Mechanical Engineering

Momentum

Fall 2020

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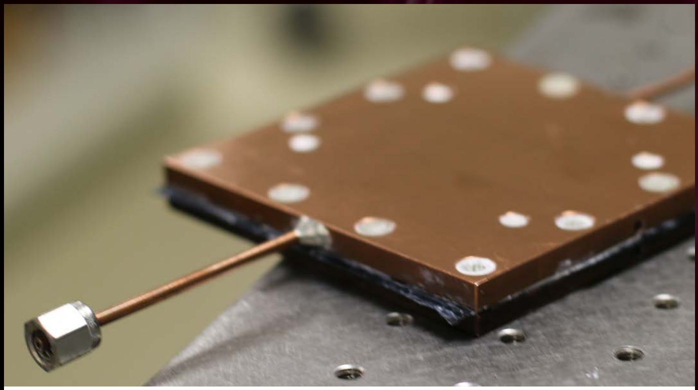
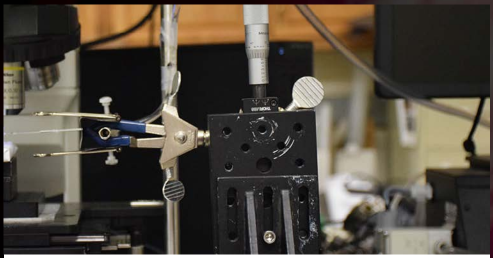
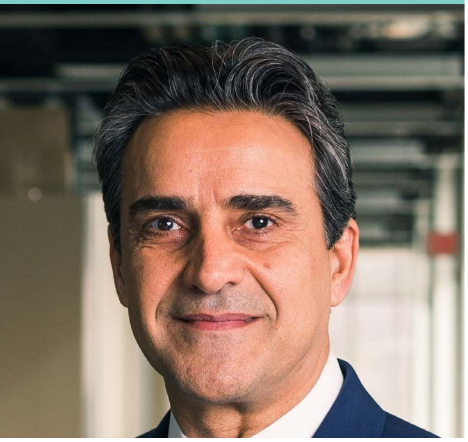






AZIM ESKANDARIAN

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

Department of
Mechanical Engineering

Sharing our research victories

Greetings, colleagues.

It is always a pleasure to report good things happening, which I feel is especially true during this season. As we continue to hope for returning to normalcy after COVID-19, I am thrilled to share with you more stories of exciting research and discovery in our department and through our national collaborations. Please browse through this issue of Momentum magazine; I promise you will be amazed by the depth, breadth, and diversity of scholarship brilliance of our faculty and students.

Through a large National Science Foundation grant, Professors Alex Leonessa from the Department of Mechanical Engineering and Divya Srinivasan from the Department of Industrial and Systems Engineering have joined forces with the University of Florida and an industry partner to develop a novel full-body experience in a fully electronic environment. Their creative work will shape the future of virtual reality in both science and entertainment. Please read about this fantastic cover page story on Page 28.

Much of our published research take cues from nature to increase the strength of manufactured materials. It is always fascinating to see how our faculty translate the natural world's ingenuity into innovative engineered materials. Pages 12 and 18 will be great places to read about that.

Assistant Professor Ling Li is part of a collaborative effort with Princeton University, sponsored by the Air Force Office of Scientific Research (AFOSR), to determine design strategies modeled from an ancient group of birds' eggshells. These natural structures have a high potential for many applications, including structural components for air vehicles. In another study published by Proceedings of the National Academy of Sciences, Dr. Li's research team focused on the cuttlefish, another species traveling in the ocean's depths. His team discovered the unique underlying microstructures that give cuttlebone the high-performance mechanical properties to be extremely lightweight, stiff, and damage-tolerant, despite the shell's composition mostly of brittle aragonite, a crystal form of calcium carbonate.

Elsewhere, our faculty are working to bring increased safety to nuclear power plants, make pedestrian foot traffic more harmonious with electric cars, engineer natural approaches to antiperspirants, and more. You will also read about a 2017 grad who has flourished in the world of industry, fueled by the rich experiences of the Senior Design program within our department.

I am grateful for your continued support and attention to our Department. I hope you are well and that you are also enjoying your successes in these unusual and challenging times.

With best regards,

Azim Eskandarian

Student team **Victor Tango** competed in the Year 3 AutoDrive Challenge competition, a completely virtual competition due to the COVID-19 pandemic. The Virginia Tech team took 3rd place overall out of 8 university teams, coming up to speed in a short time and making fantastic presentations on Social Responsibility, Concept Design, and a Simulation Challenge.

Virginia Tech has been accepted into the AutoDrive II Competition, which begins in Fall 2021.

Machine learning reduces hazards in nuclear power plants

Nuclear researcher Juliana Pacheco Duarte is part of a team using nearly $800,000 in funding from the U.S. Department of Energy to build new prediction models for hazards that could impact nuclear power plants.

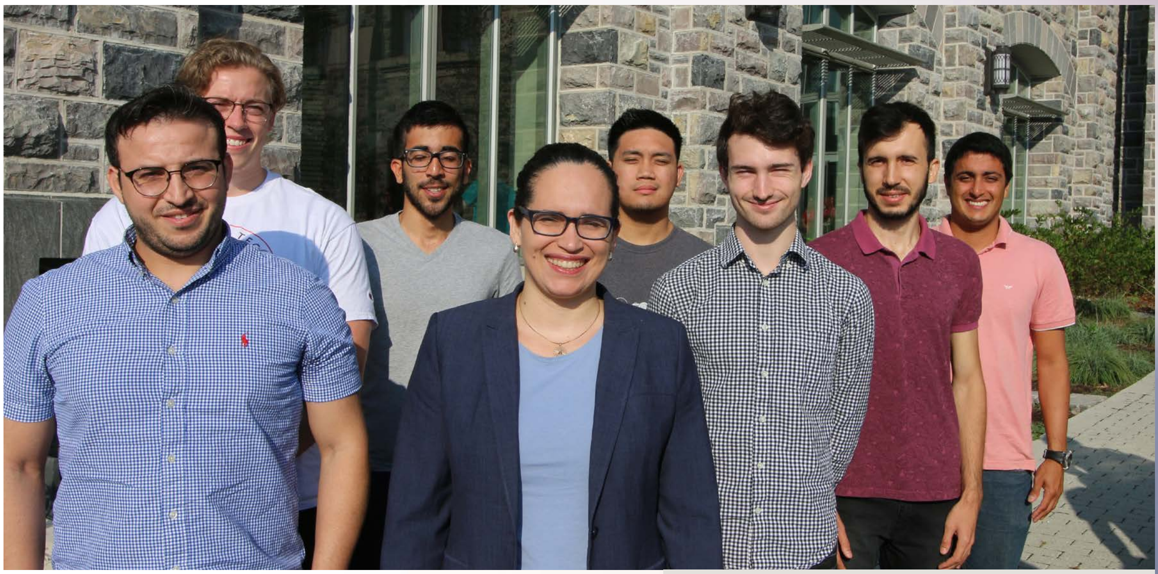
According to Duarte, nuclear energy has the potential to rapidly expand the world's energy market, but advances in technology must come with new methods for risk management. The phrase "risk management in a nuclear power plant" may immediately call to mind the avoidance of a nuclear explosion or a radiation leak such as Chernobyl, but this risk management begins with a plantwide assessment to ensure that existing local hazards do not result in an unsafe shutdown of a plant. Duarte's group will create a general risk reduction methodology to more accurately predict local hazards that, if not managed, could lead to significant events.

Though they don't usually spell environmental disaster, local hazards can still equal big costs. Aside from the radioactive elements, there are many combustible sources within a power plant. A control room, pump room, or turbine room are composed of complex networks of mechanics and electronics that demand their own safety standards. The loss of any of those peripherals could spell a major repair cost in addition to the loss of energy production.

