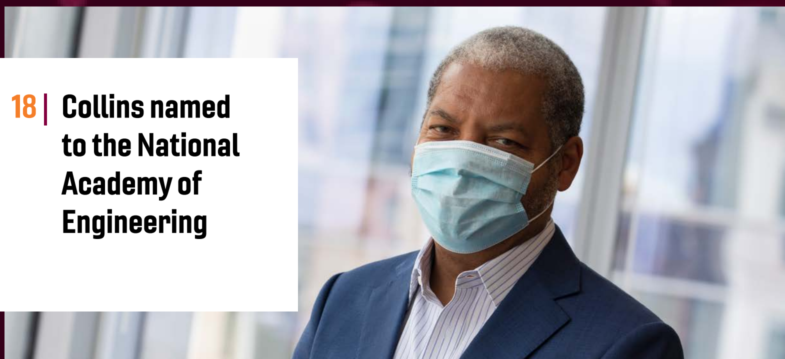
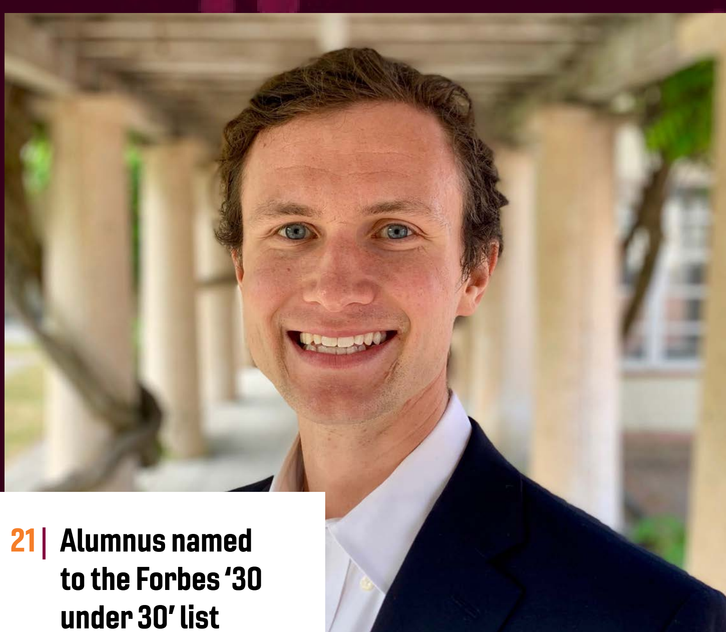
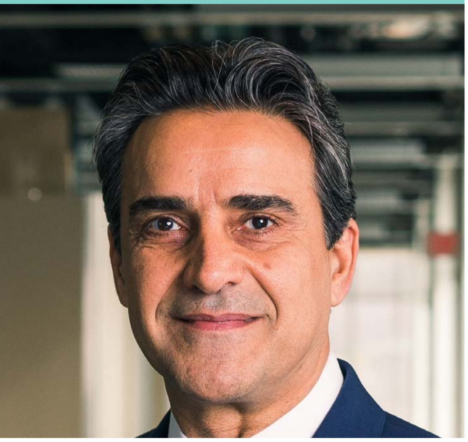






AZIM ESKANDARIAN

Department Head, and
Nicholas and Rebecca
Des Champs Chair/Professor

Department of
Mechanical Engineering

Bringing together "cool stuff"

Greetings, colleagues.

As many around the nation have received or continue to receive vaccines, we are hopeful and looking forward to returning to more normal times soon. Despite the persisting pandemic challenges, our faculty, staff, and students have shown unprecedented resiliency and adaptation. Consistently, our faculty and students' research and creative work have also continued to advance at an incredible rate. We have seen cover features, national news pickups, invitations from the industry, and a host of other notables. As we remain vigilant in stopping the spread of COVID-19, our faculty have found ways to thrive even under the most challenging circumstances. You will find a few examples of their outstanding achievements and progress in this issue.

Associate Professor Amrinder Nain's team has worked with a colleague from biomedical engineering to develop a novel approach in cellular mechanics using electroporation. This is an excellent opportunity to expand molecular medicine, genetic engineering, and cellular biophysics.

Professor Mike Roan has had an incredible start to the year, as his work to develop audible safety measures for electric vehicles has been both funded and featured. We are proud of Assistant Professor Pinar Acar, who received the Air Force Office of Scientific Research Young Investigator Award, studying magnetic fields' changes for components intended to replace rare-earth metals.

We are excited to name two new John R. Jones III Faculty Fellows, bringing the Jones family's legacy to light once again. Associate Professors Bahareh Behkam and Jonathan Boreyko both have produced some fascinating research throughout the years. It is a joy to see the deserving recognition of their outstanding work with this prestigious faculty fellowship.

Finally, among our notable recognitions, I am honored to report that Dr. Lance Collins, mechanical engineering professor and Vice President for Virginia Tech's Innovation Campus, was elected to the National Academy of Engineering. We will have a separate story about his great achievements in forthcoming volumes.

As always, I am proud to be part of this team. One of our staff recently summed it up nicely that I would like to share with you: "we just do cool stuff." Indeed we do, and I am honored to be able to share our stories with you.

With best regards,

Azim Eskandarian

ALEX PARRISH FOR VIRGINIA TECH

Work continues in the Terrestrial Robotics Engineering and Controls (TREC) Lab. From left to right, Roghaiyeh Ansari, Melanie Hook, and An-Chi Le survey a robot being outfitted for an ongoing project.

NOTABLE **ACHIEVEMENTS**

Mechanical Engineering Assistant Professor **John Palmore** will present a webinar for the Division of Scholarly Integrity and Research Compliance on February 26 at noon.

Palmore is the Principal Investigator for Virginia Tech's Combustion, Atomization, & Multiphase Physics Research (CAMPhyRe) Group. He uses computational fluid dynamics to study fuel production and its use in aviation. Palmore will be discussing the ethical considerations that inform his research. He will focus on biofuel use, aviation safety, and the benefits of the growing open science movement.

Register at **bit.ly/palmoreseminar.**

A student advised by Mechanical Engineering Professor Brian Lattimer has received recognition from the International Association for Fire Safety Science (IAFSS). A Sheldon Tieszen Student Award was awarded for the paper, "Localized Heat Transfer from Firebrands to Surfaces," authored by **Elias D. Bearinger.** He was joined by industry co-authors Jonathan L. Hodges, Fengchang Yang, and Christian M. Rippe. The paper will be published at the IAFSS conference in April 2021.

More at **bit.ly/bearingerpaper**.

