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Eagles

Articulated and Adaptive Wings

Nature-Inspired Inventions

Volume 002 of 255

WealthSphere Labs

Eagles: Articulated and Adaptive Wings

Nature-Inspired Inventions, Volume 002

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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 Wing That Changes Shape

Watch an eagle for a few minutes and you will see a wing that never holds still. Circling in a thermal, the wings are spread wide, the primary feathers fanned like fingers at the tips. Gliding between thermals, the wrists bend and the wings sweep back slightly. Diving on prey, the wings fold close to the body until the bird is a streamlined teardrop. Landing, the wings open fully, the tail spreads, the alula lifts and the feet swing forward.

All of this happens with a single pair of wings. An eagle does not carry separate equipment for soaring, gliding, diving and landing. It reshapes one wing for each job, smoothly and continuously.

Aircraft designers have wanted the same capability since the beginning of aviation. Every flap, slat, variable-sweep mechanism and folding wingtip is an attempt to give a fixed wing some of the eagle's adaptability. This volume explores what eagles do with their wings, why it works, what engineering has achieved so far, and how a designer can apply articulated and adaptive wing ideas to drones and aircraft today.

Why adaptive wings matter

A fixed wing is always a compromise. A wing sized for efficient, slow loitering has too much area and drag for fast transit. A wing sized for fast cruise needs high landing speeds or heavy high-lift devices. The more varied the mission, the larger the compromise.

An adaptive wing reduces the compromise by changing shape to suit each phase of flight. The potential benefits include:

- lower drag across a wider speed range,
- shorter takeoff and landing,
- better gust handling and ride comfort,
- new forms of flight control without conventional hinged surfaces,
- smaller storage footprint on the ground.

The costs are weight, mechanical complexity, new failure modes and harder certification. Most of this book is about managing that trade-off.

How this book is organized

Chapters 1 and 2 describe how eagles and related birds change their wing shape, and the anatomy that makes it possible. Chapter 3 covers the aerodynamics of shape change. Chapter 4 surveys the history of variable-geometry and morphing aircraft. Chapters 5 to 7 cover translation, mechanisms, materials and control. Chapter 8 presents ten design concepts. Chapters 9 to 12 cover prototyping, failure modes, approval and a design workbook.

> Figures for real birds and aircraft are rounded, typical values for orientation. Worked numbers are illustrations unless a source is named.

Chapter 1: How Eagles Use Their Wings

Eagles are large, broad-winged raptors found on every continent except Antarctica. The golden eagle and the bald eagle are among the best known, with wingspans commonly around two metres and body masses of several kilograms. Like vultures, storks and other large soaring land birds, eagles spend much of their flying time gliding and soaring rather than flapping, because flapping a large wing is expensive in energy.

Four flight modes, one wing

An eagle's day can include four quite different flight modes.

Thermal soaring. Rising columns of warm air let a bird climb without flapping. To stay inside a narrow thermal, the bird must circle tightly at low speed. Eagles spread their wings to full span, fan their tails and open the primary feathers at the tips. This configuration maximizes lift at low speed and lets the bird turn tightly.

Inter-thermal gliding. After climbing, the eagle glides to the next thermal. Now it wants to cover distance quickly with minimum height loss. It flexes its wrists, sweeps the outer wing back, partly closes the tip slots and narrows the tail. Wing area falls, and the bird glides faster.

Diving (stooping). To attack prey or descend quickly, the eagle folds its wings partly or fully against its body. Drag falls sharply and speed rises. Control is maintained with small movements of the partly folded wings and the tail.

Landing and perching. The bird must lose speed precisely and touch down gently. It spreads its wings and tail fully, raises the alula, increases angle of attack sharply and uses its legs to absorb the final impact.

The range of shape change

The table summarizes the main shape variables an eagle controls and their aircraft equivalents.

Shape variable	How the eagle changes it	Aircraft equivalent
Span	Extending or flexing the elbow and wrist	Telescoping or folding wings
Sweep	Bending at the wrist	Variable-sweep wings
Area	Spreading or overlapping feathers	Fowler flaps, extending panels
Camber	Feather flexing, wrist position	Flaps, adaptive trailing edges
Twist	Rotation at the shoulder and wrist	Ailerons, wing warping
Tip geometry	Spreading or closing primaries	Winglets, tip devices
Tail area	Fanning or folding the tail	Variable tail surfaces
Dihedral	Raising or lowering the wings	Variable dihedral (rare)

No aircraft in service combines all of these variables. Most use only two or three, usually through flaps and ailerons.

What the research shows

Studies of birds in wind tunnels and in free flight have measured how shape change affects performance. Research on swifts by David Lentink and colleagues, published in *Nature* in 2007, showed that sweeping the wings back improved performance at high speed while extended wings performed best at low speed and in turning, giving the birds a wide performance range from a single wing. Similar principles apply to eagles and other gliding birds: no single wing shape is best everywhere, and shape change lets the bird stay close to the best shape across its speed range.

Chapter takeaways

- Eagles reshape one wing for soaring, gliding, diving and landing.
- They control span, sweep, area, camber, twist, tip geometry, tail area and dihedral.