## *The clap-fling and other mechanisms*

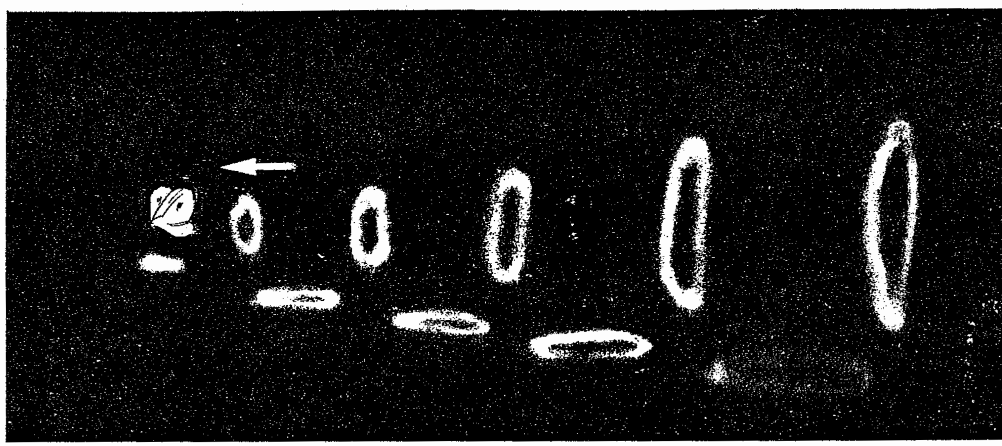
The most fascinating aerodynamic discovery of recent times arose from work carried out at Cambridge University by the late Professor Torkel Weis-Fogh. After making a number of aerodynamic calculations of insects, he came to the disconcerting conclusion that certain insects, particularly those with low Reynolds numbers and with low wing-loading, are unable to generate sufficient lift to remain airborne at all, at least according to the accepted principles of aerodynamics. The fact that insects have been flying for some 300 million years must indicate that they derive extra lift by some unknown means. The apparent paradox was taken up by Weis-Fogh who conducted a series of painstaking observations in the laboratory using high-speed cine-photography of hovering insects. Among the insects selected was *Encarsia formosa*, a tiny 1 mm parasitic wasp, often used in the biological control of aphids in greenhouses. As the insect has a wing-beat frequency of 400 cycles per second, the only way to analyze its movements was to film it with a rotating prism camera at 8,000 frames per second.

The first clue to the solution of the mystery was found in a frame-by-frame analysis of the films. It showed that the wasp hovered in the normal manner with its body vertical and the wings sweeping more or less horizontally. However, at the end of the upstroke the two pairs of coupled wings 'clapped' over the insect's back (D48-*A*). Then, after a short pause of one two-thousandth second, the wings were suddenly flung open with their hind margins still touching each other (D48-*B*). Following the 'fling' the hind margins separated and the wings moved horizontally through the air, as in conventional hovering flight.

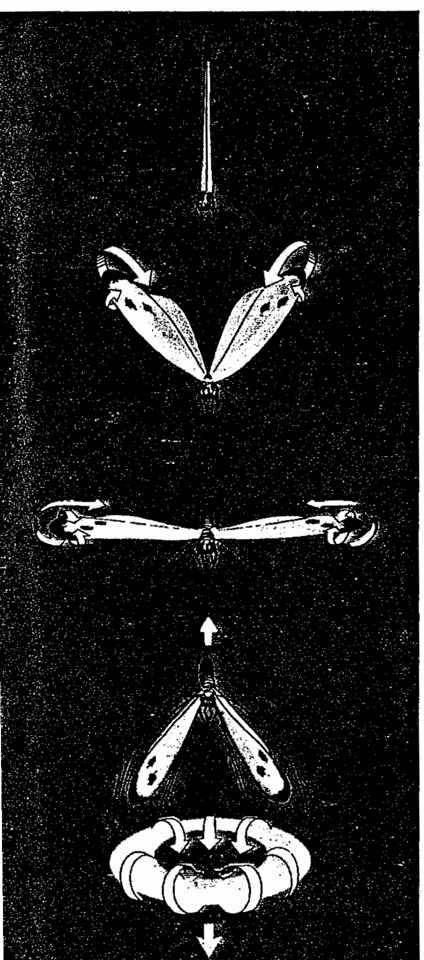
The *clap-fling* action, as Weis-Fogh described it, occurred in *Encarsia's* every wing-beat cycle, both in hovering and normal flight. Furthermore, the oscillations of the insect's vertical body showed that the lift had equalled the weight of the insect shortly after the clap position, thereby suggesting that air circulation round the wing had been built up a long time before the wings had reached maximum velocity. This is far from what would be expected of ordinary aerofoil action. After further calculations, and