Duarte's team includes Virginia Tech Professor Brian Lattimer, University of Wisconsin-Madison faculty Jun Wang and Michael Corradini, and Convergent Science co-owner and vice president Kelly Senecal. This grouping will combine expertise in the mechanics of fire, engineering physics, and custom machine learning to build predictive models for probabilistic risk assessments.

The Department of Energy made the move to improve hazard prediction models following a period of progress in understanding the properties of fire. The proposal indicates that, while new data and measurement methods have been steadily advancing the understanding of fire, many of the applied risk management models in place for nuclear power plants are based on data collected before these improvements. Duarte's team will identify what new data are needed and provide new tools to set the stage for decreased uncertainty.

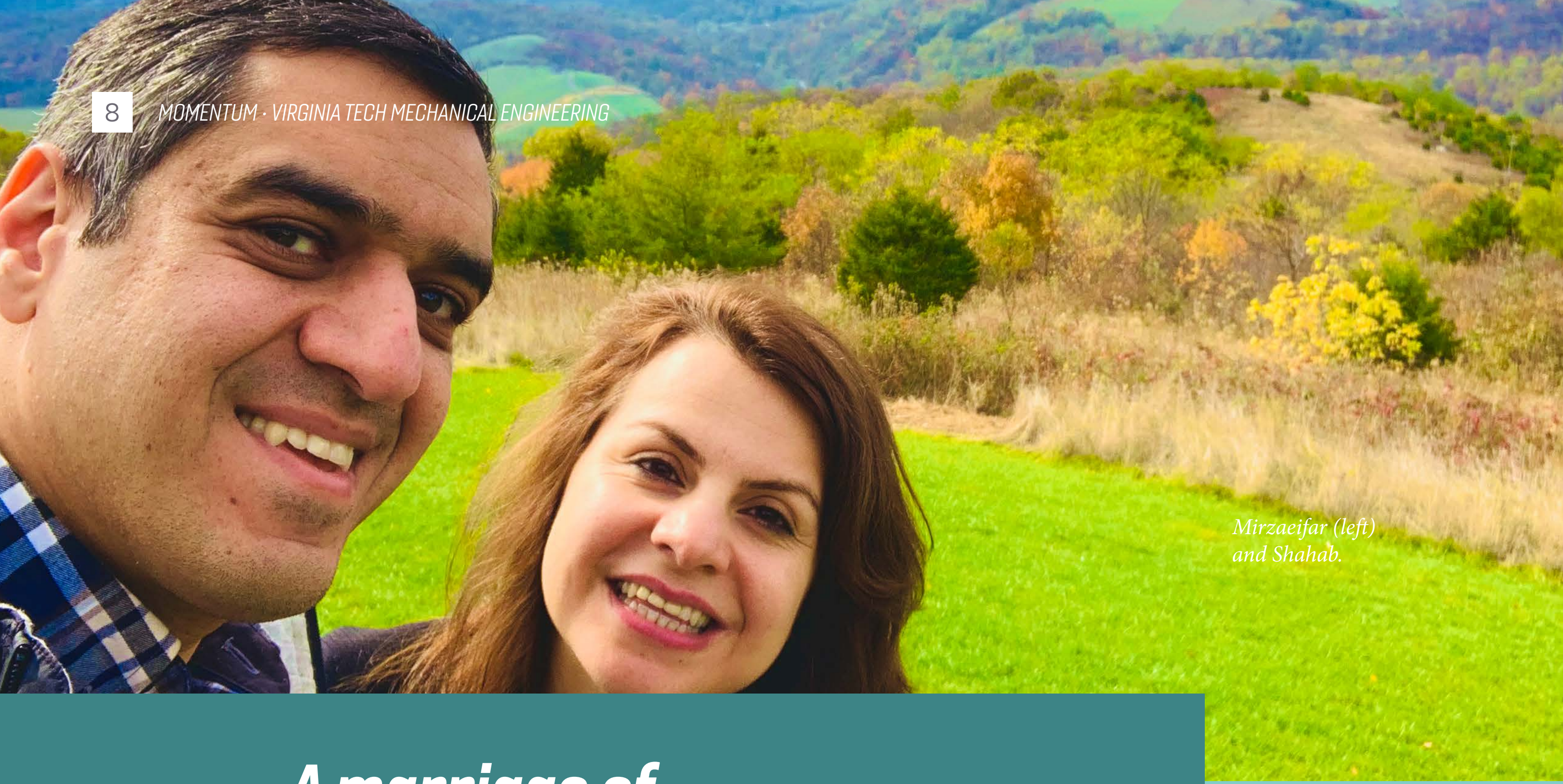
To make those connections, the group will use simulation Monte Carlo analysis, statistical analysis, and machine learning to reduce the uncertainty in describing a hazard event. This will be achieved by running a series of simulations that provide variations on hazard event conditions, conducting statistics on existing data and simulation results to identify key parameters that most significantly affect the hazard level, and using deep learning models and statistics to identify how to lower the hazard uncertainty. This will give a clearer picture of any gaps in the current data and inform a more complete approach for risk reduction.



Duarte's lab members in a photo taken before the COVID-19 pandemic. Front row, left to right: Bruno Serrao, Paul Hurley, Juliana Duarte, Abdulsalam Shakhatreh. Back row, left to right: Elvan Sahin, Jeric Demasana, Abdulla Alblooshi, Nick Burns.

This application of machine learning with simulation data will also provide additional possibilities for field engineers to more accurately assess the hazards for their specific plant. Field conditions are typically not the same as data set conditions. Machine learning models developed in this research will be able to rapidly translate what the appropriate hazard event conditions are for the given field conditions.

While the scope of the initial call from the Department of Energy was centered on fire modeling, the group's techniques could also be used for other kinds of prediction. By using adapted versions of this methodology, the impact of additional events, such as hurricanes, earthquakes and tsunamis, could also be anticipated.



Mirzaeifar (left) and Shahab.

A marriage of POLYMERS AND ULTRASOUND

During an outdoor excursion in 2016, husband and wife faculty Reza Mirzaeifar and Shima Shahab, both mechanical engineering assistant professors, batted an idea back and forth: what if they combined his work with polymers and her ultrasound research into a single project?

Since that hike, the pair have converged on a host of applications using this approach. They are working with a leading medical device company to fuel new innovations in non-invasive treatments such as targeted drug delivery and surgical techniques. The project is moving forward with more than $510,000 in funding from the National Science Foundation.

The polymer portion of the work involves using materials with shape memory properties, or the ability to return to their original shape after they are deformed. A material's return to its original shape may be triggered by temperature or some other external stimuli. In this case, the polymers are subjected to an ultrasound wave, prompting their restored shape.

Ultrasound technology is already widely used in medical applications such as diagnosis of gall bladder disease, viewing a growing fetus, and more. These familiar applications produce visual results on a screen as they pass through tissues, but sound waves can also be used to affect the properties of physical objects within the body. If these objects were made of a polymer, the ultrasound waves would cause a reaction in the polymer but cause no harm to the surrounding tissues.

Building on this idea, the couple combined the resources of both their labs to deform polymers and return them to their original shape using ultrasound waves. They found the theory to be viable, publishing their results in RSC Advances. Those early tests used samples of general polymers, subjected to standard ultrasound test waves, but the generic data proved to the researchers that the idea was worth pursuing further. The ultrasound did indeed cause a deformed shape to return to its original shape when subjected to the ultrasound, though the early test waves did not fully return the object to its initial shape.

