The effects of air content on unsteady tip vortex cavitation

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Abstract.

The phenomena of tip vortex cavitation (TVC) in unsteady incoming flows were studied experimentally in this paper. An elliptic hydrofoil with section NACA 66_2-415 was adopted as test model and high-speed video camera was employed to observe the tip vortex cavitation inception in the fixed foil with oscillation incoming flows. The effect of air content was considered in this investigation. The results show that the cavitation inception is delayed by the decrease of the non-dimensional frequency. The effect of air content in water is still very important in the case of unsteady tip vortex cavitation. The results indicate that the unsteady effect should be further considered in the scale effect study of TVC inception.

Keywords: tip vortex, cavitation, unsteady, experiment

Introduction

For the designer of naval and merchant ships cavitation is always a major concern because it induces hydrodynamic noise and vibration of marine propellers, as well as the potential of cavitation erosion. Among various kinds of cavitation tip vortex cavitation (TVC) begins in tip vortices and appears at lower ship speed than other forms of cavitation in most cases. The prediction of tip vortex cavitation inception is very important to develop high performance and quiet propellers. In practice marine propellers generally operate under unsteady conditions. The propeller blade always experiences varying pressure and velocity conditions due to the revolution of propeller, the wake of the hull and the heave movement of ship. Therefore, it is important to know the influence of unsteadiness on the inception and the development of cavitation.

Although tip vortex cavitation was extensively studied for many years, but most of the works were for tip vortex cavitation for steady situation. A very few researches related to tip vortex cavitation under unsteady conditions could be found. Hart et al. (1991[1], 1992[2]) and McKenney and Hart (1993[3]) studied a oscillating hydrofoil of rectangular planform with NACA64A309 cross section experimentally and showed an very complicated vortex structures due to the interaction between the tip vortex and the spanwise vortices shed from the trailing edge in the case of oscillating hydrofoil. Boulon, Franc and Michel (1997[4]) conducted experiments on a oscillating hydrofoil with symmetrical NACA 16-020 cross-section and an elliptical planform to study the influence of nuclei content and oscillation frequency on the inception of tip vortex cavitation. They found that the inception of tip vortex cavitation on an oscillating hydrofoil strongly depends upon the oscillation frequency and the nuclei concentration. Difference from the previous work in this paper another unsteady condition, fixed foil with oscillation incoming flows, is studied experimentally. The focus will be on the TVC inception under the effect of unsteady incoming flow and the influence of air content of water.

Experimental setup

Experiments were conducted in cavitation mechanism tunnel of China Ship Scientific Research Center (CSSRC). The tunnel has two exchanged test sections of circular and square respectively. There is a large degassing tank installed in the downstream of test section to control the air content of water and the tunnel also equipped a nuclei seeding system. In present study the test section with a square cross section of 225×225 mm was used that the maximum incoming velocity of this section can be up to 25m/s.

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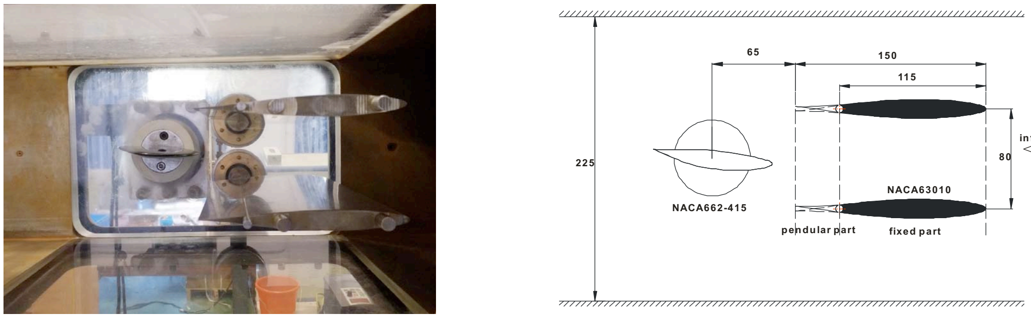

Figure 1. The arrangement of test model and swing system.

