Measuring Oscillatory Velocity Fields Due to Swimming Algae

Jeffrey S. Guasto
Haverford College

Karl A. Johnson
Haverford College

Jerry P. Gollub
Haverford University; University of Pennsylvania, jgollub@haverford.edu

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Abstract
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Keywords
biomechanics, cellular biophysics, flow measurement, fluid oscillations, hydrodynamics, microorganisms, propulsion, suspensions, velocity measurement

Disciplines
Biomechanics | Physical Sciences and Mathematics | Physics

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Measuring oscillatory velocity fields due to swimming algae

Jeffrey S. Guasto,1 Karl A. Johnson,2 and J. P. Gollub1,3
1Department of Physics, Haverford College, Haverford, Pennsylvania 19041, USA
2Department of Biology, Haverford College, Haverford, Pennsylvania 19041, USA
3Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA

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Single cells exhibit a diverse array of swimming strategies at low Reynolds number to search for nutrients, light, and other organisms. The fluid flows generated by their locomotion are important to understanding biomixing and interactions between cells in suspension. In the accompanying video (and supplementary material), we show that even the most common of propulsion mechanisms can result in surprisingly complex hydrodynamics. In particular, we study the oscillatory flows produced by the biflagellated green alga Chlamydomonas reinhardtii, which swims with a mean speed of 130 \( \mu m/s \) by beating its flagella with specific wave forms at 50 Hz.

The 8 \( \mu m \) unicellular microorganisms are confined to a 15 \( \mu m \) thin free-standing liquid film, which creates a quasi-two-dimensional environment for clear observation, and 1 \( \mu m \) particles are added to the cell suspension as flow tracers. The cells and tracers are tracked simultaneously using high-speed video microscopy (500 fps, 40\( \times \)) to measure the instantaneous velocity fields generated during the beat cycle of the cells (20 ms period). Figure 1 shows a time series of the flow field with instantaneous streamlines (red) and velocity vectors (blue, log scale), with the cell always shown at the center of the diagram, moving to the right.

Early in the power stroke, the velocity field resembles a force dipole, which differs significantly from the time-averaged flow field over the beat cycle\(^{1,2} \) [Fig. 1(a)]. The peak of the power stroke occurs when the flagella are extended perpendicular to the swimming direction [Fig. 1(b)]. As the power stroke is completed, the vortices posterior to the organism shift toward the anterior [Figs. 1(c)–1(e)]. At the peak of the recovery stroke, the flow field is again reminiscent of a dipole, but with opposite sign [Fig. 1(f)], before the cycle begins again. Such measurements of cell-generated flows are an important step in understanding the mechanics of single cells and the transport properties of active media. This work was supported by NSF Grant DMR-0803153.