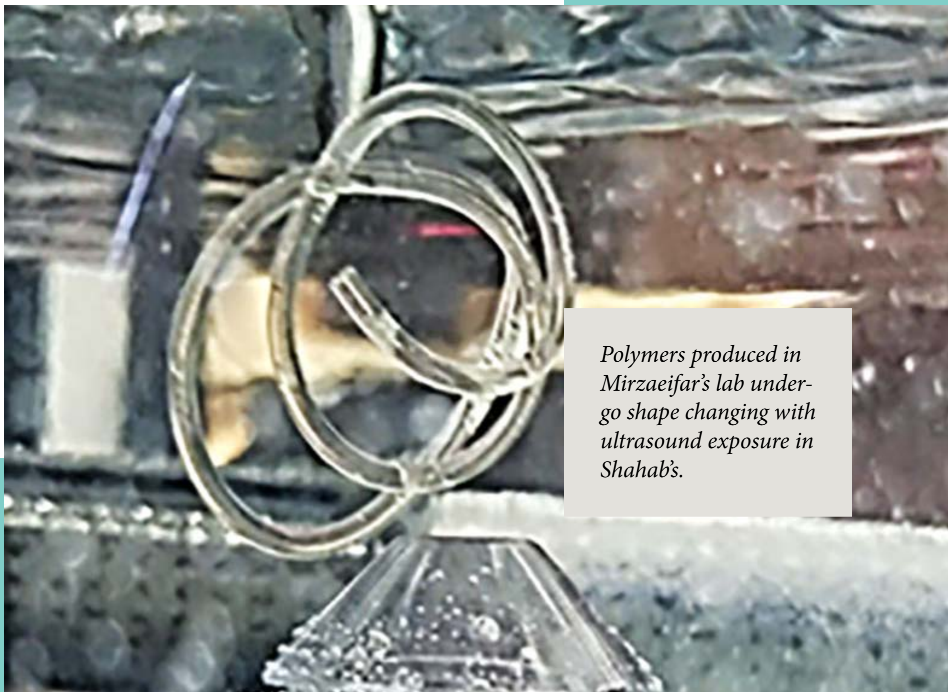
Recovery of a shape memory polymer filament when subjected to high intensity focused ultrasound waves.

The next step was to be more specific in approach. Mirzaeifar focused on responses between more specific polymers, while Shahab observed the polymer response in an increasingly fine-tuned range of ultrasound frequencies. The results have proven very favorable, Shahab said, as the group's effort has yielded materials that return to almost 100 percent of their original shape.

"While ultrasonic waves can actuate any shape memory polymer, the recovery will be partial and slow," said Mirzaeifar. "We target making a new class of shape memory polymers which are particularly designed to be stimulated by ultrasonic waves."

As the results became more promising, Mirzaeifar and Shahab approached Medshape, a company with experience creating patented medical devices. Founder Ken Gall and Basic Research Director David Safranski agreed to join the effort, giving insight into devices that might be created or enhanced with the new technology. With that guidance and their proven science, a proposal was submitted to the National Science Foundation under its Grant Opportunities for Academic Liaison with Industry program. The NSF responded with more than $510,000 to continue the research and pursuit of possible applications.

An early idea for such an application was targeted drug delivery. It could look like this: a container with drugs inside is injected or ingested into the body. Under normal circumstances, that container has enough drugs to both impact its target and also account for waste. A pill, for instance, has to have enough drugs to do the job it was intended for, but it's also typically expected that some of the pill's payload circulates to other untargeted parts of the body. In the case of this development, a drug container made of



Polymers produced in Mirzaeifar's lab undergo shape changing with ultrasound exposure in Shahab's.

Mirzaiefar's polymer could be deformed into a pill shape, but remain sealed and intact as it moved through the body. When the container reaches the area of the body that requires the drug, exposure to Shahab's ultrasound waves cause it to return to a shape that open the container. In that way, drugs could be more strategically applied.

In addition to drug delivery, there is potential to apply the approach to stent treatment. If a polymer were 3D-printed into a cylinder but then compacted, it could be placed in an artery in its compressed form. When in place, administering the ultrasound waves to the object from outside the body would return it to its original shape, causing the shape to expand and open a clogged blood vessel. The list of possibilities grows from there.

By approaching the project from both their polymer and ultrasound research backgrounds, Mirzaeifar and Shahab have been able to more harmoniously engineer a holistic method that causes the two disciplines to function in a single, unified approach. Medshape's continuing role is to ensure that the materials chosen for use are safe for medical use.

"This approach with ultrasound and polymers has the potential to revolutionize minimally invasive surgical techniques and inform new designs for implants and soft electronics," said Shahab. "Working with world's leading manufacturer of biomedical devices using shape-changing metal and polymer technologies will guide this fundamental research to solve critical industry needs."

Further findings were published in IOP Science in October 2020.

NEW FACULTY

Dylan Losey is an assistant professor whose research interests lie at the intersection of human-robot interaction, machine learning, and control theory. Specifically, he creates learning and control algorithms for robots that collaborate with people. These robots personalize their behavior, continually adapting to what the human wants and proactively helping them to achieve their goals. Overall, his research develops robots that understand -- and are understood by -- their human partners, with applications in personal, interactive, and assistive robots.

Dylan was previously a postdoctoral scholar in the Computer Science Department at Stanford University. He received his Ph.D. in Mechanical Engineering from Rice University in 2018, his M.S. in Mechanical Engineering from Rice University in 2016, and his B.E. in Mechanical Engineering from Vanderbilt University in 2014. During 2017, Dylan was also a visiting scholar at the University of California, Berkeley. He has been awarded the IEEE/ASME Transactions on Mechatronics Best Paper Award, RSS, CoRL, HRI, and BioRob Best Paper Nominations, the Outstanding Ph.D. Thesis Award from the Rice University Department of Mechanical Engineering, and an NSF Graduate Research Fellowship.

Michael Bartlett is an assistant professor whose research approach has been formed by both academic and industry experience. He hopes to have touchpoints with most of the thrust areas in mechanical engineering at Virginia Tech.

His most recent appointment was as an assistant professor at Iowa State, where he received the 3M Non-Tenured Faculty Award and the DARPA Young Faculty award. Additionally, he was honored by the Engineering Student Council with the award of Outstanding Faculty while serving in that post.

Prior to Iowa State, Bartlett was a senior research engineer in the Corporate Research Laboratory of the 3M Corporation. This gave him a foundation in the intersections of engineering and commercial implementation, as well as working with commercialization and production.

Much of the focus in Bartlett's Soft Materials and Structures Lab is on developing soft materials with extraordinary combinations of mechanical and functional properties, including electronics and machines made with liquid metal that can be stretched, bent, and even cut while remaining completely functional. This extends to smart adhesives that release on demand, and materials that sense and adapt their properties and structure to optimize performance.

Bartlett is also a recipient of the Adhesion Society Early Career Scientist Award and a DARPA Director's Fellowship, which expands on his work in multifunctional soft materials paired with technology.

FLYING ON EGGSHELLS

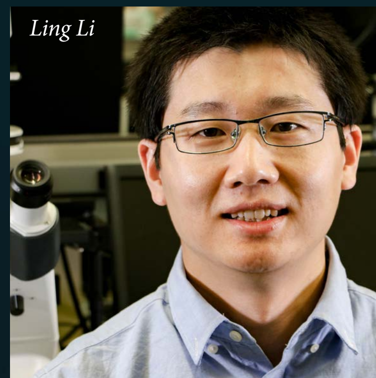
A Virginia Tech researcher is part of a collaborative effort with Princeton University to determine design strategies modeled from the eggshells of an ancient group of birds. These natural structures have high potential for implementation in many applications, including structural components for air vehicles. The project is being funded by the Air Force Office of Scientific Research (AFOSR) for a total of $850,000 for a term of three years.

Ling Li, an assistant professor in mechanical engineering, is bringing his expertise in biological structures and bio-inspired materials to the table for the analysis. He is joined by the Stoddard Lab at Princeton, which contributes expertise in egg evolution, avian morphology and coloration, and structure-function relationships.

The team is looking at the egg structures for paleognaths, the oldest group of living birds. This group of mostly flightless birds includes the ostrich, emu, and South American native tinamou. The functional design of the eggshell requires that it be strong enough to withstand physical damage and the weight of a nesting parent, but weak enough to allow a chick to hatch. To maintain the chick's life cycle, it must also resist microbial invasion yet be porous enough to allow gas exchange for the chick living inside.

