Simulation and Visualization of Flow Around Bat Wings During Flight

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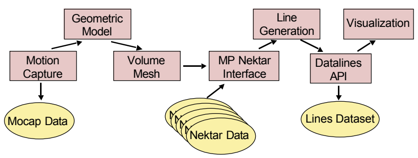
Purpose

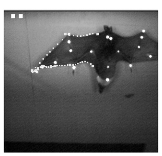
We present the first example of flow simulation and visualization over a motion-captured dynamic bat model (order Chiroptera). When bats fly, their wings undergo large amplitude motions and deformations. As a consequence, simulating and visualizing the way air flows around the bat is extremely complex, and biologists have yet to gain a full understanding of the aerodynamics and mechanics of bat flight. This poster illustrates the steps taken to arrive at this simulation. By understanding the dynamics of bat flight, we hope to make discoveries in areas such as biomechanics, aerodynamics, and evolutionary biology.



Above, a flow chart diagrams the path to arrive at the final visualization.

Data Acquisition

The Swartz Lab acquired motion capture data of bat flight by flying more than 20 individuals of several species through wind tunnels [1]. This research focuses on the data from one individual of a large-bodied (600 *g to 1 kg*) species, *Pteropus poliocephalus*. Two high-speed digital cameras tracked infrared markers on the bat. Software interpolated the camera data to arrive at 3D coordinates and converted them to a coordinate system centered at the bat's sternum marker.

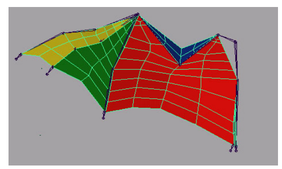


Above, markers are visible as bright white circles to the cameras used to acquire motion capture data

Geometric Model

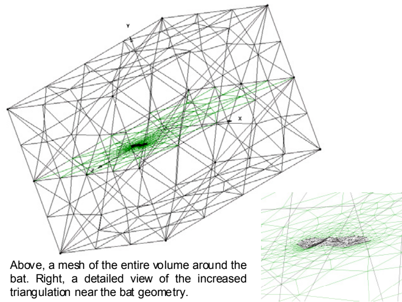
Above, shots of a wing beat taken at every 12th frame show the significant amount of deformation in the model's wings during flight.

Baricentric coordinates are used to define a point-to-point correspondence between an arbitrary mesh geometric model and a low resolution control mesh. The control mesh is a triangulation of the motion capture markers and its purpose is to drive the deformations of the geometric model. In the case presented here, the geometric model was built by fitting the motion capture markers in a reference frame and exporting to an obj format file. Using the obj model together with the motion data, a correspondence between the geometric model and the control mesh is computed for a reference frame. The geometric model is then deformed for all other frames by projecting it onto the control mesh using the baricentric coordinates.



Above, a tessellation of the geometric model's wing. Different colored regions are separated by bones.

Mesh Generation

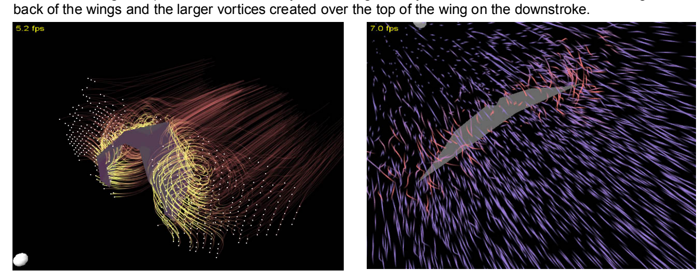


Above, a mesh of the entire volume around the bat. Right, a detailed view of the increased triangulation near the bat geometry.

We imported 60 different time steps of the dynamic model into the commercial grid-generating program Gridgen [3]. A volume of 10 by 10 by 20 non-dimensional units was defined around the bat geometry, which had a wing span of approximately 3 units at its widest point. The surfaces are triangulated such that a vertex exists every 0.1 non-dimensional units on the bat, but only every 2 non-dimensional units on the volume surfaces in order to focus on the more interesting events which occur closer to the bat. The mesh for the bat changes significantly during the wing beat. As a result, multiple tetrahedralized volumetric meshes are necessary and must be interpolated in order to achieve a simulation of an entire wing beat.

Simulation and Visualization

The fluid-simulation program, NekTar [3], calculated velocity field data in the volume surrounding the animated bat model with a Reynolds number of 100. We visualized the flow data in the CAVE, an immersive, 3D, stereo display environment. The visualization software was previously developed to view blood flow in an artery [4] and worked well to demonstrate the flow of air within the volume surrounding the bat. Images below show photos of this visualization tool. Streamlines representing the paths of massless particles show the air flow. The streamlines are seeded at λ_2 values which indicate the presence of a vortex. Another form of visualization known as eels tracks velocity both forward and backward in time from the seed point. We found interesting flow patterns around the dynamic bat geometry, such as the small vortices coming off the back of the wings and the larger vortices created over the top of the wing on the downstroke.



Left, streamlines seeded at minimum λ_2 values demonstrate vortices which occur off the back of the wings during flight. Right, another method of visualizing the air flow known as eels also shows high vorticity areas around the wings during flight.

Conclusions and Discussion

We have developed a good method of visualizing unsteady flow around unsteady geometry and completed a full iteration of the simulation-visualization process for the particular application of bats. At this time we are still unable to draw significant conclusions about how bats fly although the visualizations show many potentially interesting flow structures in bat flight which we hope to explore further. Through this research, we have developed a method of allowing the user to view data with a biased emphasis on key features—in this case on possible vortices by focusing on λ_2 values. The user of our visualization has the ability to shift between data focused on possible vortices and the general context of the data. It has been found that due to the interdisciplinary nature of this project, visualizing in this way in a 3D environment like the CAVE has been effective in allowing experts from varied fields to collaborate in new ways and see the data from new perspectives.

References

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Acknowledgements

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