Associate Professor **Jiangtao Cheng** was invited to present a section of his research to the Institute of Electrical and Electronics Engineers, the world's largest technical professional organization for the advancement of technology. His presentation was entitled, "Electrowetting and Its Applications in Adaptive Electronics Cooling, Optofluidic Solar Concentrators and Agile Beam Steering for Automatic Driving."

More at **bit.ly/cheng-ieee.**

The research of **Michael Roan**, a professor in mechanical engineering, has been featured on the cover of the January 2021 issue of the Journal of the Acoustical Society of America.

The article, "Probability of detection of electric vehicles with and without added warning sounds," is a report of Roan's ongoing research to increase safety between quiet-running electric vehicles and pedestrians.

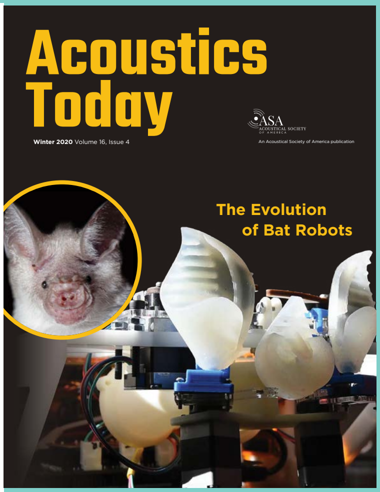
More at **bit.ly/roan-jasa**.

Steve Southward, associate professor in mechanical engineering, presented a webinar for Texas Instruments on February 5 addressing his creation of a controls lab in a virtual online environment. Southward developed a completely online version of the lab with innovative programming in Matlab, creating a realistic simulation of the hands-on experience students usually have in a classroom.

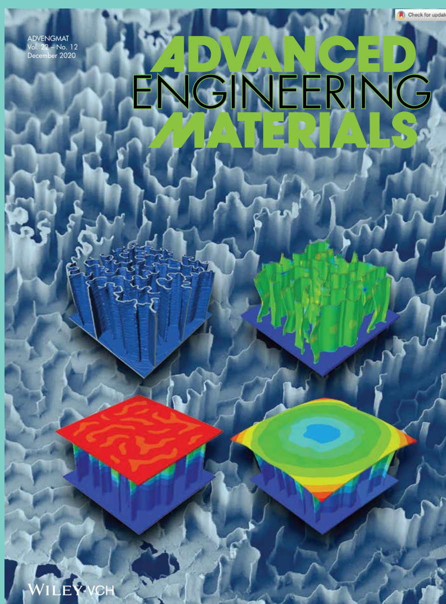
Rolf Mueller is the co-author with Yale Professor Roman Kuc of, "The Evolution of Bat Robots," featured on the cover of Acoustics Today.

The article discusses at length how the evolution of bats and the evolution of technology are converging, prompting the innovation of next-generation, bioinspired machine learning.

More at **bit.ly/mueller-at.**



NOTABLE ACHIEVEMENTS



Li *Huxtable*

Mechanical Engineering faculty members **Ling Li** and **Scott Huxtable** have joined Cornell colleague Zhiting Tian, Ph.D. candidate Ting Yang, and former mechanical engineering graduate student Eurydice Kanimba in publishing potential developments for bio-inspired heat sinks. The article was featured on the cover of the December 2020 issue of Advanced Engineering Materials.

This work investigates the thermal and mechanical performance of a bio-inspired lightweight structure, inspired by the porous internal skeleton of cuttlefish, also known as cuttlebone. The potential of using this structure as an air-cooled heat sink for electronic devices and an integrated thermal protection system is tested and systematically compared with three conventional structures based on wavy, pyramid, and cylindrical pin fin geometries.

Cuttlebone outperforms other structures in terms of compressive strength, and simulations indicate that the cuttlebone structure undergoes a graceful failure process due to the sequential buckling of the vertical walls compared with other structures.

More at **bit.ly/aem-cuttlebone**.

Lei Zuo, Robert E. Hord., Jr. Professor in the Virginia Tech Department of Mechanical Engineering, has been jointly appointed as Chief Scientist in Pacific Northwest National Laboratory (PNNL)'s Energy and Environment Directorate. PNNL is operated by R&D nonprofit Battelle for the US Department of Energy.

The joint appointment will grant Zuo access to the resources and talent serving at both PNNL and Virginia Tech, and will supplement but not replace his position at the university.

What do **COVID-19, pizza boxes,** and ***your gift*** have to do with one another?

Find out on Feb. 24.

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Virginia Tech's Giving Day 2021 is coming up on February 24-25! Help the College of Engineering reach its goal of 2,021 unique donors by making a gift to the department in support of our students and experiential learning. Be on the lookout for ways to maximize your gift's reach and impact by participating in our college-wide challenge.

givingday.vt.edu/amb/meche

Pinar Acar receives Air Force Office of Scientific Research Young Investigator Award

Mechanical engineering Assistant Professor Pinar Acar has received an Air Force Office of Scientific Research Investigator Research Program award, a three-year grant of $450,000, to study the changes in magnetic fields for components intended to replace rare-earth metals.

Rare-earth metals have become critical components of many different types of technology. As their use continues to expand for consumer devices, finding new sources for these metals has become more expensive and difficult. For military aircraft applications that require large quantities of these elements, a strong motivation has emerged to find new solutions. Acar explained that there are devices throughout a plane that use magnetics to control sensors, report problems, and keep an aircraft stable.

New-generation magneto-mechanical devices, such as printed magnetics, could be the answer to that problem, according to Acar. By using more traditional magnetic elements but arranging them along a surface at the microscopic level, one could create components with increased functionality without the need for hard-to-get metals.

Acar's group will introduce a number of variables to test the behavior of next-generation components among a range of uncertainties.

