Influence of caudal fin elasticity on swimmer propulsion

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Abstract: The aim of this study is to estimate the influence of caudal fin elasticity on swimmer propulsion. The swimmer paradigm is a simplified fish model where the fins are limited to a caudal one. This caudal fin can be either solid or elastic. The fin spine elasticity is modeled by lumped spring and dampers. The effect of the elasticity will be shown on 2D or 3D self propelled fishes.

Keywords: Swimmers, Cartesian mesh, Immersed Boundary, elasticity.

The 3D fish shape is composed by a series of ellipses centered on a discretized midline with two axis prescribed using B-Splines (to mimic a realistic fish, see fig. 1). The motion of the fish is composed of the rigid velocity computed from the flow forces and torques exerted onto the body, plus a deformation velocity. The deformation velocity is obtained deforming the midline in a plan (x, y). This deformation is usually imposed on the whole midline ("the solid" tail) [2, 1]. The deformation can also be imposed on the midline excluding the caudal tail. The motion of the caudal tail midline (a chain with links) can be computed as spring/damping system at each link. The variables are the rotation angle of each links with respect the previous one. The ODEs system is derived from hamiltonian mechanics. This ODEs system is then coupled with a flow model. The flow is modeled thanks to the incompressible Navier-Stokes equations. These equations are numerically discretized in space onto a fixed cartesian mesh that allows easy massive parallelization. The curvilinear fish boundary does not fit *a priori* the fluid mesh. This boundary is thus taken into account using a discrete sharp interface immersed boundary method [4, 5]. The temporal discretization is performed thanks to a fractional step method based on a Chorin scheme [3].

There are several ways to estimate the swim efficiency as the propulsive index [1] or the propulsive efficiency [6]. In this study we chose to characterize the efficiency using the propulsive efficiency.

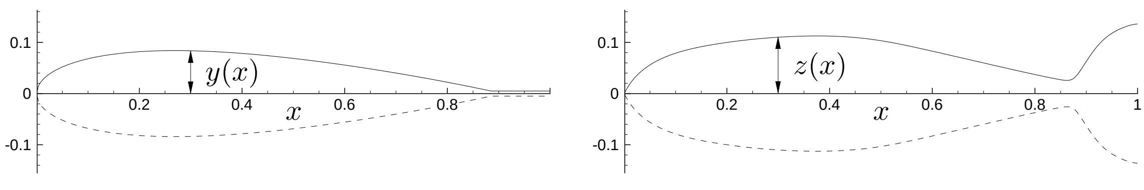

Figure 1: Representation of the ellipse axes $y(x)$ and $z(x)$ defining the fish shape.

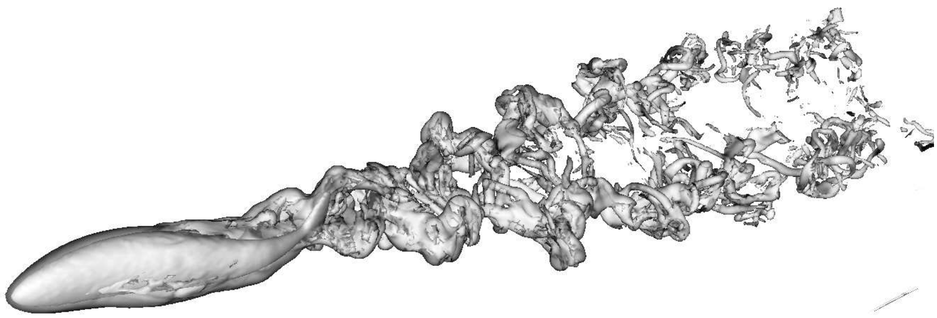

Figure 2: Iso-vorticity representation of the wake for $Re = 10^4$

Figure 2 shows the isovorticity reresentation of the wake generated by fish at Reynolds number 10^4. This correspond to small fish with length $10\,cm$ swimming at around one body length per second. The efficiency for the "solid deformation" is around 50%. The next step is to investigate if an elastic tail, obtained by a simple discrete model, can improve the efficiency for the same swimming law.

References

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