

# Momentum

Mechanical Engineering

Fall 2018



## Closing the gaps

*Controlling cells to close wound gaps*



COLLEGE OF ENGINEERING  
**MECHANICAL ENGINEERING**  
VIRGINIA TECH.

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Vol 3.3 Fall 2018

6



**New Hord Professor**  
 Michael von Spakovsky has been named the newest Robert E. Hord Jr. Professor of Mechanical Engineering.

10



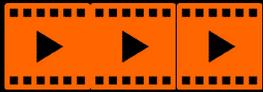
**State of the University**  
 If you didn't catch President Sands' State of the University Speech, you can watch the whole thing here.

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Professor Azim Eskandarian - ME Department Head, Nicholas and Rebecca Des Champs Professor  
 Rosaire Bushey - Communications & Outreach Manager  
 Contact us: 540-231-2965 email bushey@vt.edu

*On the cover: In this image of a cell, protrusions (highlighted by arrows) from a cell act as sensory projections to allow the cell to move across fibers.*

Connect on social



**Potts Scholars thank family**

[https://youtu.be/\\_3wfxY0SWzU](https://youtu.be/_3wfxY0SWzU)

### **THE POWER OF PHILANTHROPY**

During the Fall 2018 semester, 27 mechanical engineering students received the William A. Potts Jr. and Sr. Scholarship. The Potts family, along with many others, make an enormous impact on students through their generosity that supports students in ways that make an engineering education achievable. Thank you to our donors on behalf of all the faculty and staff of the Department of Mechanical Engineering. For a list of more scholarships that were awarded this semester, see Page 28.

## *From the Dept Head* Azim Eskandarian



# Growing: A perfect theme for the year

Growing takes a lot of different forms and this year many of those forms are on display in the department.

First, the department is growing. We added eight new faculty members who start this academic year, six in the fall and two in the spring. Our increased faculty numbers come on the heels of several years of steady growth in our student population, which includes more than 1,100 undergrads (sophomore-senior) and more than 300 graduate students.

Growth can also be seen by the number of companies who want to talk to our students, resulting in the growth of internships and jobs after graduation. We also see growth in the number of senior design teams sponsored by industry which shows us that we are providing what industry wants - students who are problem solvers, leaders, and interdisciplinary team players.

We are also seeing growth in the diversity of our student population and our faculty. Although we are working on this persistently, the growth isn't what we'd like yet, but the trend is definitely in the right direction.

In this issue, you'll see research involving growth as well, particularly in our cover story that looks at how Associate Professor

Amrinder Nain's STEP Lab uses engineering to control cells to behave in ways that could be used for wound closure.

The world of mechanical engineering is growing by getting smaller. Working at the micro and nano levels we are uncovering truths about structures and materials that would have been science fiction as little as two generations ago. Assistant Professor Ling Li is working with sea urchin spines to develop stronger, lightweight materials, while Assistant Professor Rayne Zheng is working on the 3D printing of graphene.

### **Gordon Kirk**

We are deeply saddened to report the passing of beloved Professor Emeritus Gordon Kirk on Sept. 6. A link to his obituary can be found on the opposite page. Our thoughts and prayers are with his family.

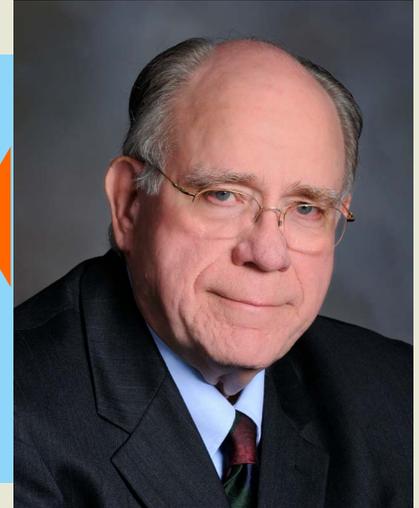
### **Distinguished Alumni**

To our ME alumni, please let us know your nomination for the 2019 Class of Distinguished Alumni. Last year we inducted the first class of ME Distinguished Alumni and we're opening nominations to any ME alums. For information, email Brandy McCoy at: [brandy07@vt.edu](mailto:brandy07@vt.edu) or to fill out a nomination form, [click the link here](#). Deadline is Jan. 15.

# Briefly

## In memoriam: R. Gordon Kirk, professor emeritus

R. Gordon Kirk, professor emeritus of mechanical engineering died Sept. 6. Kirk was conferred the emeritus status in 2013 by the Virginia Tech Board of Visitors. He came to Blacksburg in 1985 and was a member of the department for 28 years. Over the course of his career he authored or co-authored more than 175 peer-reviewed journal and conference articles, he held four patents and was a Fellow of the American Society of Mechanical Engineers and the Society of Tribologists and Lubrication Engineers. [His obituary can be found here.](#)



## Alan Kornhauser named Associate Professor, Emeritus

Alan A. Kornhauser, associate professor of mechanical engineering in the College of Engineering at Virginia Tech, has been conferred the title of associate professor emeritus by the Virginia Tech Board of Visitors.

[See the whole story at VTNews](#)

## Cutting down on food waste aim of new packaging

Mechanical engineering graduate student Mohammad Habibi is a study co-author on a paper that suggests slippery packaging may help reduce food waste from incremental deposits left in condiment and other food packaging containers. [Read the whole story at VTNews.](#)



## Looking for a good Twitter follow? We suggest...



[@Propalmore](#) - A fairly new user but covers a wide area and offers insights for students.



[@MAAPUAS](#) - Tweets often - on all things related to unmanned aerial systems.



[@DREAMS Lab](#) - Regular updates covering the world of 3D printing and additive manufacturing.



[@VTCEED](#) - Occasional tweets on engineering diversity topics of interest.



[@autodriveVT](#) - Regular tweets that show life in an ME student competition team.

# Michael von Spakovsky named Robert E. Hord Jr. Professor

Michael von Spakovsky, professor of mechanical engineering in the College of Engineering and director of the Center for Energy Systems Research at Virginia Tech, has been named the Robert E. Hord Jr. Mechanical Engineering Professor by the Virginia Tech Board of Visitors.



The Robert E. Hord Jr. Professorship of Mechanical Engineering was established by a gift from the late Robert E. Hord Jr. Hord, who earned his bachelor's degree in 1949 and a master's degree the following year, both from the College of Engineering, was an enthusiastic supporter of Virginia Tech's chemical and mechanical engineering programs.

The professorship acknowledges and rewards faculty in the Department of Mechanical Engineering who have shown exceptional merit in research, teaching, and/or service. Recipients hold the position for a five-year term.

Since joining the Department of Mechanical Engineering in 1997, von Spakovsky has advanced the foundational theories of thermodynamics. He pioneered a new theoretical framework that eliminates phenomenological models and avoids restrictions such as local or global equilibrium. His work has significantly pushed the boundaries of the science of

thermodynamics.

In particular, he and his co-workers have developed a new paradigm called steepest-entropy-ascent quantum thermodynamics (SEAQT) that unifies the kinematics and dynamics of quantum mechanics and thermodynamics into a single, self-consistent theory. With his students, he extended SEAQT to be practically applicable from the atomistic level to the macroscopic level and for generalizing the description of equilibrium thermodynamics to any non-equilibrium state.

Published in the most respected journals in physics, von Spakovsky has written more than 235 technical publications, has been involved in \$12 million of funded research projects, and has directed 15 doctoral and 41 master's degree students.

von Spakovsky's research has been widely recognized. In 2012, he and his student Charles Smith received the American Society of Mechanical Engineers Edward F. Obert Award for their work validating dynamics of SEAQT against the data by Wineland and Haroche, who won the 2012 Noble prize for their experiments.

In 2014, von Spakovsky won the ASME's prestigious James Harry Potter Gold Medal which recognizes eminent achievement in the science of thermodynamics.

von Spakovsky received his bachelor's degree from Auburn University, and a master's degree and Ph.D. from the Georgia Institute of Technology.