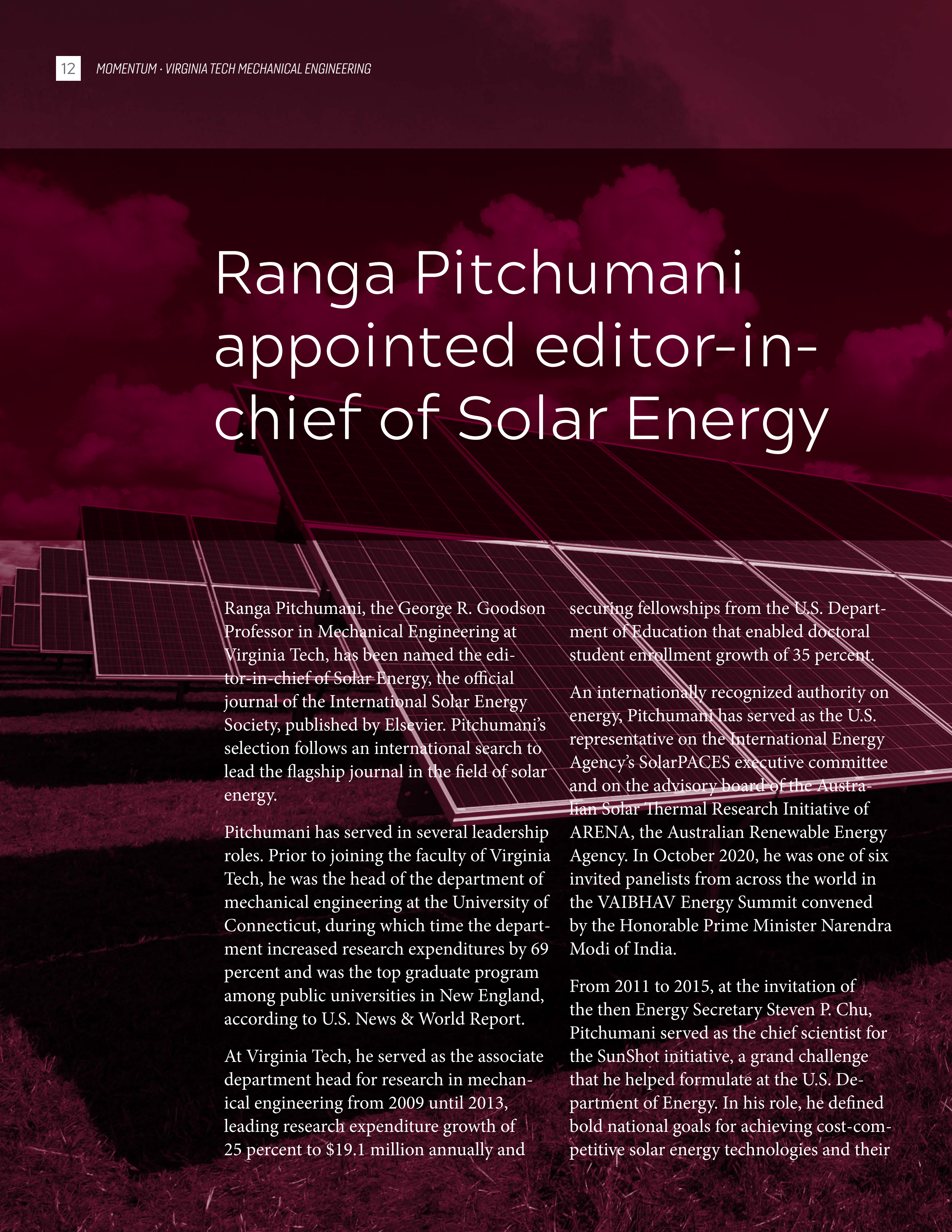
"We will analyze the long-range effects and the effects of uncertainties as magnetics change within materials," said Acar. "The improved understanding of phase transition behavior will have far-reaching benefits for science, engineering, public health, and the economy. A better comprehension of how uncertainties affect the phase transitions will minimize the risks arising from the failure of magneto-mechanical devices used in extreme environments due to the unexpected changes in their permanent magnetic properties."

Acar believes the research will advance knowledge on the phase transitions in magnetic materials that are subject to both external magnetic fields and temperature changes. Her main interest is investigation of the effects of temperature and external magnetic fields on the ferromagnetic to the paramagnetic phase transition. In the paramagnetic state, the magnetic materials lose their permanent magnetic properties, while in the ferromagnetic state, they demonstrate spontaneous magnetism.

The team will use 3-D models that simulate interacting magnetic spins and applied magnetic fields to test their theories. The group will build a theoretical solution to determine the point at which the critical phase transition occurs by developing a high-fidelity numerical framework that couples 3-D models with novel analytical uncertainty quantification techniques.

Acar has a cross-disciplinary background and academic training, with a Ph.D. in aerospace engineering from the University of Michigan, master's and bachelor's degrees from the Aerospace Engineering Department at Istanbul Technical University, and research interests in computational materials engineering, design optimization, and uncertainty quantification.

She is the recipient of the prominent International Amelia Earhart Fellowship, which is awarded annually to only a few women around the world in aerospace sciences, for her research on multiscale modeling of materials under uncertainty.



Ranga Pitchumani appointed editor-in-chief of Solar Energy

Ranga Pitchumani, the George R. Goodson Professor in Mechanical Engineering at Virginia Tech, has been named the editor-in-chief of Solar Energy, the official journal of the International Solar Energy Society, published by Elsevier. Pitchumani's selection follows an international search to lead the flagship journal in the field of solar energy.

Pitchumani has served in several leadership roles. Prior to joining the faculty of Virginia Tech, he was the head of the department of mechanical engineering at the University of Connecticut, during which time the department increased research expenditures by 69 percent and was the top graduate program among public universities in New England, according to U.S. News & World Report.

At Virginia Tech, he served as the associate department head for research in mechanical engineering from 2009 until 2013, leading research expenditure growth of 25 percent to $19.1 million annually and securing fellowships from the U.S. Department of Education that enabled doctoral student enrollment growth of 35 percent.

An internationally recognized authority on energy, Pitchumani has served as the U.S. representative on the International Energy Agency's SolarPACES executive committee and on the advisory board of the Australian Solar Thermal Research Initiative of ARENA, the Australian Renewable Energy Agency. In October 2020, he was one of six invited panelists from across the world in the VAIBHAV Energy Summit convened by the Honorable Prime Minister Narendra Modi of India.

From 2011 to 2015, at the invitation of the then Energy Secretary Steven P. Chu, Pitchumani served as the chief scientist for the SunShot initiative, a grand challenge that he helped formulate at the U.S. Department of Energy. In his role, he defined bold national goals for achieving cost-competitive solar energy technologies and their

ubiquitous integration into the electric grid. This yielded a 75 percent reduction in the cost of solar energy systems in 2017, three years earlier than planned.

For his leadership in the development of cost-effective solar energy, Pitchumani was recognized by the American Solar Energy Society with the prestigious Hoyt Clarke Hottel Award in 2017.

In his current position, Pitchumani directs the Advanced Materials and Technologies Laboratory, engaging a multidisciplinary approach to energy and sustainability. His research funding has come from many sources, including the Air Force Office of Scientific Research, Army Research Office, Office of Naval Research, Department of Energy, Department of Education, National Science Foundation, and industries. A prolific scholar, Pitchumani has co-authored over 240 articles with his research group. He is a fellow of the American Society of Mechanical Engineers; a distinguished alumnus of his alma mater, the Indian institute of Technology, Bombay; and serves on the editorial boards of several journals in the fields of energy and materials.