With each of these qualities, it is also remarkable how quickly an egg is formed. Typically, this occurs in less than 24 hours, one of the fastest biomineralization events in nature. Unlike other biological materials such as bone and shells, it has a short "life cycle", which only need to last a few weeks or months during the hatching process.

The study will approach the science holistically. Li and his colleagues from Princeton are examining the shell's


Ling Li

unique components--a mineralized outer shell paired with an inner membrane composed of collagen and proteins—and how they contribute to conflicting mechanical and other properties. The relationship between these properties and the ways they work together at different stages of the egg's life cycle will help the group get a better picture of the underlying design.

From the engineering perspective, the research team aims to distill new design concepts for developing multifunctional composites with controlled fracture properties, while from the evolutionary perspective, this study aims to uncover the general design rules of eggshells, a remarkably successful evolutionary invention of avian birds.

"Nature is very good at making strong structures from weak materials," said Li. "Teeth, bone, and seashells, for example, are extremely strong and durable, despite the fact that they are made of weak minerals and soft organic materials. Unique biological needs require the eggshells to strike a delicate balance for the mechanical properties instead of being as strong as possible. I am excited to work with my collaborators to investigate how Mother Nature achieves this and how we can utilize the design strategies learned from bird eggshells for engineering and defense applications."

Droplet biosensing method opens the door for faster identification of COVID-19

Mechanical engineering associate professor Jiangtao Cheng and electrical and computer engineering assistant professor Wei Zhou have developed an ultrasensitive biosensing method that could dramatically shorten the amount of time required to verify the presence of the COVID-19 virus in a sample. Their peer-reviewed research was published in ACS Nano on June 29.

There's significant room to improve the pace of coronavirus testing, Cheng and Zhou have found. Current COVID-19 verification tests require a few hours to complete, as verification of the presence of the virus requires the extraction and comparison of viral genetic material, a time-intensive process requiring a series of steps. The amount of virus in a sampling is also subject to error, and patients who have had the virus for a shorter period of time may test negative because there is not enough of the virus present to trigger a positive result.

In Cheng and Zhou's method, all of the contents of a sampling droplet can be detected, and there is no extraction or other tedious procedures. The contents of a microdroplet are condensed and characterized in minutes, drastically reducing the error margin and giving a clear picture of the materials present.

The key to this method is in creating a surface over which water containing the sample travels in different ways. On surfaces where drops of water may "stick" or "glide," the determining factor is friction. Surfaces that introduce more friction cause water droplets to stop, whereas less friction causes water droplets to glide over the surface uninhibited.

The method starts by placing a collected sample into liquid. The liquid is then introduced into an engineered substrate surface with both high and low friction regions. Droplets containing sample will move more quickly in some areas but anchor in other locations thanks to a nanoantenna coating that introduces more friction. These stop-and-go waterslides allow water droplets to be directed and transported in a programmable and reconfigurable fashion. The "stopped" locations are very small because of an intricately placed coating of carbon nanotubes on etched micropillars.

These prescribed spots with nanoantennae are established as active sensors. Cheng and Zhou's group heats the substrate surface so that the anchored water droplet starts to evaporate. In comparison with natural evaporation, this so-called partial Leidenfrost-assisted evaporation provides a

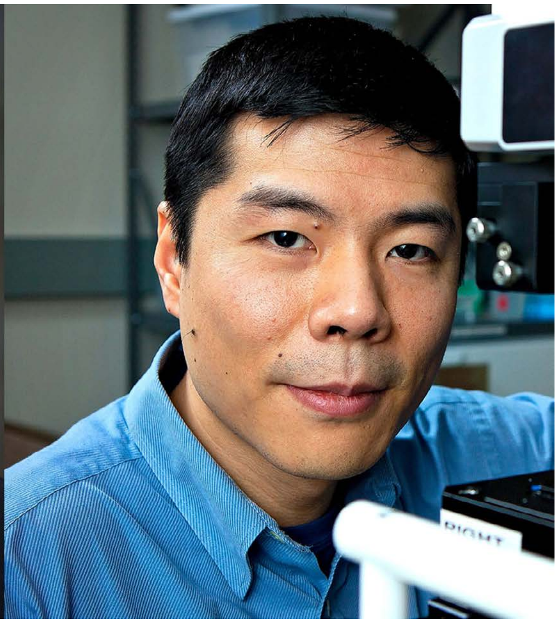
levitating force which causes the contents of the droplet to float toward the nano-antenna as the liquid evaporates. The bundle of sample particles shrinks toward the constrained center of the droplet base, resulting in a rapidly-produced package of analyte molecules.

For fast sensing and analysis of these molecules, a laser beam is directed onto the spot with the packed-in molecules to generate their vibrational fingerprint light signals, a description of the molecules expressed in waveforms. This method of laser-enabled feedback is called surface-enhanced Raman spectroscopy.

All of this happens in just a few minutes, and the fingerprint spectrum and frequency of the coronavirus can be quickly picked out of a lineup of the returned data.

Professor Cheng and Zhou's team is pursuing a patent on the method, and are also pursuing funding from the National Institutes for Health to deliver the method for widespread use.

A full summary and description of this research is available in the June 26, 2020, publication of ACS Nano.



Jiangtao Cheng (left) and Wei Zhou (right).

Polymers produced in Mirzaeifar's lab undergo shape changing with ultrasound exposure in Shahab's.

Novel method of heat conduction could be a game changer for server farms and aircraft

Jonathan Boreyko, an associate professor in mechanical engineering, has developed an aircraft thermal management technology that stands ready for adaptation into other areas.

The research was published in Advanced Functional Materials on Aug. 18, 2020.

Boreyko was the recipient of a Young Investigator Research Program award in 2016, given by the Air Force Office of Scientific Research. This award funded the development of planar bridging-droplet thermal diodes, a novel approach to thermal management. Boreyko's research has shown this new approach to be both highly efficient and extremely versatile.

"We are hopeful that the one-way heat transfer of our bridging-droplet diode will enable the smart thermal management of electronics, aircraft, and spacecraft," said Boreyko.

Diodes are a special kind of device that allow heat to conduct in only one direction by use of engineered materials. For management of heat, diodes are attractive because they enable the dumping of heat entering one side, while resisting heat on the opposite side. In the case of aircraft (the focus of Boreyko's funding), heat is absorbed from an overheated plane, but resisted from the outside environment.

Boreyko's team created a diode using two copper plates in a sealed environment, separated by a microscopic gap. The first plate is engineered with a wick structure to hold water, while the opposite plate is coated with a water-repelling (hydrophobic) layer. The water on the wicking surface receives heat, causing evaporation into steam. As the steam moves across the narrow gap, it cools and condenses into dew droplets on the hydrophobic side. These dew droplets grow large enough to "bridge" the gap and get sucked back into the wick, starting the process again.

Boreyko's approach: heat applied to the water attracting plate opposite the hydrophobic plate.

