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NUMERICAL AND EXPERIMENTAL STUDIES OF INFLUENCE OF THE CAUDAL FIN SHAPE ON THE PROPULSION PERFORMANCE OF A FLAPPING CAUDAL FIN*

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Abstract: This article presents a comprehensive study of the effects of the caudal fin shape on the propulsion performance of a candal fin in harmonic heaving and pitching. A numerical simulation based on an unsteady panel method was carried out to analyze the hydrodynamic performance of flapping caudal fins of three shapes (the whale caudal fin with the largest projected area, the dolphin caudal fin with the median projected area, and the tuna caudal fin with the smallest projected area). Then, a series of hydrodynamic experiments for three caudal fin shapes were performed. Both computational and experimental results indicate that the tuna caudal fin produces the highest efficiency. However the mean thrust coefficient of the tuna caudal fin is the smallest. It is found that although the mean thrust coefficient for the tuna caudal fin is not large, the input power of the tuna caudal fin is also quite small. So the tuna caudal fin achieves a high efficiency.

Key words: flapping caudal fin, caudal fin shape, numerical simulations, hydrodynamic experiments, hydrodynamic performance

Introduction

Fish and cetaceans have an outstanding capability to produce high thrust efficiently. However, the traditional propulsion systems used in Unmanned Underwater Vehicles (UUVs) use usually screw propellers which would consume great deal of energy. Therefore, many kinds of bio-propulsion systems are considered to be used for UUVs. Among these bio-propulsion systems, the Body and Caudal Fin (BCF) mode is widely studied. The Vorticity Control Unmanned Underwater Vehicle (VCUUV)[1] developed by Anderson et al. from Massachusetts Institute of Technology uses a bio-propulsion system with a tuna caudal fin. Nakashima[2] from Tokyo Institute of Technology developed a bio-propulsion system with a dolphin caudal fin for a two joint UUV. The caudal fin shape plays an important role on bio-propulsion systems.

The effects of the foil shape on the hydrodynamic performance of a flapping-foil were much studied. The analysis of Liu and Bose[3] is based on the potential theory and their results indicate that a lunate flapping-foil is much more efficient than a rectangle flapping-foil. Numerical simulation results by Cheng et al.[4] based on a three dimensional waving model show that the lunate flapping-foil with large aspect ratio, span-wise tapering tip and moderate sweepback angle enjoys the best efficiency. The experimental results of Liu et al.[5] show that for the same area, the larger the aspect ratio and the sweepback angle, the larger the cruising speed of a flapping-foil will be. The experiments designed by Li and Yin[6] show that the mean thrust force on a bio-caudal fin is proportional to the product of the dimensionless second moment and the plan form area.

The propulsion performance of flapping-foils of three different shapes as often used in UUV is analyzed in the following two ways. First, the hydrodynamic performance of flapping-foils is numerically simulated for the three different shapes, that is, the tuna caudal fin shape, the dolphin caudal fin shape and the whale caudal fin shape, based on a three-dimensional potential

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