"Solar Energy is the premier journal in the field with a long legacy spanning over six decades," said Pitchumani. "To be selected to steward this illustrious journal is quite humbling."

Pitchumani sees significant growth of the journal in the coming years. "We are at a turning point in history where, by any means, solar energy is rapidly growing and will be a major part of our sustainable future. The declining costs of solar energy present tremendous opportunities for innovation in diverse areas and also pose significant challenges that touch multiple disciplines. I see Solar Energy as the leading forum for the confluence of scientific advances from the various disciplines to create solutions that don't exist today."

ALEX PARRISH FOR VIRGINIA TECH

LEARNING FROM THE BRAINY BA

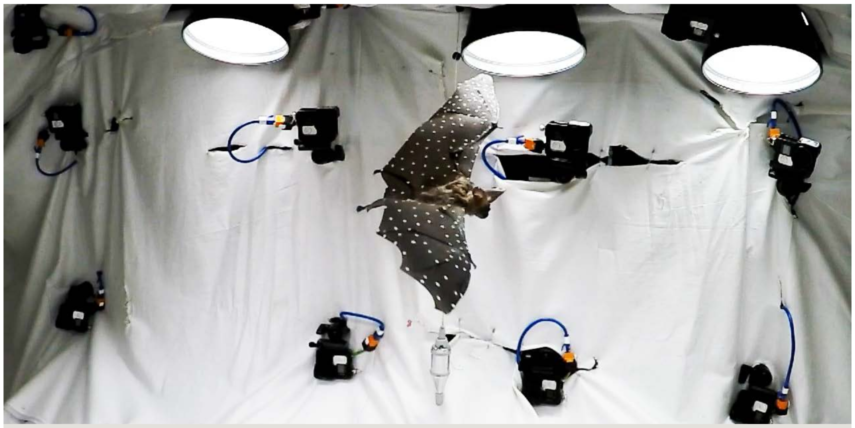
Virginia Tech researchers have teamed up with international partners to create a state-of-the-art image capture tunnel that will provide a new level of insight in the field of biomotion. Combining the efforts of faculty and student teams, their project has yielded more than $800,000 in funding from the National Science Foundation to continue the work.

The effort is led by Mechanical Engineering Professor Rolf Mueller, who has been studying the biosonar and motion behaviors of bats for more than two decades. While working in partnership with other schools around the world to observe a wide array of species, he has grown increasingly curious about the role that bat flight plays in enabling the animal's autonomous capabilities. Given that bats multitask – balancing drinking, catching insects, and other actions – while flying, using high-speed cameras to capture all of these motions happening simultaneously could enable a deeper understanding of how the animals can accomplish so many difficult tasks at the same time.

"We're looking for the 'secret sauce' behind the success of bats," said Mueller. "Our interest is particularly in their ability to navigate through dense rainforests in darkness."

An expert on bat populations around the world, Mueller knew of an ideal location to pursue further study of this question. The Brunei region of Borneo is a small area geographically, but has an extremely large and diverse population of bats. Mueller's team is particularly in search of bats capable of exceptional flight maneuvering — as Mueller calls them, the "elite" species of bats — and many species living in Brunei offer the possibility of a rich resource of data.

"There are 66 species of bat known to be in Brunei, and Brunei is about the size of Montgomery County," Mueller said. "There are bats with wingspans from 16 centimeters up to 1.8 meters. They are exceptional."



Above: a bat outfitted for motion-capture from a previous study. Left: Several members of the bat tunnel team inside the tunnel frame. The team includes Hannah-Victoria Thielman (front right), Sounak Chakrabarti (left), Yihao Hu (white shirt), and primary investigator Rolf Mueller (back).

ATS OF BORNEO

Mueller found research allies at the University of Brunei and its Faculty of Integrated Technology (FIT) who committed to building a bat house near the University, also pledging $200,000 in funding to get the project started. Dean of FIT Liyanage Chandratilak De Silva, FIT Associate Dean Juliana Haji Zaini, and FIT faculty member Wahyu Caesarendra played critical roles, as did Ulmar Grafe, field ecologist and Director of the university's Natural History Museum.

In planning creation of the image-capture tunnel, the researchers first worked to determine the kind of structure to use and how to assemble the tunnel in a place where bats were already living. To that end, Mueller created a senior design project to activate the creativity and intellect of undergraduates, and several Virginia Tech students answered the call. Senior Christian Mergl took the lead, joined by fellow mechanical engineering majors Alec Joseph Maccaro, Anuj Roy, Wenkun Liu, Armani Tagle, Jason Brannick, Spencer Kirkham IV, and Kevin Byrnes.

