How the hummingbird achieves its aerobatic feats
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The sight of a tiny hummingbird hovering in front of a flower and then darting to another with lightning speed amazes and delights. But it also leaves watchers with a persistent question: How do they do it?

Now, the most detailed, three-dimensional aerodynamic simulation of hummingbird flight conducted to date has definitively demonstrated that the hummingbird achieves its nimble aerobatic abilities through a unique set of aerodynamic forces that are more closely aligned to those found in flying insects than to other birds.

The new supercomputer simulation was produced by a pair of mechanical engineers at Vanderbilt University who teamed up with a biologist at the University of North Carolina at Chapel Hill. It is described in the article "Three-dimensional flow and lift characteristics of a hovering ruby-throated hummingbird" published this fall in the Journal of the Royal Society Interface.

For some time researchers have been aware of the similarities between hummingbird and insect flight, but some experts have supported an alternate model which proposed that hummingbird's wings have aerodynamic properties similar to helicopter blades.

However, the new realistic simulation demonstrates that the tiny birds make use of unsteady airflow mechanisms, generating invisible vortices of air that produce the lift they need to hover and flit from flower to flower.

You might think that if the hummingbird simply beats its wings fast enough and hard enough it can push enough air downward to keep its small body afloat. But, according to the simulation, lift production is much trickier than that.

For example, as the bird pulls its wings forward and down, tiny vortices form over the leading and trailing edges and then merge into a single large vortex, forming a low-pressure area that provides lift. In addition, the tiny birds further enhance the amount of lift they produce by pitching up their wings (rotate them along the long axis) as they flap.

Hummingbirds perform another neat aerodynamic trick – one that sets them apart from their larger feathered relatives. They not only generate positive lift on the downstroke, but they also generate lift on the upstroke by inverting their wings. As the leading edge begins moving backwards, the wing beneath it rotates around so the top of the wing becomes the bottom and bottom becomes the top. This allows the wing to form a leading edge vortex as it moves backward generating positive lift.

According to the simulation, the downstroke produces most of the thrust but that is only because the hummingbird puts more energy into it. The upstroke produces only 30 percent as much lift but it takes only 30 percent as much energy, making the upstroke equally as aerodynamically efficient as the more powerful downstroke.

Large birds, by contrast, generate almost all of their
lift on the downstroke. They pull in their wings
toward their bodies to reduce the amount of
negative lift they produce while flapping upward.

Although hummingbirds are much larger than flying
insects and stir up the air more violently as they
move, the way that they fly is more closely related
to insects than it is to other birds, according to the
researchers.

Insects like dragonflies, house flies and mosquitoes
can also hover and dart forward and back and side
to side. Although the construction of their wings is
much different, consisting of a thin membrane
stiffened by a system of veins, they also make use
of unsteady airflow mechanisms to generate
vortices that produce the lift they need to fly. Their
wings are also capable of producing positive lift on
both upstroke and downstroke.

To capture the details of the aerodynamics of the
hummingbird's ability to hover, Tyson Hedrick,
associate professor of biology at UNC, put tiny
dabs of non-toxic paint at nine places on a female
ruby-throated hummingbird's wing. Then he took
high-speed videos at 1,000 frames per second with
four cameras while the bird hovered in front of an
artificial flower.

Then at Vanderbilt Haoxiang Luo, associate
professor of mechanical engineering, and doctoral
student Jialei Song took the video, extracted data
on the position of the points in three dimensions
and reconstructed the varying wing shape and
position for a full flapping cycle.

Using the super-computers at the National Science
Foundation's Extreme Science and Engineering
Discovery Environment (XSEDE) and at
Vanderbilt's Advanced Computing Center for
Research and Education, the engineers created a
fluid-dynamic model that simulated the thousands
of tiny vortices that the hummingbird's wings create
and so was able to reproduce the complex web of
forces that allow these tiny miracles of nature to fly.

More information: Journal of the Royal Society
Interface, rsif.royalsocietypublishing.org/... 98/20140541.abstract