NATURE-INSPIRED INVENTIONS

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Dragonflies

Four-Wing Micro-Aircraft

Nature-Inspired Inventions

Volume 007 of 255

WealthSphere Labs

Dragonflies: Four-Wing Micro-Aircraft

Nature-Inspired Inventions, Volume 007

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Published by WealthSphere Labs · wealthspherelabs.com

About this book. This is an educational guide to biologically inspired engineering. The invention concepts in it are design ideas for study and experimentation, not tested or certified products. Worked numbers illustrate methods unless a source is named. Nothing here is engineering certification, legal advice on patents, or a substitute for qualified professional review of anything that will carry people, loads or risk.

First edition, 2026.

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Introduction: The Original Four-Wing Flyer

Dragonflies were flying long before birds, bats or pterosaurs existed. Their ancestors, the griffinflies of the Carboniferous period around 300 million years ago, included some of the largest flying insects ever known, with wingspans approaching 70 centimetres. Today's dragonflies are smaller, but they are among the most capable flyers in the animal world. They hover, fly backward, turn sharply, accelerate quickly and catch flying prey with high success.

Dragonflies fly with four wings, each of which can be controlled independently. Most flying animals use two wings, or flap four wings in tight coordination. The dragonfly's independent four-wing system gives it options other flyers do not have: changing the timing between front and rear wings to switch between efficient cruising and powerful acceleration, and producing control forces by adjusting individual wings.

For engineers designing small flying machines, the dragonfly offers ideas for four-wing flapping vehicles, tandem-wing fixed-wing designs, lightweight corrugated wing structures and precise interception guidance. This volume explores each of these, while being honest about how difficult it is to build machines that match the insect.

How this book is organized

Chapters 1 and 2 cover dragonfly flight and anatomy. Chapter 3 explains the aerodynamics of four-wing flight. Chapter 4 surveys the history of dragonfly-inspired and tandem-wing aircraft. Chapters 5 to 7 cover translation, structures and control. Chapter 8 presents ten design concepts. Chapters 9 to 12 cover testing, failure modes, approval and a design workbook.

Figures for real insects and machines are rounded and typical. Worked numbers are illustrations unless a source is named.

Chapter 1: How Dragonflies Fly

The dragonfly order

Dragonflies and damselflies make up the order Odonata, with several thousand species worldwide. Dragonflies are generally larger and stronger flyers, holding their wings out flat when at rest; damselflies are slimmer and usually fold their wings over their backs. Both spend their early lives as aquatic nymphs before emerging as flying adults.

Flight modes

Dragonflies are capable of:

- **Hovering**, holding position in still air.
- **Fast forward flight**, with some species migrating long distances.
- **Gliding**, especially in larger species on warm days.
- **Backward and sideways flight.**
- **Rapid acceleration and sharp turns** when hunting or avoiding predators.

Hunting in flight

Dragonflies catch other flying insects in mid-air. Laboratory and field studies have reported high capture success rates, in some studies above 90 percent. Rather than chasing prey directly, many dragonflies intercept it: they fly to where the prey will be. Research by Matteo Mischiati and colleagues, published in *Nature* in 2015, found that dragonflies use internal models to predict the consequences of their own movements and steer to intercept prey, with head and body movements coordinated to keep the prey's image steady on the eye.

Phase relationships between wings

Because each wing is controlled separately, dragonflies can change the timing — the phase — between the forewings and hindwings. Robert McNeill Alexander, in work published in the *Journal of*

Experimental Biology in 1984, documented unusual phase relationships in flying dragonflies. In general:

- **Counter-stroking** (the forewings and hindwings moving out of phase) is common in hovering and steady flight and is thought to be more efficient and to reduce body oscillation.
- **In-phase stroking** (forewings and hindwings moving together) is used during takeoff and rapid maneuvers, producing larger forces.

Computational work by Z. Jane Wang and David Russell, published in *Physical Review Letters* in 2007, examined these phase effects and found that the hovering phase difference used by dragonflies reduces aerodynamic power, while in-phase motion increases force.

Chapter takeaways

- Dragonflies hover, fly fast, glide, and maneuver sharply.
- They intercept prey using predictive steering.
- Changing the phase between forewings and hindwings switches between efficiency and power.

Chapter 2: Anatomy of a Four-Wing Flyer

Direct flight muscles

Most flying insects use indirect flight muscles that deform the thorax to move the wings. Dragonflies use direct flight muscles attached to the base of each wing. This allows independent control of each wing's stroke and angle — a key reason for their maneuverability.

Wing structure

Dragonfly wings are thin membranes supported by a network of veins. Several structural features stand out.

Corrugation. In cross-section, the wing is pleated rather than smooth, with ridges and valleys running along the span. This corrugation makes the wing stiff against bending along its length while keeping it light. Wind-tunnel research by Antonia Kesel, published in the *Journal of Experimental Biology* in 2000, found that corrugated dragonfly wing sections performed well at low Reynolds numbers, partly because small vortices trapped in the valleys smooth the effective shape of the airfoil.

The nodus. Partway along the leading edge, a flexible joint called the nodus lets the outer wing twist under load. Rubber-like proteins such as resilin at wing joints allow elastic deformation.

The pterostigma. Near the tip of the leading edge, a thickened, often colored cell called the pterostigma adds a little mass. Research by R. Åke Norberg in the 1970s suggested that the pterostigma helps prevent unwanted oscillations of the wing, an anti-flutter function.

Vein network. The many small cells formed by veins help stop cracks from spreading. A tear in one cell does not easily propagate across the whole wing.