
Henri Kroger

The Lure of the Dragonfly

Seeking a Quantitative Understanding of Flapping Flight

Q&A: *Jane Wang, Theoretical and Applied Mechanics*
Interviewed by Ernestina Snead, Editor

SNEAD: How did you get started with or become interested in the research topic of insect flight? What intrigued you?
WANG: I became interested in it by chance. I stumbled upon a book on the mechanics of flying and swimming, browsing in the math library at Oxford University while taking a break. (I was a postdoc in theoretical physics working on problems in random matrices.) I simply wanted to know more about it. My luck had it that the author of the book, Steve Childress, was at the institute [New York University's Courant Institute] where I would be going next. He later told me that there was not much known about the aerodynamics of insect flight.

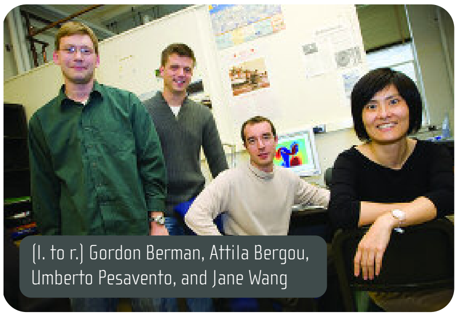
What problem did you want to solve, and how did you approach it?
Obviously, insects fly by flapping their wings. But to quantitatively predict the flow and forces created by a flapping wing is not easy. Crude calculations based on classical aerodynamics do not take us very far, and they often give us wrong answers.

The problem I started with was to calculate from the first principle the swirls of air that are generated by the flapping insect wing and to understand how these vortices push the wing so that the insects can stay airborne. This was done by solving the governing equation of the fluid flow coupled to an oscillating wing.

Why dragonflies?
They are beautiful and mysterious. Part of the mystery had to do with claims in the literature about their ability to generate extraordinarily large forces, which struck me as fascinating and dubious. So the initial idea was to get to the bottom of it. This drove much of our early work in understanding the aerodynamics of flapping flight.

When I see a dragonfly darting in the air in an up-and-down motion, what am I witnessing?
Dragonflies do episodes of hovering: they hover in one spot, and then they make quick turns. When they hover, they appear very still. If you look at the wings with a high-speed camera, you will see that the forewings and hind wings move out of phase during hovering and in phase when darting forward. You will also see the wings move in a rowing motion, pushing down with a broad side and slicing through the air in the

Photos in this article: Frank DiMeo unless otherwise noted



(l. to r.) Gordon Berman, Attila Bergou, Umberto Pesavento, and Jane Wang

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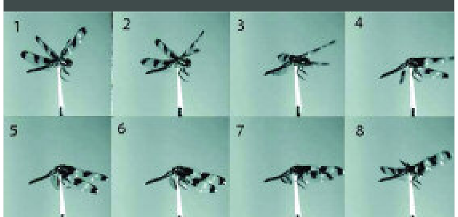

FASCINATING !

- Dragonflies do episodes of hovering: they hover in one spot, and then they make quick turns. When they hover, they appear very still.
- Their wing motions create a train of vortices; these vortices carry down the fluid momentum, so the insects can sit atop and stay airborne.
- The dragonfly pitches its wing passively. That is, it does not require the muscle to reverse the wing pitch, but instead the surrounding air helps to turn the wing, similar to how the air turns a falling leaf.
- Beyond dragonflies, we have been asking whether the hovering wing motions are optimal in some way—for example, do they minimize energy use?

upstroke. If you look more closely, you will see that as the wings change their pitches, there is a torsional wave propagating from the tip to root. If you measure the hovering motion, then you will see that the wing beat is about 40Hz, the stroke plane is oriented at about 60 degrees, the phase between the forewings and hind wings is about 160 degrees, and the time that it takes the wing to pitch is brief.

Do you study other insects?
Theoretically, yes. We study general flapping flight as a means to understand the essential mechanisms shared not only among insects, but also among birds, fish, and leaves fluttering and tumbling in the air.

This makes us rethink the dogma of drag minimizing in airplane design.

More recently, my students and I also found that the dragonfly pitches its wing passively. That is, it does not require the muscle to reverse the wing pitch, but instead the surrounding air helps to turn the wing, similar to how the air turns a falling leaf.

Something also worth noting is that the dragonfly makes use of the aerodynamic interactions between forewings and hind wings to save energy. The counterstroking is aerodynamically most efficient, and this might explain why dragonflies use it during

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hovering, which is the most energetically demanding posture.

How much of your work is computational, as opposed to fieldwork? Do you conduct field studies?
If scooping up a dragonfly and filming it is counted as fieldwork, then we do some. Most of the time, with my students and postdocs, I am trying to figure out what we are seeing by thinking about various questions, developing computational and theoretical tools to address the questions, carrying out the calculations, and understanding the results—which lead to more questions, more calculations, and occasional insights.

Can you give a chronology of what you have learned so far? For example, your first discovery, second discovery, and new developments?
The first discovery came from the solutions of the Navier-Stokes equation of a flapping wing mimicking the dragonfly wing motion. The insects are able to generate enough lift by creating a column of downward vortex jet. Their wing motions create a train of vortices; these vortices carry down the fluid momentum, so the insects can sit atop and stay airborne.

The second was to figure out what exactly went wrong in the classical calculation. It turns out that much of the weight is balanced by the aerodynamic drag, which was grossly underestimated in the classical calculations.

Beyond dragonflies, we have been asking whether the hovering wing motions are optimal in some way—for example, do they minimize energy use?

Given new developments in science and technology, do you think that some day we will have a golf cart–size airborne mode of transportation?
Yes, but I do not know when.

The two questions that drive our current work are, first, which one is more efficient, bird or plane? Would it make sense to build a flapping device like Da Vinci and many others envisioned, but failed to build? Second, would it be possible to understand how and to what degree aerodynamics has affected the evolution of insect flight? Currently, we are trying to evolve flight models on computer and hope to gain some insight into the evolution of flapping.

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