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Experimental investigation of vibrations induced by cavitating flows around a 3D hydrofoil with tip clearance

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ABSTRACT

Experimental investigations of the cavitation-induced vibrations and the correlations with the flow patterns are taken. The experiment is conducted in a closed-loop cavitation tunnel. Both the high speed camera system and the dynamic strain gauge based vibration measurement system are utilized to capture the cavitation patterns and the vibration. Based on the experimental results following conclusions can be drawn. Firstly, in the case with relatively large cavitation number, the dominating frequency of the hydrofoil is about 160Hz and changes slightly compared with that in fully wetted case. This implies the stable leading edge cavity has little effect on the vibration. Secondly, in the case with relatively small cavitation number, the dominating frequency is about 20Hz and quite different from that in fully wetted case. The unsteady shedding process of the leading edge cavity is the main reason.

INTRODUCTION

Cavitation generally occurs when local fluid pressure reduces to the saturated vapor pressure and consequently bubbles filled with vapor are formed. It is of primary importance for ship propulsion and marine vehicles because cavitation may lead to many problems such as pressure pulsations, vibration, noise and erosion. The time-dependent evolution is one of the most important flow mechanics of cavitation. The unsteady process of attached cavitation would extremely change the spatial and temporal vortex distributions around a hydrofoil[1], which will induce strong transient loads and complex hydrofoil vibrations. This cavitation-induced vibration is more complex and quite different from that induced by fully-wetted flows. Hence, it is necessary in both science and engineering issues to understand the influence of unsteady cavitation on the flow induced vibrations.

The study on cavitation-induced vibration is still so challenging that much attentions have been attracted [2]. Amromin and Kovinskaya[3] utilized a beam equation to describe the vibration of an elastic hydrofoil with an attached cavity in periodically perturbed flow, and built the correlations between hydrofoil vibrations and cavity volume fluctuations. Ausoni et al. [4] conducted the experimental studies to investigate the effects of cavitation and fluid-structures interaction on vortex generation mechanism, and revealed that the vortex-induced vibration level significantly increased at cavitation onset. Torre et al.[5] investigated the influence of cavitation on the added mass effects experienced by a hydrofoil, and found that the added mass decreases as it develops from cavitation inception to super-cavitaion. However, it is still quite challenging to reveal the mechanism between the complex cavitation flows and induced vibration.

In this paper, experiment investigation of vibrations induced by cavitating flows around a 3D hydrofoil with tip clearance are conducted to better understand the time-dependent cavitation flows and induced hydrofoil vibrations.

EXPERIMENTAL SETUP

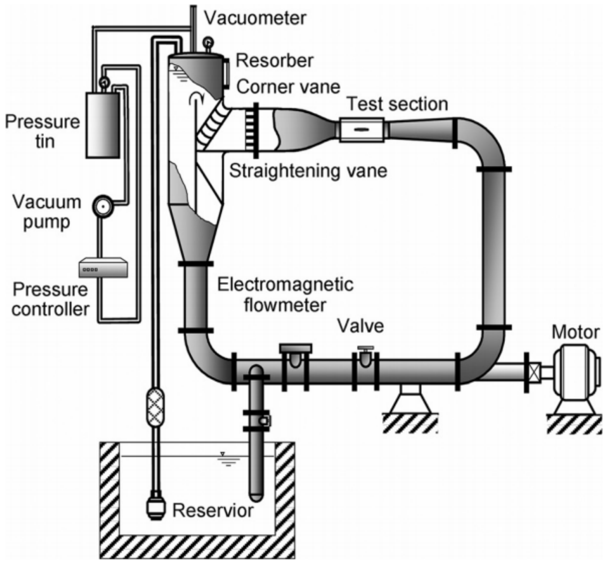

Figure 1 Schematic of the cavitation tunnel

Experimental studies are conducted in a closed-loop cavitation tunnel, which is shown in Fig. 1. The test section is 0.7m long and has a rectangular section with width of 0.07m and height of 0.19m. The axial flow pump is located 5m below the test section to drive the flow into the tunnel. To separate the undesired free stream bubbles in the flow, a tank with volume of $5m^3$ is placed upstream of the test section, with a corner vane and a straightening vane being set to reduce the turbulence level of the flow. The vacuum pump is connected to the top of the tank controlling the pressure in the tunnel. The upstream pressure and the flow velocity are measured by the pressure transducer (with 0.25% uncertainty) and the electromagnetic flowmeter (with 0.5% uncertainty) respectively.

The simplified rectangular Clark-Y hydrofoil is used in the present study, shown as Fig. 2. The critical parameters of the experiments are given in Tab. 1.

