The Virtual Aquarium: Simulations of Fish Swimming

M. Curatolo[1], L. Teresi[2]
[1]Roma Tre University, Dept. Engineering, Italy
[2]Roma Tre University, Dept. Mathematics and Physics, Italy

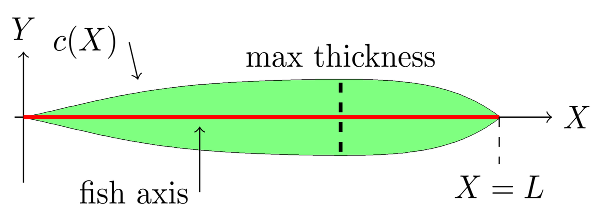
Introduction

Our goal is to reproduce the key features of carangiform swimming (1) by running 2D simulations which fully exploit the Fluid-Structure Interaction interface of COMSOL.

We simulate muscles contraction by using the notion of distortions (aka pre-strains), emphasizing the kinematical role of muscle, the generation of movement, rather than the dynamical one, the production of force (2). State variables are the displacement of the fish-like solid (material field), and the velocity of the fluid (spatial field).

Swimming Style

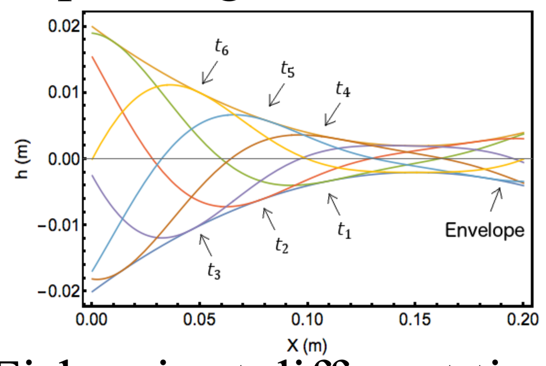
The swimming style is defined by a pattern of muscles activation, tuned both in space and in time. We first assign the transversal displacement of the axis h(X,t), and then compute the corresponding muscle-driven distortions.



