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The trinity of energy conversion

kinematics, aerodynamics and energetics of
the lesser long-nosed bat (*Leptonycteris yerbabuenae*)

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Abstract

This study was designed to get a better understanding of the movements of a flying bat, the aerial footprint, and the energy expenses during a range of speeds and to connect those measurements with each other.
The interactions of kinematics, aerodynamics and energy consumption were examined in a nectar-feeding bat species *Leptonycteris yerbabuenae*, flying in a wind tunnel over a range of flight speeds from 0 m/s (hovering) to 7 m/s. The movements of the wings were recorded with high speed cameras. The body and wing markers were digitized and transformed into three dimensional coordinates using direct linear transformation (DLT). An open flow system with a respirometry mask installed in the wind tunnel was used to measure the oxygen consumption of the bats during flight. The vortices behind a flying bat were visualized and the affecting forces calculated using stereo digital particle image velocimetry (SDPIV).

The kinematics revealed that the wing motion changed gradually from a flexible, cambered wing surface with a more horizontally-directed stroke plane at low speeds to a fairly rigid surface with a more vertically-directed stroke plane at high speeds. The wing area, angle of attack, and camber, which are determinants of the lift production, all decreased with increasing speed. The armwing is responsible for the main changes in the wing area during the wing beat. Several mechanisms allow for a very high angle of attack at low speeds without stalling, including a higher camber of the wing and a larger deflection of the leading edge flap. The leading edge flap may also contribute to adjusting the airflow over the wing by influencing the formation of the leading edge vortex. At speeds below 3.25 m/s, the handwing performs a backward flick where it is turned up side down; the low values of the stroke plane angle, the downstroke ratio and the span ratio indicate a greater contribution of the upstroke to the weight support at low speeds than at higher speeds, with higher lift production and reduced thrust production at those low flight speeds.

The wake analysis showed that, in agreement with previous studies, each wing generates its own vortex loop, which is present from the beginning of the downstroke until mid-upstroke and induces a downwash; at the end of the upstroke the reversed vortex loops are shed, inducing an upwash. The lift-to-thrust ratio shows the highest values, indicating a maximal flight efficiency at intermediate speeds. The comparison between the force coefficient of the tip-vortex and the angle of attack showed a time lag, indicating a delayed vortex shedding relative to the wing motion and the presence of unsteady effects.

The metabolic power input did not differ significantly between flight speeds. However, the two individuals differed significantly with the female having higher energetic flight costs probably due to the precedent pregnancy. It must be noted that visits to the feeder were rarely longer than 5 s during hovering flight, which could result in an underestimation of the metabolic rate for these flights. The U-shaped mechanical power output and the flat metabolic power input indicate a changing mechanical efficiency over speed, with the highest mechanical efficiency at low and high speeds.