# ME welcomes 6 new faculty

The Department of Mechanical Engineering welcomes six new faculty members for the Fall 2018 term, putting the total of full time faculty for the department at 63.

**Kaveh Akbari Hamed**, assistant professor, Ph.D. Electrical Engineering, Sharif University of Technology, Iran, 2011. Robotics, Autonomous and Dynamical Systems (RADS) graduate thrust area.



**Oumar Barry**, assistant professor, Ph.D. Mechanical Engineering, University of Toronto, Canada, 2014. RADS thrust area.



**Juliana Duarte**, assistant professor, Ph.D. Nuclear Engineering and



Engineering Physics, University of Wisconsin-Madison, 2018. Nuclear Engineering and Science thrust area.

**Erik Komendera**, assistant professor, Ph.D. Computer Science, University of Colorado, 2014. RADS thrust area.



**Ry Long**, assistant professor of practice, M.A. Sc., Mechanical Engineering, Ryerson University, Canada, 2010. Design, Materials and Manufacturing thrust area.



**John Palmore Jr.**, assistant professor, Ph.D. Aerospace Engineering, Cornell University, 2018. Energy Engineering and Science thrust area.



## Nominations for ME Society of Distinguished Alumni being accepted

The department is seeking nominations for the 2019 ME Society of Distinguished Alumni.

Nominations can be submitted by any Virginia Tech Mechanical Engineering alumni and the Class of 2019 will be inducted in May.

The only pre-requisite for nomination is that the person be a living alumnus or alumna of the department. Special consideration

should be given to nominees who have achieved extraordinary accomplishments and/or stature over the course of their professional careers, as well as their longevity, consistency, and quality of professional contributions.

For more information, contact Brandy McCoy at [brandy07@vt.edu](mailto:brandy07@vt.edu). Nominations will be accepted until Jan. 15. [Click here to nominate.](#)

# news notes

## The 2018 Distinguished Speaker Series

Oct. 4, 3:30-4:30 p.m., 310 Kelly Hall, **Professor Ronald K. Hanson** of Stanford University will discuss the Evolution of tunable laser absorption sensors for combustion and propulsion.



Nov. 1, 3:30-4:30 p.m., 310 Kelly Hall, **Professor Robert O. Ritchie** of the University of California, Berkeley, and the Lawrence Berkeley National Laboratory, will discuss Damage tolerance in engineering and biological materials.



Dec. 6, 3:30-4:30 p.m., 310 Kelly Hall, **Professor Thomas A. Zawodzinski** of the University of Tennessee Knoxville and Oak Ridge National Laboratory, will discuss Making use of renewable electrons with redox flow batteries and related 'open' systems.



## Meadows in JEGTP

Assistant Professor Joseph Meadows had his article, [Thermoacoustic instability model with porous media: Linear stability analysis and the impact of porous media](#), accepted by the ASME Journal of Engineering for Gas Turbines and Power.



Meadows

## Ben-Tzvi publications

Associate Professor Pinhas Ben-Tzvi has had four journal papers since July, including, *A geometric approach to obtain the closed-form forward kinematics of H4 Parallel Robot*, in the Journal of Mechanisms and Robotics, Transactions of the ASME; *Intelligent object grasping with sensor fusion for rehabilitation and assistive applications*, in IEEE Transactions on Neural Systems and Rehabilitation Engineering; *Design Modeling and integration of a flexible universal spatial robotic tail*, in the Journal of Mechanisms and Robotics, Transactions of the ASME; and *Discrete modular serpentine robotic tail: Design, analysis and experimentation*, in Robotics Journal.



Ben-Tzvi

Ben-Tzvi was a session chair and co-chair, and his graduate students published and presented the following peer-reviewed conference papers at the 2018 ASME International Design Engineering Technical Conferences, 42<sup>nd</sup> Mechanisms and Robotics Conference in August: *Design and implementation of an exoskeleton glove for infant medical rehabilitation*, E. Refour, B. Sebastian, P. Ben-Tzvi; *Improved alignment estimation for autonomous docking of mobile robots*, S. Sohal, W. Saab, P. Ben-Tzvi; *Dynamic modeling of a quadruped with a robotic tail using virtual work principle*, Y. Liu, P. Ben-Tzvi; and *Gaussian kernel controller for path tracking in mobile robots*, B. Sebastian, A. Williams, P. Ben-Tzvi

Ben-Tzvi and his graduate students will present the following papers at the Proceedings of the 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems in October: *A framework for modeling closed kinematic chains with a focus on legged robots*, V. Kamidi, A. Williams, P. Ben-Tzvi; *Dynamic modeling and control of an articulated tail for pre-*

cise maneuvering of a reduced degree-of-freedom quadruped robot, W. Saab, J. Yang, P. Ben-Tzvi

### Akbari Hamed in IEEE Transactions

Assistant Professor Kaveh Akbari Hamed had his paper, [Decentralized event-based controllers for robots stabilization of hybrid periodic orbits: Application to under-actuated 3D bipedal walking](#), published in IEEE Transactions on Automatic Control in August.



Akbari Hamed

### Lee receives poster award

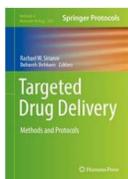
Doctoral candidate Heonjoong Lee received the best poster award from the International Conference on Thermoelectrics sponsored by the International Thermoelectric Society during a presentation in Caen, France in July. Lee works in the Center for Energy Harvesting Materials and Systems and is advised by Professor Shashank Priya, currently associate vice president for research and director of strategic initiatives in the Office of the Vice President for Research at Penn State.



Lee

### Behkam publishes book

Associate Professor Bahareh Behkam co-edited a book released in August with Professor Rachel Sirianni. The book is part of Springer's Methods in Molecular Biology series called [Methods and Protocols in Targeted Drug Delivery](#).



Behkam

### Caro in Journal of Nuclear Materials

Magdalena Caro, a staff scientist at Los Alamos National Laboratory and an adjunct professor for mechanical engineering was recently published in the Journal of Nuclear Materials. The paper is titled, [On the local density dependence of electronic stopping of ions in solids](#).



Caro

### Acar publications/presentations

Assistant Professor Pinar Acar has published the following journal papers and presented at the following conference:



Acar

*Reliability based design optimization of microstructures with analytical formulation*, Journal of Mechanical Design; *Stochastic design optimization of microstructural features using linear programming for robust material design*, AIAA Journal; [Computational modeling of crystallographic texture evolution over cubochoiric space](#), Modelling and Simulation in Materials Science and Engineering; *Reduced order modeling approach for materials design with a sequence of processes*, AIAA Journal.

Stochastic multi-scale design optimization of microstructures using a linear solver, presented at SIAM Annual Conference, Portland, Oregon.

### CenTiRe in the news

The publication Rubber and Plastic News recently featured two articles about the Center for Tire Research. The first article is called [CenTiRe proves to be true to its mission so far](#), and the second, [CenTiRe making mark as research recruitment asset](#).

### **Underwood earns degree**

Johnny Underwood, equipment and facilities specialist for mechanical engineering, received his BA in Accounting from Liberty University.



Underwood

### **Hurtado wins best paper award**

Mark Hurtado, a graduate researcher, received the INCE-USA Student Paper Award at the Inter-NOISE 2018 Conference in Chicago for the paper, Low speed control vortex axial fan design for minimum noise. Hurtado is advised by Professor Ricardo Burdisso.



Hurtado

### **Li hosts conference**

Assistant Professor Ling Li will co-organize the first International Conference on Nature-Inspired Surface Engineering June 12-14, 2019 at the Steven's Institute of Technology in Hoboken, New Jersey. The deadline for abstract submission is Jan. 31, 2019 and details can be found at the [NISE-2019 website](#).



Li

### **Hibbler earns research fellowship**

Brianna Hibbler, a doctoral student in the lab of Professor Michael Roan, received a National Science Foundation Graduate Research Fellowship. The five year fellowship provides financial support for three years and a student stipend.



