The helpful "jump"

Jumping makes take-off easier

Sea birds sometimes take to flight by pushing themselves off with strong kicks and splashes of their legs. Insects often jump by using their hind legs. The important thing to bear in mind is that they must generate "airflow" at the very beginning of their flight. Jumping, in addition to the first strokes of the wings, contributes to this generation of airflow. It also helps to protect the tips of the wings from touching the ground or water.

Largest and smallest birds

Smallest bird

We do not know what the smallest fossilized birds may have looked like. The tiniest pipsqueak that can still be found whirring through the air is probably the bee hummingbird (*Mellisuga helenae*) with a wingspan of 9 cm and a body weight of approximately 2 g. With a wingbeat frequency of at least 50 Hz, this hummingbird can actively fly as long as its energy allows.

Largest bird ever known

The absolute giant among large birds may have had the capacity for flight, though only in gliding flight through Andean uplifts and thermal winds: *Argentavis magnificens*, which had a wingspan of 7.5 m and lived in Argentina some six million years ago, is assumed to be the largest bird to have ever existed. It is believed to have weighed only 72 kg and to have reached a velocity of up to 100 km/h in gliding flight.

Largest wingspan among living birds

One of the largest birds living today is the Andean condor (*Vultur gryphus*). On average, the Andean condor reaches a wingspan of 2.90 m, at a weight of 11.4 kg. There have been individual cases of male specimens that reached a wingspan of 3.10 m at a weight of 15kg. The Andean condor thus comes very close to the limits of the capacity for active flight. Its wingbeat frequency of 1 Hz may enable the large bird to take flight, but only for short durations. The condor depends on Andean uplifts to keep itself aloft for longer runs.

Flying with 7500 times as much weight, but at the same speed

The smallest and largest living birds differ by a factor of 34 in terms of wingspan but by a factor of 7500 when it comes to weight (extreme cases). It is interesting to note that the tiniest birds and the giants fly at approximately the same speed, around 50 km/h. What then are the upper and lower weight limits for flying birds?

Upper weight limit set by evolution

Birds, like all non-parasitic animals, obtain energy from their own metabolism. They produce a certain amount of energy per unit time – a process also known as metabolic performance. Flying requires a certain amount of physical effort, the so-called flight performance. Birds can fly in a particular flight condition as long as they are able to produce a metabolic performance greater than the flight performance necessary to realize that flight condition.

Both metabolic performance and flight performance increase exponentially with a bird's body weight. Flight performance starts at a lower level, but it increases more rapidly than metabolic performance. As it turns out, the two performance curves intersect at a weight of 12 kg. It takes a bird of 12 kg almost all of its metabolic performance to take flight while still covering the other vital functions of its body. The largest birds living today are the wandering albatross (*Diomedea exulans*) with a maximum size of 3.25 m and the previously mentioned Andean condor.

