Abstract for an Invited Paper
for the DFD08 Meeting of
The American Physical Society

The “upstream wake” of swimming and flying animals revealed by Lagrangian coherent structures

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The interaction between swimming and flying animals and their fluid environments generates downstream wake structures such as vortices. In most studies, the upstream flow in front of the animal is neglected. In this study, we use Lagrangian coherent structures (LCS) to demonstrate the existence of upstream fluid structures even though the upstream flow is quiescent or possesses a uniform incoming velocity. Using a computational model, the flow generated by a swimmer (an oscillating flexible plate) is simulated and an LCS analysis is applied to the flow to identify the upstream fluid structures from the forward finite-time Lyapunov exponent (FTLE) field. These upstream structures show the exact portion of fluid that is going to interact with the swimmer. A mass flow rate is then defined based on the upstream structures and a metric for propulsive efficiency is established using the mass flow rate and the kinematics of the swimmer. We propose that the unsteady mass flow rate defined by the ‘upstream wake’ can be used as a metric to measure and objectively compare the efficiency of locomotion in water and air. In collaboration with Jifeng Peng, Graduate Aeronautics Laboratories and Bioengineering.