When stuck in water, bees create a wave and hydrofoil atop it, study finds

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Close study of bees in water revealed that they generate asymmetric waves, which they use to propel themselves forward. Credit: Chris Roh and Mory Gharib / Caltech

Walking on Caltech's campus, research engineer Chris Roh (MS '13, Ph.D. '17) happened to see a bee stuck in the water of Millikan Pond. Although it was a common-enough sight, it led Roh and his advisor, Mory Gharib (Ph.D. '83), to a discovery about the potentially unique way that bees navigate the interface between water and air.

Roh spied the bee during California's years-long drought, when the pond's fountain was turned off and the water was still. The incident occurred around noon, so the overhead sun cast the shadows of the bee—and, more importantly, the waves churned by the flailing bee's efforts—directly onto the bottom of the pool.

As the bee struggled to make its way to the edge of the pond, Roh noticed that the shadows on the pool's bottom showed the amplitude of the waves generated by the bee's wings, as well as the interference pattern created as the waves from each individual wing crashed into each other.

"I was very excited to see this behavior and so I brought the honeybee back to the lab to take a look at it more closely," Roh says.

Working with Gharib, Caltech's Hans W. Liepmann Professor of Aeronautics and Bioinspired Engineering, Roh recreated the conditions of Millikan Pond. They placed water in a pan, allowed it to become perfectly still, and then put bees, one at a time, in the water. As each bee flapped about in the water, filtered light was aimed directly down onto it, to create shadows on the bottom of the pan. Roh and Gharib studied 33 bees individually for a few minutes at a time, carefully scooping them out after a few minutes to let them recover from their swimming efforts.

A paper describing what they found was published in the *Proceedings of the National Academy of Sciences* on November 18.

When a bee lands on water, the water sticks to its wings, robbing it of the ability to fly. However, that stickiness allows the bee to drag water, creating waves that propel it forward. In the lab, Roh and Gharib noted that the generated wave pattern is symmetrical from left to right. A strong, large-amplitude wave with an interference pattern is generated in the water at the rear of the bee, while the surface in front of the bee lacks the large wave and interference. This asymmetry propels the bees forward with the slightest of force—about 20 millionths of a Newton. (For reference, a medium-sized apple held in your hand exerts about one Newton of force on your palm due to gravity.)

"The motion of the bee's wings creates a wave that its body is able to ride forward," Gharib says. "It hydrofoils, or surfs, toward safety."

Slow-motion video revealed the source of the potentially life-saving asymmetry: rather than just flapping up and down in the water, the bee's wings pronate, or curve downward, when pushing down the water and supinate (curve upward) when pulling back up, out of the water. The pulling motion provides thrust, while the pushing motion is a recovery stroke.

In addition, the wingbeats in water are slower, with a stroke amplitude—the measure of how far their wings travel when they flap—of less than 10 degrees, as opposed to 90-120 degrees when they are flying through the air. Throughout the entire process, the dorsal (or top) side of the wing remains dry while the underside clings to the water. The water that remains attached to the underside of the wing gives the bees the extra force they use to propel themselves forward.

"Water is three orders of magnitude heavier than air, which is why it traps bees. But that weight is what also makes it useful for propulsion," Roh says.

The bees do not seem to be able to generate enough force to free themselves directly from the water, but their wing motion can propel them to the edge of a pool or pond, where they can pull themselves onto dry land and fly off. Hydrofoiling is a lot more taxing for the bees than is flying, says Roh, who estimates that the bees could keep up the activity for about 10 minutes, giving them a fixed window to find the edge of the water and escape.

The motion has never been documented in other insects, and may represent a unique adaptation by bees, Roh says.

"On hot days, bee hives require water to cool off," Roh says. "So when the temperature rises, workers are sent out to gather water instead of pollen." The bees will find a water source, swallow some into a special chamber in their bodies, and then fly off. Sometimes, however, they fall in. And if they cannot free themselves, they die.

Roh and Gharib, who work in Caltech's Center for Autonomous Systems and Technologies (CAST), have already started applying their findings to their robotics research, developing a small robot that uses a similar motion to navigate the surface of water. Though labor-intensive, the motion could one day be used to generate robots capable of both flying and swimming.

The study is titled "Honeybees use their wings for water surface locomotion."

More information: Chris Roh el al., "Honeybees use their wings for water surface locomotion," *PNAS* (2019). www.pnas.org/cgi/doi/10.1073/pnas.1908857116

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