Fish-like body

$$E^{o}_{XX} = -\frac{\partial^2 h}{\partial X^2} Y$$

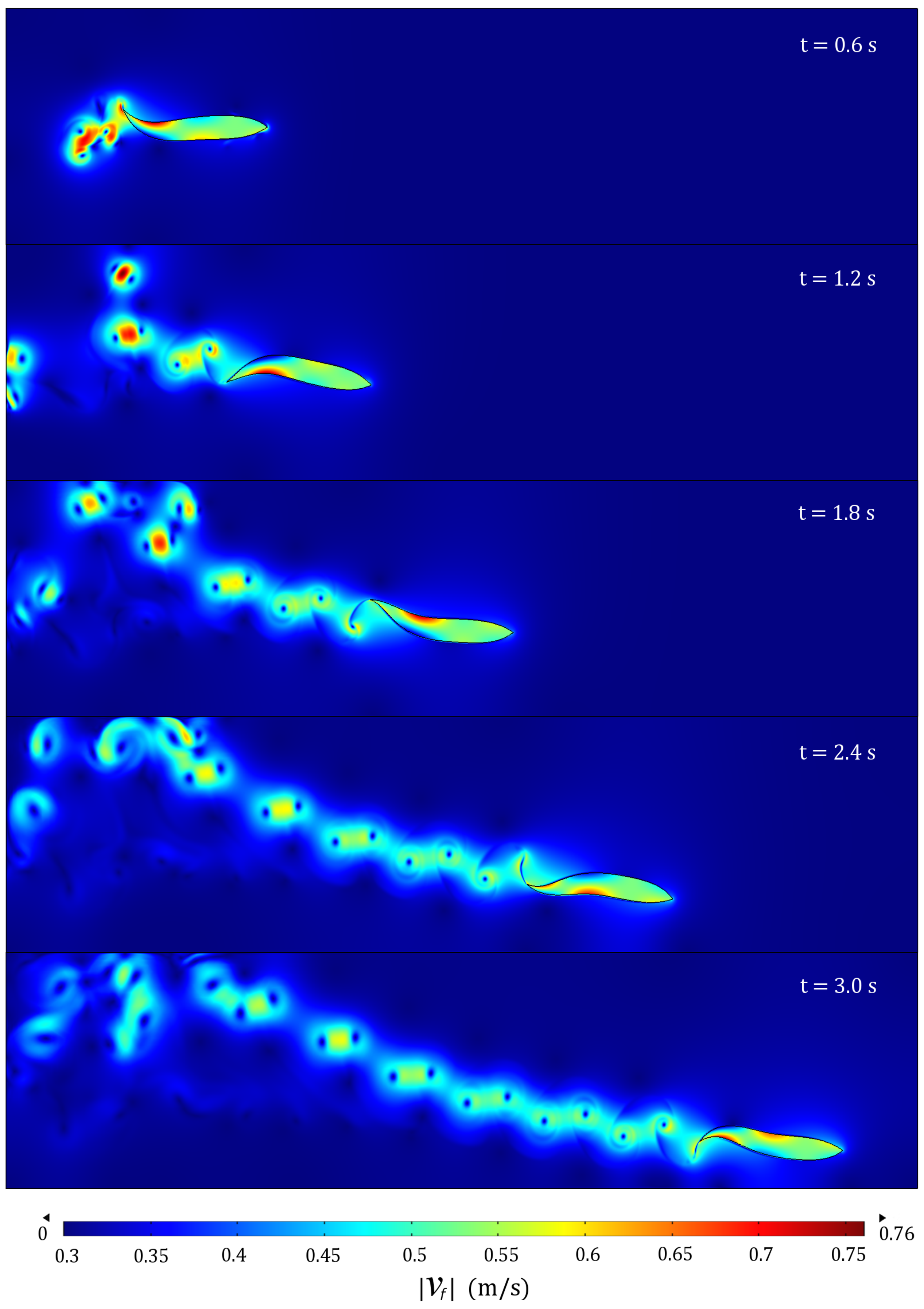
Distortion field

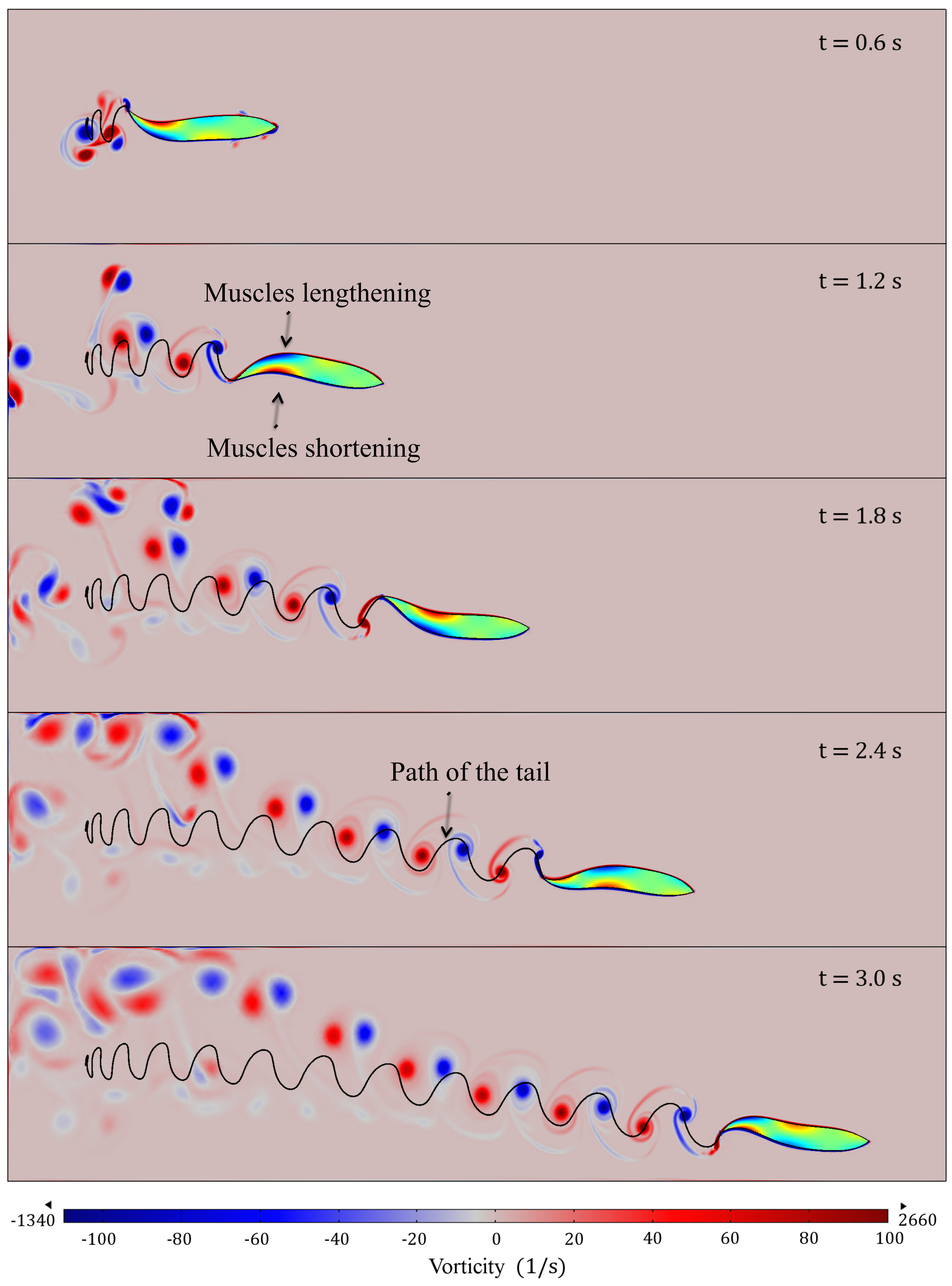


Fish axis at different times

Results

In carangiform swimming, muscles contract with a wave-like pattern running from head to tail; fish tail acts like a propeller, generating a localized thrust wake with an observable momentum jet (3). The mutual distances between the cores of the vortices do not change.