Test model is an elliptic hydrofoil with cross section NACA 66_2-415. The model is 94.2mm and 112.5mm in maximum chord and half span respectively and installed in the horizontal center of test section with the tip in the centreline of test section. The model was supported by a device which could adjust the attack angle of the foil. The tunnel installs an oscillating system in the front of test model to produce the oscillated incoming flows. The device has two hydrofoils installed in the tunnel, each hydrofoil includes a swing foil in its trailing part, as shown in Fig.1. A crank-link mechanism is set outside the tunnel and drives the two swing foils oscillating synchronously. A high-speed video camera of type of Photron APX and a LED lamp with 3000fps was used to observe the tip vortex cavitation inception and visualize the development of tip vortex cavitation. Air content of water was measured by by dissolved oxygen meter and expressed as *DO*, which is the relative dissolved oxygen to the saturation case.

Usually there are two ways to define the TVC inception criteria. One is the occurrence or disappearing of intermittent cavitation along the vortex path. The other is the occurrence of TVC core attached or detached to the tip of the foil. In present test TVC inception was distinguished by observation the images obtained by high speed video camera. In one oscillation circle TVC often experiences stretch out and draw back from the foil tip so it hardly to tell the cavitation number of attaching or detaching. Therefore, the TVC inception was defined as disappearing of intermittent cavitation along the vortex path in this paper.

Experimental results

In the experiments test model was fixed with 7°attack angle and the incoming flow oscillated with a swing mechanism in front of test foil. During the tests the oscillation amplitudes of swing foils were $\Delta\alpha = 5.7°$, 4.3°and 3.2°respectively, the oscillation frequencies were f=1.8, 3.6, 5.3 and 7.1Hz, mean incoming velocities were V= 5, 10 and 15m/s, air contents were *DO*=0.30, 0.62, and 1.01.

To represent the effect of oscillating incoming flows a non-dimensional frequency f^*, similar to the reference [4], was adopted to reduce the results, defined as:

$$f^* = \frac{fc}{V}$$

where f is oscillation frequency, V mean incoming velocity and c maximum chord of test foil.

1.1. Effect of Renolds number

The effect of Reynolds number on tip vortex cavitation inception was investigated by varying the mean incoming flow velocity. A series of cavitation inception tests were carried out in the air content *DO*=1.01 and oscillating amplitude $\Delta\alpha = 5.7°$ by changing the incoming velocity and oscillation frequency. The relation between incipient cavitation number and non-dimensional frequency was shown in Fig.2. The results demonstrate the cavitation inception is delay by the decrease of the non-dimensional frequency f^*. For each Reynolds number the TVC inception tends to become independent of the oscillation frequency at higher frequencies. But it should be pointed out that the incipient cavitation numbers in steady incoming flows (*f*=0) were 1.99, 2.97 and 7.16 for V= 15m/s ,10m/s and 5m/s respectively, which were much higher than these in the unsteady case, especially in lower Reynolds number. It indicates that the unsteady incoming flows will delay the cavitation inception.

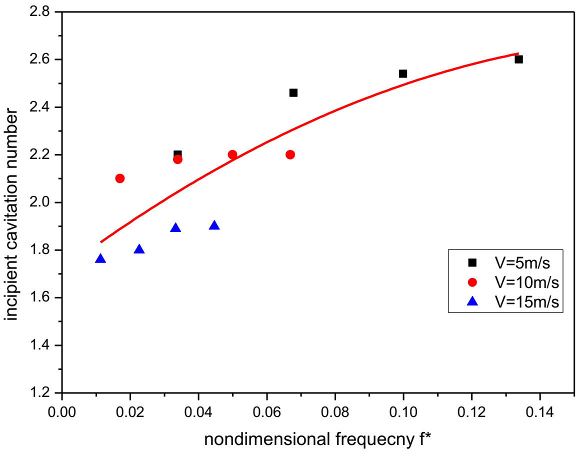

Figure 2. Incipient cavitation number vs non-dimensional frequency for different Reynolds number (Δ α = 5.7° , *DO*=1.01)