# **President Sands' 2018 State of the University**

<https://youtu.be/M6aB8wqqAXI>

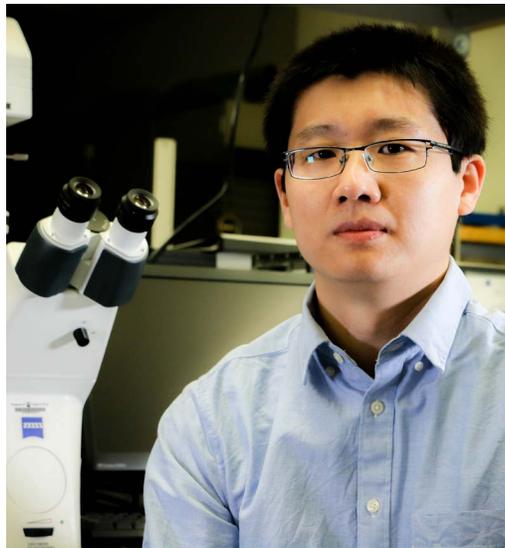
# Sea urchins may hold key to lightweight engineered materials

In the ongoing search for strong, lightweight materials, researchers are looking at an odd source – sea urchins, which have spines made of chalk, a generally brittle substance.

The highly complex three-dimensional structure of sea urchin spines that is 70 to 80 percent porous creates a stable and strong structure. Studying the sea urchin is part of a \$540,000 National Science Foundation grant being investigated by Ling Li, assistant professor of mechanical engineering in the College of Engineering.

By using design rules gathered from studying biological systems and inputting those rules into the design of bio-inspired lightweight ceramic materials, Li said he hopes the information can be applied to creating lightweight panels and other components.

“I can see this information being applicable to panels, structural support, and armor to provide impact and blast protection,” said Li. “The design is very damage-tolerant and does not fail catastrophically.” As the current work constitutes fundamental research to uncover the design principles of a biological material system, Li said his team could only look forward at the





potential for applying the lessons learned for innovative bio-inspired materials.

“We want to understand how nature designs lightweight materials with brittle components and we are trying to understand the 3-D architecture of the sea urchin spine’s structure to see if we can determine how the structure helps achieve high strength and damage tolerance given the inherent weakness of the chalk it’s made from,” said Li.

Working with co-investigator Yunhui Zhu, an assistant professor with the Bradley Department of Electrical and Computer Engineering, the team will use a synchrotron tomography technique and mathematical tools developed by the Argonne National Laboratory to obtain high-resolution 3-D volumetric data to determine how the porous network is designed in terms of connections, arrangements, and orientation.

“The project is based on characterizing and understanding the internal structure of the sea urchin spine to find out why it’s so strong,” Li said. “Sea urchin spines have been shown to perform similarly to the best ceramic cellular materials people have made in the lab in terms of relative strength.”



<https://youtu.be/W-zfSGFqp3k>

One of the differences between man-made and natural cellular structures is the non-symmetrical formation of cellular struts and nodes which also vary in thickness and orientation gradually at different locations.

“Most of our current 3-D printed materials are based on idealized geometries such as cylindrical beams with a constant cross-sectional area, which may contribute to catastrophic failure behavior in some printed ceramic solids,” Li said. “Looking at sea urchins we see curved morphologies in stark contrast to 3-D printed structures. By studying these we hope to learn how to input these natural designs into our laboratory-created materials.”

Li said that this NSF award seeks to develop methods for acquiring, handling, processing, extracting and evaluating the computational data for a hierarchical structure in order to integrate the information with 3-D data and testing, to develop engineered cellular materials.

**“By studying (sea urchins) we hope to learn how to input these natural designs into our laboratory-created materials”**

# Engineering and arts join forces at Moogfest

It's not often an engineer is featured on the [lineup schedule](#) for a music festival, but Mike Roan, a professor of mechanical engineering in the College of Engineering has done it as part of [Moogfest](#), a community of futurists who explore emerging sound technologies in Durham, North Carolina.

originally designed in the Cube, a four-story-high, state-of-the-art theatre and high tech laboratory that serves multiple platforms of creative practice, to another live music venue. The results, according to Roan, could change the way artists view sound during a live performance.



“When we think of live concerts we think of a large array of speakers facing the audience, and for decades, that has been the template for live performance,” said Roan. “Working with Tanner in the Cube in the Institute for Creativity, Arts, and Technology at the Moss Arts Center, we have really upped the ante for what is possible with immersive sound technology, and in 2017 we put some of that on display at Moogfest.”

It was during the 2017 festival that Meyer Sound got involved. Company representative Steve Ellison saw what Roan and Up-

This year, Roan, who works in areas of immersive audio, psychoacoustics, and digital signal processing, joined with Tanner Upthegrove, media engineer with the Institute for Creativity, Arts, and Technology, to provide the festival with a first-ever event – a large scale immersive audio experience.

Working with Meyer Sound, a designer and manufacturer of innovative sound solutions, Roan and Upthegrove transferred a project

the grove were doing with their scaled down version of an immersive audio system and told the pair the company would be interested in working together in the future. The future came in 2018 as Meyer Sound pulled up a semi with more than \$100,000 worth of equipment to the Armory in Durham.

“The efforts of Meyer Sound were really huge for showing what an immersive sound

system can provide,” said Roan. “It took about 30 of us two full days to fully install the speakers, computer systems and other equipment for the system. They probably spent \$200,000 to \$300,000 on a six-day show.”

Typical concert speakers run on the tried-and-true dual channel system – left and right. Fans at traditional live concerts are literally faced with a wall of sound. The system put together by Roan and Upthegrove differs in that it doesn’t use 2 channels of audio – it uses 25 and has the capability for 256. Speakers are installed at the front of the house, and an additional 25 sets of speakers are installed at about 12 feet high all around the venue. Another series of speakers are located on a totem that stands 30 feet high in the middle of the space.

“The physical presence of the speakers, despite the effort it took to install them, represent only a fraction of the time it took to set up the show,” Roan explained. “Immersive audio is not a turn-key process. A band can’t just come in and hook up to the system to get the full benefit.”

Immersive audio is a creative tool for artists, not just a way to get sound to the masses. By using the vast array of speakers and channels of sound, musicians can create pulses and waves of sound that become a part of the musical experience.

The team had to rehearse with the band well ahead of the performance with the work done in the Cube, but in collaboration with a band from Germany, [Mouse on Mars](#).

“Using live feeds from the artist we created spatial ratios, and used their input to drive coordinates for the spatialization in real time data,” said Roan. “We also had to write code for this because there were control signals flying everywhere – from the artist to us, to the lighting, to the main speakers, to the drive

speakers ... at the concert we were just thinking, ‘please, God, let this work’ because there are so many things going on.”