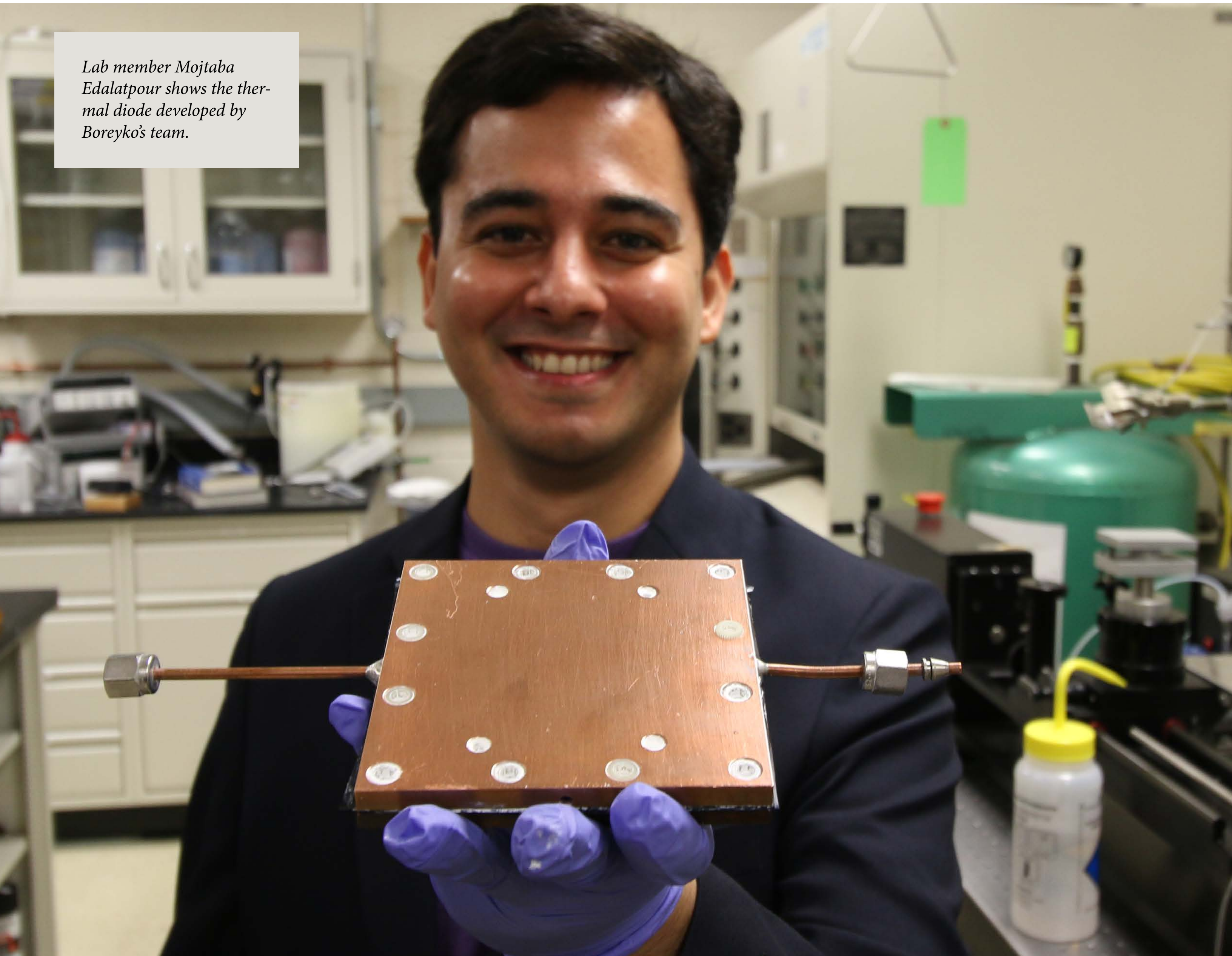
Boreyko's approach: heat applied to the water attracting plate opposite the hydrophobic plate.

If the source of heat were instead applied the hydrophobic side, no steam can be produced because the water remains trapped in the wick. This is why the device can only conduct heat in one direction.

What does this look like in practice? An object producing heat, like a CPU chip, overheats if this heat is not continually removed. Boreyko's invention is affixed to this heat source. Generated heat is transferred through the conducting plate, into the water. Water turns to steam and moves away from the source of the heat. The hydrophobic, nonconducting side prevents heat from entering via the air or other heat sources that may be near, allowing the diode to manage the heat only from its main subject.

Boreyko's team measured a nearly 100-fold increase in heat conduction when the wicked side was heated, compared to the hydrophobic side. This is a significant improvement to existing thermal diodes. According to Boreyko, current diodes are either not very effective, only conducting a few times more heat in one direction, or require gravity. This new bridging-droplet thermal diode can be used upright, sideways, or even upside-down, and would even work in space where gravity is negligible.

The team has filed a provisional patent and is in search of industry partners to carry on the work.



Lab member Mojtaba Edalatpour shows the thermal diode developed by Boreyko's team.

Researchers find cuttlebone's microstructure sits at a 'sweet spot' for lightweight, stiff, and damage-tolerant design

by **Suzanne Irby, Virginia Tech College of Engineering**

Ling Li has a lesson in one of his mechanical engineering courses on how brittle materials like calcium carbonate behave under stress. In it, he takes a piece of chalk composed of the compound and snaps it in half to show his students the edge of one of the broken pieces. The break is blunt and straight.

Then, he twists a second piece, which results in sharper shards broken at a 45-degree angle, indicating the more dangerous direction of tensile stress on the chalk. The broken chalk helps Li demonstrate what brittle calcium carbonate will do under normal forces: it tends to fracture.

"If you bend it, it will break," Li said.

In Li's Laboratory for Biological and Bio-Inspired Materials, many of the ocean animals he studies for their biological structural materials have parts made of calcium carbonate. Some mollusks use it in photonic crystals that create a vivid color display, "like a butterfly's wings," Li said. Others have mineral eyes built with it, into their shells. The more Li studies these animals, the more he's amazed by the uses their bodies find for intrinsically brittle and fragile material. Especially when the use defies that fragility.

In a study published by Proceedings of the National Academy of Sciences of the United States of America, Li's research team focused on the cuttlefish, another one of those inventive, chalk-built animals and a traveler of the ocean's depths. The researchers investigated the internal microstructure of cuttlebone, the mollusk's highly porous internal shell, and found that the microstructure's unique, chambered "wall-septa" design optimizes cuttlebone to be extremely lightweight, stiff, and damage-tolerant. Their study goes into the underlying material design strategies that give cuttlebone these high-performance mechanical properties, despite the shell's composition mostly of brittle aragonite, a crystal form of calcium carbonate.

In the ocean, the cuttlefish uses cuttlebone as a hard buoyancy tank to control its movement up and down the water column,

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Postdoctoral researcher Zian Jia examines a 3D-printed model of cuttlebone's microstructure.

to depths as low as 600 meters. The animal adjusts the ratio of gas to water in that tank to float up or sink down. To serve this purpose, the shell has to be lightweight and porous for active fluid exchange, yet stiff enough to protect the cuttlefish's body from strong water pressure as it dives deeper. When cuttlebone does get crushed by pressure or by a predator's bite, it has to be able to absorb a lot of energy. That way, the damage stays in a localized area of the shell, rather than shattering the entire cuttlebone.

The need to balance all of these functions is what makes cuttlebone so unique, Li's team discovered, as they examined the shell's internal microstructure.

Ph.D. student and study co-author Ting Yang used synchrotron-based micro-computed tomography to characterize cuttlebone microstructure in 3D, penetrating the shell with a powerful X-ray beam from Argonne National Laboratory to produce high-resolution images. She and the team observed what happened to the shell's microstructure when it was compressed by applying the in-situ tomography method during mechanical tests. Combining these steps with digital image correlation, which allows for frame-by-frame image comparison, they studied cuttlebone's full deformation and fracture processes under loading.

Their experiments revealed more about cuttlebone's chambered "wall-septa" microstructure and its design for optimized weight, stiffness, and damage tolerance.

The design separates cuttlebone into individual chambers with floors and ceilings, or "septa," supported by vertical "walls." Other animals, like birds, have a similar structure, known as a "sandwich" structure. With a layer of dense bone atop another and vertical struts in between for support, the structure is made lightweight and stiff. Unlike the sandwich structure, however, cuttlebone's microstructure has multiple layers — those chambers — and they're supported by wavy walls instead of straight struts. The waviness increases along each wall from floor to ceiling in a "waviness gradient."

"The exact morphology we haven't seen, at least in other models," said Li of the design.

