Simulation and Visualization of Flow Around Bat Wings During Flight

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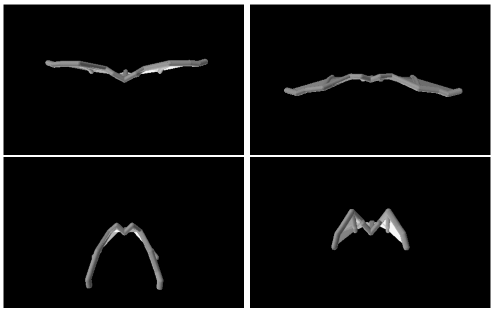

Figure 1: Frames from an animation of the polygonal geometric model of the bat show the skin represented by infinitely thin polygons and the deformation which the model undergoes.

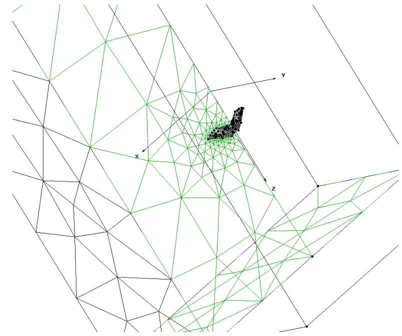

Figure 2: A user specifies, in Gridgen, which surfaces should be triangulated.

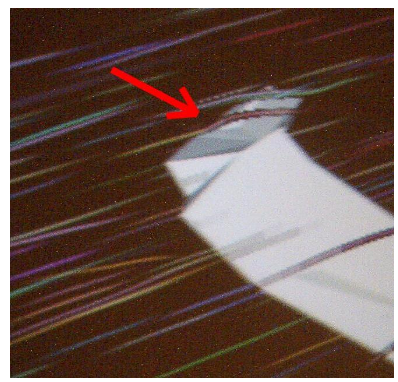

Figure 3: The red arrow in this photo taken in the CAVE points to particles moving along curved pathlines over the bat geometry.

We present the first example of flow simulation and visualization over a motion-captured dynamic bat model (order Chiroptera). By understanding the dynamics of bat flight, we hope to make discoveries in areas such as biomechanics, aerodynamics, and evolutionary biology.

Geometric Model Construction After obtaining motion capture data in wind tunnels using high-speed digital cameras [1], we created a time-varying polygonal geometric model. Wings are represented by infinitely thin tessellations of triangles. Frames from an animation of this model are shown in Fig. 1.

Mesh Generation We imported different time steps of the dynamic modelinto the grid-generating program Gridgen [2]. 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 non-dimensional units at its widest. We triangulated at a rate of 2 non-dimensional units on the surfaces of the volume and a rate of 0.1 non-dimensional units on the bat geometry. This provided a focus on the more interesting flow patterns near the bat. The triangulation was used to subdivide the volume into tetrahedral spaces.

The mesh for the bat changes significantly during the wing beat as seen in Fig. 1. As a result, multiple 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 dynamic bat geometry. 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. Fig. 3 shows a photo of this visualization tool. Pathlines representing the paths of massless particles show the air flow. The length of a given pathline indicates velocity – longer paths represent faster particles. We found interesting flow patterns around the dynamic bat geometry, such as small vortices coming off the back of the wings and larger vortices created over the top of the wing on the downstroke.

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References [1] S Swartz, M-F I Aguirre, and K Bishop. "Dynamic Complexity of Wing Form in Bats: Implications for Flight Performance." Functional and Evolutionary Ecology of Bats. Eds. Akbar, McCracken, and Kunz. Oxford U. Press. [2] Pointwise, Inc. 213 S. Jennings Ave. Fort Worth, TX 76104. [3] T Warburton. *Spectral/hp Methods on Polymorphic Multi-Domains: Algorithms and Applications*. Ph.D. Thesis, Brown U., RI, 1999. [4] J Sobel, A Forsberg, D H Laidlaw, R Zeleznik, D F Keefe, I Pivkin, G Karniadakis, P Richardson, S Swartz. Particle flurries: Synoptic 3D pulsatile flow visualization. IEEE CG&A, 24(2):76-85, 2004.