UNIQUE FEATURES OF THE KINEMATICS AND DYNAMICS ASSOCIATED WITH THE FLIGHT OF BATS

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Flapping flight is the single most evolutionarily successful mode of animal locomotion: there are today over 1000 species of bats, more than 9000 living species of flighted birds, and somewhere between millions and tens of millions of species of flying insects. Bats differ from birds and insects in several key respects. Their wing skeleton is highly jointed and consequently has many degrees of kinematic freedom. In addition, both the skeletal structure and the wing membrane of bats is extremely elastic and undergoes significant deformation during the wing cycle. These morphological features likely contribute to the extreme manouverability that bats routinely demonstrate during flight. In this paper we present experimental data from a research program motivated by the following fundamental questions: a) what are the aerodynamic capabilities of bats - how do they differ from that of birds and insects? What are the quantitative aerodynamic metrics by which we can measure the animals' performance? b) We know that bats have several morphological and physiological features that are unique in the animal kingdom. What are the roles, if any, of these different features in the observed aerodynamic capabilities of bats? c) How can we model the aeromechanical behavior of the bat so that might guide engineered vehicles that take advantage of bats' capabilities?

In addressing these questions, we have conducted flight cage experiments with live bats and have measured their detailed kinematic motion. In addition, using PIV, we have made measurements of the wake velocity structure behind the animal as she flies. As the animals fly through a flight cage their body and wing motion is captured by a pair of high-speed (500 fps) infrared cameras positioned on the floor looking upwards. The twin camera arrangement allows for the acquisition of the complete three-dimensional motion of the bat. The flight cage is seeded with a light mist of micron-sized aerosol particles generated by a custom-built Laskin nozzle fog generator. As the bat flies through the flight cage it trips a laser beam-break sensor which initiates the data acquisition sequence. After a pre-set delay the wake flow is illuminated by a sequence of laser pulses using a pair of Nd:YAG lasers. The motion of the tracer particles is captured by a pair of high-resolution CCD cameras. The velocity field is then extracted using standard 3D-PIV procedures from the pair of images. By piecing together several image pairs, captured from the wake as a function of time, a complete portrait of the wake flow behind the animal over the course of the wing beat cycle is acquired. Using this data we can obtain estimates regarding the strength of the shed vorticity and the morphology of the wake vortex structure. Comparisons between the wakes generated by bats and the wakes generated by insects and birds will also be presented. Finally, we will show data taken from a series of wind tunnel tests in which key features of the live animal tests are mimicked in controlled conditions. Although these models do not emulate the flapping motion, the effects of the elastic wing membrane on the resultant aerodynamic characteristics of the wing are measured and compared with comparable traditional (rigid) wings.

Keywords: aerodynamics, bats, flexible wings