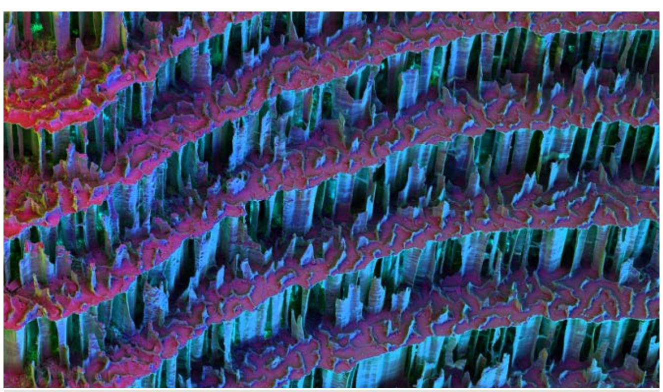
This wall-septa design gives cuttlebone control of where and how damage occurs in the shell. It allows for graceful, rather than catastrophic, failure: when compressed, chambers fail one by one, progressively rather than instantaneously.

The researchers found that cuttlebone's wavy walls induce or control fractures to form at the middle of walls, rather than at floors or ceilings, which would cause the entire structure to collapse. As one chamber undergoes wall fracture and subsequent densification — in which the fractured walls gradually compact in the damaged chamber — the adjacent chamber remains intact until fractured pieces penetrate its floors and ceilings. During this process, a significant amount of mechanical energy can be absorbed, Li explained, limiting external impact.

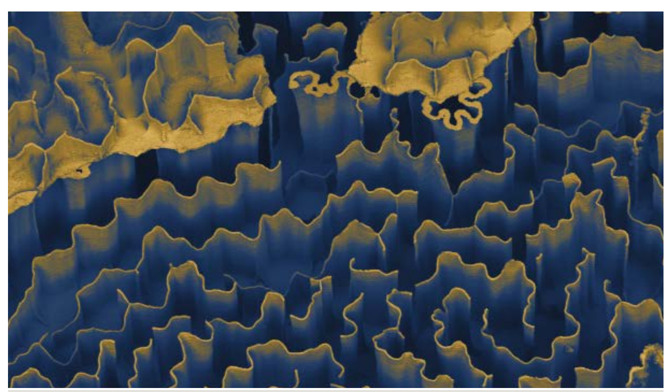
Li's team further explored the high-performance potential of cuttlebone's microstructure with computational modeling. Using measurements of the microstructure made with the earlier 3D tomography, postdoctoral researcher Zian Jia built a parametric model, ran virtual tests that altered the waviness of the structure's walls, and observed how the shell performed as a result.

"We know that cuttlebone has these wavy walls with a gradient," Li said. "Zian changed the gradient so we could learn how cuttlebone behaved if we went beyond this morphology. Is it better, or not? We show that cuttlebone sits in an optimal spot. If the waviness becomes too big, the structure is less stiff. If the waves become smaller, the structure becomes more brittle. Cuttlebone seems to have found a sweet spot, to balance the stiffness and energy absorption."

Li sees applications for cuttlebone's microstructural design in ceramic foams. Among foams used for crush resistance or energy



A scanning electron microscopic image of cuttlebone, showing its chambered microstructure.



Supporting the chambers of cuttlebone's microstructure are uniquely wavy walls.

LEFT PHOTO BY JAMES C. WEAVER, RIGHT PHOTO BY TING YANG, ZIAN JIA, AND LIUNI CHEN

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Study co-authors Zian Jia, Ling Li, and Ting Yang, from left to right. Their study was supported by the National Science Foundation and the Air Force Office of Scientific Research.

absorption in packaging, transportation, and infrastructure, polymer and metal materials are the more popular choices. Ceramic foams are rarely used because they're brittle, Li said. But ceramics have their own unique advantages — they're more chemically stable and have a high melting temperature.

If cuttlebone's properties could be applied to ceramic foams, their ability to withstand high heat paired with newfound damage tolerance could make ceramic foams ideal for use as thermal protection units in space shuttles or as general thermal protection, Li believes. His team has been evaluating that application in a separate study.

Though the team has already begun to look up from the sea to the sky at the possibilities that cuttlebone inspires, their study of the shell's fundamental design strategies is just as important to Li.

"Nature makes a lot of structural materials," Li said. "These materials are made at room temperature and regular atmospheric pressure, unlike metals, which can be detrimental to the environment to produce — you need to use high temperatures and refraction processes for metals.

"We're intrigued by such differences between biological structural materials and engineered structural materials. Can we bridge these two and provide insights in making new structural materials?"

INCREASING SAFETY FOR ELECTRIC CARS AND PEDESTRIANS

An interdisciplinary research group at Virginia Tech is using an award of $550,000 to create a virtual environment to test safety measures for the interaction between electric vehicles (EVs) and pedestrians. The award is an 18-month project funded by the Safety through Disruption (Safe-D) University Transportation Center.

EVs brought a significant change to the automotive world when Toyota started mass production of the Prius hybrid in 1997. The Prius engine and many like it introduced a combination of both gas and electric power. This gave the horsepower of gasoline when it was needed, engaging all-electric mode at other times to conserve fuel and reduce emissions.

All-electric mode has another notable difference when compared to an internal combustion engine: noise. While a gas engine announces itself from a distance, electric engines make almost no sound, and are easily drowned out by other ambient noise. Car noises are actually a critical safety measure, making the presence of a vehicle known when approaching pedestrian crosswalks and other areas where foot traffic might intersect with automobiles. This is particularly important for pedestrians with a visual impairment.

To solve this potential safety problem, manufacturers have been developing an acoustic vehicle alerting system (AVAS) for use in new electric and hybrid electric vehicles. These systems make a continuous noise when the car is moving slowly, its loudness between that of a normal conversation and a garbage disposal.

Legislation has been moving forward to require these safety measures on EVs, with the most prominent examples coming from the United States and the United Nations Economic Commission for Europe. While the law creates a range of decibel levels, there are many approaches for the type of sound that might best be put into use. Early choices included such options as spaceships and choirs.

The Virginia Tech project will bring legislation together with practical implementation and testing. Taking lead on the project is

Michael Roan

mechanical engineering professor Michael Roan of the Acoustics, Signal Processing, and Immersive Reality (ASPIRe) Lab. He is joined by Luke Neurauter of the Virginia Tech Transportation Institute and General Motors Engineer Doug Moore.

Roan has worked with General Motors on two previous projects to test the use of various sounds for both legally blind and sighted pedestrians. These projects illuminated the need for additional work in two main areas: First, systems are needed that uniformly broadcast sounds around the front of the vehicle, and second, better understanding is needed to develop warning sounds that are highly detectable, but contribute little to noise pollution.

The group will be testing in the a 3D virtual acoustic environment of Roan's ASPIRe lab. This will enable the use of a 58.2 high density loudspeaker array and a high-resolution wavefield synthesis system, where the researchers will create an immersive virtual sound environment of street noises and alert sounds. Conducting the tests in this simulated environment will greatly reduce costs while increasing test repeatability and accuracy. Additionally, the virtual acoustic environment will provide car makers with the ability to test detectability performance of their EV sounds in a large number of background noise environments.

Virginia Tech lab proves the concept of a natural approach to antiperspirants

Sweating is a natural function of the human body, allowing a body to cool itself as sweat emerges from glands and evaporates. Separately, this process may produce odors as bacteria present on the skin break down sweat proteins. A deodorant kills the bacteria that produce the odor, while an antiperspirant clogs sweat ducts to prevent sweat from emerging in the first place.

This clogging is commonly achieved by the use of metallic salts. There remains debate as to whether or not these metallic salts contribute to heath risks such as cancer, but demand by consumers for more natural alternatives to antiperspirants containing these metals (a sort of "just-in-case" scenario) is rapidly growing.

The Virginia Tech Nature-Inspired Fluids and Interfaces Lab, led by Associate Professor Jonathan Boreyko, has just made a major breakthrough in the study of natural antiperspirants. Their theory is this: If the sweat can begin to evaporate while still inside of the sweat duct, before it emerges onto the skin, the sweat's own minerals will crystallize to clog the duct. In other words, the mixture of sodium, chloride potassium, calcium, urea, and bicarbonates naturally present in sweat can do the same work as the metallic salts used in commercial antiperspirants.