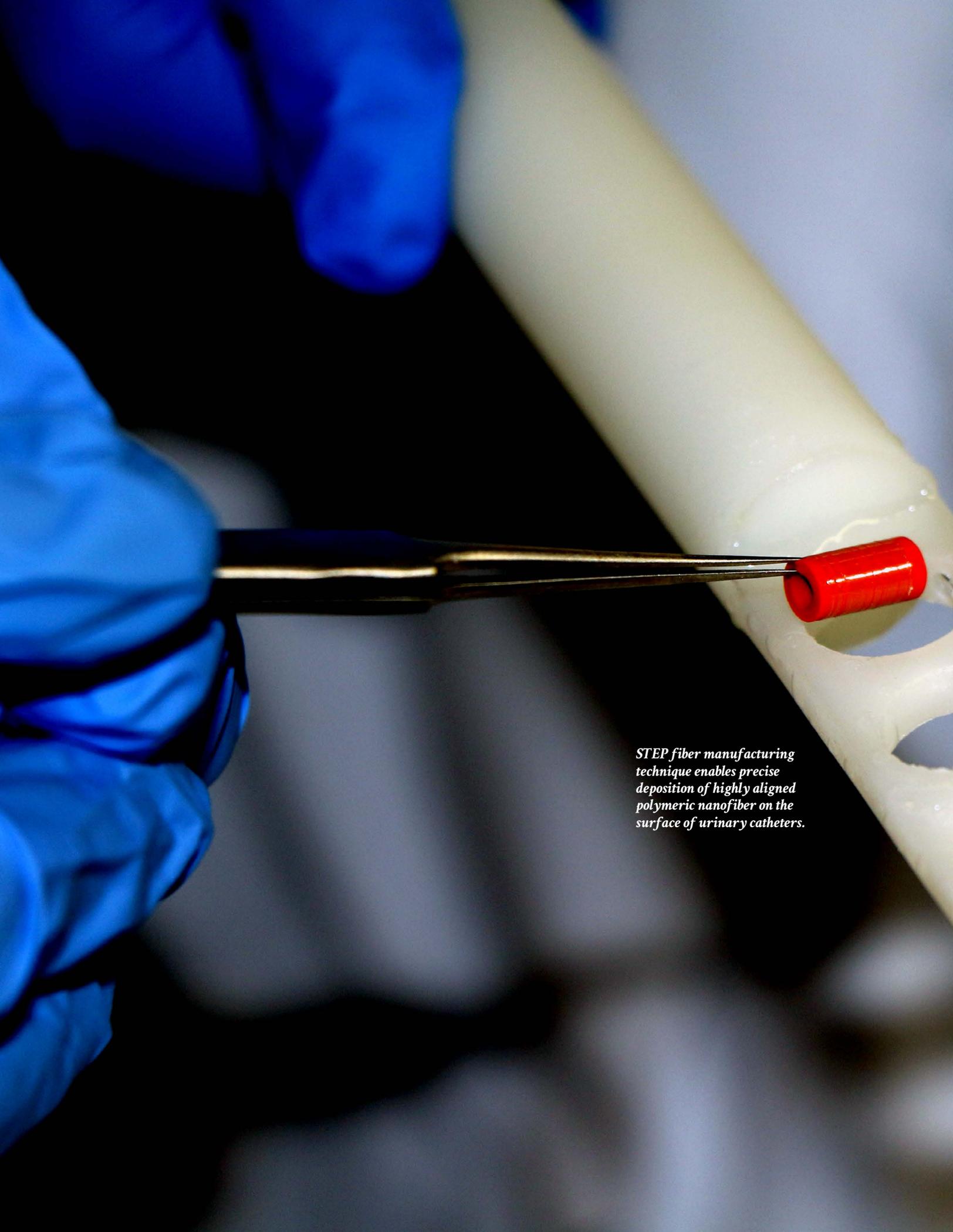


To make everything work in real time, Roan relies on an audio over internet system called Dante, a protocol from the company Audinate, that allows for the near instantaneous switching of channels from the two blocks of eight Leopard speaker arrays at the front of house, to the six giant subwoofers, to the totem speakers, and to those around the arena. With that many speakers, it’s not surprising things can get pretty loud.

“At some points in the concert the noise was peaking at around 118dB,” Roan said. “Two of the six giant subwoofers were tuned to 22-13hz. You can’t actually hear anything below 20hz, so they are just designed to shake your body – if you get too close to one your vision will go blurry because they make your eyeballs resonate.”

With the success of Moogfest 2018, Roan is already planning for next year. “We are in discussions with Meyer Sound and Moogfest management,” Roan said. “Speaking to Steve [Ellison], he said we should plan on it being ‘bigger and better’.”

Moogfest 2019 will be held April 25-28 in Durham, N.C.



*STEP fiber manufacturing technique enables precise deposition of highly aligned polymeric nanofiber on the surface of urinary catheters.*

# Modeling framework may lower biomedical device infections

A recent article in the American Chemical Society's Applied Materials & Interfaces journal introduces a new thermodynamic-based modeling framework to solve a problem that may one day result in lowering the instances of biomedical-device associated infections.

The modeling breakthrough came from an interdisciplinary team of Macromolecules and Innovation Institute faculty led by Bahareh Behkam, an associate professor of mechanical engineering in the College of Engineering, working with Amrinder Nain and Michael Ellis, also associate professors in mechanical engineering, and Professor Alan Esker, Chair of the Chemistry Department in the College of Science.

"Healthcare-associated infections (HAIs) are a major cause of death in the United States and add up to \$45 billion in additional health care costs annually," Behkam said. "Up to seventy percent of HAIs are attributable to microbial biofilm growth on implantable medical devices, particularly catheters."

Because items like catheters are inserted into the patient's body, the buildup of biofilm is often only detected after symptoms occur, which is after the infection has taken hold. In fact, catheter-associated infections are the most common cause of secondary bloodstream infection with substantial mortality rates.

For many years, the gold standard for prevention of microbial adhesion, the first step to microbial biofilm formation, has been the chemical modification of the



*Graduate students Carolyn Mottley and Zhou Ye assembling the experimental bioreactor setup.*

surface of these devices using antimicrobial compounds. “You can chemically modify the device, but these chemical coatings have a limited life-cycle and are known to contribute to the emergence of antibiotic-resistant microbes,” Behkam said. “The other method is to physically modify the surface of the device by creating a texturized layer that will repel the microbes and keep them from forming a biofilm for longer periods of time.”

Non-toxic physical modification of surfaces as an antifouling strategy is a relatively new area of research. “For over a decade now, researchers have been working on determining how surface texture affects microbial adhesion and biofilm formation process,” Behkam said. “Experiments involve varying surface texture

material, geometry, size, and spacing to see what combination provides the best outcome. However, the main problem is the absence of theoretical insight into the best surface texture parameters – so researchers test as many surface texture designs as they can afford and choose the best design. However, is it the best design, or just the best based on the limited number of tests they have conducted?”

The issue, as Behkam and her collaborators saw it, was that microbiologists and chemists had always focused on high-throughput testing methods – that is, designing a test that would maximize the number of results that could be achieved – instead of a mathematical model that would provide vastly more data based on probabilities and then testing those



# "It's pretty difficult to put life into mathematical equations"

*Bahareh Behkam*

that showed the greatest promise.

"It is pretty difficult to put life into a mathematical equation," Behkam admits. "There are so many variables as to what type of organisms there are, what the surface might be like, a host of biological and environmental factors. Our team approached this challenging problem from a thermodynamic view. Instead of trying to predict how many organisms would stay on a surface, we looked at how much energy change it takes for an organism to stay on a surface. The larger the required energy change, the less desirable a surface is for an organism. The less desirable a surface, the fewer organisms that will attach. That was the approach we took."

