Straighten up and fly right: Moths benefit more from flexible wings than rigid (w/ Videos)

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The wing of a *Manduca sexta*, or tobacco hawkmoth, reveals the extent of deformation during flight. Credit: Armin Hinterwirth, University of Washington

Most scientists who create models trying to understand the mechanics and aerodynamics of insect flight have assumed that insect wings are relatively rigid as they flap.

New University of Washington research using high-speed digital imaging shows that, at least for some insects, wings that flex and deform, something like what happens to a heavy beach towel when you snap it to get rid of the sand, are the best for staying aloft.

"The evidence indicates that flexible wings are producing profoundly different air flows than stiff wings, and those flows appear to be more beneficial for generating lift," said Andrew Mountcastle, a UW doctoral student in biology.

He used particle image velocimetry, a technique commonly used to determine flow velocities in fluids, to study how air flows over the wings of Manduca sexta, or tobacco hawkmoths. The method combined laser light and high-speed digital video to model air flow.

A hawkmoth's wings are controlled by muscles on the insect's body and have no internal muscles of their own. The bulk of the wing is something like fabric stretched back from a stiff leading edge, fabric that is elastic and bends from inertia as the wing accelerates or decelerates through each stroke.

To test the wings' function, they were attached to mechanical "flappers" that moved back and forth 25 times a second, the same frequency at which the moths flap their wings, with the focus on how the wings deformed with each motion reversal. While the machine placed the wings at the same dominant angle as in normal moth flight, it could only approximate natural motion in one axis of rotation, compared with the three axes controlled in actual moth flight.

For the research, wings were removed from moths and tested in the mechanical "flapper" immediately, while they maintained most of their natural elasticity. After that the wings were allowed to dry for 12 to 24 hours and covered with enough spray paint to restore their original mass, then the wings were tested again in their more rigid state. The high-speed video, when viewed in slow motion, provided graphic detail of how the wings deformed as they flapped.

"That gave us two profoundly different deformations when we flapped the wings at natural wing-beat frequencies," Mountcastle said.

The "fresh," or flexible, wings had a mean deformation of 1.6 millimeters (about 64-thousandths of an inch) for each of five motion reversals, while the dry, stiff wings had a mean deformation of 1.15 millimeters (about 46-thousandths of an inch). By comparison, a freely hovering moth had a mean deformation of 1.52 millimeters (about 61-thousandths of an inch).

"Our results show that the flexible wings are doing a better job of generating lift-favorable momentum than are the stiff wings. They also are inducing airflow with greater overall velocity, which suggests the production of greater force for flight," Mountcastle said.

He is the lead author of a paper on the work, published in May in the journal *Experiments in Fluids*. Co-author is Thomas Daniel, a UW biology professor. The work was funded by the Defense Advanced Research Projects Agency, the National Science Foundation and the Joan and Richard Komen Endowed Chair.

"As a biologist, I am interested in the evolutionary implications of what we see here. To understand the selective pressures that have acted on wings through their evolution, we have to understand the functional implication of wing forms and their material properties," Mountcastle said.

He noted that insect wings have a wide variety of shapes and functions, and trying to understand how such diversity came about "is a really interesting biological question."

"There also is interest in developing tiny insect-like flapping robots, and certainly these results are relevant to that field," he said.

Source: University of Washington (news : web)