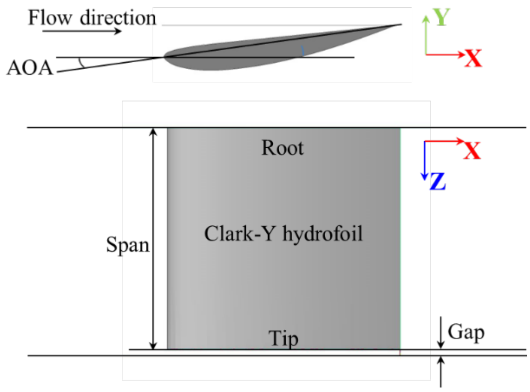

Figure 2 Schematic of the rectangular Clark-Y hydrofoil with tip clearance

Table 1 Summary of test conditions

Parameters	Value
Chord length, *C* (mm)	70
Span, *s* (mm)	68
Angle of attack, AOA (°)	4
Gap size, *G* (mm)	2.0
G/thickness, τ	0.244
Tunnel section length, *L* (mm)	700
Tunnel section height, *H* (mm)	190
Tunnel section breadth, *B* (mm)	70
Velocity of main flow, U_∞ (m/s)	7.8
Chord-based Reynolds number, *Re*	546,000
Cavitation number, σ	3.22~0.41

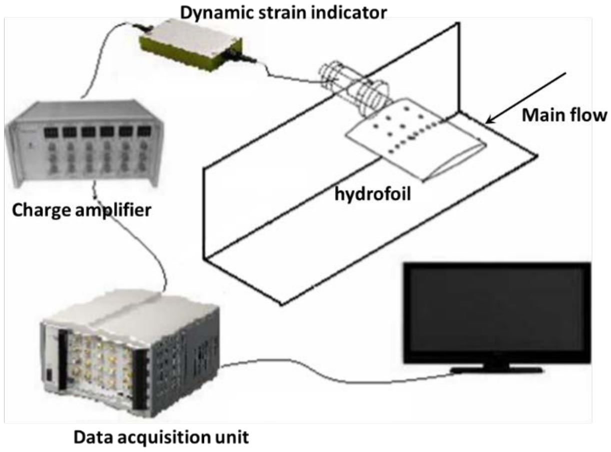

Figure 3 Hydrofoil vibration measurement system

Hydrofoil vibration measurement system consists of dynamic strain indicator, charge amplifier and data acquisition unit. The dynamic strain gauge is attached to the steadying bar of the hydrofoil, which is fixed as a beam shown in Fig.3. The flow induced vibrations can be well captured through this measurement. To better indicate the relationships between the cavitating flows and induced vibrations, high speed camera is also utilized to capture the flows patterns of cavitation.

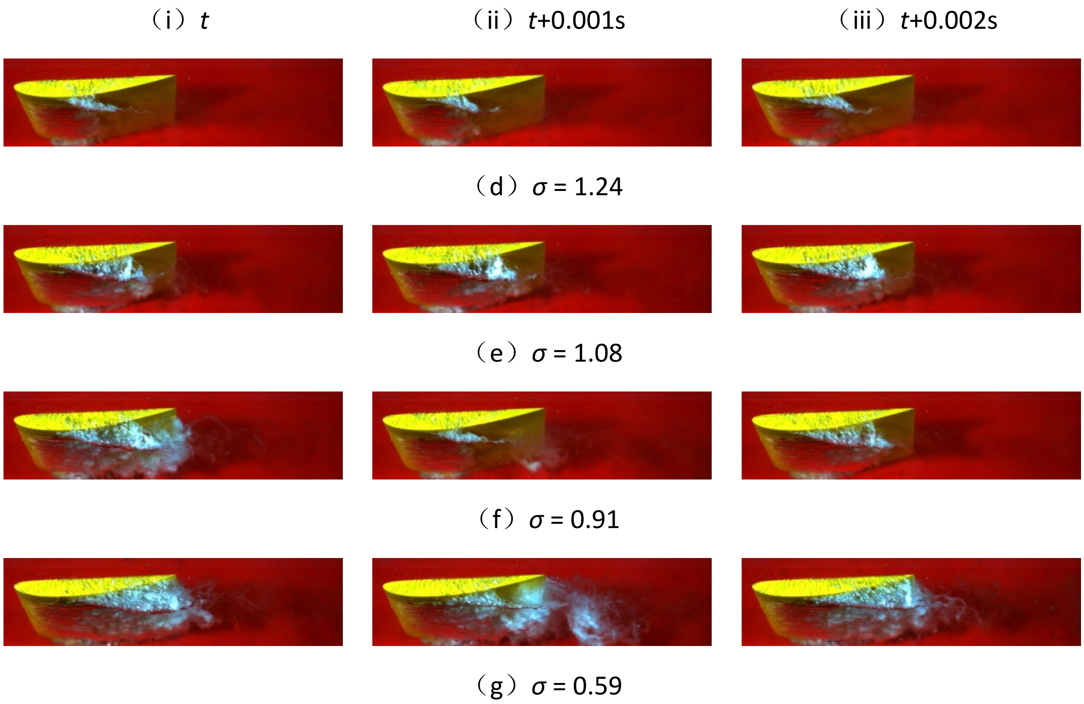

Figure 4 Flow patterns of cavitation around the hydrofoil with different cavitation numbers

