Exploration of Bat Wing Morphology Through A Strip Method and Visualization

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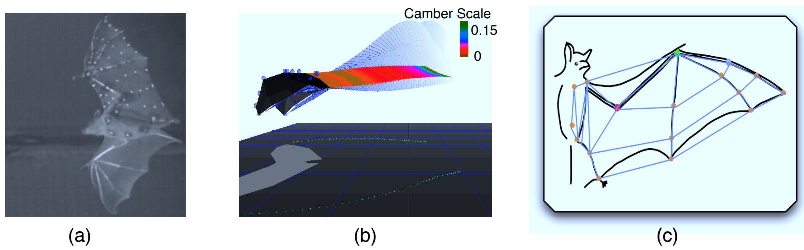

Figure 1: *(a) Frame from the video recorded in a wind tunnel; (b) visualization tool showing wing wake structure (in blue) and camber (in colors from a L*a*b color space); (c) wing mesh (in blue).*

Abstract

We present a visual exploration tool that lets biologists navigate through complex bat wing geometries by combining a novel modeling method and an interactive visualization approach. Our work contributes the following: a new method for camber measurement during flight, a new curve fitting method, 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 attributes 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 at the leading edge that follows the airflow, coinciding with the measurement method from airfoil theory.

Our visualization tool (Figure 1) 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. Marker points are interpolated using an overconstrained least-square polynomial fit, and a third-order polynomial is used for filling gaps. In each frame, the wing mesh is reconstructed using eight triangles and six quadrilaterals. chosen according to the observed movement: the joints that were likely to move together are 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 is used to computer the intersection [Foley et al. 1995] and a third-order Fourier sine series is used to 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 a significant cognitive and perceptual load. To address this issue, we provide a visualization tool to show camber variations through coloring in a perceptually uniformed 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.

The results of wing camber are mapped to the L*a*b color space at L=30. 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 for many flights the modeling approach produces more precise representation of the dynamics of flights and thus enabled made possible fast and accurate interpretation of camber shape.

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References

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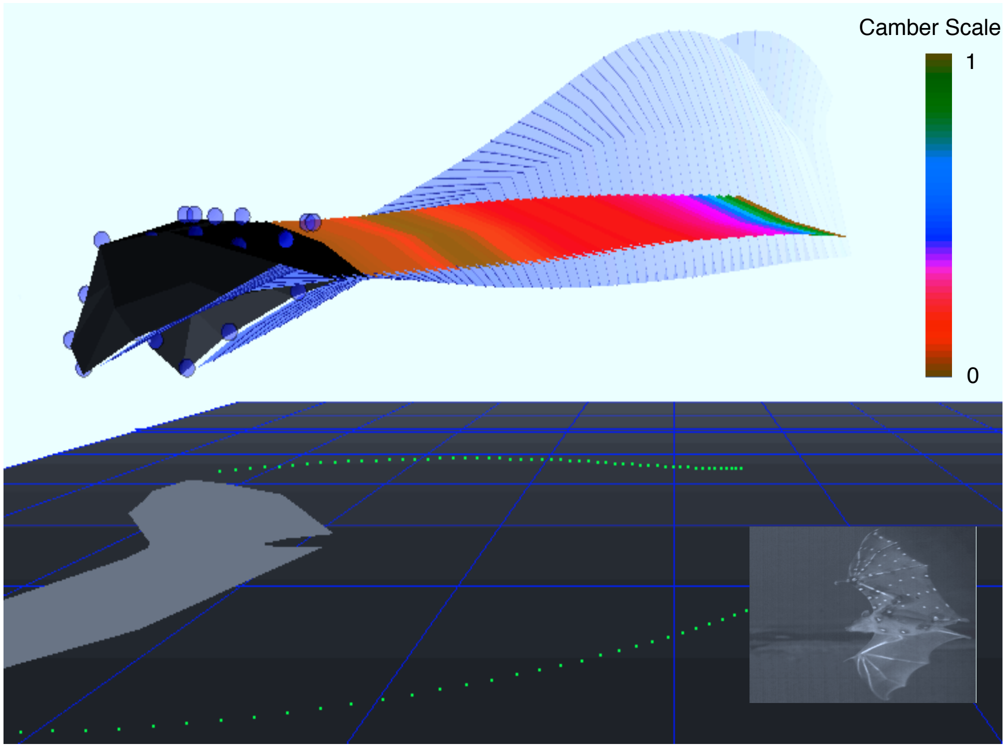