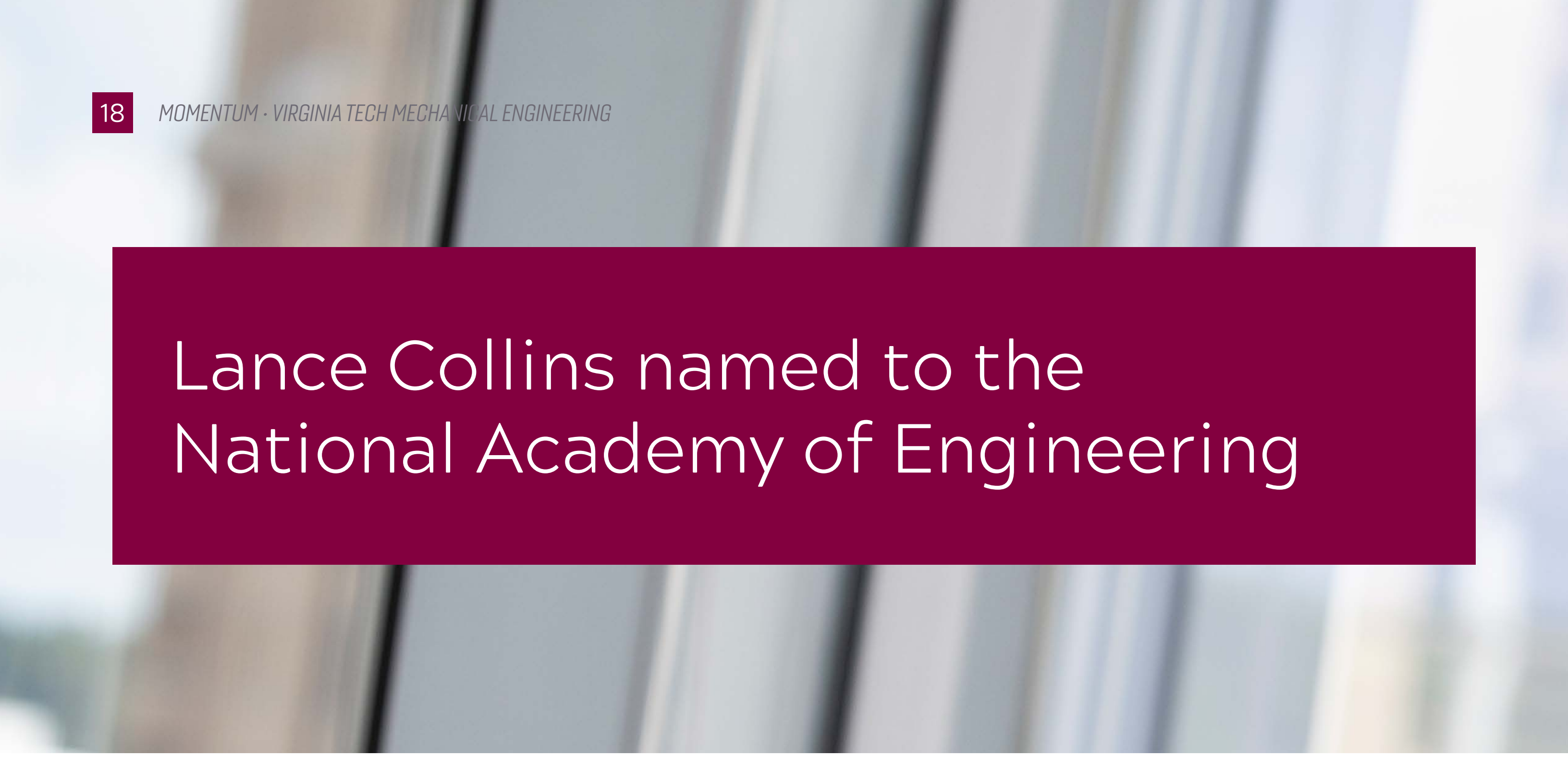
The plan was to capitalize on the large bat population to create a captive group of diverse animals trained to fly through the tunnel on command, demonstrating their unique skill set. Mueller found partners in Brunei to assist with putting a research facility in place.

Once the student team finished their tunnel design plans, an additional student team convened to do the work of bringing together a functional camera array. Two of those students, undergraduates Sounak Chakrabarti and Hannah-Victoria Thielmanm, won an Honorable Mention Award for a presentation of the project at the 2020 Virginia Academy of Science Fall Undergraduate Research Meeting in November.

The final tunnel design is 8.6m long, 2.9 m wide, and 3.3m tall. Observations will be recorded on 50 synchronized high-speed video cameras with illumination from 40 camera lights, and with 40 ultrasonic microphones.

Mueller's plan is to complete the integrated build, combining the tunnel design with the student-built array, and to ship the completed tunnel to Brunei. He aims to start making observations of "elite" bats soon.

"The collaborative research platform in Brunei will allow us to combine first-hand access to biodiversity with world-class experimental facilities," said Mueller. "This will enable Virginia Tech researchers and their international collaborators to gain new insights for technology right from the source."



Lance Collins named to the National Academy of Engineering

Lance R. Collins, vice president and executive director of the Virginia Tech Innovation Campus, is one of 106 new members elected to the National Academy of Engineering for 2021, among the highest professional distinctions for an engineer.

Collins, the Joseph Silbert Dean of Engineering at Cornell University for a decade before joining the Innovation Campus last year, is being honored for his contributions to understanding turbulent processes, leadership in engineering, and contributions to the diversity of the profession.

"I am excited, humbled and honored by the opportunity to join leaders at the National Academy of Engineering," Collins said. "I share this honor with the mentors, colleagues, and students at Cornell who guided me and supported my research and ideas. It infuses me with energy as we move forward to build partnerships and create a new model of graduate education at the Virginia Tech Innovation Campus."

Collins, who led Cornell's College of Engineering from 2010-20, was a key member of the leadership team that successfully bid to partner with New York City to build Cornell Tech, which opened its Roosevelt Island campus in 2017. He first joined Cornell in 2002 as a professor in the Sibley School of Mechanical and Aerospace Engineering.

Collins' appointment to Virginia Tech culminated an international search for the leader of the Innovation Campus, which was announced by the university as part of the state's successful effort to attract Amazon's HQ2 to Northern Virginia.

The Innovation Campus leader has made recruiting a diverse faculty and student body among the highest priorities of his new job in Northern Virginia. He came to Virginia Tech last month with a proven record in that area.

At Cornell, Collins accelerated efforts to diversify the college's faculty and student body: From 2010 to 2020, the proportion of underrepresented minority students increased from 8 to 19 percent and the undergraduate female enrollment from 33

to 50 percent.

Cornell Engineering's Class of 2021 is the first in the college's history to contain more women than men. For these efforts, he received the inaugural Mosaic Medal of Distinction from Cornell Mosaic, created to recognize alumni, faculty, and administrators for their leadership in creating opportunities and access for diverse communities, and the 2018 Edward Bouchet Legacy Award from Howard University and Yale University, which recognizes educators and advocates who promote diversity and inclusion.

His success was also recognized with the establishment of the Lance R. Collins Fellowship, created to support Cornell engineering graduate students from traditionally underrepresented populations.

Prior to Cornell, Collins spent 11 years as an assistant professor, associate professor, and professor of chemical engineering at Penn State University. His research combines simulation and theory to study a variety of turbulent flow processes such as multiphase turbulence, including atmospheric clouds, turbulent combustion, and drag reduction due to polymer additives.

His work on mechanisms of droplet breakup in turbulence was recognized with the 1997 Best Paper Award from the American Institute of Chemical Engineers. He is a fellow of the American Physical Society, the American Association for the Advancement of Science, and the American Institute of Chemical Engineers. Collins has more than 100 publications from his research, and he has supervised 16 Ph.D. students during his career.

In addition to leading the Innovation Campus, Collins has a faculty appointment in Virginia Tech's Department of Mechanical Engineering.

New members will be formally inducted in a ceremony during the National Academy of Engineering's annual meeting on Oct. 3, bringing the organization's total U.S. membership to 2,355.

Jonathan Boreyko named John R. Jones III Faculty Fellow

Jonathan Boreyko, associate professor of mechanical engineering in the College of Engineering at Virginia Tech, has been awarded the John R. Jones III Faculty Fellowship in Mechanical Engineering by the Virginia Tech Board of Visitors.

