"Coupling a vortex particle-mesh method to a multi-body system solver for the simulation of articulated swimmers"

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ABSTRACT

Flow control is a key, challenging aspect in a plethora of fluid mechanics applications. In this light, aquatic swimmers represent a system of great interest from a theoretical and engineering perspective. Indeed, fish have learned to master the surrounding liquid environment through the passive and active actuation of their compliant bodies, bending to their needs the very topological and turbulent nature of the flow. This prompted the investigation of a number of bioinspired solutions ranging from pulsatile propulsion to aeroelastic and stall delaying mechanisms. To this end, we present a hybrid approach that combines a Vortex Particle-Mesh (VPM) method to a Multi-Body System (MBS) solver for the characterization of aquatic locomotion at intermediate Reynolds numbers.

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COUPLING A VORTEX PARTICLE-MESH METHOD TO A MULTI-BODY SYSTEM SOLVER FOR THE SIMULATION OF ARTICULATED SWIMMERS

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Key words: Vortex Particle-Mesh method (VPM), Flow-Structure Interaction (FSI), Biomimetic Propulsion, Multi-Body Systems (MBS)

Flow control is a key, challenging aspect in a plethora of fluid mechanics applications. In this light, aquatic swimmers represent a system of great interest from a theoretical and engineering perspective. Indeed, fish have learned to master the surrounding liquid environment through the passive and active actuation of their compliant bodies, bending to their needs the very topological and turbulent nature of the flow. This prompted the investigation of a number of bioinspired solutions ranging from pulsatile propulsion to aeroelastic and stall delaying mechanisms. To this end, we present a hybrid approach that combines a Vortex Particle-Mesh (VPM) method to a Multi-Body System (MBS) solver for the characterization of aquatic locomotion at intermediate Reynolds numbers.

Typically Fluid-Structure Interaction (FSI) problems have been handled by finite volume and finite element methods through arbitrary Lagrangian-Eulerian techniques \[\text{[1]}\]. Here, a moving fitted mesh tracks the solid-fluid boundaries and the governing equations for the solid and the fluid are solved separately. However, this approach is inherently problematic when large deformations or multiple bodies are accounted for, since costly mesh reinitializations are required to prevent computational elements distortion. A possible alternative technique relies on Vortex Particle method in combination with vortex sheets to account for the flow-solid interaction \[\text{[2]}\]. Although mathematically appealing, this method entails large computational cost to guarantee the convergence and consistency between fluid and body forces.

The present work relies on (i) a penalization method, which handles the solid and the fluid in a unified and continuous manner, and (ii) a reprojection method, which physically captures the solid-flow transfer of linear and angular momentum. This approach has been implemented and demonstrated in a previous work where VPM methods were employed...
to capture the incompressible viscous flow physics [3]. By characterizing swimming gaits via prescribed kinematics, it produced benchmark results for eel-like swimmers both in two and three dimensions.

Here, we extend the two dimensional methodology proposed in [3] by treating the swimming body as a simplified MBS, whose deformations are dictated by hydrodynamic forces and actuation torques. The body is composed of N elliptical sections linked by massless rotational joints (Fig 1). By means of the reproduction step we compute the hydrodynamic torques acting on the joints. A classical fourth-order Runge-Kutta method is then used for the time integration of the multi-body dynamics equations expressed in relative coordinates through the Euler-Lagrange formalism [4]. The resulting deformation is then used within the penalization step to enforce rigid motions inside the body.

The following approach is assessed on the three-links swimming agent benchmark test presented by Kanso et al. [5] and Eldredge [2].

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