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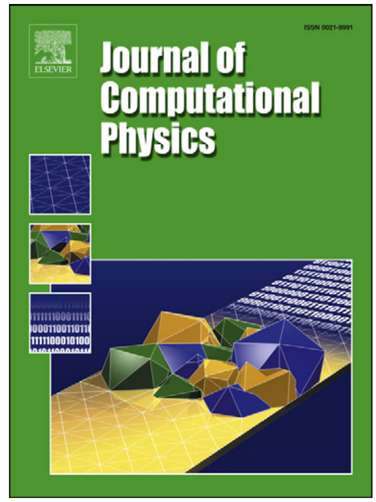

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Numerical Simulation of Fluid-Structure Interaction with the Volume Penalization Method

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Abstract

We present a novel scheme for the numerical simulation of fluid–structure interaction problems. It extends the volume penalization method, a member of the family of immersed boundary methods, to take into account flexible obstacles. We show how the introduction of a smoothing layer, physically interpreted as surface roughness, allows for arbitrary motion of the deformable obstacle. The approach is carefully validated and good agreement with various results in the literature is found. A simple one dimensional solid model is derived, capable of modeling arbitrarily large deformations and imposed motion at the leading edge, as it is requiblack for the simulation of simplified models for insect flight. The model error is shown to be small, while the one dimensional character of the model features a reasonably easy implementation. The coupled fluid–solid interaction solver is shown not to introduce artificial energy in the numerical coupling, and validated using a widely used bechmark. We conclude with the application of our method to models for insect flight and study the propulsive efficiency of one and two wing sections.

Keywords: Fluid-structure interaction, Insect flight, Volume-penalization method, Spectral method

1. Introduction

The numerical simulation of fluid-structure interaction is of fundamental interest in computational fluid dynamics (CFD) given the challenging applications encounteblack, for example the numerical simulation and optimization of insect flight, swimming fish or sailing boats.The fluid can deform the solid, which in turn alters vortical structures, and vice-versa. The key feature is thus that the fluid-solid interface is not known a priori, but rather is a part of the solution itself. Some systems can be simplified by considering rigid solid bodies, a rather strong simplification that still proves to be challenging by its own, if the obstacle moves or features a complicated shape. Aside from the experimental approach, the method of numerically solving the coupled problem proved suitable for a large variety of problems, from swimming fish [1, 2], flying insects [3, 4] to parachutes [5, 6].

The time-varying interface in fluid-structure interaction (FSI) problems is more than an ingblackient to be added to existing codes; it rather requiblack developing entirely new tools, especially if large deformations are involved, which is the case in the present work. A broad classification of FSI algorithms can be made either by the coupling of fluid and solids, where

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