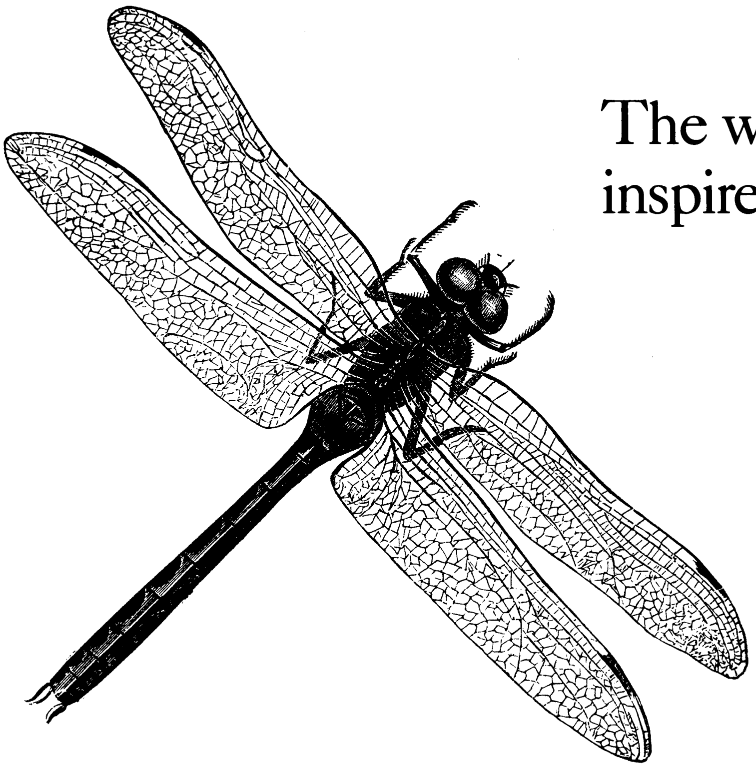
On the Wings of a Dragonfly



The way a dragonfly flies may inspire new aircraft designs

Deep in the sun-searched growths the dragon-fly
Hangs like a blue thread loosened from the sky —Dante Gabriel Rossetti

By IVARS PETERSON

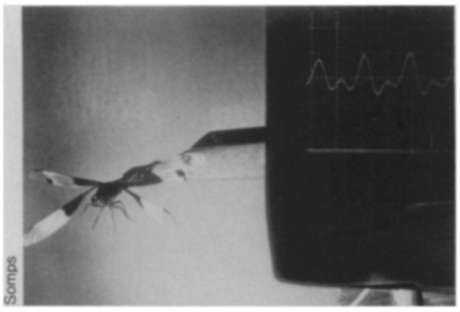
The dragonfly is an elegant creature of light and air. Seen as a hovering thread, a living flash of light or a luminous windmill in the dusk, this ancient flier flits with an enviable ease and grace.

Remarkably nimble, this insect can hover at will, then instantly dart sideways or backward. It can fly as fast as 30 miles per hour and lift up to 15 times its own weight. It's no wonder that aeronautics engineers are starting to probe the secrets of a dragonfly's aerodynamic agility.

Recent studies show that dragonflies use "unsteady aerodynamics," a mode of flying radically different from the smooth flight of airplanes and soaring or gliding birds. Dragonfly wings churn up the air to create a whirling airflow that a dragonfly controls and uses to provide lift. In contrast, airplanes rely on the smooth flow of air over the upper and lower surfaces of their wings. For these flying machines, turbulence can be deadly.

"Unsteady aerodynamics never got much attention in the past," says Mohamed Gad-el-Hak of Flow Research Co. in Kent, Wash. "It was just too complicated."

Nevertheless, with the help of special wind tunnels and water tanks, computers, scale models, stroboscopic photography and unwitting insect subjects, several groups of investigators, largely funded by the U.S. Air Force, are now looking into unsteady flows. This research may eventually lead to a new generation of "supermaneuverable" fighter aircraft or perhaps a more efficient design for turbines used in power plants and elsewhere.



Somps

A dragonfly, fixed to the arm of a force balance, shows off its ability to generate lift.

