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Hummingbirds

Hovering Flapping-Wing Drones

Nature-Inspired Inventions

Volume 005 of 255

WealthSphere Labs

Hummingbirds: Hovering Flapping-Wing Drones

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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: The Bird That Hovers

A hummingbird can hang motionless in front of a flower, back away, dart sideways, rise straight up and stop dead in mid-air — all with a body that may weigh less than a coin. It is the only group of birds capable of sustained hovering, and it does so with a flapping wing that behaves in some ways more like an insect's than a typical bird's.

For engineers building very small flying machines, the hummingbird is a natural reference. Small multirotor drones work well, but at very small sizes their efficiency drops, they are noisy, and they are vulnerable to collisions and gusts. Flapping wings offer a different set of trade-offs: possible efficiency advantages at small scale, gentle contact with obstacles, quieter operation and remarkable agility.

This volume explains how hummingbirds hover, the aerodynamics of flapping flight at small scale, the history of flapping-wing micro air vehicles, and how designers can approach hovering flapping-wing drones in practice. It is candid about the difficulties: flapping-wing drones remain much harder to build and control than rotorcraft, and few have left the laboratory.

How this book is organized

Chapters 1 and 2 cover hummingbird flight and anatomy. Chapter 3 explains the aerodynamics of hovering and flapping. Chapter 4 surveys the history of flapping-wing micro air vehicles. Chapters 5 to 7 cover translation, mechanisms and control. Chapter 8 presents ten design concepts. Chapters 9 to 12 cover testing, failure modes, approval and a design workbook.

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

Chapter 1: How Hummingbirds Fly

The hummingbird family

There are over 300 species of hummingbirds, all native to the Americas. They range from the bee hummingbird of Cuba, the smallest living bird at around 2 grams, to the giant hummingbird of the Andes at around 20 grams. Most feed on nectar, which supplies the high energy they need, and supplement it with small insects for protein.

Hovering

To feed from flowers, a hummingbird hovers with its body tilted upward and its wings sweeping back and forth in a nearly horizontal plane. The wings move in a figure-of-eight path, and the wing turns over at the end of each stroke so that the leading edge leads in both directions. This allows the wing to produce lift on both the forward stroke (downstroke) and the backward stroke (upstroke).

Most birds produce little useful force on the upstroke. Hummingbirds are an exception. Research by Douglas Warrick, Bret Tobalske and Donald Powers, published in *Nature* in 2005, used flow visualization to estimate that a hovering hummingbird produces roughly three-quarters of its weight support on the downstroke and one-quarter on the upstroke. That is more balanced than in other birds, though less symmetric than in many hovering insects.

Wingbeat frequency

Hummingbird wings beat very fast. Small species beat their wings at frequencies of 50 to 80 times per second or more; larger species beat more slowly, at around 10 to 20 times per second. The general rule, true across flying animals, is that smaller flyers flap faster.

Agility

Hummingbirds can accelerate and turn very quickly, fly backward, and recover from collisions and gusts. Courtship dives of some species involve high speeds and accelerations. Their agility comes from fast wing control, a light body and a high ratio of muscle power to weight.

Energy

Hovering is expensive. Hummingbirds have among the highest mass-specific metabolic rates of any vertebrate. At night, many species enter torpor, lowering their body temperature and metabolic rate to save energy. Energy, for both birds and machines, is the central constraint of hovering flight.

Chapter takeaways

- Hummingbirds are the only birds that hover for sustained periods.
- Their wings produce lift on both downstroke and upstroke, with about three-quarters of weight support on the downstroke.
- Small species flap very fast; hovering is energetically expensive.

Chapter 2: Anatomy of a Hovering Bird

The wing skeleton

The hummingbird wing is unusual among birds. The upper arm and forearm bones are short, and the hand bones are long. Most of the wing is the hand and its primary feathers. The shoulder joint allows a very large range of motion, including the rotation that turns the wing over between strokes.

In effect, the hummingbird flies with a stiff, mostly hand-based wing that pivots at the shoulder — closer to an insect wing or a rotor blade than to the flexible, folding wing of an eagle.

Flight muscles

Hummingbirds have very large flight muscles relative to their body mass. Most birds have a large downstroke muscle (the pectoralis) and a much smaller upstroke muscle (the supracoracoideus). In hummingbirds, the upstroke muscle is relatively larger than in most birds, consistent with the useful work done on the upstroke.

Feathers

Hummingbird flight feathers are stiff and form a compact, flat wing. Some species have specialized feathers that make sounds during courtship dives, showing that feathers can be tuned for acoustic as well as aerodynamic roles.

Sensing and control

Hummingbirds rely heavily on vision to hover precisely, using visual motion cues to hold position in front of a flower even in moving air. Research has shown that they respond strongly to visual patterns moving around them, adjusting their position to stabilize the image.