Passive swimming in low Reynolds number flows

P. Olla*

The possibility of microscopic swimming by extraction of energy from an external flow is discussed, focusing on the migration of a simple trimer across a linear shear flow. The geometric properties of swimming, together with the possible generalization to the case of a vesicle, are analyzed. The mechanism of energy extraction from the flow appears to be the generalization to a discrete swimmer of the tank-treading regime of a vesicle. As illustrated in the figure below, the swimmer takes advantage of the external flow by both extracting energy for swimming and "sailing" through it. The migration velocity is found to scale linearly in the stroke amplitude, and not quadratically as in a quiescent fluid. This effect turns out to be connected with the non-applicability of the scallop theorem in the presence of external flow fields.

*ISAC-CNR and INFN, Sez. Cagliari, I–09042 Monserrato, Italy

1P. Olla, Phys. Rev. E 82, 015302(R) (2010)

Figure 1: Swimming strategy in a plane shear flow $\mathbf{U} = (0, \alpha X_1, 0)$. The $X_1$ and $X_2$ axes in the laboratory frame point respectively to the right and upwards. The swimmer rotates passively in the shear flow and is transported upwards or downwards depending on its horizontal position (coordinates in rotating frame indicated by small case). At the same time it undergoes deformations that can be induced in principle exploiting the external flow. When the trimer reference frame is oriented at $\pi/2$ with respect to the laboratory frame (left), arm 23 contracts. This maximizes the drag along $X_1$ by bead 1’s Stokeslet field (continuous line). The opposite occurs when the trimer is oriented at $-\pi/2$ (right). The end result, after a complete rotation, is a net displacement transverse to the left; transverse therefore to $\mathbf{U}$. Dashed lines identify the strain component of $\mathbf{U}$. 