Vortex-induced vibration of a composite hydrofoil with a blunt trailing edge

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**Abstract**

Following the work of Liu et al. [1], they experimentally investigate the cavity dynamics and vibrations of composite hydrofoils with different ply angles. They found strong fluid-structure interaction between the composite hydrofoils and vortex. This work is focused on the vortex-induced vibration at zero angle of attack in a flow with a linearly changing speed. It is interesting to observe two dominant vibration frequencies of the composite hydrofoil in lock-in condition, while only one main vibration frequency is observed for the stainless-steel hydrofoil. The results provide a new insight into the understanding of the mechanisms relevant to complex bend-twist coupling effects of composites on vortex-induced vibration.

**Keywords**: Vortex-induced vibration; composite hydrofoil; Lock-in; Beat

1. Introduction

 The use of composite materials for propellers [2] is becoming more prevalent due to the advantage of high specific strength and specific stiffness, the resistance to corrosion erosion, and cavitation erosion compared to traditional metallic alloys such as steel, aluminum, or bronze. In addition, the passive shape-adaptive characteristics of laminated fiber composites can be utilized to tailor blade deformations to improve the hydrodynamic performance and suppress incipient cavitation number [3-5]. However, the composite's flexibility leads to strong structural deformations and vibrations, especially in the lock-in or resonance conditions the structural vibration amplitude is significantly amplified, and it is likely to cause fatigue cracks and failure of the propellers. In addition, the anisotropic characteristics of composite structures make it more complex to investigate the vortex-induced vibration in cavitating flow.

Because of the material anisotropy of composite hydrofoil, the application of either a bending or twisting moment by itself produced both bending and twisting of a material specimen [6], which was called the bend-twist coupling effect. The objective of this paper is to experimentally investigate the influence of positive and negative bend-twist coupling effects on vortex-induced vibration, especially in lock-in condition around composite hydrofoils.

1. Experimental method

The experimental measurement is conducted in the Ecole Polytechnique Fédérale de Lausanne (EPFL) high-speed cavitation tunnel [7]. The test section is 0.15m2 square by 0.75m long. The chordwise direction is defined as the *x*-axis and the leading edge of the hydrofoil is set as *x*/*c*=0. The spanwise direction is defined as the *y*-axis and the root of the hydrofoil is set as y/s=0. The high-speed camera is set as a sampling frequency of 10 000 fps to observe the wake flow. The vortex-induced vibrations are measured with the help of a piezoelectric accelerometer. The *NACA* 0009 hydrofoil [8] is truncated at 90% of its original chord length *c*0 =110 mm, the resulting chord length *c* is 100mm, and the trailing edge thickness *h*0 is 3.22mm. In addition, the effective span of the hydrofoil is 140 mm, and the maximum thickness is 10mm at the canter of the chord. The hydrofoils are mounted at a fixed incidence *α*0 = 0°. And the angle of attack *α*0 is defined as when the hydrofoil deforms under the cavitation load. The operating velocity changes from 5 m/s to 18 m/s linearly, and the pressure is fixed at 4 bar in a cavitation-free regime.

The composite hydrofoils are all made of epoxy resin reinforced with the same nominal layup of carbon fiber reinforced polymers (CFRP), and the primary difference is the orientation of the structural carbon layers relative to the spanwise axis of the hydrofoils: 0°, 45°, and -45°. For simplicity, the three composite hydrofoils are denoted as CFRP 00, CFRP 45, and CFRP-45. A rough strip made of glue and 125 *μ*m diameter sand is placed on both sides of the hydrofoil, 4 mm downstream from the stagnation line and 4 mm wide. The fiber thickness of each layer is 0.2 mm so the thickest part of the hydrofoil has 50 layers. Note that the fiber orientation is defined with respect to the spanwise direction, being positive in the clockwise direction, as shown in Figure.1.



Figure.1 Geometric dimension of the hydrofoil and definition of composite hydrofoil's ply angle

1. Results and discussions

To investigate the difference in vortex-induced vibration between composite hydrofoil and stainless-steel hydrofoil, Figure 2 shows the spectrum of the vibration acceleration for the tripped transitions for the composite and stainless-steel hydrofoils for different inlet speeds, which are obtained by the short-time Fourier transform (STFT) method. It is well known that the dominant vibration frequency is related to the vortex shedding frequency before lock-in. A lock-in of the vortex shedding frequency onto the first torsion frequency occurs for the speed range from 12.6 m/s to 14.5 m/s for the stainless-steel hydrofoil, with an intense vibration amplitude. It's interesting to observe that the vibration frequency in lock-in conditions is different from that of the stainless-steel hydrofoil. Two dominant frequencies (*f1* =458 Hz and *f2* =514 Hz) can be observed when lock-in occurs, while the first torsion frequency *ft* is490 Hz by simulation method. The difference between both frequencies is the "beat frequency" causing an interference pattern between two signals. Note that this phenomenon is not attributed to the interaction between the first two natural frequencies mentioned in previous studies, because the first bending frequency *fh* of CFRP -45 hydrofoil is 97 Hz and it is much lower than these two frequencies. It may be because the first torsion natural frequency *ft* is modulated by another frequency *f* =28 Hz. Moreover, strong bending deformation is observed in lock-in condition, although the CFRP -45 hydrofoil should manifest the first torsion mode shape like the stainless-steel hydrofoil. This interesting phenomenon is due to the bend-twist coupling effects of composites.

1. Conclusions

The present work investigates the vibration characteristics around composite hydrofoils at different speeds by experimental method. The vibration frequency of the composite hydrofoil in lock-in condition manifests two main frequencies but not a signal and intense frequency like a stainless-steel hydrofoil. Moreover, a beat phenomenon is observed before the lock-in onset for the CFRP -45 hydrofoil.

 

Fig.2 Spectrum of the vibration acceleration obtained by STFT for the CFRP -45 hydrofoil (left) and stainless-steel hydrofoil (right) at different speeds.

1. References

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