Once Smitten

By April Frawley

Bat studies enamor scientists, engineers with promises of elusive secrets

The air inside the cave felt cool and damp, a welcome contrast to the sizzling summer heat in East China’s Shangdong Province.

Virginia Tech researcher Thomas Tucker positioned his motion-capture scanners throughout the cave. Around him, a mere 20 feet away, hundreds of bats clung to the walls.

Tucker proceeded with his work, undeterred by the possibility that bats might take flight and swarm around his head.

His objective was to capture images of the bats and triangulate their movements with scanners equipped with technology called “lidar,” which uses light pulses to generate 3-D images.

The idea was to show how the bats hugged the walls and worked in concert as they exited the cave. It’s a process that seems chaotic, but is actually intricately orchestrated by the animals’ sophisticated sonar.

“I didn’t realize there were so many types of species and that each bat perceives space differently,” said Tucker, an associate professor of creative technology in the School of Visual Arts. “The one we were focusing on has a complex radar system, and not all bats have it.”

Outside the cave, waiting for the swarm of bats to emerge, was Nicole Abaid, who would use Tucker’s data as part of her research.

An assistant professor in the Department of Biomedical Engineering and Mechanics at Virginia Tech, Abaid studies how systems involving multiple intelligent agents coordinate to complete big tasks.

As it turns out, bats exemplify this collective behavior.
“Bats operate on the same sonar frequency, but they have no problems, such as jamming,” Abaid said. “Understanding how they do that can help engineers design better systems that use active sensing, such as a swarm of underwater vehicles.”

Bats — unlike fish, which Abaid has also studied — don’t have any biological mechanism that links them together. Instead, they rely on echolocation — nature’s version of sonar — to sense each other and operate collectively as they stream out of their cave.

How they manage this feat has long been a scientific puzzle. The answers could help engineers trying to develop new technologies.

“People have been looking at bat sonar for 60 years, and we cannot reproduce it,” said Rolf Mueller, an associate professor in the Department of Mechanical Engineering of the College of Engineering, who blazed the trail that led Abaid and Tucker to study bats in Chinese caves. “How can they use sonar and do all the things they can do that we cannot?”

More than meets the eye

Bats owe some of their supersensory capabilities to specially shaped facial structures.

Depending on the species, bats emit ultrasonic waves either through their mouths or their noses. In some bats, exquisitely detailed skin outgrowths called noseleaves seem to serve as miniature megaphones to shape the waves.

Bats receive signals through their ears, and certain species can reshape their ears to enhance their biosonar. And they can adjust at lightning speed.

Human beings need three-tenths of a second to blink an eye. In a single tenth of a second, a bat can change the shape and reposition its ear, adjusting its ultrasonic hearing pattern.

Bats’ uncanny abilities — and other engineering marvels of the natural world — inform research at the Center for Bioinspired Science and Technology, which Mueller directs. The center is partially supported by the Institute for Critical Technology and Applied Science (ICTAS) at Virginia Tech.

Mueller splits his time between his lab at ICTAS II in the life science corridor on Virginia Tech’s Blacksburg campus and his lab at Shangdong University in China, home to one of the largest collections of bat specimens in the world.

“A good thing about China is it is blessed with bats,” Mueller said. “The bats there are diverse and plentiful despite pollution.” Particularly important for Mueller, two groups of bats in China have especially sensitive sonar systems.
Fascinated with bats since he was a master's student at the University of Tuebingen, Mueller spends about four months a year in China, where he and his team keep 20 bats in a colony.

He hosts graduate students and visiting professors from various disciplines annually to study the creatures. Along the way, Mueller has lured many a curious investigator into caves inhabited by the leathery, screeching creatures of gothic fiction.

“To understand bats, we need people to help who have different backgrounds,” Mueller said. “Bats have many properties that push the boundaries of what animals can do, so I have found it not to be a difficult sell.”

Tucker, who is associated with the Institute of Creativity, Arts, and Technology (ICAT), usually scanned sites and landmarks for historic preservation. But he was also adept at motion-capture technology, a tool he had used to study and assess early signs of injuries or valued traits in working dogs.

Mueller thought the motion-capture technique would be useful for studying bats, and so he lured Tucker into the fold. The 30 days he worked studying bats in China flew by, and he hopes to return. Like other researchers at Virginia Tech, the fascination with the flying mammals had gotten into his blood.

“That is my agenda,” Mueller said.

**Shaping the signal**

Leonardo da Vinci respected the bat.

In his notes, the famous Renaissance artist-scientist sketched a flying machine with a wingspan that exceeded 30 feet. The invention was unmistakably inspired by bats: The wings had pointed tips and were designed to twist as they flapped, powered by a pilot lying face down with hand cranks and foot pedals.

It would be 400 years before aviation pioneers Orville and Wilbur Wright demonstrated the first practical airplane on Dec. 17, 1903.

And despite all the developments in air travel since then, one thing hasn’t changed: airplanes still have fixed wings.

