Even iconic fliers get it wrong: Most birds have not evolved optimal wing-shapes

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A female Anna's Hummingbird hovering as hummingbirds do best. Credit: Benton Walters

Even the giant wings of the albatross are not "optimally" shaped for their extraordinary long-distance migrations, according to new University of Bristol research. The study, published in *Nature Communications*, reveals that many bird species possess wing shapes surprisingly ill-suited to their flight performance. In contrast, penguins and hummingbirds stand out as exceptions, having evolved wing shapes closely matched to their specialized style of movement.

The study aimed to test the evolution of optimal body shapes, specifically exploring whether large groups of birds have evolved wings that are the ideal shape for flight.

Researchers used a technique called theoretical morphospace. This approach helps scientists understand why some birds evolved wing shapes to fit their flight, and others didn't.

Using this approach, scientists generated a grid of potential wings capturing all the shapes that could exist in nature regardless of whether they are seen in real birds. Researchers then tested the relative performance of each theoretical wing, producing a "performance surface." These surfaces have peaks and valleys much like a topographic map, but where peaks represent more optimal shapes.

After establishing the location of the peaks, researchers plotted real birds on top of the map of performance, to determine how optimal their wings are.

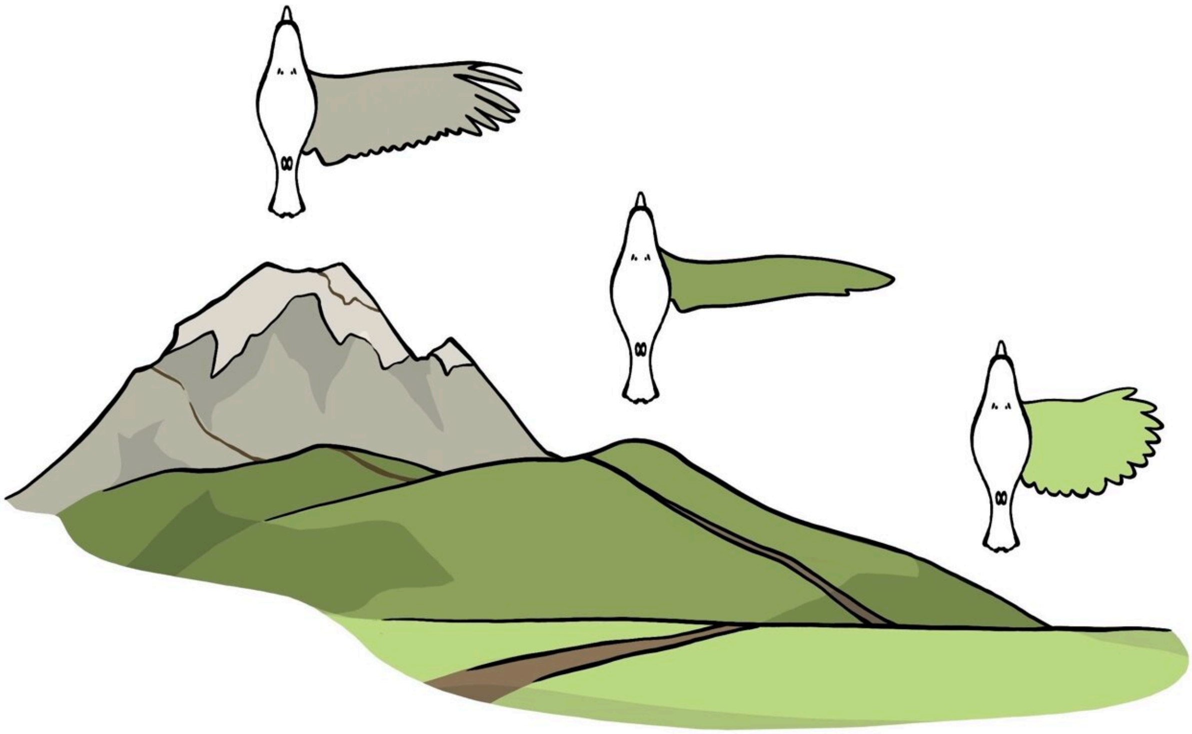
A selection of the abundance of wing shapes found in modern birds. From collections at the Burke Museum of Natural History and Culture. Credit: Burke Museum of Natural History and Culture

They were then able to test each wing shape against different aerodynamic properties to define what the optimal bird wing shape should be for multiple different styles of flight. This information was then compared with a sample of 1139 modern real bird wings, allowing the researchers to identify just how well adapted specific groups of birds are for the flying that they do.

By testing theoretical wings and then adding in real birds after, this method allows the researchers to determine what the absolute most-optimal shapes are without making assumptions about how well-shaped a particular bird wing is.

Lead author Benton Walters, Doctoral Researcher in the School of Earth Sciences at the University of Bristol, said, "There has been a base assumption in evolution that animals have evolved the best possible shape for what they do (known as adaptationist thinking). However, in recent years there have been challenges to this way of thinking. Our research allowed us to test optimality and show, in large groups like birds, that many wing shapes are in fact sub-optimal."

Among the top performing birds in the study were hummingbirds, while the authors were surprised to see how well penguins scored—possessing optimally shaped wings for flight, but using them to propel themselves through the water the way other birds do in the air.



The performance landscape illustrated. Bird wings change shape as they evolve up the path towards more optimal, higher regions. Credit: Beau Jones

The majority of birds occupy the middle and lower ends of performance surfaces, particularly passerines, the most abundant group of modern birds. "It turns out for many birds, including most of the ones you see every day, that good enough is good enough when it comes to flight," Walters said.

"Two bird groups that surprised me for not being optimal were albatrosses and terns, both famed for their long-distance, globe-spanning flight. It turns out you don't have to be optimally shaped to perform the impressive feat of migrating from the Arctic to Antarctic and back every year like Arctic Terns do," Walters added.

"Our research shows variation in optimization, including some highly optimal wings. However, the evidence suggests there shouldn't be a broad continued trend towards 'better' wing shapes over time going forward," Walters said.

The research team plan to apply this method to other groups of flying animals, particularly bats and extinct flying reptiles called pterosaurs. Wings and powered flight evolved independently in these three groups, so understanding whether optimal wings evolved in other animals that fly a similar way could give new insight into the way function influences the evolution of shape.

Walters said, "It will be especially interesting to add the wings of early fossil birds like Archaeopteryx to this analysis, that will allow us to see how well these animals flew and how wing shapes changed since birds first evolved."

The results could be potentially valuable for thinking about future aircraft, Walters added. "There is a lot of interest in borrowing designs from nature to improve human technology, a process called bioinspiration. This research shows that which animals you choose to borrow from really matters when it comes to flight, but that there are potential good options for planes with bird-inspired wings."

More information: Benton Walters et al, Theoretical morphospace reveals mixed optimisation of the avian wing planform for flight style, *Nature Communications* (2026). DOI: 10.1038/s41467-026-70692-w

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