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

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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.

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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...
valves, pumps, etc.), fluid-structure-interaction phenomena, 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 phenomena can become more
complicated, since the structures are often deformable and involving self motion. The re-
search 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 experi-
mental 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 propul-
sion, 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 down-
stream, which pushes the jellyfish swimming forward. However, flow visualization stud-
ies [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 com-
parison 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 pro-
late 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