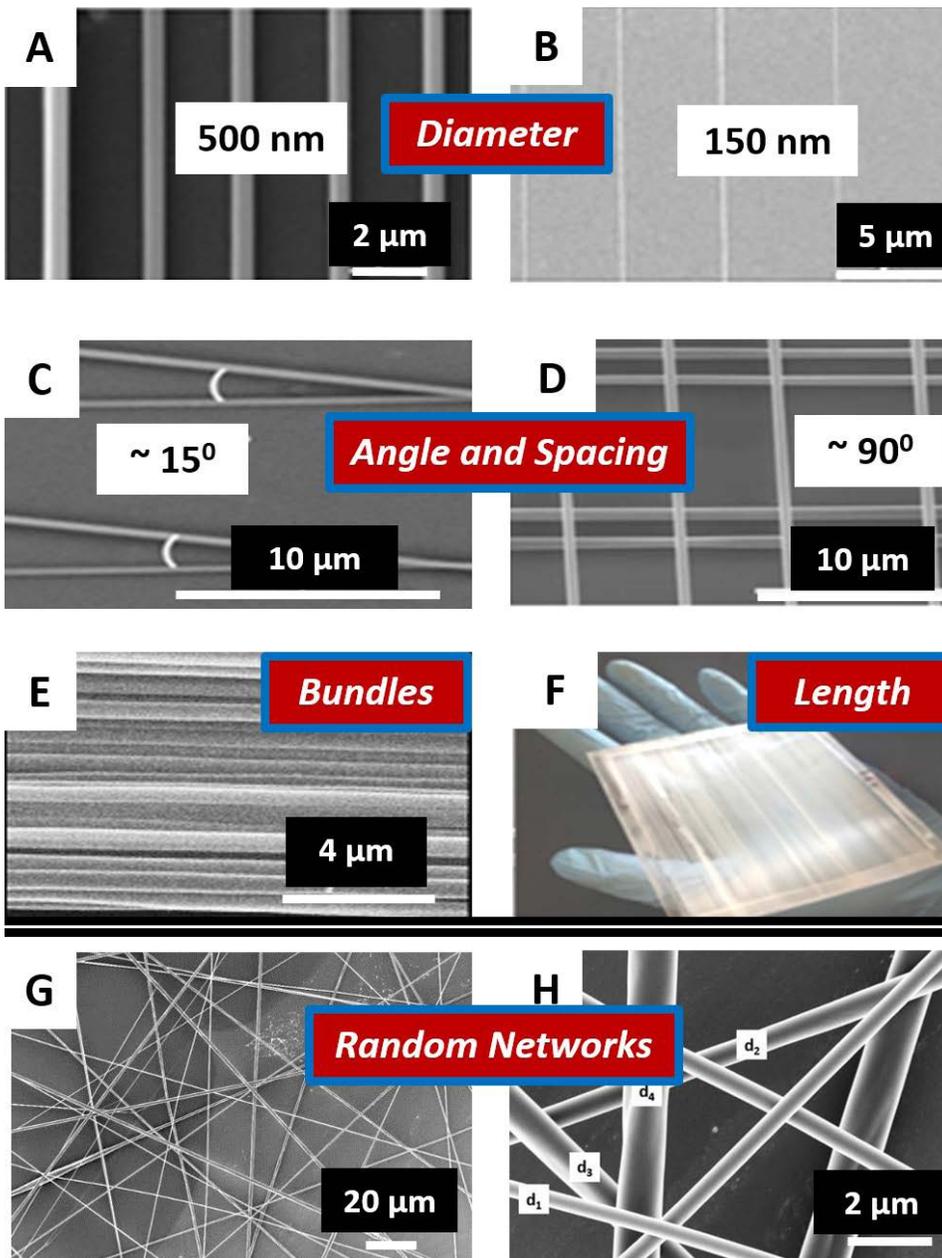
After creating the mathematical model and running computer simulations, the team chose the most likely candidates from the computer model. Using Nain's patented STEP technology, they created nanofiber coated surfaces of precise diameter and spacing and placed them in a bioreactor to assess microbial adhesion to these engineered surfaces.

"The live tests validated our model for the predictive design of surface patterns that

optimally reduce microbial attachment," Behkam said. "We applied the model to different medical catheters made from different primary device materials such as polyurethane, latex, and silicon and we were able to show that irrespective of the material, the model is valid and shows us the texture to reduce microbial adhesion, and optimize the device for surface functionality."

Equipped with the validated model and unique surface texturizing technologies, Behkam is now turning toward determining the long-term function of these engineered surfaces. Because the process of adding textures to a device is scalable, cost-effective, and can take place at the end of manufacturing, Behkam said she believes the process can be incorporated for a minimal cost per unit, and she has spoken with medical device manufacturers who have expressed interest in the concept. To translate the technology and the predictive model, the engineers have paired up with a team of urologists to mitigate biofilm formation on implantable urological devices.

# Cell migration key to developmental biology, wound healing, cancer metastasis

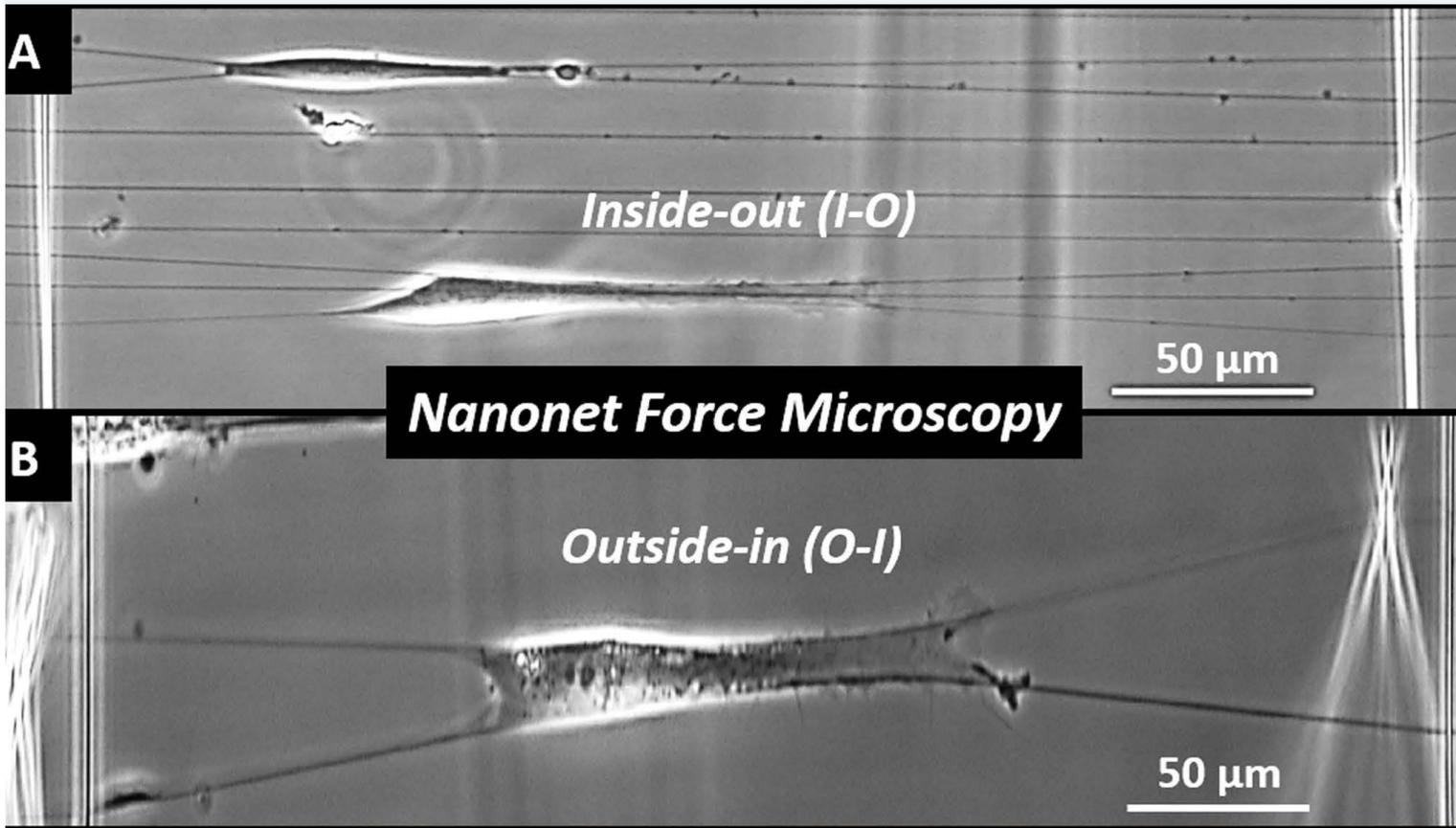


Cells, like people, use roads and paths to move around, and are predisposed to prefer some pathways over others. This preference could, according to Amrinder Nain, associate professor of mechanical engineering in the College of Engineering, help researchers create materials that will assist in understanding cell migration vital in developmental biology, wound healing, and cancer metastasis.

To make cells move, Nain came up with a patented approach to build fiber networks, called Spinneret Based Tunable Engineered Parameters (STEP). Because STEP doesn't use electricity, it provides fine control of fiber spacing, fiber diameter, and fiber orientation (Figure 1).

"Inside the body, collagen is fibrous in nature, but the individual fibers are tiny - anywhere from 30-70 nanometers in diameter

**Figure 1**  
 Non-electrospinning  
 Spinneret based Tunable  
 Engineered Parameters  
 (STEP) fiber manufacturing  
 platform



**Figure 2**

*Nanonet Force Microscopy (NFM) for measuring cellular forces*

– and cells don't attach to them because the cells are too large, at about 20 microns," Nain explained. "So, what happens in nature is that these fibers bundle together to form larger diameter structures from 200 nanometers to several microns." To put things in perspective, thousand microns fit in a millimeter and thousand nanometers fit in a micron. To give some idea on scaling, a strand of human hair varies in diameter anywhere from 50-200 microns.

