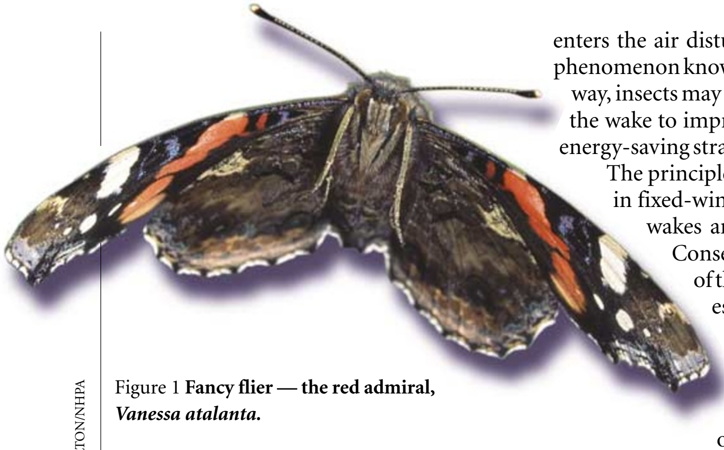

Figure 1 **Fancy flier — the red admiral, *Vanessa atalanta*.**

STEPHEN DALTON/NHPA

with superfast digital electronics.

Understanding of insect aerodynamics has to start with the wing-beat cycle of alternating downstroke and upstroke. At the beginning of the downstroke, the wing (as seen from the front of the insect) is in the uppermost and rearmost position, with the leading edge pointing forwards. The wing is then pushed downwards and forwards and rotated continuously, so that the angle of attack changes considerably during this downward motion. At the end of the downstroke, the wing is twisted rapidly, so that the leading edge points backwards, and the upstroke begins. During the upstroke, the wing is pushed upwards and backwards and rotated again, which changes the angle of attack throughout this motion. At the highest point, the wing is twisted again, so that the leading edge points forward and the next downstroke begins. So the wing is never in steady motion: it stops twice in each wing-beat cycle, and accelerates and decelerates between the stroke reversals. The resulting airflow varies considerably in time, but exhibits no turbulence (that is, it is laminar). This 'unsteady action' was first elucidated by Weis-Fogh[9] and decisively demonstrated by Ellington[10].

Weis-Fogh discovered the 'clap-and-fling' mechanism, in which the wings touch each other (clap) and then separate rapidly (fling), producing a short-lived inflow of air as vortices, which provide extra lift. Butterflies and certain wasps use clap-and-fling, but other insects do not, presumably because of the wing bashing involved with this technique. Instead, they increase lift by generating a leading-edge vortex (LEV)[1,2], which persists during each wing stroke and is shed at the end of it. In this process, a large vortical structure is created along the leading edge of the wing, where it persists despite the wing's acceleration and deceleration during each stroke or half-cycle.

Insects combine use of the LEV with exploitation of the wake shed from a wing's trailing edge — that is, the sheets of vortices that are left behind or, in hovering, are pushed downwards. In the hover, the wing retraces its path during each half-cycle. So it enters the air disturbed by its own wake, a phenomenon known as wake capture. In this way, insects may recycle the momentum of the wake to improve lift, so using a subtle energy-saving strategy[6].

The principle of LEV has been applied in fixed-wing aircraft[11], and unsteady wakes arise in helicopter flight[12]. Consequently, the observations of the aerodynamics involved, especially those of hovering, are amenable to mathematical modelling[3]. But data on flying organisms have been obtained only from tethered insects or electromechanical wing models. Tethered flight, in which an insect is glued to a metal rod and made to fly artificially, is clearly unnatural. Scaled models are experimentally more convenient. But the relevant kinematics are only approximations, and the models lack an elastic wing response and (obviously) do not respond to stimuli such as visual cues.

The problem, of course, is that free-flight data on insects are fiendishly difficult to obtain: the animals are tiny, their wings beat rapidly and techniques that do not impede movement are required. Getting detailed yet accurate quantitative data remains out of reach. But Srygley and Thomas[4] show that, despite all the difficulties, valuable qualitative experiments can be carried out.

This is not the first time free-flight information has been gathered (it's been done with dragonflies[13]). Rather, the novelty of Srygley and Thomas's work lies in their imaging and assessment of the gross features of the airflow around their butterflies. They then interpret these features by seeking flow patterns among the smoke streamlines, using an approach known as critical point theory. This theory has a stock of typical mathematical patterns, each with known properties. If any of these patterns can be spotted in the smoke visualization images, inferences can be made about the aerodynamics involved.

For example, Srygley and Thomas could find no discernible spanwise flow (that is, air flow from wing base to tip) inside the LEV in red admirals; such a flow occurs strongly in the *Manduca* hawkmoth[1] but weakly in fruitflies[2]. And they observe the existence of two parallel LEVs when a butterfly accelerates, but none at all when it flies forward steadily. This would suggest that the double vortices are a 'high lift' device used when rapid motion is required. Overall, however, the most remarkable finding is that red admirals (Fig. 1) seem to employ all the known lift-generating mechanisms in flight: clap-and-fling, LEVs, wake capture and rotational lift (this last is akin to the extra lift conferred on a tennis ball by spin). The butterflies appear to switch effortlessly among these mechanisms from stroke to stroke.

Disadvantages of this type of visualization

NATURE

100 YEARS AGO

The services which photography has rendered to science are now well recognised, and its value for purposes both of observation and record is well known and admitted. It is probably not so well known that methods now exist by which not only the form, but the colour, of natural objects can be represented with approximate fidelity. We are fortunate in being able to illustrate this fact by a plate giving some excellent reproductions of birds' eggs, produced under the superintendence of Mr. H. E. Dresser, entirely by photographic methods, and without the intervention of an artist. There is no need to dwell on the value of such work. For many scientific purposes it is as important to record colour as shape, and if this can be done in a trustworthy manner, a new and useful power is placed at the disposal of the teacher of science and of the writer of scientific books. The difficulty about the three-colour process of photography is that it is extremely difficult to make certain that the colours are reproduced with sufficient accuracy for scientific work. Accuracy enough for pictorial purposes is easily attained, but absolute truth to nature is quite another thing.

From *Nature* 11 December 1902.

50 YEARS AGO

Born in Paris a century ago, on December 15, 1852, Antoine Henri Becquerel came of a family long distinguished in the world of physical science. Educated at the École Polytechnique, Paris, his early studies were concerned with the magnetic rotation of the polarization plane of light... and the absorption of light by crystals. In 1892 he was appointed professor of physics at the Musée d'Histoire Naturelle — a chair held before him by his father, Alexandre Edmond Becquerel (1878), and by his grandfather, Antoine César Becquerel (1837). Three years later he became professor of physics at the École Polytechnique. His greatest achievement was the result of a lucky accident, but at the same time it was the culmination of a long series of carefully planned experiments. In 1896 he found that photographic plates, protected against ordinary actinic radiations, were fogged by emanations from uranium ores. His paper entitled "Sur les radiations émises par phosphorescence"… ushered in the new era of radioactivity. Their discoverer in 1903 shared the Nobel Prize for Physics with Pierre and Marie Curie, who in 1898 had isolated radium from pitchblende.

From *Nature* 13 December 1952.