D48 The clap-fling mechanism

2.7



D49 Butterflies leave invisible trails of vortex rings analogous to the wing-tip vortices of aircraft



D50 Clap-fling-ring mechanism of cabbage white butterfly

inspired thought, Professor Weis-Fogh found a rational aerodynamic explanation. During the clap the air around the insect is nearly motionless, but as the wings are flung open, it rushes in to fill the growing wedge-shaped space created between the upper surfaces. Thus, as the hind margins separate to begin the downstroke, the wings carry a vortex of air formed during the fling. In this way, circulation and lift are established by the wings as soon as they begin their downward sweep.

Since the discovery of the clap-fling mechanism in this minute wasp, a similar action has been observed in many other insects, including fruitflies, moths, butterflies and lacewingflies (P28, 37 & 38). In the lacewingfly (Chrysopa) the wings are sometimes clapped at the end of the downstroke as well as the upstroke. Even more intriguing is the fact that the lacewingfly's two pairs of wings, which do not necessarily beat together, being controlled by direct flight muscles, sometimes clap 90° (quarter cycle) out of phase with one another.

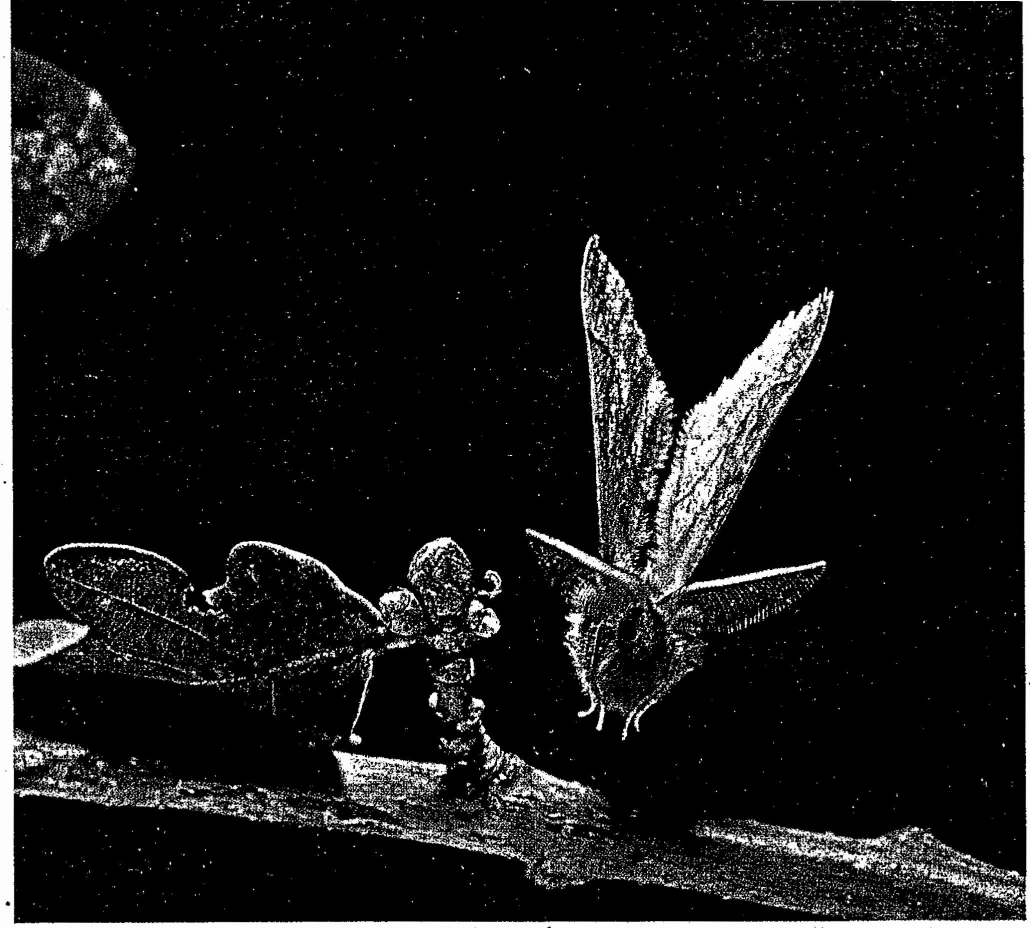
In the case of the cabbage white butterfly (Pieris brassicae), the clap-fling works in an entirely different way, as is shown by the latest research conducted by Charles Ellington at Cambridge University. It appears that this butterfly has a unique form of flight: it seems to blow a series of 'smoke rings' which are left trailing in its wake (D49). In take-off, hovering and slow flight the downstroke always begins with the wings clapped, but rather than being flung open about the hind margins, they are flung open about the body, which remains nearly horizontal as the wings move vertically downwards (D50). The bound vortices created by the fling, instead of circulating across the wing from leading to trailing edge, move over the wing-tips in a similar way to tip vortices. So, unlike the usual clap-fling or normal aerofoil action, lift is not derived through a Magnus effect, but is generated in the following intriguing way.