In biomedical engineering, there has been a long-standing push to study cell behavior using fiber networks. A popular technique to form fiber networks that's been used in the past couple of decades is electrospinning. The first patent on electrospinning was issued in 1902, and electrospinning uses a high electric charge (~5-20 kilowatts) to form a network of fibers. A typical American home, by contrast, uses about 30 kilowatt hours of electricity per day.

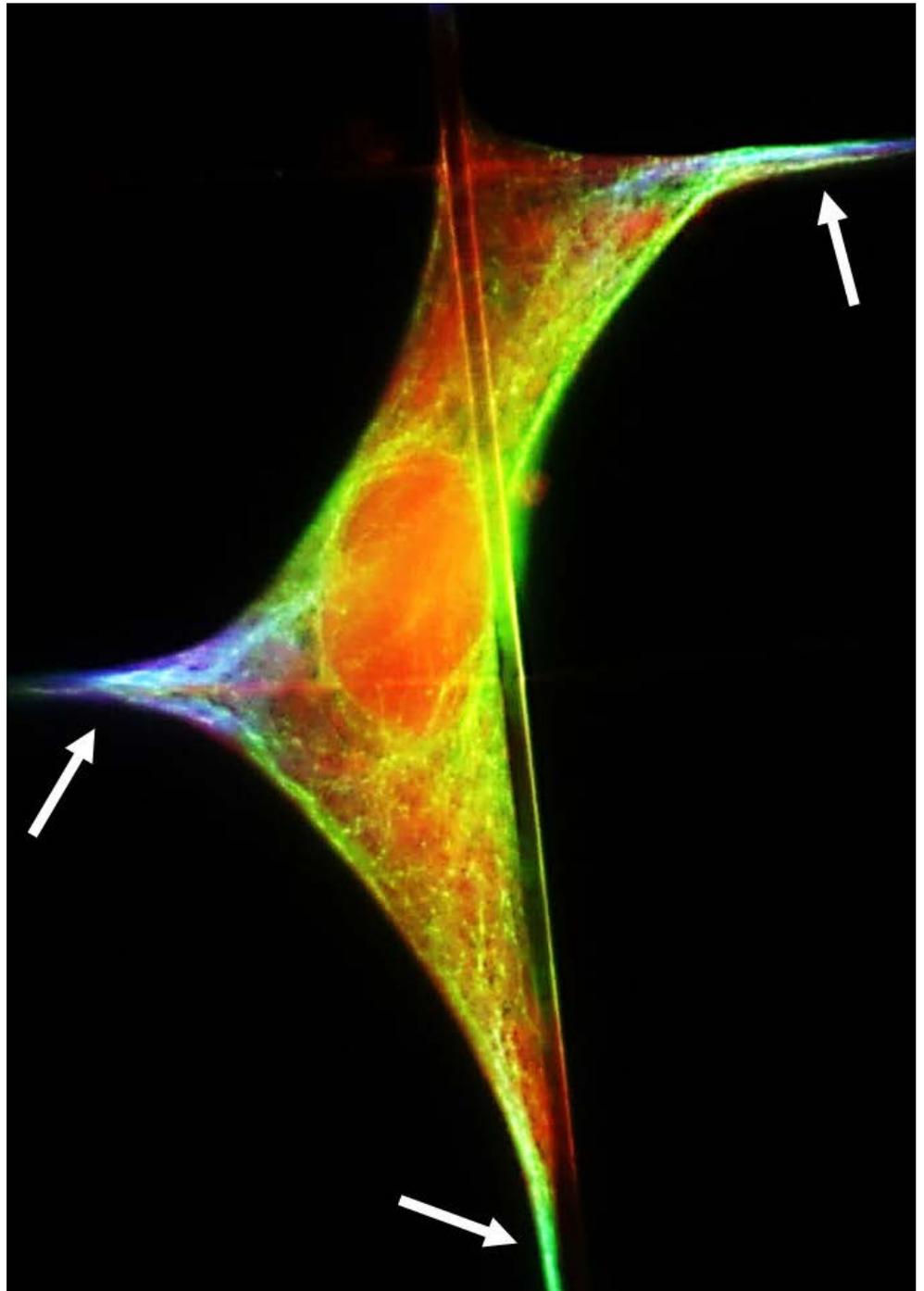
"Electrospinning uses pretty high voltages," Nain said, "but STEP does not use any electric source to form fibers, thus providing us very high degree of control over our fibers. That control allows us to study the role of alignment, fiber diameter, and orientation in cell behavior."

Coupling STEP with a separate patent by Nain and Bahareh Behkam, associate professor of mechanical engineering, called Nanonet Force Microscopy (Figure 2), his group can measure the forces exerted by a single cell or a collection of cells. Furthermore, they can stretch cells to understand their mechanical properties and to test efficacy of drugs.

“Our interest lies in looking at fundamental cell behavior and relating it with the forces the cells are exerting,” Nain said. “For instance, we might look at the difference in forces between a diseased cell and a non-diseased cell, and how the forces are altered in migration or how they respond to the addition of drugs. This is all part of what we’re trying to understand.”

In two recent papers from 2017, Nain used the fiber networks to study the protrusions formed by cancer cells, and engineer closing and non-closing wound gaps.

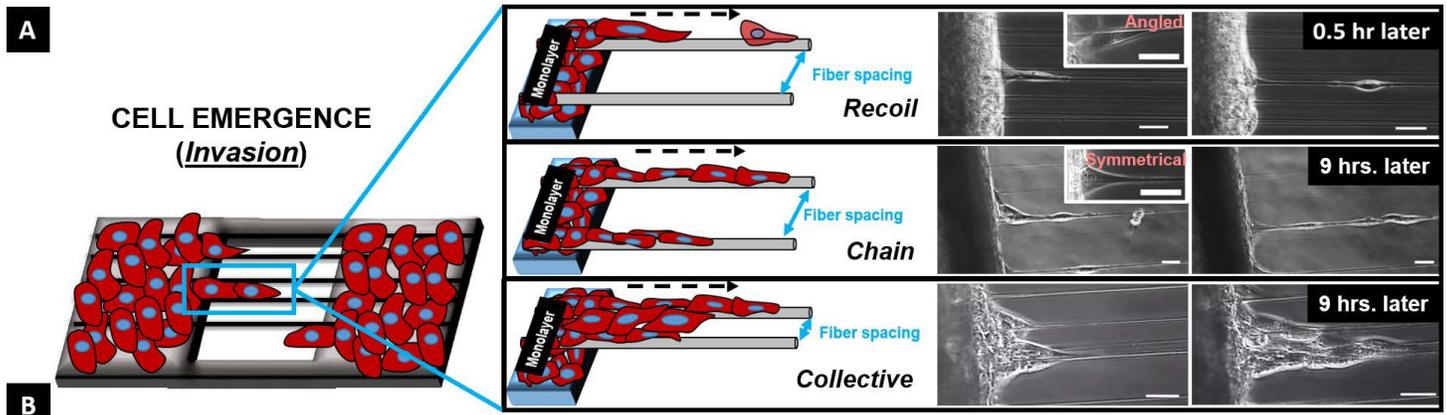
“Because we have good control of the fiber networks, we are able to study multiple cell behaviors in a repeatable and controlled fashion that has not been easy to do before. It’s a very elegant process,” Nain said. “In December [2017], we had a paper in ACS Nano, in which we were studying how to isolate protrusions – finger-like sensory projections from cell bodies (Figure 3). Think of it like walking in a dark hallway, and eventually you will start sensing with your arms. These sensory devices are protrusions and



**Figure 3**  
*Cellular protrusions shown by white arrows*

## Figure 4

Cell invasion in single recoil, chain and collective modes is regulated by both diameter and spacing of nanofibers.