The Jones Faculty Fellowship was established in 2006 to acknowledge and reward mid-career faculty who have shown exceptional merit in research, teaching, and/or service. Jones, a member of the Class of 1967 who earned his bachelor's degree in mechanical engineering, is a retired executive of American Electric Power. He has been a member of the Department of Mechanical Engineering Advisory Board since 1998.

Recipients hold the title of Jones Faculty Fellow for a period of five years.

A member of the Virginia Tech faculty since 2014, Boreyko directs the Nature-Inspired Fluids and Interfaces Laboratory, a rapidly growing group in the Department of Mechanical Engineering with 30 journal publications since 2017.

Boreyko has had an impressive record of conducting cutting-edge research in the area of biomimetic surfaces and systems with applications in water harvesting, energy harvesting, anti-icing, phase-change heat transfer, and advanced materials.

In his career, Boreyko has received 13 externally funded grants totaling $2.6 million. Two of his grants have come from the National Science Foundation, including the prestigious CAREER Award, and the highly competitive Air Force Office of Scientific Research Young Investigator Research Program (YIP) Award.

Boreyko's research has also been supported by other government funding agencies and industry, including the U.S. Department of Agriculture, GreenShift Corporation, Bemis Company, Collins Aerospace, Proctor & Gamble, 3M, and Brookhaven National Laboratory. His funding is spread across various science and engineering disciplines, inducing vapor chambers, anti-icing technology, slippery oil-impregnated surfaces, synthetic trees, antiperspirant technology, fog harvesting, and pathogen transport in wheat crops.

Boreyko received his bachelor's degree from Trinity College and a Ph.D. from Duke University.

Alumnus David Mackanic named to the Forbes '30 under 30' list

David Mackanic was named a featured honoree for 2021 Forbes "30 under 30" in the category of Energy, recognizing young innovators who are making a big impact.

The 27-year-old entrepreneur and innovator started his professional journey as a mechanical engineering major at Virginia Tech, completing his undergraduate degree between 2011 and 2015. While he was seeking that first degree, he also spent a lot of time engaged in undergraduate research, immersing himself in the science that would eventually inspire inventions of his own.

The labs of Michael Ellis, Robert Moore, and Scott Huxtable became Mackanic's second home, and he enrolled in internships to increase his knowledge of the industry. From his sophomore year on, Mackanic dove into learning the basics of energy transfer and the properties of the materials that store energy. As a student, he helped develop polymers and nanomaterials that go to work in high-performance batteries, and learned how to change their properties to make them work even better.

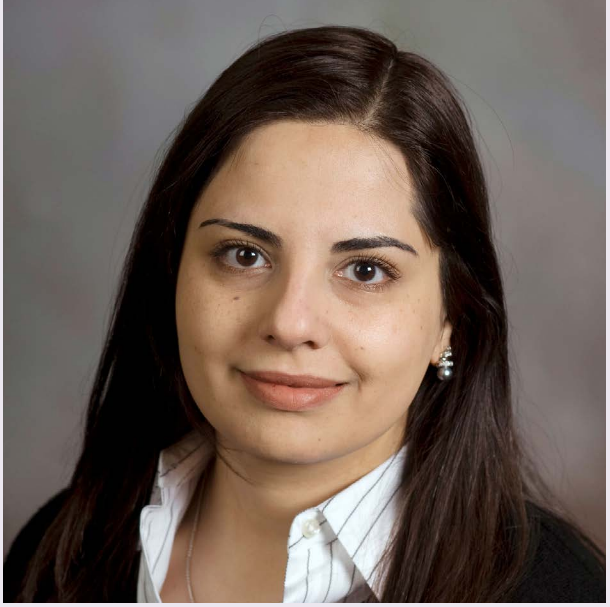
What kept him diligent wasn't learning the science, though, Mackanic said. He was motivated by the potential of those technologies to do something important. "I wasn't always a science kid," said Mackanic. "But once I got into engineering, I felt a sense of duty to use my technical skills to make an impact in the world."

That focus kept him moving through his senior year, with Mackanic finishing his undergraduate experience in a senior design project on the hybrid electric vehicle team. As he looked for his next step, he was drawn to the technology hub of Silicon Valley. This led him to apply to Stanford University, pursue his doctorate, and capitalize on the innovative environment of the area.

The atmosphere was one in which Mackanic flourished. In pursuit of his Ph.D., he continued developing new technology for batteries and found peers who also had experience in commercializing technologies. With confidence in his product development and new business insight, he launched Anthro Energy.

The company soon picked up several accolades. In 2020, Anthro was a semi-finalist for the MIT Clean Energy Prize and won startup funds from several different innovation groups. Even in this cycle of growth, Mackanic remains focused on his foundational beliefs.

"I want to use my time in a way that makes a difference, and my main goal is to see the technology become a reality," Mackanic said. "I've seen science as a way to create meaningful change, and that's something I want to pursue."



Bahareh Behkam named John R. Jones III Faculty Fellow

Bahareh Behkam, associate professor of mechanical engineering in the College of Engineering at Virginia Tech, has been awarded the John R. Jones III Faculty Fellowship in Mechanical Engineering by the Virginia Tech Board of Visitors.

The Jones Faculty Fellowship was established in 2006 to acknowledge and reward mid-career faculty who have shown exceptional merit in research, teaching, and service. Jones, a member of the Class of 1967 who earned his bachelor's degree in mechanical engineering, is a retired executive of American Electric Power. He has been a member of the Department of Mechanical Engineering Advisory Board since 1998.

Recipients hold the title of Jones Faculty Fellow for a period of five years.