Figure 2: *The visualization tool showing one frame of bat flight.*

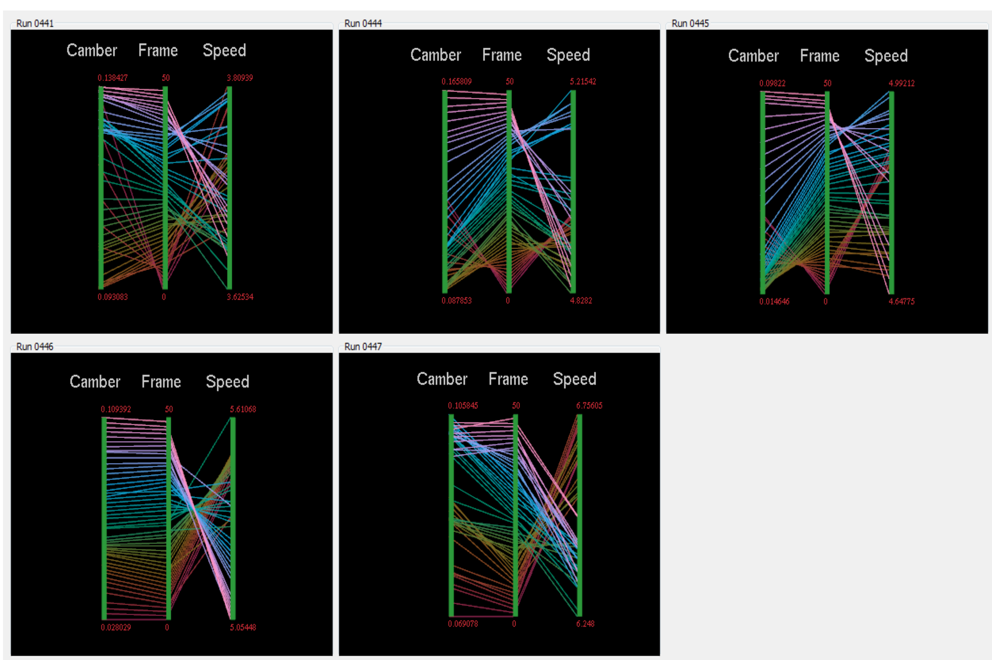

Figure 3. Multivariate data visualization using parallel coordinates which represent each dimension (here camber, frame, and speed) as a vertical axis parallel to all the others. The line joining the specific values of each one of its variables represents an element of the data set. The data represent five runs of one individual of bat flight in the wind tunnel at the Brown University ordered by the average flight speed with increasing speed from left to right and top to bottom. The visualization shows that camber variances in the top row of "Run0441", "Run 0444", and "Run 0445" are similar. The variations are bigger between some frames for the fastest flight of Run0447. The graphs also show the instantaneous speed change during flight.

Figure 3

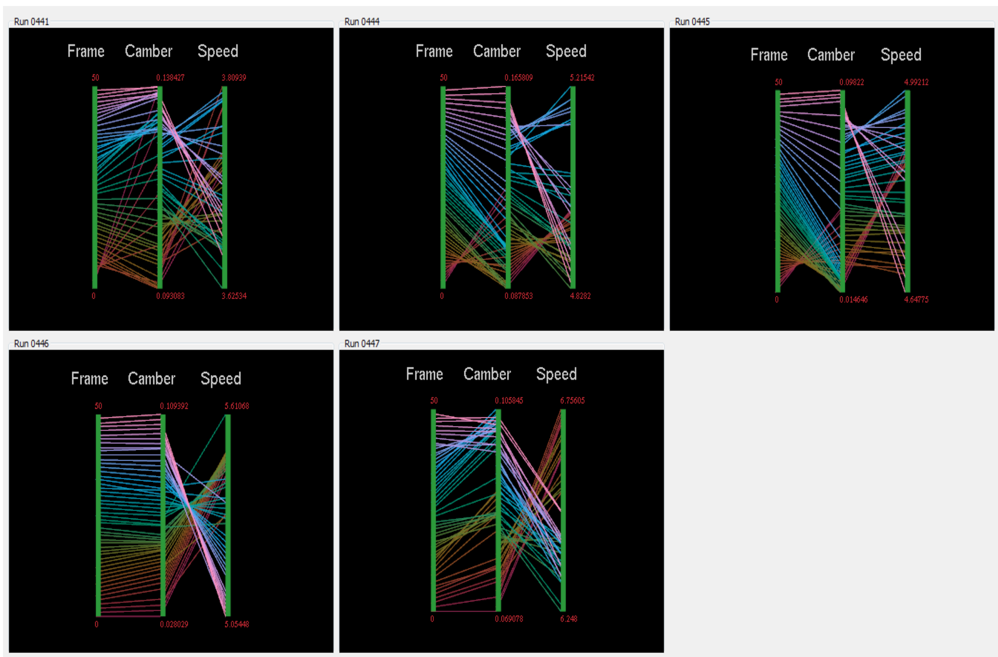

Figure 4. Multivariate data visualization using parallel coordinates which represent each dimension (here frame, camber, and speed) as a vertical axis parallel to all the others. Note that the data are the same as Figure 3, but the two axes, frame and camber, are exchanged. These graphs show that bats might have used camber differently at lower (of runs in the 1st row) and higher flight speed (of runs in the 2nd row). A negative correlation between camber and speed is observed, i.e., the higher the camber, the lower the local flight speed.

Figure 4