Available online at www.sciencedirect.com
ScienceDirect
Journal of Hydrodynamics
2011,23(4):422-430
DOI: 10.1016/S1001-6058(10)60132-1
www.sciencedirect.com/science/journal/10016058

HYDRODYNAMICS OF A FLAPPING FOIL IN THE WAKE OF A D-SECTION CYLINDER*

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(Received June 13, 2011, Revised July 8, 2011)

Abstract: The water environment of swimming fish in nature is always complex which includes various vortices and fluctuations. In order to study the interaction between the fish and its surrounding complex flow, the physical model with a D-section cylinder placed at the front of a flapping foil is employed. The D-section cylinder is used to produce vortices to contact with the foil as well as the vortices shed from the foil. According to the experimental work of Gopalkrishnan et al., there are three interaction modes between vortices shed from the cylinder and the flapping foil, which are expanding wake, destructive interaction and constructive interaction. Here in this article, three of those typical cases are picked up to reproduce the vortices interaction modes with the modified immersed boundary methods and their hydrodynamic performances are studied further. Results show that, for expanding wake mode and destructive interaction mode, the incoming vortices contact with the foil strongly, inducing relative low pressure domains at the leading-edge of the foil and enlarging the thrust of foils. For constructive mode, the foil slalom between the shed vortices from the D-section cylinder do not contact with them obviously and the foil's thrust is only enlarged a little.

Key words: flapping foil, fish propulsion, vortices interaction, thrust enlargement

Introduction

Fish swimming in nature has many advantages such as high speed, high efficient, high maneuvering and low noise producing. Unlike traditional propeller based ship propulsion, fishes oscillate their body or fins to obtain thrust and swim forward and their outstanding propulsion performances are far beyond those of current manmade ships or underwater vehicles. Hence, studies on fishes' distinctive swimming abilities and their hydrodynamic mechanism may provide new ideas on ship design and illuminate the future of marine industry and human life.

A great amount of endeavor has been devoted to fish swimming studies in the past decades. Among these, there are two simple models to represent fish swimming, the travelling wave plate and the flapping foil (wing). Here in this article, the flapping foil model will be employed for study. The flapping foil (wing) undergoing a combined motion of heaving and pitching can be considered as a simple model of the caudal fin motion in the thunniform propulsion and has been well studied in the last two decades. In the 1980s, the wake structures of a plunging and pitching airfoil was captured in laboratories and the reversed Kàrmàn vortex street was observed when the foil owed thrust. An approbatory explanation of the flapping foil thrust is that an unsteady jet is formed behind the flapping foil and generates thrust acting on the foil. After that, the research group of Prof. Triantafyllou at Massachusetts Institute of Technology (MIT) conducted a series of experiments on the flapping foil. They first investigated the relationship between the flapping Strouhal (St) number and the foil propulsion performance. Flapping foil usually reach its maximum propulsion efficiency when its Strouhal number ranges from 0.25 to 0.35[1] and these results coincide with the fish swimming behavior in nature. They also systematically studied the propulsion performance of the two-dimensional flapping foil which includes the thrust owing mechanism[2], effects of each flapping parameter[3], effects of angles of attack[4] and performance

* Project supported by the National Natural Science Foundation of China (Grant No.10872181), the National Key Basic Research Program of China (973 Program, Grant No. 2009CB724303) and the Fundamental Research Funds for the Central Universities (Grant No. 2010QNA4015).
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