1.2. Effect of oscillation amplitude

The test was conducted in the condition of mean incoming velocity V=10m/s, and air content DO=0.30 with three oscillating amplitudes, Δα= 5.7°, 4.3°and 3.2°. The result is showed Fig. 3. It clearly demonstrates that the cavitation inception is delayed when the oscillating amplitude of incoming is increase. Also for each oscillation amplitude the TVC inception number tends to become independent of the oscillation frequency at higher frequencies.

1.3. Effect of air content

Three air contents, DO=0.30, 0.62, and 1.01, were tested in the condition of mean incoming velocity *V*=10m/s, and oscillating amplitude, Δα= 5.7°. The result is shown in Fig. 4. It clearly shows the similar tendency that the cavitation inception is delayed with the decrease of the oscillation frequency for different air content of water. But the cavitation inception is heavily delayed in the degassing water where the air content is much lower.

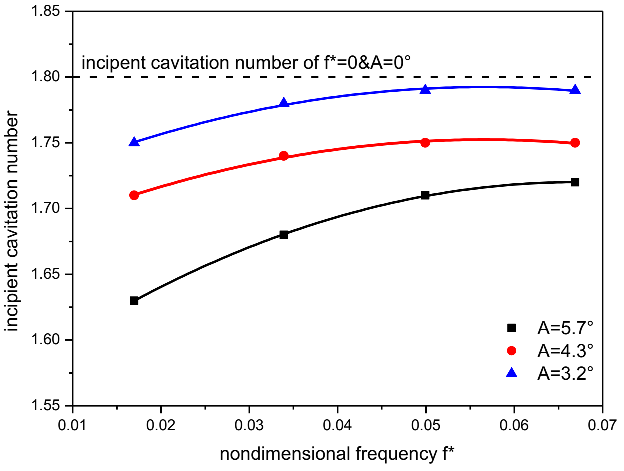

Figure 3. Incipient cavitation number vs non-dimensional frequency for different oscillation amplitudes

(*V*=10m/s, *DO*=0.30)

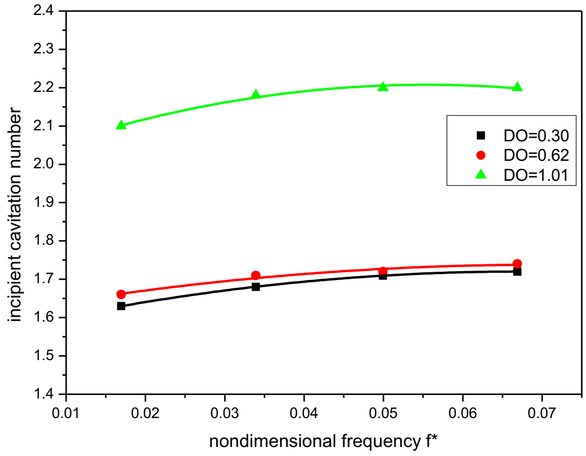

Figure 4. Incipient cavitation number vs non-dimensional frequency for different air contents
($\Delta\alpha$ = 5.7° , *V*= 10 m/s)

Conclusions

The tip vortex cavitation inception in unsteady incoming flows, formed by the swing foils in front of test model, was investigated experimentally in this paper. The effects of oscillation frequency, Reynolds number, oscillation amplitude, and air content of water were studied. The results show that the cavitation inception is delay by the decrease of the non-dimensional frequency f^*. But this delay tends to become independent of the oscillation frequency at higher frequencies. The decrease of air content and increase of oscillation amplitude will delay TVC inception.

The experimental results also show that the oscillating incoming flow will heavily delay the TVC inception compared to the steady case. It indicated that the unsteady effect should be further considered in the scale effect study of TVC inception.

Acknowledgments

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