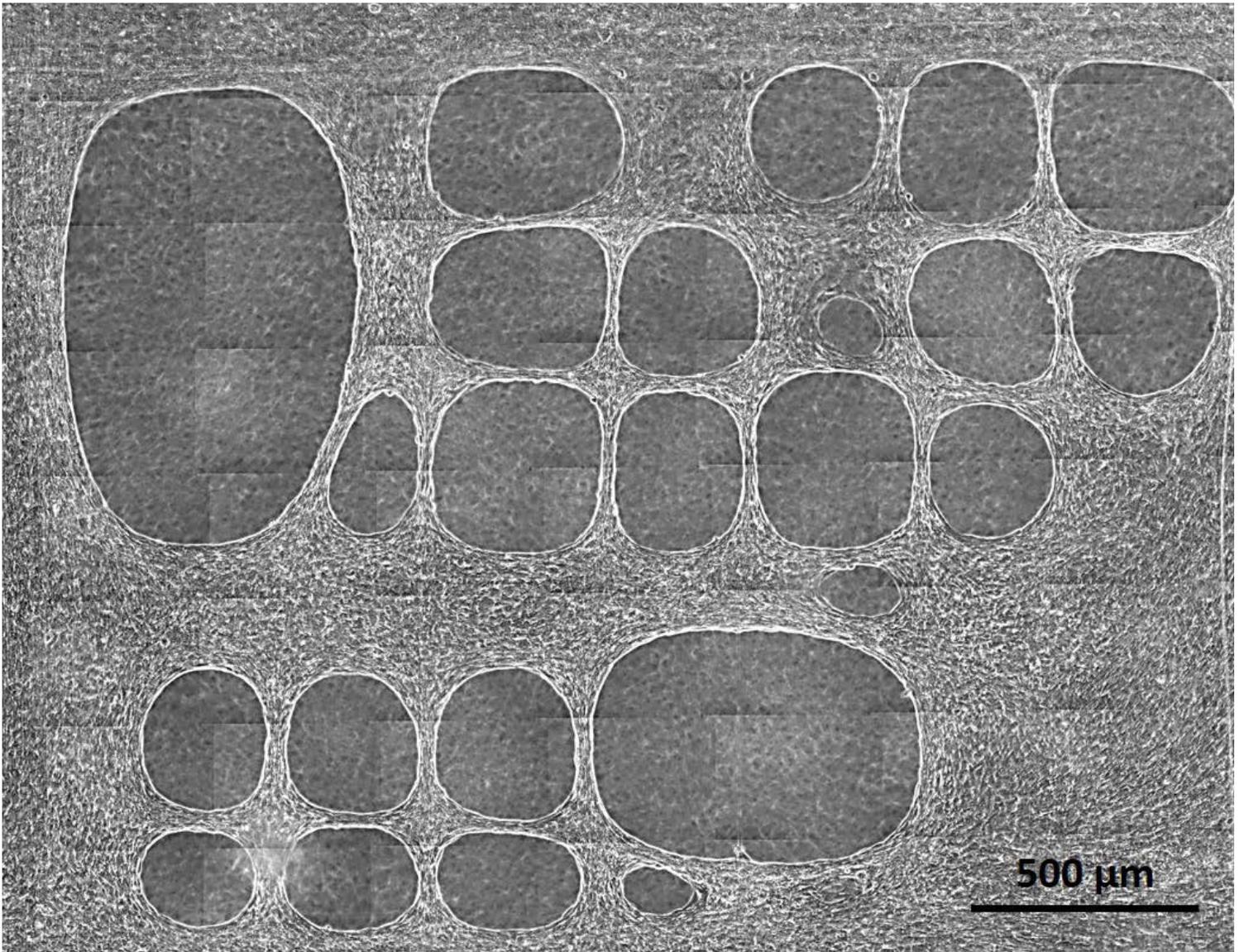


that's exactly what cells are doing in our bodies."

As cells move they pick paths by sending out a protrusion, and if the cell finds what it needs, the protrusion matures and the cell moves in that direction. Nain and his collaborators set up a platform to study protrusions as cells migrate.

"Now we can see the protrusion in the direction of migration as well as lateral protrusions independent of direction of migration," Nain said. "Because our system can elicit lateral protrusions of varying sizes and shapes in a controlled manner, we can study them individually to see how they form, how they mature, and what length they extend to. The big question we can then answer is, are all protrusions across all cell types the same?"

"We have pioneered 'Prototyping', a new method based upon biophysical metrics that can distinguish protrusive behavior across disease models and cell types in a controlled and repeatable manner. Using a human breast cancer model, we found that the length of protrusions was longer in cancerous cells compared to non-cancerous counterparts; and that breast cancer cells were more sensitive to the diameter of the fiber, than say, a brain cancerous cell," Nain said. "You can't really compare the two types of cells, but the sensitivity was there." To understand fiber curvature contributions to protrusion formation, Behkam group designed flat ribbon fibers that matched the circumference of round fibers, thus providing a direct comparison between flat and round geometry. They found that on flat ribbons of varying widths, cells formed protrusions of a universal size, whereas on round fibers, the protrusion sizes and lengths varied with diameter. Because the protrusions are sensitive to diameter, it's important that they be observed and studied in vitro with round fibers of diameters found inside the body.



“Knowing this sensitivity to cylindrical platforms, we did a study [published in *Molecular Biology of the Cell*] where we showed protrusion driven cell invasion on fibers of varying diameters,” Nain said. “We suspended fibers and put cells on either side. Based on both the separation distance between the fibers and the diameter of fibers, the cells will come out singly, or if the fibers are closer together, they will move as a stream (Figure 4).”

This behavior of invasion is similar to reported *in vivo* streaming of cells from a tumor. Interestingly, single cells invaded by recoiling, similar to release of a stretched rubber band. “Post invasion, we observed that depending upon the distance and orientation of fiber networks, migrating cells from both sides approached each other and formed gaps that closed or did not (Figure 5), thus providing a new method to study wound healing,” Nain and Behkam said.

They identified a critical distance of ~375 microns beyond which there was no gap closure. “There is more study to be done, but we now have a way to engineer gaps based on the separation distance of the fibers. We

## Figure 5

*Design of fiber networks to study closing and non-closing gaps in wound healing.*

have taken the first few steps, and now the next steps are to work with clinicians, dermatologists, and biologists who study why some cells can induce gap closure while others cannot. We're beginning to work with those folks now to develop a strategy," Nain said.

Nain's goal is to create a custom suture made of a scaffolding that can be implanted to induce closure.

"If we can interface a fiber in a certain way, we can make cells stream out in a way that can potentially close gaps. It can help people," Nain said.

Currently, fibers can be made out of biodegradable and biocompatible materials, but Nain says he's not at the finish line yet.

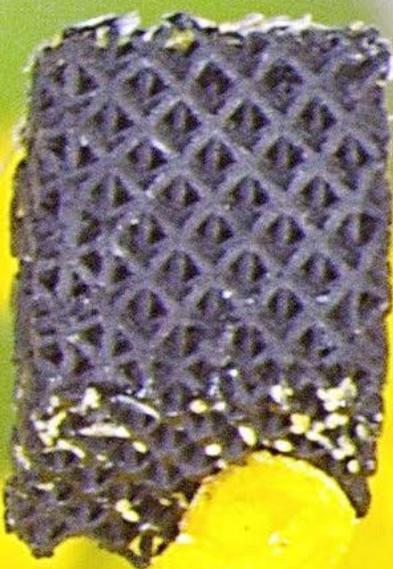
"One part of this is fundamental science and the other is translational ability," Nain said. "If you have sound science, it will lead to a translational strategy. We want to understand what it is that is so special about certain cells and their environments, and how we can tune the environment to force cells to behave in a certain way." The fundamental research and testing in a lab setting is key to success of implantable sutures in humans.