“That imposes some limitations in take-off, landing, and maneuverability at low speed,” said Javid Bayandor, an associate professor in the Department of Mechanical Engineering.

“For 100 years, we've viewed flight in one particular way,” Bayandor said. “The only way we can generate enough lift to take off is by applying thrust generated by a propulsion system.”

And increased propulsion means increased fuel consumption.
Smaller vehicles inspired by bats’ flapping flight could be much more energy-efficient. Bayandor imagines that this could dramatically change local air travel and even personal commuting: he tells his students that they might one day send their kids off to elementary school with winged backpacks.

But the principles of bat flight are elusive.

During flapping, bats continuously distort the shape and size of their wings, which makes understanding their flight challenging.

“The bat is singular because it has very minute control over its motion,” said Danesh Tafti, the William S. Cross Professor and interim department head of the Department of Mechanical Engineering. “Bats have control of all their fingers and the webbing in between, and because of this, it’s difficult to replicate their wing motion. It is a very challenging problem to simulate on a computer.”

Tafti’s goal is to break the wing motion down into simple parts to help engineers develop a true, bat-inspired robotic wing.

“That is my long-term vision,” he said. “If the team comes together, we could do some really good stuff, from measurements to making a bat-like robot.”

Once developed, the tiny devices could be used for a variety of purposes, including locating people or searching small, difficult-to-reach spaces.

Bayandor’s team at the Crashworthiness for Aerospace Structures and Hybrids (CRASH) Lab has already built award-winning robotic birds modeled after seagulls. They are currently at work on the robotic bat, dealing with topics ranging from understanding the complete flight kinematics in bats, to their unsteady aerodynamics.

They aim to create a fully representative, bioinspired flying system and collaborate with Mueller as well as mechanical engineering professors Francine Battaglia and Andrew Kurdila.

Bayandor agrees with Mueller that there’s just something beguiling about bat research: “It manages to entice a lot of students,” he said.

**Decoding the hive mind**

Abaid, another Mueller colleague, is interested in bats because she studies swarms and other collective systems in nature whose behavior could be useful in engineered systems.

Imagine a swarm of underwater vehicles gliding across the ocean floor, able to spread out, coordinate, locate, and move among each other in the dark depths without the need for a leader making every decision. A
multiple-agent, wireless system of this type could cover more ground than a submarine could, at a fraction of the cost. It could be invaluable for collecting climate data, for example.

Bat-inspired communication could also enhance air traffic control systems, said Abaid, who is working with doctoral student Yuan Lin. “When bats wake up in the evening, how do they schedule who goes through cave?” she mused.

But first researchers have to truly understand how bats echolocate and work collectively using sonar. Scientists know about a couple of important strategies. Bats avoid frequencies that scramble their sonar senses, something that is a challenge for man-made devices.

“They also seem to be able to eavesdrop on each other,” said Abaid, who was named one of Popular Science magazine’s Brilliant Ten in 2014. “They may get information from the echoes of their peers. If we can figure out how to do this, we can develop systems that benefit.”

And it’s not just engineered systems that could benefit from some batty upgrades. Bats have strong social ties, dynamics that could also help humans work better as teams.

“With humans, we feel like we are above subconscious interactions, but we are not,” Abaid said. “If we share music, we will find we are walking in step to it.”

**The art of bats**

Dane Webster had always found himself at the intersection of art and science, using his skills in 3-D animation to create models and visualizations for short films and games.

His interests led him to the Institute for Creativity, Arts, and Technology, where researchers from diverse disciplines come up with innovative ways to tackle problems and conduct research.

An associate professor in the College of Architecture and Urban Studies and director of the master of fine arts in creative technologies program, Webster had deployed his animation expertise for colleagues in the gaming and film worlds.

Mueller, meanwhile, needed help with a project to scan and animate the anatomy of bat specimens. Technical problems with computerized tomography, or CT scans, were making it difficult for him to create anatomical models up to his standards, so he turned to Webster through ICAT.

This time, instead of building monsters for movies, Webster built a bat.

That effort led to a second project with Anupam Gupta, a graduate student in the Department of Mechanical Engineering, who wanted to analyze how sonar beams change when bats alter the shape of their noses.
Their animation of the dynamic behavior of bat noseleaves for the 166th meeting of the Acoustical Society of America in San Francisco in December 2013 was awarded first prize in the “gallery of acoustics” competition. For the art students, “bat projects” are an entryway to the world of funded research.

With help from Webster’s models, Mueller and his students have built a prototype of a bat-inspired sonar system, which was presented at the May meeting of the Acoustical Society of America.

“It is not the norm in the arts to work on real-world applications,” Webster said. “The students take it seriously and they work very hard on it.”

Like Tucker, Webster quickly succumbed to bat fever. He and his team created animations of vampire bat specimens for a Smithsonian exhibit in the National Museum of Natural History. While working on a clip that appears to show a bat skeleton coming to life, Webster was fascinated to learn that vampire bats run on their wrists and one-quarter of all mammals are bats.

“If I had more hours in the day, I would spend more time reading about bats,” Webster said.