Riding raindrops

Nowack, Dickerson, Hu/Georgia Tech

Mosquitoes regularly collide with raindrops up to 50 times their own body mass and yet, remarkably, they live on to bite another victim. **Stephen Ornes** explains how scientists have figured out how these insects survive such a violent impact

Stephen Ornes is a science writer based in Nashville, Tennessee, US, e-mail stephen@stephenornes.com

To humans, falling rain usually amounts to little more than a minor inconvenience. After all, we are big and raindrops are small – they splatter on our heads and sleeves, and we end up a little wetter. But a mosquito's mass is only 2–3μg and the largest raindrops may weigh up to 100μg. To those tiny bugs buzzing about in the rain, a gentle spring shower comes on like a downpour of London taxis, cascading from the sky at terminal velocity. No matter how quick a bug may be, it is going to get hit.

And yet, they live. Furthermore, they even prefer environments where mid-air rain collisions are part of everyday life.

"Mosquitoes live in damp, tropical environments, around waterfalls and places where it's going to rain," says David Hu, an engineer at the Georgia Institute of Technology in Atlanta. "They are up to 50 times lighter than a raindrop, and we knew that they had to have some interesting way to survive daily occurrences of rain in their environment."

To explore these suspicions, scientists in Hu's lab have been bombarding the flying, biting insects – obtained from the Center for Disease Control and Prevention, across town – with simulated showers. They recorded the collisions with high-speed cameras, and after months of analysis attributed the lowly mosquito's survival to the same property that makes a raindrop so threatening: its mass. Reporting in a study led by graduate student Andrew Dickerson in the journal *PNAS* in June, the engineers explicated the pest's manoeuvrings and explained the underlying physics (**109** 9822).

What saves the mosquito is conservation of momentum. A raindrop has a large mass and falls at about 6–9 m/s. The flying mosquito has little mass or velocity. As a result, say the Georgia Tech engineers, when the two collide, the raindrop barely slows, which means its impact force is minor – something on the order of 2–6 mN. The sturdy exoskeletons of mosquitoes can easily endure such a heavy load, so the collision does not crush them.

It does, however, take them for a wild ride.

Tai chi masters

If a mosquito is sitting on solid ground when it is struck, the story ends differently. When a raindrop hits the ground or lands on a person, it breaks. On the ground, with nowhere to go, a mosquito would suffer an (unsurvivable) impact of about 10 000 times its own weight in force as the raindrop splatters. That is why it is imperative for a mosquito struck while in flight to keep the raindrop intact: if it broke the surface tension of the drop, it would become coated with water, crash to the ground and die.

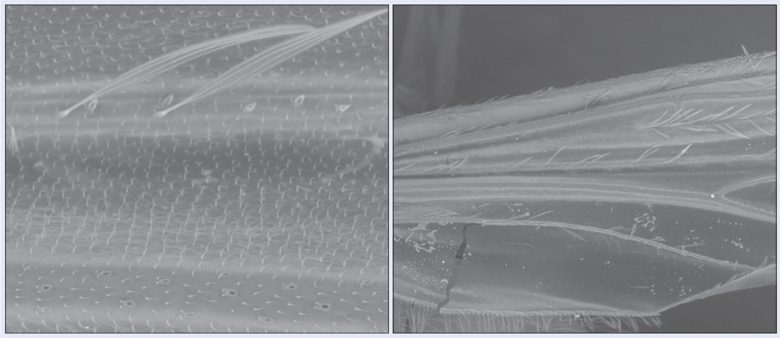
But that is not what happens when the bug is flying. Hu likens the situation to punching a balloon, with the raindrops being the fists. They may punch with might and force, but the balloon still does not break, despite repeated beatings. "The force applied is equal to the force resisted, and the mosquito doesn't resist," he says. Its water-hating hydrophobic wings are also helpful (figure 1).

Instead, like miniature masters of tai chi, the bugs go with the flow. And that flow is fast: the researchers estimate the acceleration at 100–300 times that from gravity, g – which may be near the upper end of survivable acceleration rates in the animal world. Fleas, often cited as the champions of short-term acceleration, propel themselves at a mere 135g.

In the Georgia Tech experiments, on average the mosquitoes fell about 13 body-lengths, or 39 mm, when hit. Dickerson, who led the mosquito experiments, says he did not initially expect the mosquitoes to be able to escape. But they do; after the fall but before they splat on the ground, the mosquito and the raindrop part ways.

"I was surprised that they were able to separate from the raindrop so quickly," he says. "I thought that as soon as they were hit, they would be pushed to the ground."

1 Waterproof wings



Scanning electron microscope images of a mosquito wing. The hairs increase the surface area, increasing the mosquito's hydrophobicity.

Dickerson and Hu, Georgia Tech

Instead, he says, the mosquito slides out from under the drop and recovers. (But not for long; the researchers found that during a rainstorm, a mosquito gets hit by a sizable drop on average once every 26 seconds.) That escape manoeuvre is an amazing phenomenon to witness – not because it is particularly virtuosic, but because it seems sloppy and accidental. Dickerson and Hu, after a few trials, caught it on video (http://dickerson.gatech.edu/file/Mosquitoes.html).

Pesky test subjects

When viewed in slow motion, the video shows what the human eye hides: mosquitoes can take a beating and, after a quick fall, slide out from under the drop without breaking it.

From the perspective of a mosquito, Dickerson points out, the whole process seems passive: you are flying along, you get pummelled by rain, you fall and you separate, all without exerting any real action.

"Mosquitoes have a high drag form, with their legs and wings spread," he says. "When the raindrop pushes the mosquito along, you get some instability between the two, and wherever that instability shows up, it is going to pull the mosquito out from under the raindrop."

To capture the process on video, the researchers had to come up with a novel experimental set-up. They found that dripping water on mosquitoes was easy enough, but approximating the speed of raindrops was difficult. When they dropped water on the mosquitoes from three storeys above, the water travelled fast enough, but they "still got a lot of aerodynamic variation and couldn't get the drops to hit one spot". The researchers succeeded when they set up a jet that fired water at the bugs at raindrop speed – about 9 m/s – and turned on the high-speed camera. The footage demonstrated the forces at play: the mosquito buckles on impact, surface tension keeps the drop intact and the bug slips away unharmed.

Dickerson, who is still working on mosquitoes, says an understanding of how the bugs survive may give us new ideas for how to kill them. That may not be good news for these little insects, but it could help those working on the diseases spread by these nasty blood-suckers. ■