Numerical Study of Hydrodynamic Performance of a Hydrofoil with Vibration Trailing Edge

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Abstract. In order to study the influence of trailing edge vibration to the hydrodynamic performance of hydrofoil, the large eddy simulation and moving wall boundary condition methods were used to simulate the flow field of NACA66-mod hydrofoil with different trailing edge vibration amplitude (VA) and frequency. First, the numerical simulation methods are verified by comparing with experimental data. Then the flow field of hydrofoil was simulated to study the influence of vibration frequency and amplitude to hydrodynamic performance. The result shows that the vibration amplitude and frequency has significantly influence on the trailing edge vortex shedding. The intensity of the vortex increases rapidly with the vibration amplitude increasing. The lift and drag coefficients are influenced by the vibration amplitude and frequency.

1. Introduction
The hydrodynamic performance of ship propeller is a key indicator during the design process. So the hydrodynamic performance of the propeller had been paid more attention for a long time. Even if the hydrodynamic performance of propeller had been improved greatly recent years, we still had a limited understanding of the complex mechanisms involved in the interaction between propeller blade and fluid. When the propeller working underwater, the interaction between blade and fluid will causes the vibration of blade. The vibration of blade has much affection on the propeller hydrodynamic performance. So it is important to understand the interaction mechanism between the blade and fluid.

From the early 20th century, several analytical, experimental, and computational studies had investigated different aspects of oscillating foil. The theoretical explanation of thrust generation by an oscillating airfoil was first presented by Knoller [1] and independently by Betz [2] in the early 1900s. They noted that, during oscillating motion, an airfoil makes an effective angle of attack that results in a normal force vector with both lift and thrust components. In 1922, Katzymayr [3] was the first to experimentally verify the Knoller–Betz effect. Subsequently, several experiments have demonstrated the capability of an airfoil to generate thrust during oscillating motion. Lewin and Haj-Hariri [4] numerically studied the two-dimensional (2-D) viscous flow around a symmetric airfoil undergoing sinusoidal plunging motion. They found that the wake patterns strongly depend on the shedding of the leading-edge vortices and their interaction with trailing-edge vortices.

In this paper, first the numerical method was introduced. Then the flow field was calculated. Finally the effects of the vibration amplitude and frequency on the hydrodynamic performance were studied.
2. Numerical method
The unsteady flow field of a two dimensional NACA66-mod foil was simulated using the commercially available computational fluid dynamics package Fluent with an unsteady incompressible solver and second-order upwind spatial discretization. The Large eddy simulation method was used. The chord length of the hydrofoil is 150mm. The trailing edge is blunt. The moving wall boundary condition was applied to trailing edge region to control the trailing edge motion. The vibration amplitude of the wall was linear depending on the coordinate in the chord wise direction. The starting point of the vibration was located at 80% chord length and the rest parts were rigid wall, as shown in Fig.1. The sinusoidal moving motion of the hydrofoil is defined by the following equation:

\[ Y(t) / c = A(x - 0.8c) \sin(2\pi ft) \quad 0.8c \leq x \leq c \]  

(1)

Where c is chord length, f is vibration frequency, t is the time, A is the vibration amplitude.

The vibration amplitude is varied from 0.000067c to 0.0033c. The inflow speed is 10m/s and Re basing on the chord length is 1.5×10^6. The frequencies are 400Hz, 800Hz and 2000Hz.

The vibrating motion of the hydrofoil was modeled by the introduction of a source term in the flow governing equations. The vibration amplitude and frequency of the hydrofoil were controlled by Fluent User Defined Functions (UDF) scheme. The dynamic mesh technology was used to refresh the flow field mesh depending on the trailing edge wall vibration.

The whole computational domain is shown in Fig.2. The upstream is 5c and the downstream is 8c in the x direction. The O-type grid system is generated and the number of grid points used was 1000×140 (wall×normal).

3. Result and discussion
3.1. Numerical method validation
Large eddy simulation method is used to solve the flow field of a hydrofoil with rigid wall, and the numerical simulation results of pressure coefficients with different angle of attack are compared with experimental data [5], as shown in Fig.3. It can be seen that the numerical simulation results are in very good agreement with the experimental data.
3.2. Hydrodynamic performance Discussion

The vorticity contours of hydrofoil with rigid wall are shown in Fig.4. It can be seen that the trailing edge vortex shedding is not regular. At the reduced frequencies $f_c/U=12$ (Fig.5) and $f_c/U=30$ (Fig.6), the vorticity distributions of the hydrofoil with vibration amplitude $0.000067c$ are similar to that of the hydrofoil with rigid wall, it indicated that the vibration amplitude of the hydrofoil at 0.000067c has little influence on the vorticity distribution. When the vibration amplitude of the hydrofoil increased to 0.0033c, the vortex intensity increased and the regular vortexes are generated. When the vibration amplitude reached 0.0066c, the vortex intensity became stronger and the vortexes became more obviously. It shows that the effect of vibration amplitude to the vorticity distribution becomes greater with vibration amplitude increasing.

![Figure 3. Pressure coefficient with different angle of attack](image)

![Figure 4. Vorticity contours of hydrofoil with rigid wall](image)
The Cd and Cl at different vibration amplitude are shown in Fig. 7. It is can be seen that when the vibration amplitude smaller than 0.00067c, the Cd change slightly with the reduced frequency increasing and the Cd of the moving wall is a little higher than that of the rigid wall. When the vibration amplitude larger than 0.0033c, the Cd decreased at first and then increased. The Cd rises quickly at high frequency at high vibration amplitude. The Cl of the hydrofoil with moving wall is higher than that of rigid wall. When the vibration amplitude of the hydrofoil is under 0.00067c, the Cl is slightly changed except at fc/U=12. At fc/U=12 the Cl decreased. The Cl reduced quickly at the vibration amplitude equal to 0.0033c and 0.0067c when fc/U > 12.
Figure 7. Variations of (a) Cd and (b) Cl with frequency for NACA66-mod hydrofoil

4. Conclusion
The trailing edge with different vibration amplitude and reduced frequency are simulated, and the characteristics of the trailing edge vortex shedding and trailing edge vibration are compared. The results show that the vibration frequency has significantly influence on the trailing edge vortex shedding. The intensity of the vortex increases rapidly with the vibration amplitude increasing. The lift and drag coefficients are changed with the vibration amplitude and frequency changing.

Acknowledgments
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References
[1] R. Knoller, Die Gesetze des Luftwiderstandes, Flug- und Motortechnik(Wien), 3, 1909, pp. 1–7.
[2] A. Betz, Ein Beitrag zur Erklarung des Segelfluges, Zeitschrift fur Flugtechnik und Motorluftschiffahrt, 3, 1912, pp. 269–272.
[3] R. Katzmayr., Effect of Periodic Changes of Angle of Attack on Behaviour of Airfoils, NACATM-147, 1922.
[4] G. C. Lewin and H. Haj-Hariri, Modelling Thrust Generation of a Two-Dimensional Heaving Airfoil in a Viscous Flow, Journal of Fluid Mechanics, 492, 2003, pp. 339–362.
[5] Y.T. Shen and P.E. Dimotakis, The Influence of Surface Cavitation on Hydrodynamic Force. 22th American Towing Tank Conference, St.John’s Canda,1989.