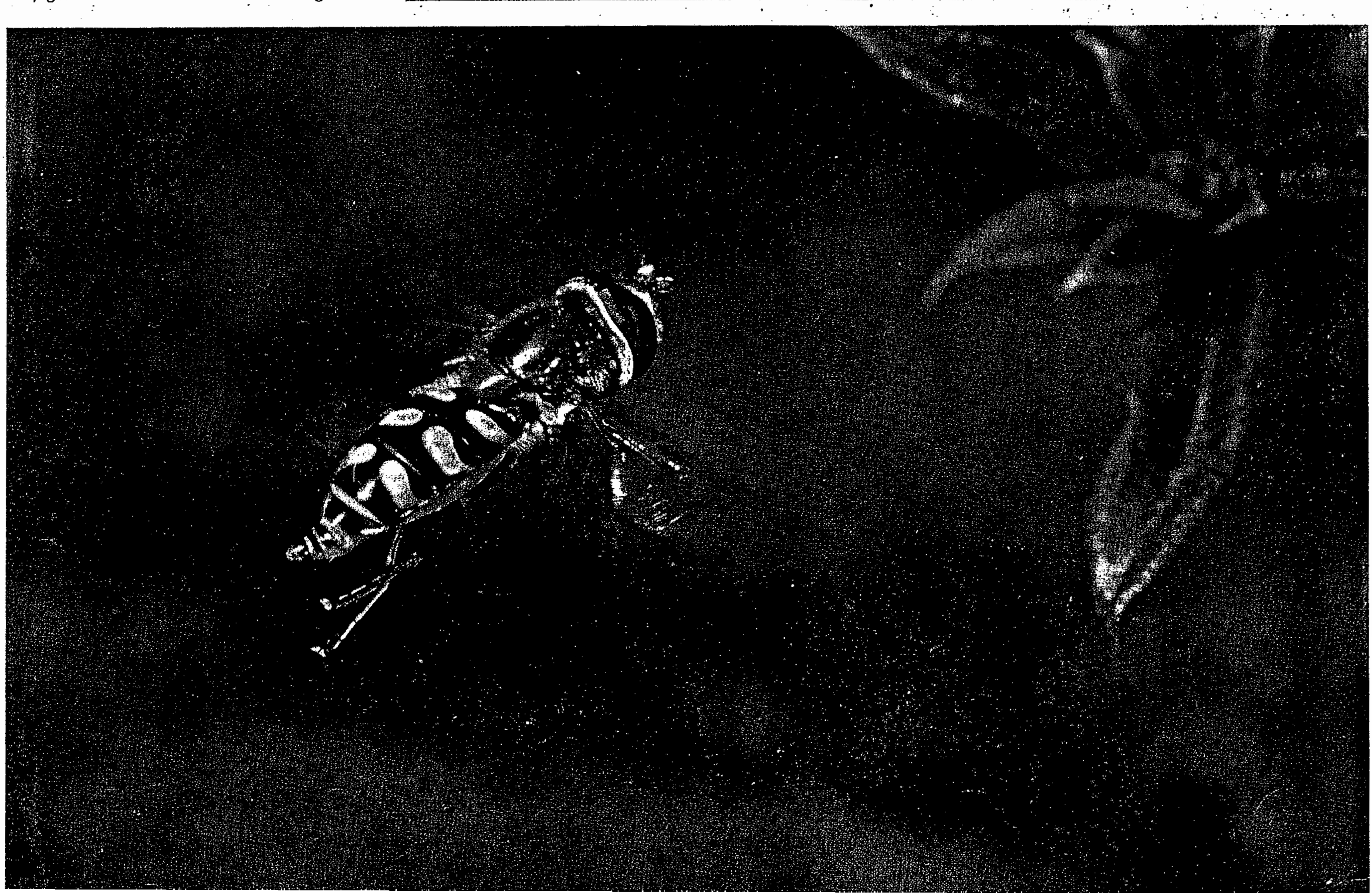
At the end of the downstroke the vortices are shed to form one large vortex ring. The fling is used to generate a vortex of air directly beneath the insect, while the force needed to create the ring sustains the insect's weight. Thus, the butterfly does not fly in a conventional aerodynamic way at all, but obtains an upward reaction from the vortex rings which are flung downwards. The effect is analogous to the downwash of normal aerofoil action, but instead of being created in a steady flow, is produced in an