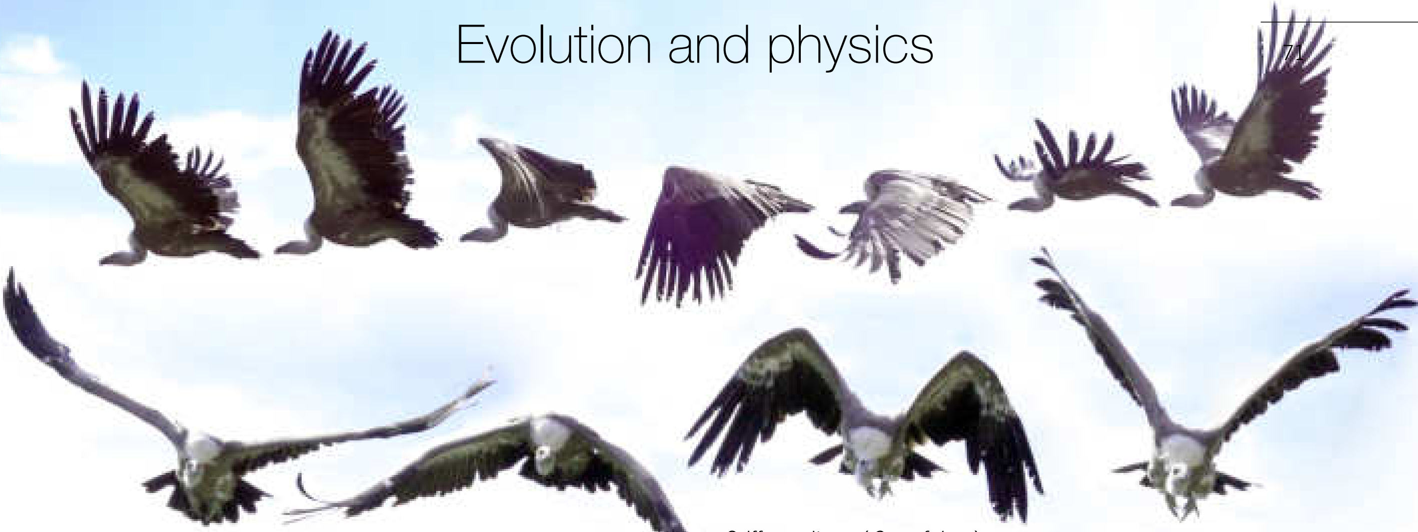
Evolution pushing the physical limits

It is interesting to see how close evolution has brought birds to the physical limits. The average body weight of the heaviest living birds that can fly (mute swan *Cygnus olor*, California condor *Gymnogyps californianus*, great white pelican *Pelecanos onocrotalus*, Kori bustard *Ardeotis kori*) lies at around 18-20kg.

These birds still have the capacity for active continuous flight, but birds with higher body weight, such as heavy male specimens of the bustard family, can only make short jumps into the air. Unless they are kept in the air by an external source of energy, which would ultimately be the sun, which creates thermal winds and other forms of uplift. Birds with a body weight of up to 15kg may be able to fly under such conditions, as illustrated by the Andean condor. The Andean condor is, in fact, an example of evolution that pushes the physical limits.

Amazilia hummingbird (*Amazilia amazilia*)

Campbell E.K., Tonni E.P. **Size and Locomotion in Teratorns (Aves: Teratornithidae)** *The Auk Washington DC100, 390-403 (1983)*
Nachtigall, W. **Vogelzug und Vogelflug** *Rasch und Röhring, Hamburg, Zürich (1987)*
Pennycuick, C. **Animal flight** *Studies in biology 33, London (1972)*



Griffon vulture (*Gyps fulvus*)

Lower weight limit

On the other hand, the smallest bird species do not have any problems achieving the necessary flight performance through their metabolism; they are "energetic giants," so to speak. Their muscles are more efficient per unit mass than the muscles of "morphological giants".

The smaller species may be "energetic giants", but ...

However, a prerequisite is that they eat enough food to keep their metabolism running at a peak rate. Hummingbirds thus need to consume nectar around the clock. While they rest at night, they lower down their metabolism and body temperature in order to save energy (*torpor*). This is also the case with the smallest bird indigenous in our latitudes, the kinglet (genus *Regulus*). Despite their nocturnal torpor, they are barely left with energy in the morning, which is why they must immediately resume food consumption. Otherwise they would be dead in a matter of half a day.

Energetic relations, which ultimately mirror physical conditions – the relation between surfaces and body mass, for instance – thus govern an animal's life and its evolution in every detail. This also applies to bird migration.

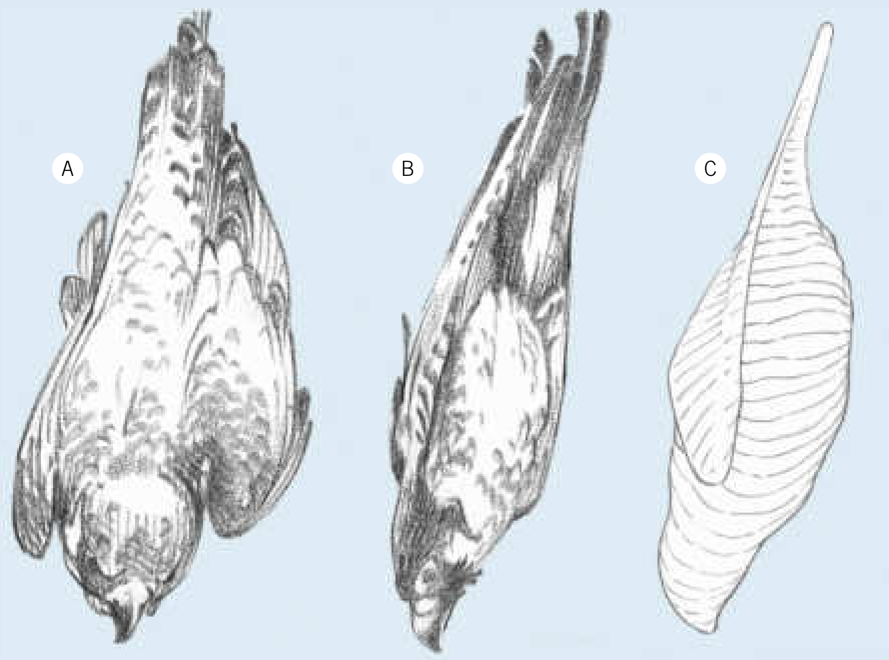
"Ecological types"

