A fluid-structure interaction solver for the study of the propulsion of a passively deformed fish fin

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ABSTRACT

The three-dimensional fluid-structure interaction of the flexible fins and/or bodies is common in the swimming of aquatic animals, but accurate and efficient numerical methods for simulating such phenomenon are still limited in literature. In this paper, to investigate the propulsion performance of a caudal peduncle-fin locomotor, which is inspired by a biomimetic robotic caudal fin presented by (Ren et al., 2016), a fluid-structure interaction (FSI) solver is developed by combining our in-house finite volume method based fluid code (Liu et al., 2016) and a three-dimensional structural finite element solver CalculiX (Dhondt, 2004). Their coupling is achieved in a partitioned approach via preCICE (Bungartz et al., 2016), a coupling library for partitioned multi-physics simulations. Two benchmark studies including a flexible beam in the wake of square cylinder and a flapping flexible plate are conducted to validate the proposed multi-physics numerical tool.

In the present work, a caudal peduncle-fin swimmer whose biological template is the Bluegill Sunfish is modeled. The model consists of a rigid peduncle and a flexible fin which pitches in a uniform flow. The flexible fin is modeled as a thin plate assigned with non-uniformly distributed stiffness. The numerical results indicate that the compliance has a significant influence on the performance. Under the parameters studied in this work, the medium flexible fin exhibits remarkable efficiency improvement as well as thrust augment, while the least flexible fin shows no obvious difference from the rigid one. However, for the most flexible fin, although the thrust production decreases sharply, the efficiency reaches the maximum value. Similar wake flows between our simulations and the obtained experimental results (Esposito et al., 2012) using digital particle image velocimetry (DPIV) techniques are observed. It is be noted that by non-uniformly distributing the rigidity across the caudal fin, our model is able to replicate some fin deformation patterns observed in both the live fish and the experimental robotic fish.

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