Low-order models of swimming in an inviscid fluid

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The net locomotion of a deformable body submerged in an infinite volume of fluid depends critically on the dynamic coupling between the body shape deformations and the unsteady motion of the surrounding fluid. A mathematical description of this coupling at finite Reynolds numbers would require taking into account the detailed effects of viscosity which are primarily manifested in the dynamics of the thin shear layers around the body that separate at the body tail to create vortical structures. The classical studies of Wu and Lighthill addressed this problem in two different ways. Wu considered a *planar* deformable plate swimming in an inviscid fluid and used the assumption of small shape amplitudes which enables one to solve for the trailing vortex sheet analytically and investigate the problem of optimum shape deformations in the sense of minimizing the energy lost in creating the trailing wake, [1]. Lighthill, on the other hand, studied the swimming of a *slender* body due to large amplitude deformations and avoided solving for the complex wake dynamics by considering the momentum balance in a control volume containing the deformable body and bounded by a plane attached at its trailing edge, [2].

In this talk, we present a derivation of the laws governing the swimming of a deformable body in response to prescribed (actively controlled) shape deformations and the effect of the wake vorticity, [3]. The underlying balance of momenta, though classical in nature, provide a unifying framework for the swimming of planar and three-dimensional bodies and they hold even in the presence of viscosity. When applied to the swimming of slender bodies, the derived equations can be viewed as a generalization of Lighthill's slender body theory. When neglecting vorticity, the derived equations reduce to a known model for the locomotion of an articulated body in potential flow. We examine locomotion in potential flow through a number of examples. In one class of examples, we compute the locomotion gaits due to, both flapping and undulating, shape deformations and investigate *distance-optimal* deformations for the corresponding body geometries, [3], [5,6]. In another class of examples, we consider a rigid body interacting dynamically with surrounding point vortices and we demonstrate that the rigid body can *swim* in the direction opposite to the motion of point vortices at no energy cost, [4].

References

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