It only makes sense to draw comparisons between similar "ecological types". Among flying birds, there is a maximum mass ratio of 7500:1. A common ostrich weighs up to 100 kg. Numerally speaking, the mass ratio between an ostrich and the smallest hummingbird species would be seven times greater. However, such a comparison makes little sense from a functional point of view.

Common ostrich (*Struthio camelus*)

Falcons: the fastest animals in the world

Gyrfalcon (*Falco rusticolus*)



Ponitz B., Schmitz A., Fischer D., Bleckmann G., Brücker C.
Diving-Flight-Aerodynamics of a Peregrine Falcon (*Falco peregrinus*)
PLoS ONE 9(2): e86506. doi: 10.1371/journal.pone.0086506 (2014)
Ciesieleski L.C. **Der Gerfalke** *Westarp Wissenschaften, Hohenwarsleben (2007)*

Nosediving at 90 m/s and more

Right: The images on the right-hand side were taken at an interval of 1/60 of a second. The falcon in these images flies 2 m in 1/12 s against a static background, that is, at a speed of 24 m/s or 86 km/h – which is quite remarkable for a bird. The fastest bird is the peregrine falcon, which can reach a speed of more than 340 km/h (95 m/s) in a nosedive. In these images, the falcon flies after a lure that a falconer swings on a cord in circles before letting go. In the first images, the falcon is about to miss its turn and is struggling against centrifugal force, which is acting to force the bird out of its circular path, with its wings fully spread and held almost vertically upright. Towards the end of the image series, the falcon assumes its normal flight position as it drops its wings to a more horizontal angle and folds them slightly in. It is striking that the head is always held horizontally even when its wings are spread in an extreme vertical position. In the first images, the head is tilted away from the wings at a 90° angle. This allows the falcon to maintain spatial orientation even during such flight manoeuvres.

Detailed scientific studies

The most detailed studies (Ponitz et al 2014) have been carried out on trained peregrine falcons as they dive down a steep 60m high dam. They do not reach the same velocity extremes as in free airspace (up to 320 km/h), but they come close with a velocity of 80 km/h. Their peak acceleration was 1.2 g. During the first phase, the wings are almost tucked in; the transitional area from the proximal to the distal portion of the wing acts as a kind of secondary wing bend (A). The falcon navigates by slightly changing this posture. During the final phase, the legs and wings are tight against the bird's elongated body; the bird now forms a unique body that offers little resistance to airflow (B). Wind-tunnel models have been constructed based on such images in order to analyse their behaviour in high-speed tunnels. At the highest Reynolds numbers (cf. pp. see page 56f.), which correspond to a velocity of 144 km/h during nosedive, an astonishingly low minimum frontal area drag coefficient of only around 0.08 was measured.

Gyrfalcon (*Falco rusticolus*)

Clumsy only outside of water

African or black-footed penguin (*Spheniscus demersus*)

From Antarctica to the equator

All penguins live in the southern hemisphere. The Humboldt penguin (*Spheniscus humboldti*), for instance, is endemic to the Pacific coast of the southernmost areas of South America. It is a member of the genus of banded penguins, to which the Galapagos penguin (right-hand page) also belongs. The Galapagos penguin is the only penguin species that can be found on the Galapagos Islands, and it may thus be said to live almost in the "northern hemisphere".

Incapable of flight but muscular

All penguins no longer have the capacity for flight, but their body shape and shortened wings are perfectly adapted to fast swimming underwater. Since penguins generate thrust on both the upstroke and the downstroke, they have equally strong upstroke and downstroke muscles. That is why their shoulder blades, to which the muscles that control the upstroke are attached, have a very large surface compared to the shoulder blades of other birds.