“Scalloping” with friends

Zoppello MARTA, Politecnico di Torino - Torino

Inertialess hydrodynamics is notorious for its time-reversibility constraints. Reciprocal motion is unable to produce net propulsion, as per the celebrated Scallop Theorem [3] : a scallop, composed of two rigid rods hinged at one extremity, cannot go anywhere in an inertialess fluid by performing a periodic motion. In nature, microorganisms exploit a variety of swimming strategies to break time-reversibility in the system. One way is to increase the number of swimmers : two scallops swimming together can in fact produce net propulsion. In this case, non-local hydrodynamic interactions induce an unequal distribution of momentum on each swimmer in such a way that time-reversibility of the ensemble is broken, thus both scallops are able to swim despite their individual reciprocal motion. In this work, we explore the controllability of two inherently non-controllable units by exploiting the non-local nature of their mutual interaction. More precisely our model rely on Resistive Force Theory [1], which is a good approximation of hydrodynamic forces at low Reynolds number for slender swimmers, even interacting ones [2], and allows us to cast the equations of motion as ODEs. These equations can be seen as control systems where the controls are the velocity of deformation of the swimmers.
Even if the coupled swimmers taken singularly are non-controllable units, we prove that taking into account the hydrodynamic interaction they can achieve a net motion after a periodic sequence of shape changes. Moreover, under suitable approximations we are able to optimize the displacement [4].

[1] J. Gray, G. J. Hancock. *The propulsion of sea-urchin spermatozoa.* Journal of Experimental Biology, **32**, 1955.

[2] Y. Man, L. Koens, E. Lauga. *Hydrodynamic interactions between nearby slender ?laments.* EPL, **116**, 2016.

[3] E. M. Purcell. *Life at low reynolds number.* American Journal of Physics, **45**, 1977.

[4] M. Zoppello, M. Morandotti, H. B. Gadhéla. *Controlling non-controllable scallops.* Submitted, 2022.

Contact : `marta.zoppello@polito.it`