RESULTS AND DISCUSSIONS

Figure 4 shows the flow patterns of cavitation around the hydrofoil with different cavitation numbers. It can be found that in the case with σ = 1.24, attached cavitation near the leading on the suction side is stable compared with those in cases with lower cavitation numbers. The length of the attached cavitation increases in case with σ = 1.08, and quite small bubbles can be observed at the end of the attached cavity. In the case with σ = 0.91, large-scale cavity shedding process can be observed. In the case with σ = 0.59, the attached cavity can reach the trailing edge of the hydrofoil and the cloud cavity shedding process can still be observed.

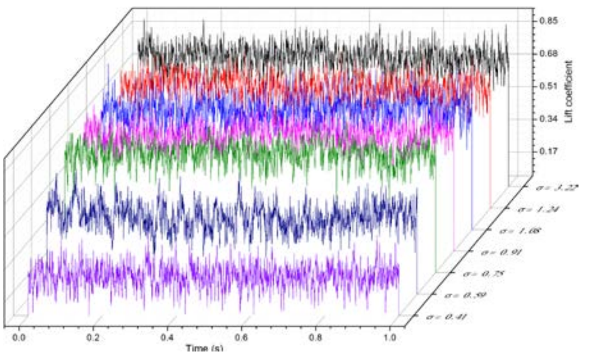

Figure 5 Time evolution of the vibration with various cavitation numbers

The measured time evolution of cavitation-induced vibrations are show in Fig.5, and their frequency spectrum is given in Fig.6. In the figure, σ = 2.39 represents fully wetted case, in which the vibrations are induced by the conventional single phase flows. As the decrease of cavitation number, the leading edge cavitation grows gradually from stable attached cavity to unsteady shedding process. The influence of cavitation and induced vibration can be well descripted by comparing the vibration in cavitating cases with those in fully wetted case.

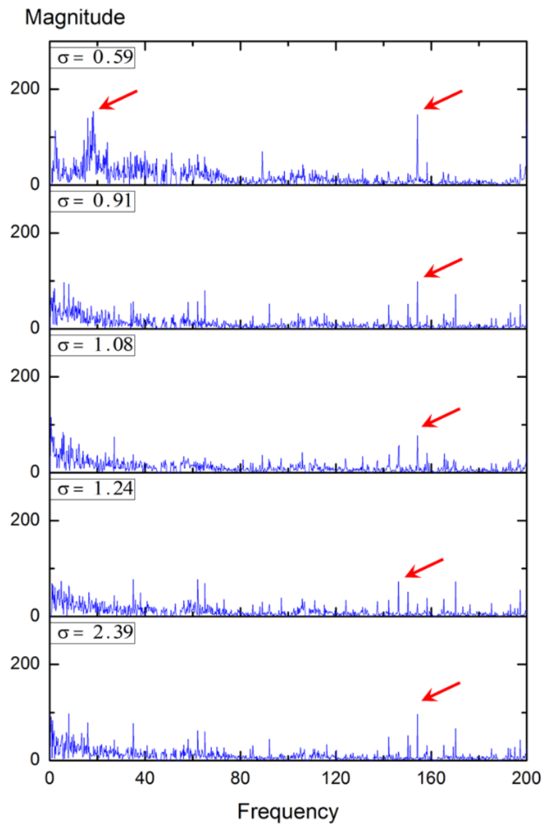

Figure 6 The frequency spectrum of hydrofoil lift with different cavitation numbers

In the figures it can be found that the dominating frequency is about 160Hz in fully wetted case with σ = 2.39, and changes slightly as the cavitation number decreases until σ = 0.91. The dominating frequency become 20Hz in the case with σ = 0.59, which is nearly the same as the cloud cavity shedding frequency. This implies that in the case with relatively small cavitation number, the cloud cavity process becomes the main reason for the hydrofoil vibration.

CONCLUSIONS

In the present study, the cavitation induced vibrations and the correlations with cavitation evolutions are investigated using experimental method. Following conclusions can be drawn,

In the case with relatively large cavitation number, the dominating frequency of the hydrofoil is about 160Hz and changes slightly compared with that in fully wetted case. This implies the stable leading edge cavity has little effect on the vibration.

In the case with relatively small cavitation number, the dominating frequency is about 20Hz and quite different from that in fully wetted case. The unsteady shedding process of the leading edge cavity is the main reason.

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