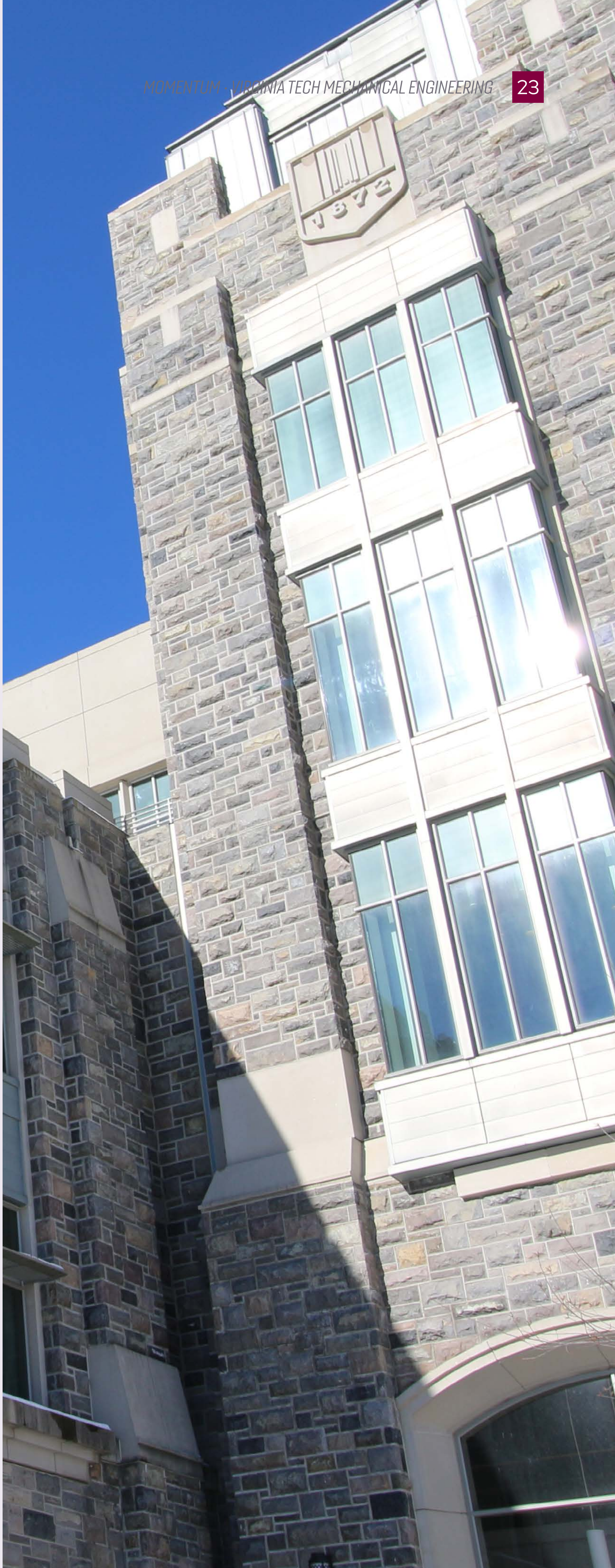
A member of the Virginia Tech faculty since 2008, Behkam is an internationally recognized leader in biohybrid microrobotics. Behkam's research expertise is in micro/nanoscale systems engineering, with a focus on biomedical applications. Her research is highly interdisciplinary and combines knowledge and methodology from engineering and biological sciences to advance fundamental understanding in both disciplines and apply that understanding to develop new technology.

Her lab's current research thrust areas are in (i) bio-hybrid micro/nano-robotics and living machines, and (ii) interfacial mechanics of pathogen-biomaterial and pathogen-host cell interactions. Specific foci include engineering bacterial communities for collaborative task completion, developing a bacteria-based drug delivery platform for cancer therapy, investigating bacterial and fungal adhesion and biofilm formation, and studying mammalian cell migration in multi-cue environments.

She has mentored eight Ph.D., 11 master's, and 45 undergraduate students. Together with her students and collaborators, Behkam has published one book, three book chapters, and more than 60 journal and peer-reviewed conference proceedings papers. Her articles have appeared in such prestigious journals as Advanced Science, ACS Nano, ACS Applied Materials and Interface, Lab on Chip, and ACS Synthetic Biology. The research work from her laboratory has been awarded the 2012 Adhesion Society Peeble Award, the 2013 ASME-NEMB Aline Best Paper Award, and 2014 ASME-NEMB Best Poser Award, and the 2018 MARSS Best Conference Paper Award.

She was a recipient of the Virginia Tech's College of Engineering Outstanding New Assistant Professor Award in 2012. Her innovative work on bacteria-based cancer therapy resulted in a 2015 National Science Foundation (NSF) Faculty Early Career Development (CAREER) award.

Behkam received her bachelor's degree from Sharif University of Technology (Iran) and a master's degree and Ph.D. from Carnegie Mellon University, all in mechanical engineering.



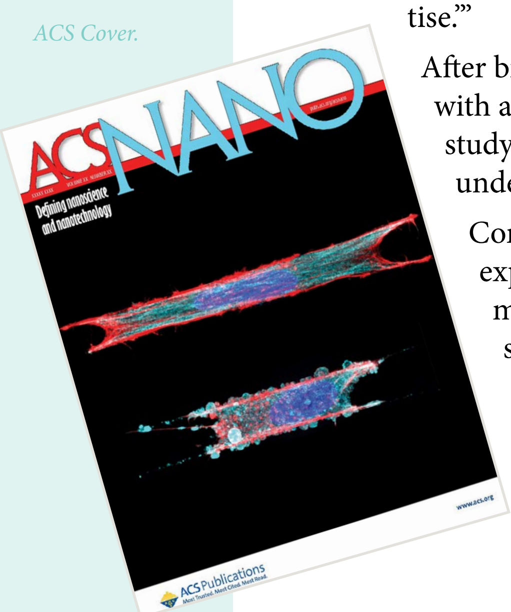
SHOCKING *THE* CELLULAR WORLD

Engineers' collaborative work discovers force signature of cells undergoing electroporation

The idea to collaborate came to Rafael Davalos and Amrinder Nain in a conversation on the stairs. Davalos, the L. Preston Wade professor in biomedical engineering and mechanics, and Nain, associate professor of mechanical engineering, both have research space at the Kelly Hall location of the Institute for Critical Technology and Applied Science at Virginia Tech.

"We crossed paths on the second-floor staircase landing," said Nain. "I said, 'I do force measurement of single cells, you use electric fields on cells.' We knew of each other's research and wondered what we could do with our combined expertise.'"

ACS Cover.



After brainstorming, they came up with a plan to see if they could study the forces exerted by a cell undergoing electroporation.

Combining their respective expertise in cell force measurement and electroporation in a single study published as the cover feature of American Chemical Society's (ACS) flagship ACS Nano journal, Nain and Davalos discovered a mechanical response from cells that may open doors to medical advances. They discovered an unusual biphasic response that could change the way the medical field understands and approaches techniques using electroporation.

Electroporation has been used in many medical applications, such as gene transfection and electrochemotherapy, since the 1980s. The basic aim is to apply a voltage to a cell; that voltage then pulses across the cell's membrane and at certain magnitudes causes pores, or "holes," to form in it. In this study, the researchers improved upon an established method of electroporation, in which medicines or genes are injected into holes formed in a cell's membrane.

While much is known about the methods of creating these openings, the cell's mechanism for resealing has remained largely unexplored. According to the researchers, by investigating the mechanical responses as cells contract following electroporation, they could gain a deeper understanding of how cells adapt their structure to promote their recovery. Unlocking cell recovery could in turn advance knowledge of cell mechanics and membrane permeability, as well as improve techniques harnessing electroporation, like gene transfection, electrochemotherapy, and other cancer treatments.

