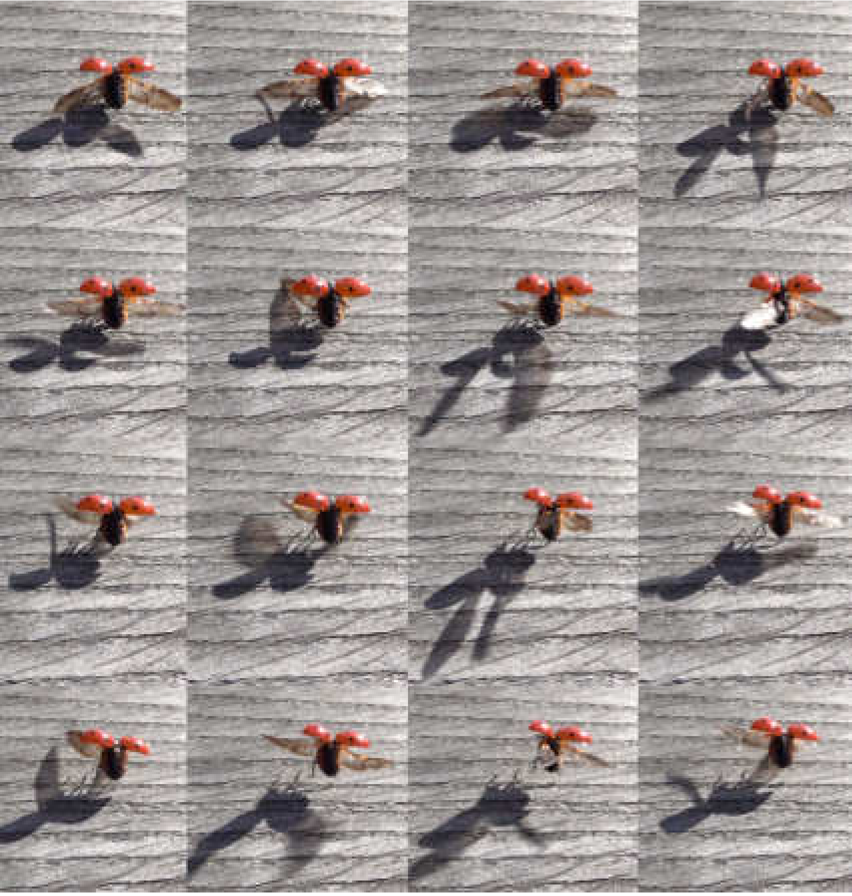

A “flip switch” enabling the wing’s double unfolding

The shadows in the image series above clearly illustrate that the ladybird’s wings are easily twice as long as its elytra. So a simple folding of the wings is not enough to tuck them away. They must be folded twice at least. The unfolding of the wings is achieved by means of a bistable vein mechanism (functioning like a flip switch, which is also stable in two positions), which then leads to a stiffening of the wings’ surfaces. See also the illustrations on p. 138.

The elytra are also used during flight

It is often assumed that the elytra’s sole purpose is to protect the membranous wings. They are simply spread during flight and then act as aerofoils, which, as measurements have shown, they do quite efficiently. The image series to the left shows, however, that they flap along with the hindwings albeit with a phase shift. That is to say, they actually act as flapping wings, though they only contribute to 15 % of the aerodynamic force.

80 wingbeats per second

Both image series on this page were shot at 240 frames per second. The process pictured above thus lasted about $1/16$ of a second and the series to the left twice as long ($1/16$ second for the left and right column respectively). From this we can deduce a wingbeat rate of about 80.

Balancing with the abdomen

Tilt stability during slow flight

In several individual shots, it can be seen that the small white (*Pieris rapae*) raises its abdomen slightly. This is relevant for its flight stability, especially during slow flight, when it appears to be hovering. The butterfly must always make sure to "counter-balance" any torque forces. This balance is necessary to ensure tilt stability.

Raising and lowering the abdomen

When the aerodynamic forces act ahead or behind the centre of mass, the flying object is prone to rotations about the lateral axis, head up or head down depending on the current position of the wings. The butterfly's inertia, and especially that of its heavy abdomen, dampens such tilt vibrations, but they are not completely eliminated.

Trimming like fighter planes

When the butterfly raises or lowers its abdomen, it can achieve a sort of trimming and adapt it to the desired flight condition. In the past, fighter planes were equipped with a trim weight, which could be moved forward and backward by means of a crankshaft. The butterfly's raising and lowering of its abdomen functions in the same way.

Flying with dishevelled wings?

The image to the left shows how ragged the trailing edge of a butterfly's wing can be. This butterfly's wing is only moderately torn; there are even worse cases of insects with torn wings that can still fly. An extreme example of this are large flies that spend a whole season circling the top of a mountain, a popular gathering spot for males and females for the purpose of copulation. After one such season, the trailing edges of a male's wings are typically quite frayed. They can still fly quite well, albeit not as effectively and fast as before. Since the airflow around the wings is no longer optimal, these flies buzz noticeably – a sure sign of aerodynamic stall. Moreover, flying under such conditions costs more metabolic energy than usual.

