How Bats Fly: Canonical Description of Wing Kinematics and Dynamics of a Straight Flying Insectivorous Bat (*Hipposideros Pratti*)

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Bats are some of the most agile flyers in nature with highly articulated and complex wing motions. Because of the complex three-dimensional wing motion, it is challenging to systematically investigate different bat flight regimes across different species. To overcome this challenge, a novel three-dimensional geometric decomposition framework is developed and applied to decompose the complex kinematics into physical modes commonly used to describe flapping flight, namely, flapping mode, pitching, stroke deviation, together with streamwise and spanwise cambering modes. The decomposition is combined with aerodynamic simulations to investigate the cumulative effect of each mode on force production and the mode’s primary contribution to the unsteady vortex dynamics and consequently to lift and thrust production. For the near level *H. pratti* steady flight investigated, the results show that the flapping mode by itself induces drag and very little lift. With the inclusion of the spanwise varying pitching mode, lift production increased by a factor of 3 with positive thrust production resulting from the favorable wing orientation during the upstroke. It was discovered that the wing twist introduced by the spanwise varying pitch angle acted to maintain a near constant effective angle of attack across the wingspan during the downstroke. The primary contribution of the chordwise cambering mode which amounted to between 15-20% of maximum chord length was found to stabilize the evolution of the Leading Edge Vortex (LEV) during the downstroke to increase mean lift by about 35%. Spanwise cambering was perhaps the most complex mode with maximum values exceeding 50% of chord length. This mode was instrumental in reducing negative lift by preventing the formation of strong LEVs during the upstroke. The aerodynamic analysis also established the effect of each mode on the aerodynamic angle of attack and the strong correlation between lift generation and the effective angle of attack.

Danesh Tafti is the William S. Cross Professor in the Department of Mechanical Engineering at Virginia Tech. He obtained his Ph.D. from the Mechanical Engineering Department at Penn State University in 1989. After two years of post-doctoral work he joined the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign, where he held positions of Research Scientist, Senior Research Scientist, and Associate Director. He joined the Mechanical Engineering Department at Virginia Tech in 2002 where he directs the High Performance Computational Fluid-Thermal Science and Engineering Lab. In 2009, he was named the William S. Cross Professor of Engineering. He has served as the Chair of the departmental promotion and tenure committee from 2008-2012 and as the Interim Department Head from 2014 to 2015. His research interests are in high-end, multiscale, multiphysics simulations of single and multiphase systems in the broad areas of propulsion, energy and biological systems. He has over 220 peer reviewed publications to his credit and has given several invited, keynote, and plenary lectures at national and international conferences. He is a Fellow of ASME, Associate Editor of ASME J. Heat Transfer and editorial board member of the Int. J. Heat and Fluid Flow.