Testing the theory

To explore this idea, the group constructed an artificial "sweat rig" to investigate the possibilities. They used a microchannel made from pulled glass to serve as an artificial sweat duct, and created the function of a sweat gland by using pressurized gas to push synthetic sweat across tubing and into the connected glass duct.

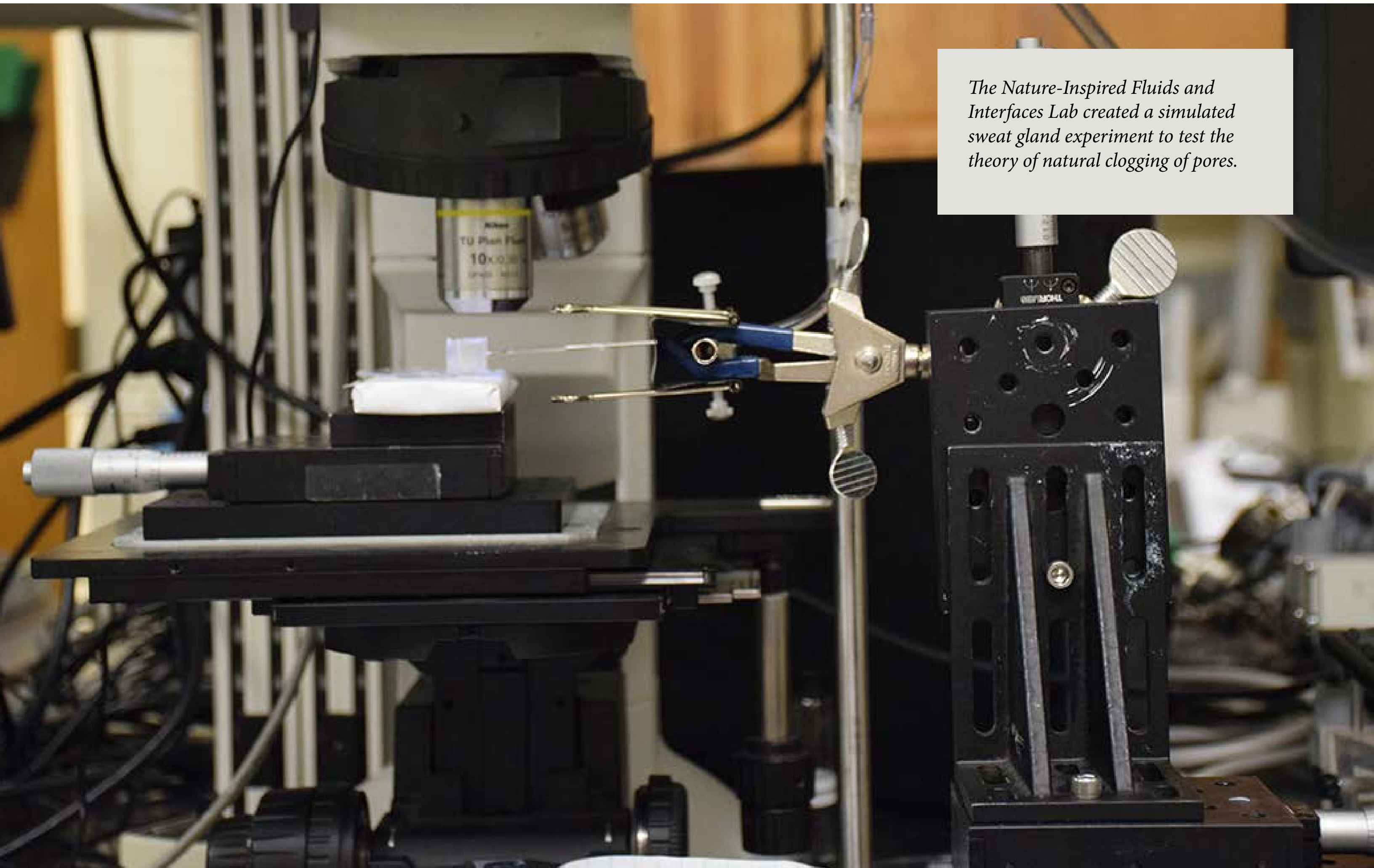
To prove the concept, three different scenarios were tested. The first was a control, where no product was placed near the artificial sweat duct. For the second test, researchers placed a dry cube of the organic, silicon-based polymer PDMS near the exit of the duct. Finally, for the third test, the PDMS cube was infused with propylene glycol, a chemical that is highly attractive to water. These three scenarios allowed for a direct comparison of how sweat flowed when the duct was completely open, versus near a regular object, versus near an evaporation-inducing object.

The team observed the flow of the synthetic sweat, which has the same minerals as natural sweat, by focusing a microscope on the artificial duct. For the first two scenarios, the sweat flowed freely from the outlet of the sweat duct, which would correspond to sweat emerging onto the skin. But for the third scenario, where the duct was placed close to the evaporation-inducing material, the duct became clogged within seconds. A gel-like plug formed within the duct near the exit, creating a seal. Even when the pressure pushing the liquid was increased, the clog was able to maintain the seal.

"Over the past few years in particular, I've noticed that my wife and many of her friends have been transitioning to more natural cosmetic and cleaning products," said Boreyko. "There is also an increasing push from regulatory agencies, particularly in Europe, to restrict the use of metals in antiperspirants. Our research has discovered the most natural antiperspirant in existence: the minerals within the sweat itself! It is exciting to find that simply making the sweat evaporate faster can cause natural mineral plugs that have the potential of replacing metal-based products in the future."

With the concept proven, the team is moving toward application. Possibilities for extending the concept to human trials could include using an applicator stick, similar in form to current products, or a wearable adhesive. In either case, the next goal is to demonstrate in a human trial that the proper water-attracting product could facilitate natural clogging from the body's own sweat.

Findings from this research were published in the journal *ACS Applied Materials & Interfaces* on Nov. 16, 2020.



The Nature-Inspired Fluids and Interfaces Lab created a simulated sweat gland experiment to test the theory of natural clogging of pores.

Graduate student Connor Herron works with virtual reality components in Alexander Lenoessa's lab.

Virginia Tech leads a team pursuing more immersive virtual reality

Two Virginia Tech professors are part of a team focused on developing new technology for the virtual world: a full-body experience in a fully electronic environment.

The project is funded by a $1.5 million grant from the National Science Foundation. Virginia Tech contributors are Professor Alex Leonessa from the Department of Mechanical Engineering and Associate Professor Divya Srinivasan from the Grado Department of Industrial and Systems Engineering. They are joining forces with Eric Jing Du, a professor from University of Florida, and industry partner HaptX.

Virtual reality has been a technological pie-in-the-sky development for decades. Movies and television shows have fueled imagination and inspired commercial developments, but the expectation created by fantasy has yet to find its full realization. While science fiction often presents the idea as fully immersive, casting ideas, such as Star Trek's holodeck and the world of the Matrix, VR has been a heavily visual experience.

The addition of gloves allowed users to interact within virtual environments in ways that expanded the virtual reality world, adapted for video games in developments such as the Nintendo Power Glove and the cyber glove. NASA adapted this approach as well, building its Virtual Interface Environment Workstation in 1990 for an operator to physically move objects from a remote location. In each of these experiences, a user would watch their virtual hands perform virtual tasks in a virtual environment. The feedback to a user remained visual.

In recent years, such developments as HaptX Gloves have added an additional dimension to the experience: a virtual environment that returns a touch response to a user's hand. Programmed microfluidic pockets within gloves respond based on the actions in a virtual environment, creating a tactile response in addition to a visual one. A user would not just experience the virtual world visually, they would also feel weight, shape, and texture across their hand and fingertips.