Long necks, giant wings

Conclusive evidence of biological kinship

Within the clade Neuropterida, we can find the order of net-winged insects (Neuroptera, once known as Planipennia). The most widely-known net-winged insects are the green lacewings (Chrysopidae). Some *Chrysoperla* species have golden eyes, which is why lacewings are also called "gold eye" (Goldaugen) in German. Antlions (Myrmeleonidae) are another group of net-winged insect species. Their larvae are known as doodlebugs due to the cone-shaped marks they leave in the soil.

Green lacewings: hearing and being heard ...

Green lacewings are a group of insect species that are particularly striking in the bright-green or brownish colour of their large wings. Due to the size of their wings, they are quite cumbersome in flight. They are mostly nocturnal, and like many moths, they have an auditory organ that enables them to capture the ultrasonic calls of bats in order to let themselves drop quickly and escape on time. Some species produce soft chirping sounds, which are used as species-recognition signals during courtship.

... and cunning disguise

Imagines and larvae are avid leaf-eaters. The larvae of green lacewings bear hooked bristles on their backs, which are provided so that they can throw the remains of aphids they have sucked dry to the back of the larva's body with their long mandibles, where these dead aphids remain stuck as camouflage. In this manner, the larvae of green lacewings manage to catch aphids from colonies that are guarded by ants without being recognized.

Aspöck, U., Haring, E. Aspöck, H. **The phylogeny of the Neuropterida: long lasting and current controversies and challenges (Insecta: Endopterygota)** *Arthropod Systematics & Phylogeny 70 (2): 119-129 (2012)*

Aspöck, U., Aspöck, H. **Kamelhälse, Schlammfliegen, Ameisenlöwen ... Wer sind sie? (Insecta: Neuropterida: Raphidioptera, Megaloptera, Neuroptera)** *Stapfia (Linz) 60: 1-34 (1999)*

The animal pictured here is a *Nothochrysa fulviceps*, a large, widespread, but rather rare species. You can see well the fine-mesh, net-like veins of the wings, which earned this whole group of insects its name. Some of these species can be found in our homes during autumn, where they look for a safe winter habitat.

Unmistakable with their long necks

Snakeflies (Raphidioptera) are an order of net-winged insects comprising about 225 species worldwide (though only on the northern hemisphere). The genera within this order are divided into two families. These insects are distinguished by their elongated prothorax (neck) and their wings that are folded over the abdomen, which lend them an unmistakable appearance.

On their way, whirring ...

All snakeflies are terrestrial in all stages. The imagines are diurnal and not good at flying, so they usually just walk or travel a few centimetres in flight, whirring close to vegetation. Some species (especially those whose larvae develop in the soil) prefer to dwell on low to moderately high scrub vegetation. The members of the family Raphidiidae are all predators that primarily feed on aphids; the imagines of the rarer family Inocelliidae feed mostly on pollen. The animal pictured here is a Xanthostigma xanthostigma, a species that is more common in our regions. The long ovipositor at the rear of its abdomen indicates that it is a female.

Charles S. H. **Acoustical Communication during Courtship and Mating in the Green Lacewing *Chrysopa carnea* (Neuroptera: Chrysopidae)** *Annals of the Entomological Society of America 72 (1): 68-79 (1979)*

Aspöck, H., Aspöck, U., Rausch, H. **Die Raphidiopteren der Erde, 2 Bände** *Goecke & Evers, Krefeld, ISBN 3-931374-27-0 (1991)*

Enormous jumping power

Strained to breaking point

The jumping force of grasshoppers is enormous. The leverage ratios of its hind legs are optimally developed for this purpose. The powerful jumping muscles of the thick femur (upper thigh) contract only for a short moment, but they do so with great force. In the process, the ligaments are strained almost to the point of rupture. Technically speaking: Taking the large desert locus *Schistocerca gregaria* as an example, the factor of safety is only about 1.25.

10 g acceleration!

At the start of the jump, the thin and thus light tibia supports itself on the ground. The initial acute angle between the femur and the tibia is stretched to almost 180° within a few milliseconds. The grasshopper then launches itself up into air diagonally. The desert locus, in fact, accelerates with a force that corresponds to 10 times the acceleration of gravity. They can jump a distance of a metre. During the jump, the flight machinery is fired up.

Tremendous acceleration values in the animal kingdom

Click beetles (Elateridae) and jumping plant-lice (Psylloidea) are typical examples of so-called “explosion jumpers”. The soldiers of some termite species have hooked mandibles that cross over each other. With the enormous centrifugal force that is released upon snapping open their mandibles, these termites can easily tear up an ant. Similarly astonishing cases can be observed in the kingdom of plants, as shown on the right-hand page.

Brown R. H. **Mechanism of locust jumping** *Nature (Ldn) 214, 939 (1967)*
Scott, J. **The locust jump: an integrated laboratory investigation.** *Advances in Physiology Education Published 1 March 2005 Vol. 29 no. 1, 21-26 DOI: 10.1152/advan.00037 (2004)*