From Beating Hearts to Flapping Fins: Insights into Biological Flows Powered by High-Fidelity Immersed Boundary Methods

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ABSTRACT:

The continuous growth in computing power coupled with new computational algorithms and data-enabled methods, is opening up exciting areas for research and discovery at the intersection of fluid dynamics and biology. Consider the mammalian heart, which has been sculpted by millions of years of evolution into a flow pump par excellence. During the typical lifetime of a human, the heart will beat over three billion times and pump enough blood to fill sixty Olympic-sized swimming pools. Each of these billions of cardiac cycles is itself a manifestation of a complex and elegant interplay between several distinct physical domains including hemodynamics, electrophysiology, muscle mechanics, flow-induced valves dynamics, acoustics, and biochemistry. In the arena of biolocomotion, fish are known to employ their highly flexible bodies and fins to extract energy from vortices and propel themselves in water with grace and efficiency that is the envy of all engineers. The buzzing of mosquitoes might be annoying to us, but the lifecycle of these insects is intimately tied to the generation of aeroacoustic wing-tones in ways that we do not yet understand. Previous investigations of such problems were often limited by the tools at hand, but modern computational tools are enabling the exploration of such multi-physics problems with a level of fidelity and precision that is unprecedented. In my talk, I will describe how the power of high-fidelity sharp-interface immersed boundary methods has enabled us to attack problems ranging from the chemo-fluidics of clot formation in the heart and aeroacoustic sound generation by flying insects, to the hydrodynamic mechanisms that schooling fish may exploit to increase thrust and efficiency.

BIOGRAPHY:

Rajat Mittal is Professor of Mechanical Engineering at the Johns Hopkins University with a secondary appointment in the School of Medicine. He received the B. Tech. degree from the Indian Institute of Technology at Kanpur in 1989, the M.S degree in Aerospace Engineering from the University of Florida, and the Ph.D. degree in Applied Mechanics from The University of Illinois at Urbana-Champaign, in 1995. His research interests include computational fluid dynamics, vortex dominated flows, biomedical engineering, biological fluid dynamics, fluid-structure interaction, and flow control. He has published over 200 technical articles on these topics and holds multiple patents in associated technologies. He is the recipient of the 1996 Francois Frenkiel and the 2022 Stanley Corrsin Awards from the Division of Fluid Dynamics of the American Physical Society (APS), and the 2006 Lewis Moody as well as 2021 Freeman Scholar Awards from the American Society of Mechanical Engineers (ASME). He is a Fellow of ASME and the American Physical Society, and an Associate Fellow of the American Institute of Aeronautics and Astronautics. He is an associate editor of the Journal of Computational Physics, Frontiers of Computational Physiology and Medicine, the Journal of Experimental Biology, and the International Journal for Numerical Methods in Biomedical Engineering.