Engineers develop batlike wings that boost hovering efficiency and flight performance

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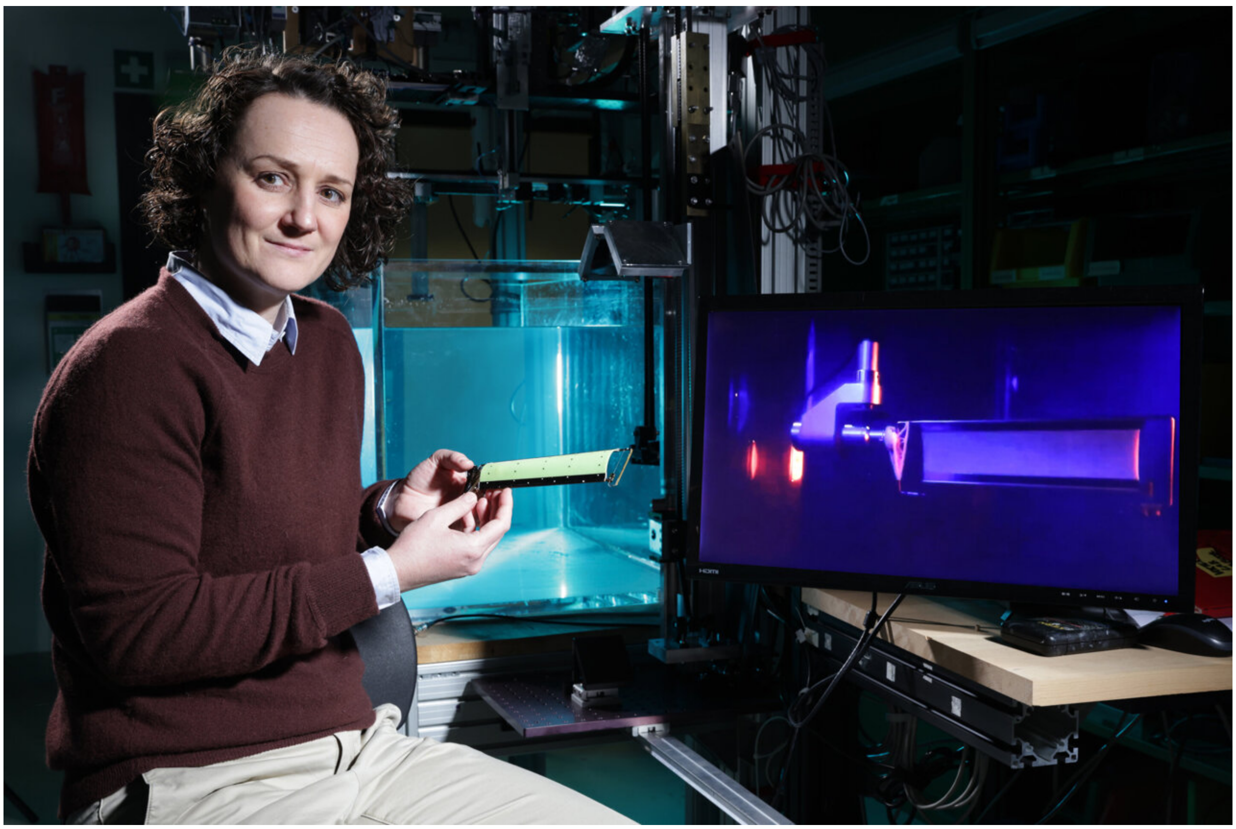

Karen Mulleners with her lab's flexible membrane wing. Credit: Alain Herzog

In 1934, French entomologist Antoine Magnan wrote that bumblebees "should not be able to fly," as their small wings should theoretically not be able to produce enough lift. It took modern high-speed camera technology to uncover what allowed airborne insects to fly: the leading-edge vortex. This phenomenon occurs when air flow around the leading edge of flapping wings rolls up into a vortex, creating a low-pressure region that boosts lift.

On the other hand, bats—with their flexible membrane wings—are able to fly just as well as insects, if not more efficiently. In fact, some bats have been found to expend as much as 40% less energy than moths of a similar size.

Researchers in the Unsteady Flow Diagnostics Laboratory in EPFL's School of Engineering set out to study the aerodynamic potential of more flexible wings using an experimental platform with a highly deformable membrane made from a silicone-based polymer. They found that instead of creating a vortex, the air flows smoothly over the curved wings, generating more lift and making them even more efficient than rigid wings of the same size.

"The main finding of this work is that the gain in lift we see comes not from a leading-edge vortex, but from the flow following the smooth curvature of the membrane wing," says former EPFL student Alexander Gehrke, now a researcher at Brown University. "Not only does the wing have to be curved, but it has to be curved by just the right amount, as a wing that is too flexible performs worse again."

Gehrke is the first author on a paper describing the work that has been published in the *Proceedings of the National Academy of Sciences*.

Design insights for drones or energy harvesters

The researchers mounted the flexible membrane onto a rigid frame with edges that rotate around their axes. To help visualize the flow around the wing, they immersed their device in water mixed with polystyrene tracer particles.

"Our experiments allowed us to indirectly alter the front and back angles of the wing, so we could observe how they aligned with the flow," says Unsteady Flow Diagnostics Lab head Karen Mulleners. "Due to the membrane's deformation, the flow wasn't forced to roll up into a vortex; rather, it followed the wing's curvature naturally without separating, creating more lift."

Gehrke says that the team's results provide important insights for biologists as well as engineers.

"We know that bats hover and that they have deformable membrane wings. How the wing deformation affects the hovering performance is an important question, but doing experiments on live animals is not trivial. By using a simplified bio-inspired experiment, we can learn about nature's fliers and how to build more efficient aerial vehicles."

Experimental flexible wing set-up. Credit: Gehrke/Mulleners EPFL

He explains that as drones get smaller, they are more strongly affected by small aerodynamic perturbations and unsteady gusts than larger vehicles like airplanes. Standard quadrotor drones stop working at a very small scale, so one solution could be to use the same flapping wing motions as animals to build improved versions of these flyers that can hover and carry a payload more efficiently.

The team's findings could also be used to upgrade existing energy technologies like wind turbines, or to commercialize emerging systems like tidal harvesters that passively harness energy from the ocean's currents. Advances in sensors and control technology, potentially combined with artificial intelligence, could enable the precise control required to regulate the deformation of flexible membrane wings and adapt the performance of such flyers to varying weather conditions or flight missions.

More information: Alexander Gehrke et al, Highly deformable flapping membrane wings suppress the leading edge vortex in hover to perform better, *Proceedings of the National Academy of Sciences* (2025). DOI: 10.1073/pnas.2410833121

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