One approach is to see how insects do it. Dragonflies are good subjects because they are relatively simple flying creatures. They each have two pairs of fairly rigid, transparent wings that are always extended. The front and rear pairs are not latched together, but operate independently. In addition, the insects don't change the shape of their bodies or wings in order to take off, glide or fly.

"There are other organisms that we suspect use the same kind of mechanisms," says Marvin Luttges of the University of Colorado in Boulder, "but they're not really so simple as the dragonfly." A hummingbird's wings, for instance, change shape continually during a stroke, while feathers in different locations pop up or stay down at various times.

"The nice thing about dragonflies is that you don't have to worry about feathers, about changes in wing shape during a stroke," says Luttges. Moreover, the fact that dragonflies have been around for more than 200 million years points to a safe and successful aerodynamic design.

But dragonflies still have to be captured in the wild, something that in certain areas of the world can be done only during the summer, while they are in their flying stage. At the University of Colorado, that task fell to graduate student Chris Somps, who netted dozens of dragonflies in marshes around Boulder. Somps also developed a technique for tethering a temporarily anesthetized insect by gluing its hard body to a small wire. The wire was part of a force balance that allowed the researchers to measure vertical lifting forces generated by the dragonfly as it beat its wings from 25 to 30 times a second.

Using carefully synchronized stroboscopic flash photography and streams of nontoxic smoke, Luttges and Somps observed dragonfly flight. Reporting in the June 14 SCIENCE, they confirmed that rapid changes in a dragonfly wing's speed and angle of attack do indeed generate vortices and unsteady flows. The vortex patterns created by the wings were surprisingly repeatable.

The researchers found that when a dragonfly's front pair of wings generates a small vortex of rapidly whirling air, the back pair, which may be down while the front pair is up or vice versa, captures the extra energy in that vortex's spin. This gives the air flowing over the top of a dragonfly's rear wing a much higher speed than the airflow along the wing's lower surface, and the wing generates more lift.

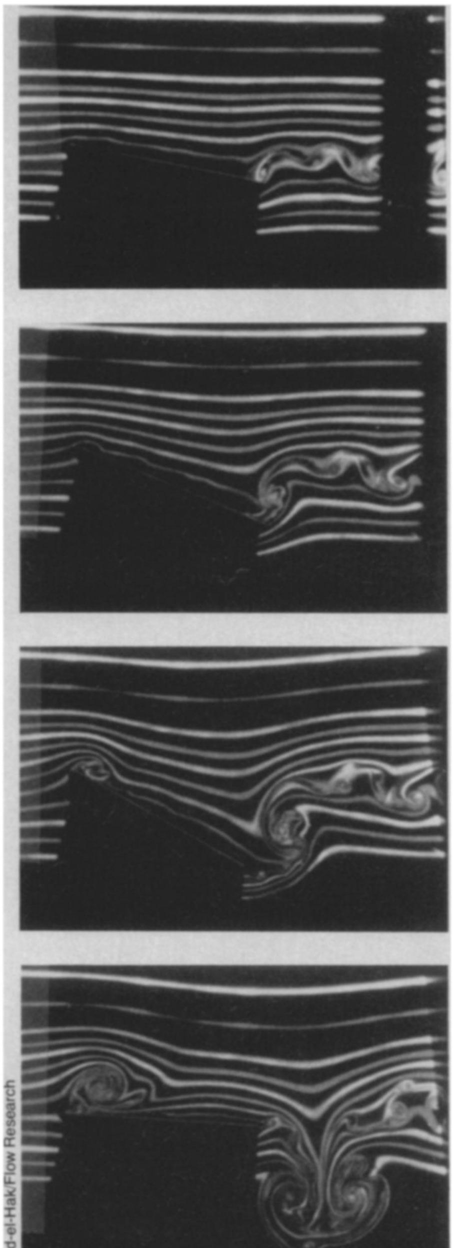
Applying this principle to aerodynamic design, however, is tricky. "The effect has to be simple and predictable," says Luttges. "No pilot wants an erratic response from an aircraft.

