NATURE-INSPIRED INVENTIONS

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From living designs to working machines

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Bats

Morphing Membrane-Wing Aircraft

Nature-Inspired Inventions

Volume 009 of 255

WealthSphere Labs

Bats: Morphing Membrane-Wing Aircraft

Nature-Inspired Inventions, Volume 009

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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.

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Introduction: A Wing Made of Hands and Skin

Bats are the only mammals capable of true powered flight, and they fly in a way quite different from birds. A bird's wing is made mainly of feathers attached to a stiff arm. A bat's wing is a living membrane of skin stretched between greatly elongated finger bones, the arm and the body. The bat can bend each finger, change the tension in the membrane, and reshape the whole wing during every stroke.

The result is a wing of extraordinary flexibility. Bats can turn tightly in cluttered spaces, fly slowly while hunting insects, hover briefly at flowers, and land upside down on a ceiling. Their wings are covered in tiny sensory hairs that report the airflow. In terms of shape change, a bat wing has more degrees of freedom than almost any other flying surface, natural or engineered.

For engineers, bats inspire two lines of work: membrane wings, whose flexibility adapts passively to loads, and morphing wings whose shape is actively controlled through many joints. This volume explains how bat wings work, the physics of membrane wings, the history of membrane and bat-inspired aircraft, and how designers can apply these ideas to drones and aircraft.

How this book is organized

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

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

Chapter 1: How Bats Fly

The bat order

There are around 1,400 species of bats, about a fifth of all mammal species. They range from tiny insect-eating bats weighing a few grams to large fruit bats with wingspans over 1.5 metres.

Flight styles

- **Insect hunting.** Many small bats hunt insects at night, flying slowly and maneuvering sharply in clutter, guided by echolocation.
- **Open-air hunting.** Some bats hunt high in open air, with narrower wings for faster, more efficient flight.
- **Fruit and nectar feeding.** Fruit bats and nectar bats fly between plants; some nectar bats hover briefly at flowers.
- **Long-distance flights.** Some species migrate or commute long distances to feed each night.

Maneuverability

Bats are among the most maneuverable flyers. They can turn in a radius of little more than a wingspan, fly through gaps narrower than their outstretched wings by partly folding, and catch insects in their wing membranes or tail membranes.

Upside-down landing

Bats roost hanging upside down. To land, many species fly up to a ceiling, flip over and grab it with their feet. Research by Daniel Riskin and colleagues, published in the *Journal of Experimental Biology* in 2009, showed how bats use asymmetric wing movements — inertial maneuvers using the mass of their wings — to rotate their bodies for these landings.

Aerodynamic findings

Research led by Anders Hedenström, published in *Science* in 2007, used flow visualization in a wind tunnel to show that bats generate complex wakes, with each wing producing its own vortex structure and lift produced partly on the upstroke. A further study by Florian Muijres and colleagues, published in *Science* in 2008, showed that slow-flying nectar bats use a leading-edge vortex to boost lift, as many insects do.

Chapter takeaways

- Bats fly with skin-membrane wings stretched over long fingers.
- They are highly maneuverable and can land upside down.
- They generate complex wakes and use leading-edge vortices in slow flight.

Chapter 2: Anatomy of the Bat Wing

The skeleton

The bat wing contains the bones of the arm and hand. The upper arm and forearm are long; the fingers — except the thumb — are extremely long and support the membrane like the ribs of an umbrella. The thumb remains short and free, with a claw used for climbing.

Each wing has many joints: the shoulder, elbow, wrist and the multiple joints of each finger. Altogether, a bat can control its wing shape through a large number of degrees of freedom.

The membrane

The wing membrane, called the patagium, consists of two layers of skin with blood vessels, nerves, elastic fibers and small muscles between them. It has several regions:

- the membrane between the body and the fifth finger, which provides most of the lift,
- the membrane between the fingers, forming the outer wing,
- a small membrane in front of the arm, which can be raised to adjust the leading edge,
- in many species, a tail membrane between the legs and tail.

Elastic and muscular control

Elastic fibers in the membrane are arranged in patterns that make it stiffer in some directions than others. Tiny muscles within the membrane can change its tension. This lets the bat control how much the membrane bulges under load — and therefore the camber of the wing.