The Experimental Study of the Influence of Modal to the Noise of the Hydrofoil

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Abstract. In order to study the influence of modal to the noise of the blade, the tests of modal and noise are carried out in the cavitation tunnel. The modal of hydrofoil was measured in the water and the noises of the hydrofoil with different inflow velocity were tested. The results show that the frequency of the peak of the noise spectrum is not changed with the inflow speed increasing. The amplitude of the peak increases first and then decreases with the inflow speed increasing. The structural characteristic of the hydrofoil has important influence on the noise and the frequency of the peak is equal to the modal frequency.

1. Introduction
The propeller noise which is one of the three major noise sources of the vessel plays an important role in the vessel noise. So in order to develop the low noise design methods and reduce the vessel noise, it is necessary to study the propeller noise generation mechanism. The noise generation mechanism of the propeller is extremely complicated. So in this paper, a hydrofoil is used to study the noise characteristic of the propeller.

In the aspect of theoretical predictions, Ffowcs Williams and Hawkings [1] extended Lighthill’s theory [2] to the noise from turbulence in the presence of arbitrary moving surfaces, which was suitable for studying the acoustics of rotating machinery, such as propellers and rotors. The FW-H equation is a rearrangement of fundamental conservation laws of mass and momentum into an inhomogeneous wave equation, which provides a theoretical model to describe the propagation of noise from the moving surface to the far field. The detailed flow field information provided by CFD (computational fluid dynamics), was used as source data to calculate the far-field noise radiation by using FW-H method. The couple numerical methods are used for the prediction of foil noise [3, 4].

Experimentally, Paterson [5] conducted measurement of vortex shedding noise of a series of isolated airfoils at low Reynolds numbers and concluded that airfoil vortex shedding noise was found to be discrete rather than broadband, the effects of airfoil thickness change and finite airfoil span on the noise were found to be small. As the development of the technology, over recent years, the use of phased arrays of microphones in the study of aeroacoustic sources has greatly increased. Its popularity is due in large part to the seemingly magical presentations of array-processed results, which pull out features of noise source distributions on both wind tunnel models and full-scale aircraft. The locations of noise source of the airfoil are studied by phased arrays of microphones [6].

However, generally the simulation computation and experiment that have been done to study the noise of foil had an assumption of the rigid wall and the influence of structure to the noise had not be
considered. The recently research from the institutes of Russia and German found that the elasticity of the propeller has much effect on the propeller radiation noise. The fluid-structure interaction of deforming hydrofoils and propellers had been paid more attention in recent years. The FSI algorithms and models are coupled to study the behavior of composite hydrofoils and propellers in cavitating and subcavitating conditions [7, 8]. The researches which are presented in the literature are mainly focused on the hydrodynamic and hydroelastic performance. However, the hydroacoustic had not been considered and there are few studies on the influence of the structural characteristics on the hydrofoil noise. The interaction mechanism of propeller and the noise is nuclear now. So it is necessary to operate the study on the influence of the structural characteristics on the hydrofoil noise.

This paper presents the results of an experimental study of the relation between hydrofoil structural characteristics and noise. First the experimental facilities are introduced. Then the noise spectra and nature frequency of the hydrofoil are compared to make sure that the structural characteristic has important influence on the hydrofoil noise. Finally, the relation between the sound pressure and inflow speeds is studied.

2. Experimental setup

The hydrofoil geometry is shown in Fig.1. The hydrofoil was designed rely on the NACA66-mod foil. The span is 224mm. The chord is 100mm. The thickness of the trailing edge is 0.53mm. The hydrofoil was made of aluminium with Young’s modulus of $E=71\text{GPa}$, density of $\rho=2770\text{kg/m}^3$, and Poisson’s ratio of $\nu=0.33$.

![Figure 1. Hydrofoil](image)

The modal was measured in the cavitation water tunnel at china ship scientific research centre. The hydrofoil was fixed to a wall at its root through a rigid mounting unit by which its angle of attack could be controlled. There was a 1 mm clearance between the free tip of the cantilever hydrofoil and the other end of the tunnel wall. The test setup is shown in Fig.2. In order to test the modal, four PCB352C68 acceleration sensors are used to measure the vibration acceleration. A metal rod was used to excite the hydrofoil.

![Figure 2. The test setup of modal](image)
The noise test was carried out in the high speed cavitation water tunnel. The test section of the tunnel is 0.225m×0.225m×1.6m (WHL) in which the operating velocity and pressure range are 1m/s-25m/s and 10kpa-500kpa absolute respectively. The test section is shown in Fig.3. The hydrofoil was mounted horizontally at mid-height of the test section. The hydrofoil was fixed to a wall at its root through a rigid mounting unit by which its angle of attack could be controlled. There was a 1 mm clearance between the tip of the cantilever hydrofoil and the other end of the tunnel wall.

![Figure 3. Experimental setup](image)

To measure the noise, B&K 8103 hydrophone which is normal to the middle of the trailing edge was located at the bottom of the test section. The hydrophone data were collected using a NI4462 board at a sampling frequency of 20 kHz for a sample time of 10s. The angle of attack is 0 degree. The inflow speed varies from 4m/s to 10m/s at 0.2m/s interval.

3. Results and discussion
The spectra of the vibration acceleration of different acceleration sensors are shown in Fig.4. The hydrofoil is excited at different position on the wall and the acceleration sensors got the similar results. The peak frequencies of the acceleration spectra of different sensors are the same. So we can get that the peak frequency is wet modal frequency of the hydrofoil and the frequency is 1140Hz.

![Figure 4. The spectra of the vibration acceleration at four acceleration sensor](image)

The noise of the hydrofoil was measured under the inflow speed which varies from 4m/s to 10m/s at 0.2m/s interval. The hydrofoil noise is compared with background noise at inflow speed 6m/s and 8m/s which are shown in Fig.5. The green line is the spectra of background and the red line is the
spectra of hydrofoil. It shows that the broadband part of background noise is closely to that of the hydrofoil. There are some peaks at hydrofoil noise spectra and the sound pressure level of the peak is higher than that of background. In this paper, the attentions are focused on the characteristics of the peaks, so the test results are satisfied for the study of the hydrofoil noise.

![Figure 5. Comparison of background noise and hydrofoil noise](image)

The noise spectra of hydrofoil under partial inflow speeds are compared. The results are shown in Fig.6. There are many peaks in the spectrum and the amplitude of the noise spectrum varies with the inflow speed changing. There is a conspicuous tone around 1150Hz under different inflow speeds. The frequency of the first peak is the same to the wet modal frequency. It is shown that the peak in the noise spectrum is related to the wet modal.

![Figure 6. Noise spectrum of hydrofoil under different inflow speeds](image)

In order to study the relation between the inflow speed and the noise characteristics, the amplitude of the peak in the noise spectrum under different inflow speeds are shown in Fig.7. It can be seen that first the sound pressure increases with the velocity increasing and it reaches the maximum at velocity 8.4m/s, then the sound pressure decreases with the velocity decreasing.
4. Conclusion
An experimental study was conducted to investigate the influence of the modal to the hydrofoil noise. The wet modal is tested and the noise under different inflow speeds is measured. The relation of the sound pressure and the inflow speeds is studied. The following observations had been made:

1. The structural characteristics of the hydrofoil have much effect on the noise.
2. The peak frequency of the noise is equal to wet modal frequency under different inflow speeds.

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