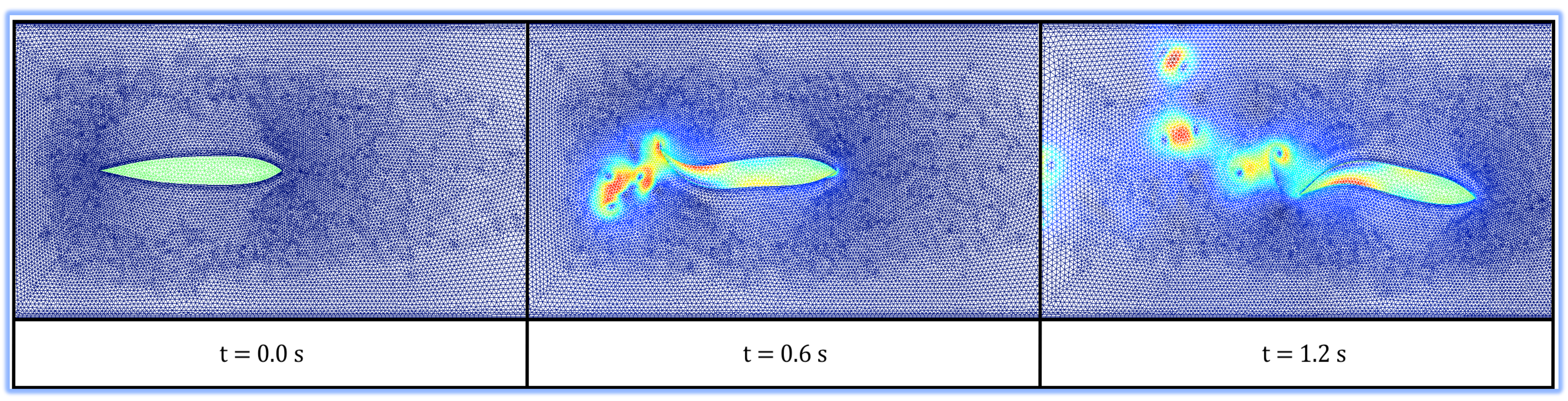


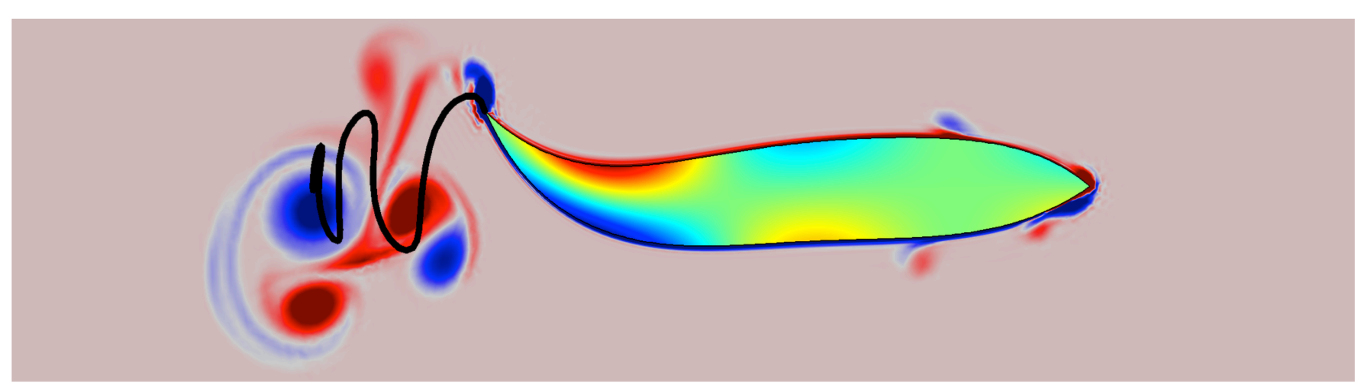


Snapshots of fish swimming with fluid velocity (left) and vorticity (right); muscles stroke (red colored) bends the fish and produces the swimming thrust. A long wake lies behind the fish.

Computational Methods

We need both moving mesh to solve the FSI for short time intervals, and re-meshing to track the long swimming path we aim at simulating. Left: evolution of mesh during swimming; Right: wake generation at onset of swimming (t=0.6 s).





References:

1. J. J. Videler. Fish Swimming, Springer-Science+Business Media, B.V. (1993).
2. P. Nardinocchi, L. Teresi. On the Active Response of Soft Living Tissuess, J. Elasticity n.88:27–39 (2007).
3. G.V. Lauder, P.G.A. Madden. Learning from Fish: Kinematics and Experimental Hydrodynamics for Roboticists, Int. J. Automation and Computing, n.4:325-335 (2006).