Researchers learn how swimming ducks balance water pressure in their feathers while diving

June 2 2021

Credit: Pixabay/CC0 Public Domain

A team of students working with Jonathan Boreyko, associate professor in mechanical engineering at Virginia Tech, has discovered the method

ducks use to suspend water in their feathers while diving, allowing them to shake it out when surfacing. The discovery opens the door for applications in marine technology. Findings were published in *ACS Applied Materials & Interfaces*.

Boreyko has a well-established body of work in the area of fluid mechanics, including the invention of a fog harp and the use of contained, recirculated steam as a cooling device. As his research has progressed throughout the past decade, the mechanics of duck de-wetting has been one of his longest-running projects.

"I got this idea when I was at Duke University," said Boreyko. "I had a really bad parking spot, but my walk took me right through the scenic Duke Gardens. I passed by ponds with lots of ducks, and I noticed that when a duck comes out of the water, they'd shake their feathers and water would fly off. I realized that what they were doing was a de-wetting transition, releasing water that was partially inside of their feathers. That was the germ of the idea. In my research, purely by coincidence, I was studying the same kind of thing. I realized that these transitions work only if the water isn't allowed to get all the way to the bottom of the porous feather structure."

Boreyko remained intrigued with how the balance was struck, curious about the mechanisms that allow a duck to hold water in its feathers without sinking completely. He brought Farzad Ahmadi into his lab in 2014 as a graduate student, sharing that intrigue in one of their early meetings. Ahmadi picked up the project and dove into the finer details. Their first approach was simple—they attempted to force a single drop of water through a natural duck feather.

"It didn't work," said Ahmadi. "Then we had the idea to build a pressure chamber to force a pool of water through several layers of feathers."

Under pressure

The team first needed to ensure the water could only penetrate directly through the feathers, as opposed to simply leaking around their outer edges. To achieve this, they sealed one feather at a time, leaving only a small area exposed. The researchers sealed each layer, leaving an area exposed in the same place on each surface. This allowed them to create a column of exposed feather surfaces upward through the stack. A thin pool of water was poured over the top exposed surface. The stack was placed in a pressure chamber, and gas pressure was employed to push the water downward through the feathers. A camera was placed at the bottom to observe the water as it passed through the layers.

Feathers have micro-sized openings in them, tiny slots that allow pressurized water to pass through. A duck sitting on the surface of a pond isn't encountering any water pressure, so the water penetration is negligible. A duck diving downward, however, encounters a steady increase in hydrostatic pressure, something familiar to anyone taking a dive into the deep end of a pool.

Ahmadi discovered that as the number of feather layers increases, the pressure required to push water through all the layers must also increase. This establishes a kind of baseline, a maximum pressure up to which feathers hold the water entering them, but do not allow the water to reach a duck's skin.

"Our hypothesis was to use multiple layers of feathers so that the water only comes in part way, but there are air pockets under that," Boreyko explained. "As long as those air pockets are present, it prevents something called irreversible wetting. As long as the wetting is only partial, they can shake it out when they surface."

Ahmadi also discovered that species of ducks tend to have the exact

number of feather layers needed to avoid irreversible wetting during their dives. A mallard, for instance, has four layers of feathers. The maximum depth to which a typical mallard dives corresponds to a hydrostatic pressure that invaded a three-feather stack but not four. In this way, at least one layer of feathers remains dry after a dive, allowing the duck to shake out the water when it emerges.

Designing synthetic feathers

Having established the foundational mechanics of duck de-wetting, Boreyko's team set out to create a synthetic material that works in a similar way. The team made bio-inspired feathers from a thin sheet of aluminum foil, laser cutting an array of slots one-tenth of a millimeter wide to mimic the barbules of a duck feather. They also re-created the hairy nanostructure of feathers by adding an aluminum nanostructure to the aluminum barbules.

The synthetic feathers produced nearly identical results during testing, a credit to the strength of nature's design. Application and scaling of this technology is a logical next step for Boreyko, and he has a few ideas.

This layer effect may be helpful for trapping air pockets in desalination membranes, mechanisms that remove salt from seawater. Boreyko also thinks there is potential for applying layered synthetic feathers to the exterior of a boat, to make the boat travel more easily through the water and reduce the amount of barnacle-like organisms that cling to the hull.

"If we think of a ship moving over the water as an engineered bird, right now it's swimming naked," Boreyko says. "We wonder if clothing the ship in feathers could impart the same enhancements that waterfowl benefit from."