P37 A lacewingfly (*Chrysopa*) taking off; in the lower image the wings are in the 'clapped' position

P38 A high-speed flash exposure of 1/25,000th second has caught the wings of this feathered thorn moth (*Colotois pennaria*) beginning their fling action. As the wedge-shaped space grows between the wings' upper surfaces, air rushes in so that when the hind margins separate, each pair of wings carries a vortex of air providing 'early' circulation

P39 Unlike most other hovering animals, hoverflies beat their wings up and down through a small stroke angle and keep their bodies more or less horizontal as in normal forward flight. As yet no satisfactory explanation has been found to explain how they gain sufficient lift while hovering





interrupted sequence. It is interesting to note that the shape of butterflies' wings, with their low aspect ratios and consequent high level of induced drag, is unsuitable for the generation of lift by normal aerofoil action, but is perfect for this function. Moreover, the erratic up and down motion so characteristic of the flight path of many butterflies and moths, particularly those with low aspect ratios and low wing-loading, can now be explained, as the timing of these abrupt movements corresponds to the shedding of the vortex rings.

The discovery of the clap-fling and the 'clap-fling-ring' represents a breakthrough in the understanding of insect flight. There can be little doubt that both mechanisms are far more widespread among insects than has hitherto been observed. No explanation, however, has yet been found as to how hoverflies and dragonflies hover. Unlike normal hovering, these insects beat their wings obliquely up and down through a small stroke angle, while their body axis remains horizontal, as in forward flight (P39). There is no question of any fling action, yet calculations reveal that normal steady-flow aerofoil action is quite incapable of providing them with enough lift to keep them airborne. There must be some other means by which these insects establish air circulation round their wings, but the details are still far from clear.

Although insects have been in the air for millions of years and have witnessed the changing scenes of life on this planet before birds or man learnt to fly, it is only now that we are beginning to appreciate the amazing complexity of their flight. They have taught us that our understanding of the science of aerodynamics was incomplete and have led us to the study of the aerodynamics of non-steady airflow. We are still only at the threshold of knowledge about insect flight, and it would seem that we still have much to learn from nature.