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Barbs of a feather support flight together

By Stephen Riffle February 22, 2019

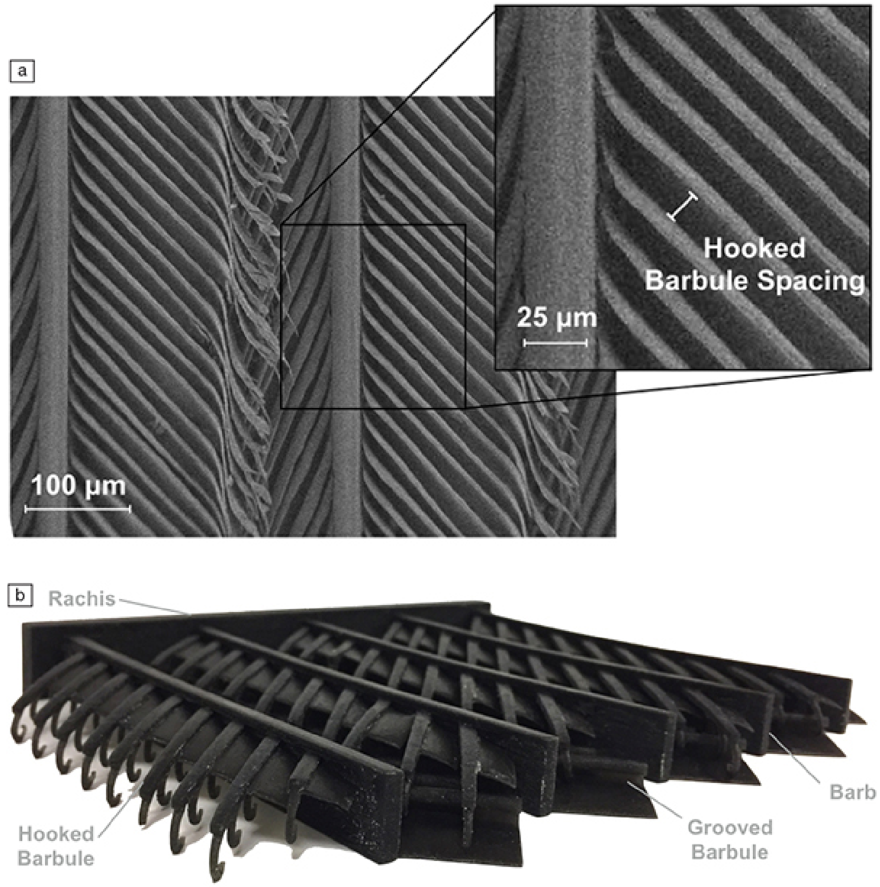
If given unlimited funds, Tarah Sullivan would develop a synthetic feather—one that accurately recreates the nanoscale and microscale properties of avian flight feathers. Feathers hold a wealth of structural secrets that, if mimicked, could inspire the design of feathered planes and may have the potential to mitigate disaster during earthquakes. In a study recently published in *Science Advances*, Sullivan, Marc Meyers, and Eduard Arzt tap into the mathematical and submicroscopic properties of bird flight.

Bones in the avian wing are primarily composed of collagen and hydroxyapatite. Together, these materials form nanoscale fibers that are precisely layered over one another to create lightweight, but fortified, bone. Although it is strong, there is a mechanical limit to what it can withstand. In their article, Sullivan and her colleagues determined that the length of a bird's humerus—the bone that connects a bird's wing to its body which is subject to significant force during flight—can be predicted as a function of both the bird's mass and its constant bone strength. These findings explain why avian wing bones disproportionately scale with body mass: To prevent bone failure during flight.

The research team also found that birds have evolved a surprising adaptation in their feathers that may be critical to flight. Sullivan found that with modern technologies like scanning electron microscopes and three-dimensional (3D) printers, she could revisit the feather in a way others couldn't previously.

"It was a lot cooler than either of [Dr. Meyers or I] thought it would be. It's like a secret that's been in the feather. It's kind of neat!"

That secret turned out to be hiding between feather barbules. Feathers generate lift by capturing air under a uniform structure of tightly assembled barbs. Critical to forming this structure are barbules, microscopic extensions from the barbs that interhook with one another through a velcro-like mechanism. Sullivan made an important discovery in observing that the spacing between adjacent barbules in the feathers of two birds whose mass and overall size is significantly different—Anna's hummingbird (*Calypte. anna*) and the Andean condor (*Vultur gryphus*)—were nearly identical. This suggests barbule spacing is independent of a bird's mass.



Barbules as connecting elements between feathers. (a) Their spacing is measured as the distance between barbules. (b) An additively manufactured bioinspired model demonstrates the orientation of the barbule membrane flaps between barbules.

"[We] expected it to scale up, but, low and behold, the barbules had the same spacing!" says Meyers. The reason for this remarkable consistency is unclear, but it may have to do with permeability.

Membranous flaps between feather barbules have been shown to form a barrier that catches air during a bird's downstroke while giving way to air during the upstroke—thus reducing unwanted downward force. This insight was enhanced by the use of additive manufacturing whereby Sullivan and her colleagues used a 3D printer to reconstruct feather barbules and their interspersed membranes on a macroscale (shown in the accompanying figure). This allowed them to explore how the membranes were likely to operate under various airflow conditions. The finer details of this bioinspired model is in an article that is currently under review.

So why wouldn't the barbule spacing scale with a bird's mass? Meyers suggests that the efficiency of the barrier may decrease if it did, ultimately decreasing its ability to generate upward lift.

The potential implications of these findings are uncertain, but no less exciting. Bret Tobalske at the University of Montana studies the comparative biomechanics of locomotion. He described the results as being both “interesting and novel,” going on to say that “it advances our understanding of the design of birds…[and]…that opens up avenues for testing biological materials.”

Sullivan and her colleagues would agree. They previously revealed that structural features of avian flight feathers—such as the spatial change in material organization across a feather’s length—could be adapted to fortify buildings against the forces experienced during earthquakes.

Meyers is optimistic that their recent observations will inspire future innovation as well.

“We are becoming more aware of biodesigns and are moving away from monolithic materials,” Meyers says. Studies like this, he says, enable the human imagination: “Ideas will come out for components of wings, beams, and maybe there will even be an airplane that uses something like feathers. I don’t know exactly, but the human imagination is boundless.”

Read the article in *Science Advances (http://advances.sciencemag.org/content/5/1/eaat4269)*.

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