Low Reynolds Number Locomotion

Though there a number of mechanisms used for locomotion in the small animal world, the following sections will focus on the fluid motions produced by the long, thin organelles called cilia and flagella. In many circumstances the oscillatory motions of cilia and flagella produce a mean translational motion and, in consequence, it is important to define two Reynolds numbers, one for each kind of motion. The Reynolds number defined by the propulsive velocity, U, and the typical dimension of the organism L is UL/ν where ν is the kinematic viscosity of the organisms liquid environment; values range from 10^{-6} for many bacteria to about 10^{-2} for spermatozoa, and most of the organisms considered here lie within this range. Equally important is an oscillatory Reynolds number, Re, based on the radian frequency of beating of the organelle, ω, and the typical length of that organelle, ℓ, ($Re = \omega\ell^2/\nu$); typical values of this quantity are about 10^{-3}. Thus the fluid motions that result are dominated by viscous forces and the inertial forces usually play little part in the mechanics. Of course there exist organisms in all ranges of Reynolds number, but the difficulties in the fluid-mechanical analyses when the Reynolds numbers approach unity are such that little quantitative work has as yet been done for natural swimming in this regime. In other sections, (Blc), (Bld) and (Ble), we reviewed the fluid flow tools that are used to analyze the low Reynolds number flows associated with the hydromechanics of cilia and flagella and the reader is encouraged to review these sections before proceeding with the sections which follow.

Hancock (1953) seems to have been the first to attempt to use linear superposition of the Stokes flow singularities [permissible because the basic equations for Stokes flow are linear] in order to construct the fluid mechanics of flagellated microorganisms; his classic work with Sir James Gray (Gray & Hancock 1955) remains a landmark in this respect for both biologists and fluid dynamicists. These works are the forerunners of slender-body theory and resistive-force theory as applied to microorganism locomotion.

In the sections which follow we deal first in section (Dff) with the mechanisms that prokaryotic organisms use to propel themselves though the fluid mechanical analyses of these locomotions is appropriately delayed until section (Dfg) which focuses on the various flagellar mechanisms used by eukaryotes and prokaryotes. Section (Dfh) completes the microorganism sections with a description and analyses of ciliary systems for propulsion.