NUMERICAL INVESTIGATION OF AQUATIC LOCOMOTION WITH CEPHALOPOD-LIKE APPENDAGES

Asimina Kazakidi[1], Dimitris P. Tsakiris[1,*], Fotis Sotiropoulos[2], John A. Ekaterinaris[1,3]

[1] Foundation for Research & Technology - Hellas, Greece;

[2] University of Minnesota, USA; [3] University of Patras, Greece

Abstract

Aquatic locomotion, with the use of cephalopod-like appendages, was investigated with computational fluid dynamics simulations. Two numerical approaches, the immersed boundary (IB) and a finite volume (FV) body conforming method were compared in order to find the mesh requirements for deforming geometries and forced motions. The objective of this work is to validate and exploit the generality of the IB approach to complex locomotion simulations.

Introduction

The appendages of cephalopods (i.e., the arms and tentacles of squids and cuttlefish, the octopus arms, and the nautilus tentacles) are muscular hydrostats, composed of a tight 3D musculature of constant volume [Kier, 1985]. In addition to jet propulsion, cephalopods may use their arms and, for squids and cuttlefish, also their fins [Anderson, 2000], to escape quickly. We are interested in the individual role of the arms in aquatic locomotion [Sfakiotakis, 2012], which has not been investigated in detail.

Methods

Cephalopod appendages can perform a wide variety of flexible and agile movements and, therefore, the main difficulty in numerical flow simulations around such time-varying geometries is that the computational mesh must deform over time, following the motion of the body (*body-fitted methods*). Large grid deformations, however, are difficult to perform without re-meshing and may affect the stability and accuracy of the numerical scheme [Thomas, 1979]. An alternative approach, which has attracted much attention in recent years, is the use of *fixed-grid methods*, in which a moving (immersed) boundary is defined on a stationary, fluid computational domain [Peskin, 1972]; thus, these immersed boundary (IB) methods are capable of handling arbitrarily large deformations. Here, we used both approaches, to determine the mesh requirements for capturing the boundary layer.

Results

A right circular conical frustum with an aspect (length to mean-diameter) ratio of ~18:1, a taper (length to base-diameter) ratio of ~10:1 and two rows of cylindrical suckers, was used in the simulations for movements in quiescent fluid. The flow field is governed by the incompressible Navier-Stokes equations. Numerical simulations were carried out with a finite-volume method (Fluent, ANSYS, Canonsburg, PA) and an immersed-boundary method [Ge, 2007]. Figure 1 displays a cross-correlation case between the two methods, of a solid-body oscillatory motion.

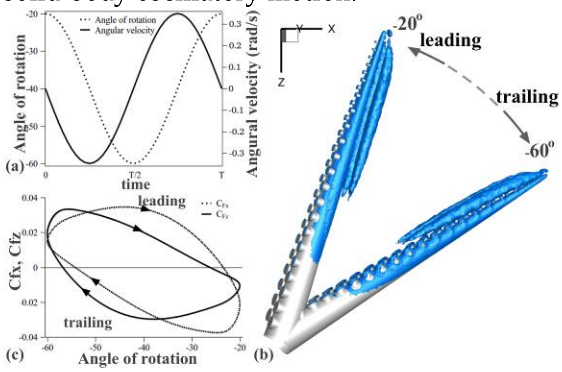

Figure 1: (a) Motion profile. (b) Instantaneous iso-contours. (c) C_{Fx} and C_{Fz} force coefficients.

Discussion

Aiming at a computation tool able to model intense motions, as found in aquatic locomotion instances, two numerical methods were compared. The immersed boundary method demonstrates its suitability for handling such motions. We aim to further adjust this method for special flow characteristics of time-varying geometries under complex prescribed motions.

References

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