Advances in Applied Mathematics and Mechanics
Adv. Appl. Math. Mech., Vol. **6**, No. 3, pp. 307-326

DOI: 10.4208/aamm.2013.m409
June 2014

A Numerical Study of Jet Propulsion of an Oblate Jellyfish Using a Momentum Exchange-Based Immersed Boundary-Lattice Boltzmann Method

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Received 19 November 2013; Accepted (in revised version) 17 January 2014

Available online 21 May 2014

Abstract. In present paper, the locomotion of an oblate jellyfish is numerically investigated by using a momentum exchange-based immersed boundary-Lattice Boltzmann method based on a dynamic model describing the oblate jellyfish. The present investigation is agreed fairly well with the previous experimental works. The Reynolds number and the mass density of the jellyfish are found to have significant effects on the locomotion of the oblate jellyfish. Increasing Reynolds number, the motion frequency of the jellyfish becomes slow due to the reduced work done for the pulsations, and decreases and increases before and after the mass density ratio of the jellyfish to the carried fluid is 0.1. The total work increases rapidly at small mass density ratios and slowly increases to a constant value at large mass density ratio. Moreover, as mass density ratio increases, the maximum forward velocity significantly reduces in the contraction stage, while the minimum forward velocity increases in the relaxation stage.

AMS subject classifications: 60-08, 65C20, 68U20
Key words: Lattice Boltzmann method, immersed boundary method, momentum exchange, oblate jellyfish, locomotion.

1 Introduction

It has been generally known that researching fluid-structure-interaction (FSI) problems are become more and more important in engineering applications and biology kinematics. In mechanical engineering, in order to well design the devices (such as aircraft, heart

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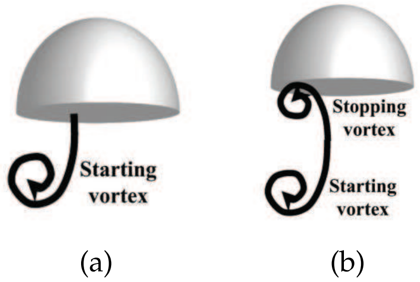

Figure 1: Schematic of a jetting medusa with vortex rings in the wake [17].

valves, pumps, etc.), fluid-structrue-interaction phenomenas, that play a key role in the dynamic stability of structure, should be required the consideration. Otherwise, the devices can be broken because of the negligence of FSI oscillations. In civil engineering, the FSI investigations should be done as well. Failing to consider the effects of FSI oscillations, many civilian projects (such as bridges, dams, Marine platform etc.) would perhaps lead to disastrous consequences. In biology kinematics, the dynamics of many motions are due to the force generated by FSI (On a macroscopic scale, such as swimming fish, flying birds, falling leaves, and so on. On a mesoscopic scale, including swimming sperms inside the body liquid, red cells in blood, etc.). Where, FSI phenomenas can become more complicated, since the structures are often deformable and involving self motion. The research of motion principle of creatures is significant in military and civil application. For example, the study of insect's flight ability is essential for design of micro air vehicles; Swimmer can benefit from the swimming fish; and so on. In present paper, the research subject is swimming jellyfish to provide an insight into the thrust mechanism.

In the past decades, there have been growing research interests on the dynamics of jellyfish owing to its not overly complex structures [1–17]. Based on intensive experimental investigations [2, 6, 13, 17], the fluid interactions and patterns of flow around the swimming jellyfish have been well described qualitatively. The swimming of the jellyfish depends upon rhythmic contraction and relaxation of their swimming bells. Jet propulsion, as a principal thrust-generating mechanism, is a commonly effective dynamics in the jellyfish swimming. Jet propulsion of the jellyfish generates starting vortex rings (see Fig. 1(a)) in their contraction and produces stopping vortex rings which rotate opposite to the starting vortices (see Fig. 1(b)) in their relaxation. Subsequently, the two kinds of vortex rings interact and develop to azimuthal instabilities as they propagate downstream, which pushes the jellyfish swimming forward. However, flow visualization studies [2, 3, 6, 11, 15] disclose that the jet-propulsion of the jellyfish with more oblate bell has a more complex wake pattern than those with more prolate bell. The kinematic comparison of the jellyfish bell contraction by four species of hydromedusae [16] indicates that the propulsion of the oblate jellyfish is fundamentally different from that of the prolate jellyfish: the oblate jellyfish contracts primarily near the bell margin, and produces a broader, lower velocity jet.

The quantitative characteristics of the flow surrounding of the jellyfish are likely to