Exploration of Bat Wing Morphology through A Strip Method and Visualization

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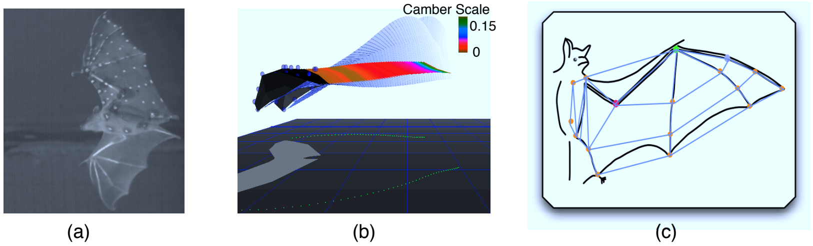

(a) (b) (c)

Figure 1: *(a) Frame from the video recorded in a wind tunnel; (b) visualization tool showing wing wake structure (in blue) and camber (in colors from a L*a*b color space); (c) wing mesh (in blue).*

Abstract

We present a visual exploration tool that facilitates biologists navigating through complex bat wing geometry by combining a novel modeling method and an interactive visualization approach. Our work contributes to the following: a new method to quantify the dynamic kinematics during flight, a new curve fitting method that measures camber, and a new tool for time-varying data visualization for biological knowledge discovery.

Keywords: simulation and visualization, flight dynamics, computational modeling

1 Our Approach

Bats are known to fly with amazing maneuverability and agility, in part because of their unique aeromechanical features such as highly elastic wing membranes and deforming wing bones. However, the details of how the wing membrane changes shape during flight are poorly understood. Our modeling research quantifies wing camber (which measures the curvature of the wing) using an aerodynamically meaningful approach, called a strip method. Unlike an existing approach to calculating the cross section parallel to the sagittal plane, our method takes the section parallel to the oncoming airflow, coinciding with aerodynamic theory.

Our visualization tool (Figure 1(b)) allows biologists to query and compare camber at any time instance. The camber is calculated in four steps. 3D wing motions are tracked and digitized at seventeen anatomical marker locations on the wing and body (Figure 1(a)). Marker points are interpolated using an overconstrained least-square polynomial fit. A third-order polynomial is used for filling gaps. In each frame, the wing mesh is reconstructed using eight triangles and six quadrilaterals (Figure 1(c)). The choice was made according to the observed movement: the joints that were likely to move together were placed on same patch. We then calculate the cross section that is parallel to the oncoming flow and perpendicular to the wing surface. A half-edge algorithm was used to computer the intersection [Foley et al. 1995]. We use a third-order Fourier sine series to fit a smooth curve to the discrete line segments on the cross section. Finally, we calculate the camber by dividing the maximum distance between that curve and the chord by the length of the chord.

Camber shape is time varying and interpreting such data in 3D imposes cognitive and perceptual load to biologists. To address this issue, we further provide a visualization tool to show camber variations through coloring in a perceptually unformed coloring space. A color space is said to be perceptually uniform if the perceptual difference between any two colors in just noticeable difference units is equal to the Euclidean distance between the two colors in that color space.

Results of wing camber is mapped to the L*a*b color space at L=30 (Figure 1(b)). The green to blue colors represent higher cambers; and the red and orange colors represent the lower cambers. The visualization shows that the larger camber variation occurs at the beginning and the end of the stroke. The wake structure is shown in a light blue color to provide a spatial reference. Preliminary results suggested that the modeling approach produced more precise representation of the dynamics of flights thus enabled fast and more accurate interpretation of camber shape among many flights.

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