Insects impress by their agility and their performances in flight. Understanding the aerodynamic mechanisms involved constitutes a considerable challenge for biologists, physicists, but also for engineers responsible for Micro Air Vehicle’s design, whose principal model remains insects’ flapping flight.

During the last few years, some of the characteristic kinematic patterns allowing us to explain the significant aerodynamic forces generated during flight as well as the underlying fluid dynamics had been unraveled. However, if major elements such as wings kinematics or leading edge vortex production are now partially understood for hovering flight (Walker et al. 2010) as well as for forward flight (Bomphrey et al. 2006), the aerodynamic mechanisms involved during the take-off phase remained unstudied. The substantial lift and power required as well as the involvement of the ground make take-off a particularly interesting manoeuvre to decipher.

The aim of this study is therefore to understand the wing kinematics and vortex production operating during an insect’s take-off and how they could interact with the ground to take advantage of its proximity.

To that end, a detailed kinematic study of an insect during take-off was carried out, completed by an analysis of fluid dynamics during the manoeuvre, intimately related to forces production.

Cabbage white butterflies (*Pieris rapae*) were selected on the basis of good wing condition wings and strong flight motivation. The experiments were performed at the Research Institute on Insect Biology (Tours University).

**Kinematics experiment**

A cabbage white butterfly marked with a fine-tipped marker pen on the wings’ leading and trailing edges, was placed at the bottom of a flight cylinder and filmed during take-off at 1000 frames per second by three synchronized high-speed digital video cameras. The calibration, as well as the film analyses, were then performed with dedicated software to obtain high-resolution, deformable surfaces (Walker *et al.* 2009). Marked points as well as some natural features on the insect’s wings and body were manually tracked throughout take-off. The 3D coordinates of these tracked points were then used to reconstruct wing surfaces, allowing us to follow in detail the motion and the deformation of the wings throughout the take-off phase (Figure 1).
Three take-off sequences were selected for three individuals, each composed of 5 stroke cycles, to perform a complete analysis of the forewing kinematics.

Applying the previously described reconstruction and motion analysis method, we were able to extract from these videos various kinematic parameters such as the flight speed, the angular wing speed, the wingbeat frequency and the wingbeat amplitude. Measurement of the local angle of attack and of the local camber along the wing length through the take-off flight revealed the deformations of the wings occurring during the manoeuvre. The variations of these different parameters were monitored during take-off.

Fluid dynamics visualization experiment

In parallel, fluid motions created by the insect during its take-off flight were explored by Particle Image Velocimetry. The insect was placed at the bottom of a previously seeded enclosure, parallel with, and at various distance from, a vertical and continuous laser sheet crossing the box from side to side. Take-off flight sequences were then recorded at 2000 frames per second with two high speed digital video cameras: one camera, placed perpendicular to the laser sheet, to enable the capture of PIV frames, while another one overhung the arena, to record where the laser sheet crossed the insect’s wing. Various ‘insect/laser’ distances were tested to get the flow visualization at different spanwise positions along the insect’s wings.

PIV analysis was performed on 20 of the 70 videos, representing the take-off phase of 10 individuals. Flow measurements were analyzed during the first downstroke of the insect at four different spanwise positions: on the body, the wing root, mid-wing and wing tip.

The high variability of recorded parameters (e.g. speed, flight direction, kinematics) between the different sequences prompted us to analyze each experiment independently.

A high resolution analysis was then performed. The velocity vectors around the insect and the vorticity generated as well as vortex size variation and the evolution of their position on the wing through the first downstroke were calculated (Figure 2).
Through these two experiments, this study should unveil aerodynamic mechanisms providing sufficient lift and power amounts to perform the ground-to-air transition in this insect – a phenomenon that still remains elusive.

Quantifying these mechanisms in terms of aerodynamic forces remains difficult on free flying insects, the described fluid dynamics experiment will be later coupled with a complementary approach on a flapping robot taking off. Resulting repeatable PIV data at different points along the model will allow aerodynamic forces estimation around its flapping wings. Merging those two datasets should result in a better knowledge the aerodynamic forces produced by the insect during take-off.

References