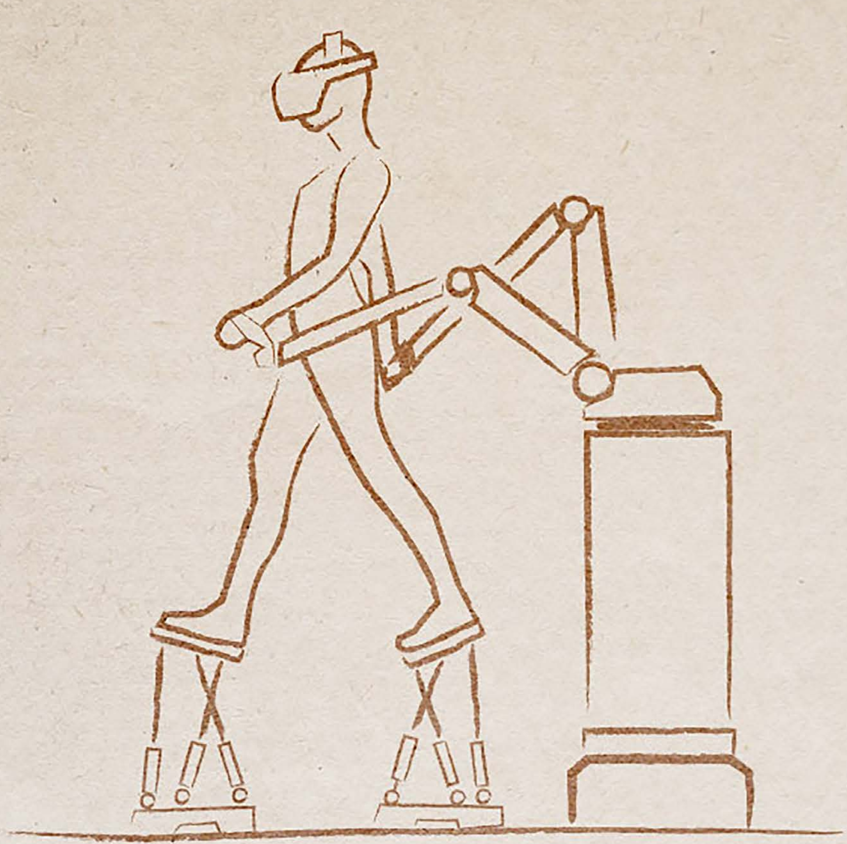
The next step

Being able to move around a virtual environment presents its own set of challenges. Video games normally accomplish this by using joysticks or keypads, meaning that a user is essentially pushing buttons with their fingers to achieve virtual reality walking. Other input devices, such as pads and devices that fit like shoes, require some form of walking in place to input the motion.

Virginia Tech is working with University of Florida and HaptX to bring together motion, touch response, visual interaction, and more. The hopeful result is a full-body virtual reality rig that allows users to see the environment through a headset, achieve touch via the HaptX gloves, and both walk and interact by using an exoskeleton.

The project is called ForceBot, drawing on the term "force feedback," the general classification of controls that impact objects in the virtual environment. Responsive robotics working with a user's feet would allow walking, simulate changes in terrain, and move a user through the electronic world. Additional robotics in a hand and arm rig would provide resistance for pushing and pulling simulated solid objects, while the HaptX gloves complete the experience with touch response. The visual headset would allow a user to see the electronic environment unfold before them.

"We are excited to have the opportunity to develop a fully immersive virtual reality experience, providing realistic full-body interactions," said Leonessa. "Virtual reality is a familiar technology, but the untapped potential it holds is vast."



Early sketch of what ForceBot might look like.

NOTABLE ACHIEVEMENTS

The Virginia Tech Institute for Critical Technology and Applied Science (ICTAS) awarded Engineering Faculty Organization (EFO) Opportunity Seed Investment Grants to two mechanical engineering faculty.

Juliana Pacheo-Duarte was selected to receive an ICTAS EFO Opportunity Seed Investment Grant of $10,000 for the proposal, "Accelerated Experiments to Investigate Chloride-Induced Stress Corrosion Cracking."

Jiangtao Cheng was selected to receive an ICTAS EFO Opportunity Seed Investment Grant of $10,000 for the proposal, "Handy Seawater Desalinator by Heat Localization in Photothermal Film."

The American Institute of Aeronautics and Astronautics chose the technical paper, "Development of a Ducted Propulsor for BLI Electric Regional Aircraft – Part I: Aerodynamic Design and Analysis," co-authored by **Wing Ng**, as the 2019 AIAA Inlets, Nozzles, and Propulsion System Integration Best Paper Award from the 2019 AIAA Propulsion and Energy Forum and Exposition.

Graduate student **Ahmed Sallam** won first-place award in the Frank Pao CEHMS Research Competition, for his virtual presentation on "Reflective acoustic holograms for fine manipulation of sound." Sallam works in the lab of Assistant Professor Shima Shahab. His research area is investigating Acoustic Holographic Lenses used in biomedical and automotive sensing applications.

Ranga Pitchumani presented on the topic of "Sustainable Future Fuels" at the Global Summit of Overseas and Resident Indian Scientists and Academicians.

Associate Professor of Practice **Robin Ott** completed a Graduate Certificate in Engineering Education.

Jiangtao Cheng was selected to receive an ICTAS Diversity and Inclusion seed investment, supporting the building of direct faculty-to-faculty research partnerships between faculty at Virginia Tech and faculty at historically black colleges and universities and other underrepresented college programs. The award totals $20,000 over two years.

Cheng also gave a keynote talk entitled "Governing Mechanisms and Mathematical Description of Nanoscale Transport of Interfacial Liquids on a Solid Surface" on July 13, 2020 in the ASME Fluids Engineering Division's Summer Meeting, which was held virtually.

Staff member **Cathy Hill** completed a Supervisory Excellence Certificate through Virginia Tech Human Resources in November.

ALISHA KONST '17 NAMED A "WOMAN BREAKING THE MOLD 2020"

A 2017 mechanical engineering graduate has been recognized by Plastics News as one of its "Women Breaking the Mold" for 2020. The recognition celebrates the contributions of women professionals in the plastics industry.

Alisha Konst graduated with a bachelor's degree in mechanical engineering, completing a journey that began in her family's garage. Growing up in Botetourt County, Virginia, she was constantly in the garage working on engines with her dad. Two Harley-Davidson motorcycles and a 1956 Ford Pickup provided her first glimpse into the inner workings of automobiles, sparking her curiosity to more deeply understand how things work.

During her senior year, Konst joined a senior design team focused on designing and building a large submarine-towed module to transport, deploy, and recover large displacement unmanned undersea vehicles. While her interest in vehicles propelled her into that group, her role on the team didn't include working on engines. She worked with several other students on the design of the module, spending most of her time calculating drag coefficients and working with carbon fiber weave patterns used to make the hull of the module stronger.

This project, forged by the classroom learning that brought her to that point, launched a fresh set of interests. After she graduated, Konst looked at several career paths, eventually settling on one that pulled together both her mechanics experience and senior design project skills. Today, she works for the MAAG Group as research and development manager in the Eagle Rock, Virginia, plant. Her branch produces large plastic processing equipment.

"Had I not had that experience in senior design, I don't know if I would have done as well. The ability to come up with a plan and think through problems was all a part of senior design."

Konst found early success in a company that actively pursues talent, and was also fortunate to find herself among mentors

PHOTO COURTESY OF MARTIN BAUMANN

who were dedicated to her success. She started in the production area, working on building for six months. With a couple retirements on the horizon, the company was looking for new leadership who could pick up the mantle. Konst expressed her interest, and the company matched her with current employees who could help her try her hand at the new role.

Beyond job training, MAAG Group was also responsible for recognizing her talent. Plastics News put the call out for nominations for their "Women Breaking the Mold" award in early 2020, and Konst was nominated for the award by Martin Baumann, Vice President and General Manager of MAAG Group Americas.

"Manufacturing in the USA offers challenging and rewarding positions for women. Often it isn't their first choice," said Baumann. "I am glad that we have Alisha on our team and she made that choice many years ago. We will be actively promoting and supporting such career paths working with Virginia Tech."

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