In the study, Davalos and his graduate students in the Bioelectromechanical Systems Laboratory, engaged in *in vitro* electroporation, a method of administering electrical pulses to tissue to treat cancer. Electroporation was applied to numerous types of cells, including human glioblastoma and mesothelioma cells. Nain and his graduate students in the Spinneret based Tunable Engineered Parameters (STEP) Laboratory engaged in creating precisely controlled, suspended fibrous environments. This brought a unique perspective to electroporation, enabling careful observation of cellular mechanical response throughout the process.

In their experiments, the researchers were able to culture cells on suspended nanofibers, rather than on the flat bottom of a petri dish, which allowed them to mimic the native fibrous environment found inside the body. In Nain's lab, researchers used nanonet force microscopy, a method pioneered by Nain, to measure cell forces. Cells attached to the nanonets and bent the flexible fibers, enabling the measurement of their contractile forces. In Davalos' lab, the nanonets were assembled in a custom microfluidic device housing two electrodes.

"Cell properties and forces can be hard to understand intuitively," said Phillip Graybill, a mechanical engineering doctoral student and first co-author on the study publication. "How much force is a nanonewton anyway? Other methods of characterization tend to be somewhat abstract, but in this study, the nanofibers provided a visually fascinating method to investigate cell behavior. Images of the nanofibers bending under the force of a cell brought these values to life."

"Cell forces have been studied before, to understand various biological phenomena, but never in the context of electroporation," added Aniket Jana, a mechanical engineering doctoral student and first co-author on the study. "Our approach to monitor cell force dynamics provides a direct way of understanding the physical recovery mechanisms of cells following electric field treatments."

The unique experimental setup led the team to their fundamental discovery. When high electric fields were applied, cellular forces decreased, which was concurrent with the formation of pores in the cell membrane. Cell force recovery coincided with membrane resealing, but the recovery showed an unusual biphasic response: increase and decrease in forces before the cells finally recovered their original contractility. Applying forces (contractility) is fundamental to the nature of cell. Cells exert this force, mediated by the cytoskeleton, to divide themselves, migrate, or heal wounds.

To the researchers, this biphasic response made it clear that cytoskeletal dynamics play a significant role in cell shape and force recovery.

Nain explained that cell membrane disruption is linked to the loss of contrac-

Top:
Amrinder Nain, associate professor in mechanical engineering

Bottom:
Rafael Davalos, professor in biomedical engineering and affiliate faculty in mechanical engineering

SHOCKING THE CELLULAR WORLD *(CONTINUED)*

tility-bearing cytoskeleton inside the cell. He described the cytoskeleton as a dynamic and responsive meshwork; its re-establishment is required for recovery of the cell's contractility and shape.

"It is remarkable how the cell cytoskeleton can fully recover within just a couple of hours, despite extensive damage caused by electric fields," Jana said. "This shows the strong will of cells to live even after extreme perturbations. Such incredible cell adaptability in our suspended nanofibers further highlights how cancer cells can evade electric field treatments and still continue on metastasizing."

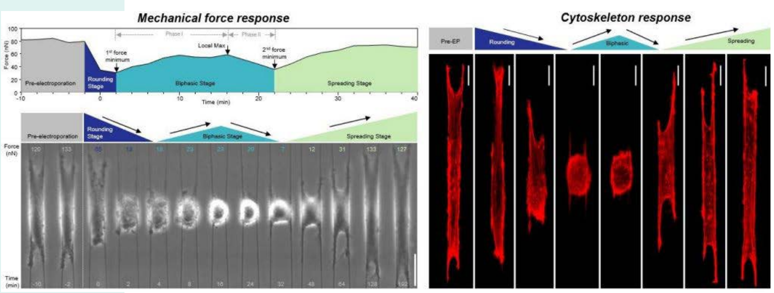


Image of cell properties, displaying the mechanical force response (left) and the biphasic response of the cytoskeleton (right).

"It was amazing to see just how dynamic and responsive cells really are after electrical disruption," added Graybill. "It was exciting to find that the loss of contractile force measured in one cell type also occurred in other cell types, because this suggested that this behavior is consistent across many cell types.

"This was exciting, because a better understanding of cell recovery may improve techniques where cell recovery is desirable, such as in gene transfection, electrofusion, electrochemotherapy, or where cell recovery is undesirable, such as in cancer treatments, where it's preferable for the cancerous cells to die."

The researchers believe their new understanding of cell contraction and recovery has important implications for electroporation's use in various applications, including molecular medicine, genetic engineering, and cellular biophysics. Nain said that the biphasic response they observed could enable the injection of larger particles into the cell, without having to use a higher electric voltage.

The cell membrane is like an insulator, and when you apply a voltage, the electrical pulse travels across the membrane, explained Davalos. At a critical voltage, pores form on the cell. The magnitude of the electric field controls whether or not pores will form in the membrane, while the various pulse parameters dictate the size of the particle that can be put into the cell.

Trying to increase those parameters could affect the particle size one can inject, but the higher the electrical voltage, the more likely the cell is to die. There is also a very narrow window where pores are open and able to receive materials before the cell reseals. The overall goal of electroporation is to disrupt the cell so that substances – such as medicine or DNA – can be injected into it. Identifying and understanding how long the disruption lasts is thus very important.

"This shows the strength of collaboration across disciplines," Nain said. "I knew about the electric field research by Davalos and wondered how we could integrate nanonet force microscopy, the cell force measurement platform developed in my lab, with electrical fields. Together, we have discovered a new phenomenon in a well-established field."

In Nain and Davalos' study, the cells attached to suspended fibers were able to sustain high electrical voltages while enabling the precise measurement of forces. This holds great promise to deliver macromolecules in the cells efficiently, they said.

"This platform has broadened that reversible window," Davalos said. "This is exciting because the opportunity for introducing larger particles increases without the risk of killing the cell. This could have major implications in genetic engineering and molecular medicine. Achieving this in realistic fibrous environments opens new possibilities for translating the technology."

The research was conducted by an interdisciplinary team from multiple engineering backgrounds. Philip Graybill and Aniket Jana, Ph.D. students in mechanical engineering, are equal authors on the publication, and are joined by Rakesh Kapania, Norris and Laura Mitchell Professor in the Kevin T. Crofton Department of Aerospace & Ocean Engineering.

Aniket Jana (left) and Philip Graybill (right) conduct research in engineering labs.

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