"Until no more than 10 years ago, people saw these kinds of flows as terrible," he says. Turbulence was and often still is viewed as a villain, causing aircraft crashes or robbing turbines of their efficiency. In the case of helicopter rotors, blades sometimes fail because each blade continually runs into the turbulent wake of the preceding blade, causing vibrations that eventually weaken the metal.

"If we can get to a point where we can control [this unsteady flow]," he notes, "helicopters could be designed to take advantage of it." The same ideas could apply to aircraft designed to land within short distances and the whirling blades of a turbine. One company designing a new racing car is already looking at ways of generating unsteady flows on demand as a way of directing lift downward so that their car tracks better at high speeds.

To get the information needed for new aerodynamic designs, research groups at the University of Colorado, Illinois Institute of Technology in Chicago, Boeing Co. in Seattle and elsewhere are doing more than just studying insects. Computer simulations and wind tunnel tests also play an important role.

Luttges and his colleagues, for instance, are studying ways to retrofit existing airplane wings to give extra lift when needed. One possibility is the installation of a flap or "fence" that would automatically flip up near the leading edge of a wing when an aircraft goes into an unexpected stall. This "roughness" would



Gad-el-Hak/Flow Research

When a model of a rectangular wing with a sharp leading edge is towed (toward left) down a long water tank, streams of fluorescent dye make the flow patterns visible. These side views illustrate the generation of vortices when the wing, initially horizontal, quickly pitches from 0° to 30° above the horizontal and back to 0°. Shown are the patterns at 4.6°, 14.7°, 29.4° and back at 4.8°.

create vortices that increase lift over the rest of the wing surface, possibly averting a crash.

Another possibility is to stick a small, extra wing near the front of an airplane. This "canard" would mimic a dragonfly's technique by sharply shifting its angle of attack to generate vortices to order. The larger rear wing could then coast along on these aerial whirlpools.

The "intelligent" wing, a much more sophisticated concept, would require sensors that monitor flying conditions continuously and materials or structures that respond instantly to any sudden changes. The high-speed electronic circuits and strong, flexible composite materials to make this possible are already to some extent available, but very little is known yet about how to use the components effectively.

"There are lots of ideas floating around," says Gad-el-Hak. Nevertheless, an airplane that actually uses unsteady flows is far away. "There's a lot of study that has to be done first," he says. "What we need to do now is to lay the foundations for unsteady aerodynamics."

In his laboratory, Gad-el-Hak studies the flow patterns that arise when three-dimensional models of wings abruptly and periodically change their pitch (the angle between the wing and the direction of fluid motion). In these experiments, models are towed along an 18-meter water channel in which fluorescent dyes mark the flow patterns.

"We use water because dye techniques give you colored pictures that are a lot clearer than the smoke pictures generated in a wind tunnel," says Gad-el-Hak. In addition, unlike a wind tunnel in which the air blows past a stationary model, the water channel allows the model to move against a quiet background.

As a result, Gad-el-Hak produces striking pictures of the vortices generated when a "lifting surface" suddenly changes its angle of attack. The flow patterns depend strongly on the shape of the wings, the sharpness of the leading edges and how quickly attack angles change.

"Now that we are beginning to understand these effects, can we manipulate or control them to our benefit," Gad-el-Hak asks, "to make aircraft that maneuver better or move faster?" The idea is to expand aircraft "flight envelopes," which set limits on their speed and acceleration and establish other constraints. "Some insects have envelopes that are better than anything we know as far as aircraft are concerned," he says.

There's more to learn from insects too. "I can't really say that we understand the way in which a dragonfly exacts its control over the flow," says Luttges. He and his colleagues are now delving into the dragonfly's nervous system. They want to see what the dragonfly does, simply by changing the pitch and speed of its wings and the phase relationship between its front and back pairs, to generate just the right type of vortices for a particular maneuver.

The work on dragonflies, combined with earlier studies of insects like wasps, suggests that insects probably have a number of different ways of generating and using unsteady flows, says Luttges. "[This] may signal the existence of a whole new class of fluid dynamic uses that remain to be explored." □