"Mechanical engineering is poised to make significant contributions in translational medicine and it is important that we embrace mechanobiology, biophysics and bioengineering in our curriculum at undergraduate and graduate levels," Nain said



<https://youtu.be/X7qpRUPQ2jc>

# Researchers develop process to 3D print one of Earth's strongest materials



*Zoomed in graphene octet truss on strawberry blossom*

STORY BY ANDREW TIE  
MACROMOLECULES  
INNOVATION INSTITUTE

Researchers from Virginia Tech and Lawrence Livermore National Laboratory have developed a novel way to 3D print complex objects of one of the highest-performing materials used in the battery and aerospace industries.

Previously, researchers could only print this material, known as graphene, in 2D sheets or basic structures. But Virginia Tech engineers have now collaborated on a project that allows them to 3D print graphene objects at a resolution an order of magnitude greater than ever before printed, which unlocks the ability to theoretically create any size or shape of graphene.

Because of its strength - graphene is one of the strongest materials ever tested on Earth - and its high thermal and electricity conductivity, 3D printed graphene objects would be highly coveted in certain industries, including batteries, aerospace, separation, heat management, sensors, and catalysis.

Graphene is a single layer of carbon atoms

organized in a hexagonal lattice. When graphene sheets are neatly stacked on top of each other and formed into a three-dimensional shape, it becomes graphite, commonly known as the “lead” in pencils.

Because graphite is simply packed-together graphene, it has fairly poor mechanical properties. But if the graphene sheets are separated with air-filled pores, the three-dimensional structure can maintain its properties. This porous graphene structure is called a graphene aerogel.

“Now a designer can design three-dimensional topology comprised of interconnected graphene sheets,” said Xiaoyu “Rayne” Zheng, assistant professor with the Department of Mechanical Engineering in the College of Engineering and director of the Advanced Manufacturing and Metamaterials Lab. “This new design and manufacturing freedom will lead to optimization of strength, conductivity, mass transport, strength, and weight density that are not achievable in graphene aerogels.”

Zheng, also an affiliated faculty member of the Macromolecules Innovation Institute, has received grants to study nanoscale materials and scale them up to lightweight and functional materials for applications in aerospace, automobiles, and batteries.

Previously, researchers could print graphene using an extrusion process, sort of like squeezing toothpaste, but that technique could only create simple objects that stacked on top of itself.

“With that technique, there’s very limited structures you can create because there’s no support and the resolution is quite limited, so you can’t get freeform factors,” Zheng said. “What we did was to get these graphene layers to be architected into any shape that you want with high resolution.”

This project began three years ago when Ryan Hensleigh, lead author of the article and now a third-year Macromolecular Science and Engineering Ph.D. student, began an internship at the Lawrence Livermore National Laboratory in Livermore, California. Hensleigh started working with Zheng, who was then a member of the technical staff at Lawrence Livermore National Laboratory. When Zheng joined the faculty at Virginia Tech in 2016, Hensleigh followed as a student and continued working on this project.

To create these complex structures, Hensleigh started with graphene oxide, a precursor to graphene, crosslinking the sheets to form a porous hydrogel. Breaking the graphene oxide hydrogel with ultrasound and adding light-sensitive acrylate polymers, Hensleigh could use projection micro-stereolithography to create the desired solid 3D structure with the graphene oxide trapped in the long, rigid chains of acrylate polymer. Finally, Hensleigh would place the 3D structure in a furnace to

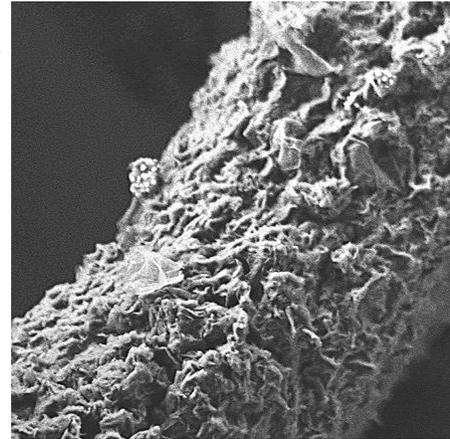
burn off the polymers and fuse the object together, leaving behind a pure and lightweight graphene aerogel.

“It’s a significant breakthrough compared to what’s been done,” Hensleigh said. “We can access pretty much any desired structure you want.”

The key finding of this work, which was recently published with collaborators at Lawrence Livermore National Laboratory in the journal *Materials Horizons*, is that the researchers created graphene structures with a resolution an order of magnitude finer than ever printed. Hensleigh said other processes could print down to 100 microns, but the new technique allows him to print down to 10 microns in resolution, which approaches the size of actual graphene sheets.

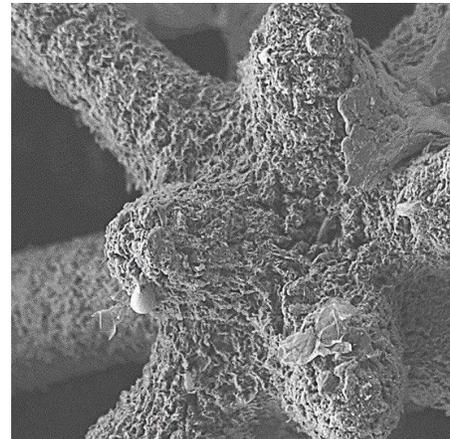
“We’ve been able to show you can make a complex, three-dimensional architecture of graphene while still preserving some of its intrinsic prime properties,” Zheng said. “Usually when you try to 3D print graphene or scale up, you lose most of their lucrative mechanical properties found in its single sheet form.”

Co-authors include Huachen Cui, a doctoral student in Zheng’s lab, and six people from Lawrence Livermore National Laboratory – James Oakdale, Jianchao Ye, Patrick Campbell, Eric Duoss, Christopher Spadaccini, and Marcus Worsley. Zheng and Hensleigh are funded by an Air Force Young Investigator Award (Dr. Jaimie S. Tiley) and the National Science Foundation.



Above: Zoomed-in scanning electron microscope picture of a graphene octet-truss at a resolution of 1 micrometer.

Below: Zoomed-in scanning electron microscope picture of a graphene octet-truss at a resolution of 10 micrometers.



# Scholarships

The following is a list of scholarships presented to mechanical engineering students in Fall 2018. The list is not all-inclusive.

Virginia Tech Mechanical Engineering William A. Potts Sr. & Jr. Scholarship

Virginia Tech Mechanical Engineering Jerry D. Watkins and Merle M. Watkins Scholarship

Virginia Tech Alfa Laval Thermal Inc. Mechanical Engineering Scholarship for the Advancement of Heat Transfer Technology

Virginia Tech George E. Schultz Memorial Mechanical Engineering Scholarship

Virginia Tech Mechanical Engineering Stanley & Margaret Giddings Scholarship

Virginia Tech Herbert L. Duff Jr., and Marian Miller Duff, Class of 1948, Mechanical Engineering Scholarship

Virginia Tech William S. Cross Engineering Scholarship

Virginia Tech Mechanical Engineering Stanley Ragone Memorial Fund Scholarship

Virginia Tech Mechanical Engineering W. Andrew A. Jones '88 Memorial Scholarship

Virginia Tech Mechanical Engineering H.C. and Terry Yu Endowed Scholarship

Virginia Tech Mechanical Engineering John R. Jones III Endowed Scholarship

Virginia Tech Mechanical Engineering Monte Alan Marcum Scholarship

Virginia Tech Mechanical Engineering Deborah R. Tillotson Engineering Scholarship

Virginia Tech Dhulipala Scholarship in Mechanical Engineering

Virginia Tech Mechanical Engineering Benjamin Squires '48 Memorial Scholarship

Virginia Tech Thomas Watkins Drewry Mechanical Engineering Scholarship

Virginia Tech Mechanical Engineering Atlas Fraley Memorial Scholarship

Virginia Tech Hamilton H. Mabie Mechanical Engineering Scholarship

Virginia Tech Mechanical Engineering Square D Company Scholarship

Virginia Tech Pierce T. Angell Mechanical Engineering Scholarship

Virginia Tech Mechanical Engineering Hobart A. and Mollie L. Weaver Scholarship

Virginia Tech Mechanical Engineering Hugh Smith Miles Jr. Scholarship



*next issue*

*Test for Echoes*