The Hydro-Elastic Response of a Surface-Piercing Strut in Wetted and Ventilated Flows

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Long Abstract

Introduction

Atmospheric ventilation is a phenomenon common to lift-generating devices that pierce or operate near the free surface. Under suitable conditions, air may enter from the free surface into low-pressure regions of flow to form a stable aerated cavity that is open to the atmosphere, constituting fully ventilated flow. Through this process, a previously-wetted body may be operating at a phase-boundary, yielding unknown ramifications on the effective system added mass, damping, and stiffness terms. Additionally, the transitional events between wetted and ventilated flows can incur large load fluctuations. The combination of rapidly-changing loads and rapidly-changing system parameters demonstrates a need to study the fluid-structure-interaction (FSI) response of deformable bodies in ventilated flows. Ventilated flow around a flexible hydrofoil presents an extremely complicated flow not adequately predicted by classical theories of aeroelasticity [2, 1]. The proximity of the free surface, finite-span effects, and the presence of both light (gaseous) and dense (liquid) phases violate the assumptions of most aeroelastic analysis. Moreover, as ventilated cavities grow and collapse, the hydrodynamic added mass, damping, and stiffness of a ventilated body may exhibit periodic modulation, creating the possibility of parametric excitation [3].

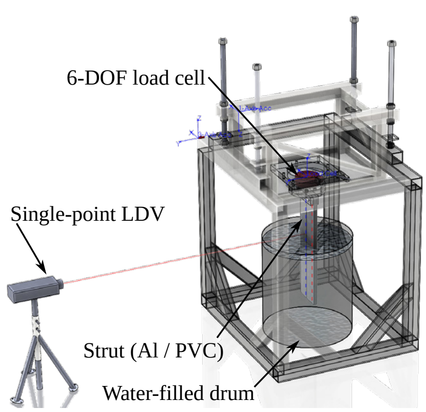
1. Methods

Experiments are ongoing at the University of Michigan to study two geometrically-identical, surface-piercing struts made of aluminum and PVC at varying depths of immersion, in still water, and in wetted and ventilated flows. For still-water tests, a large steel frame was constructed, to which was a struts is attached in a vertically-cantilevered configuration, with the free tip suspended in a freshwater-filled drum at a specified depth. Instrumentation includes a six-component force/torque transducer, a single-point laser doppler velocimeter (LDV), and several accelerometers. In the case of the PVC strut, aluminum spars are instrumented with strain gauges and installed in the strut's interior, permitting static and dynamic deflections both in bending and twisting to be inferred in real-time. The experimental setup is illustrated in figure 1a.

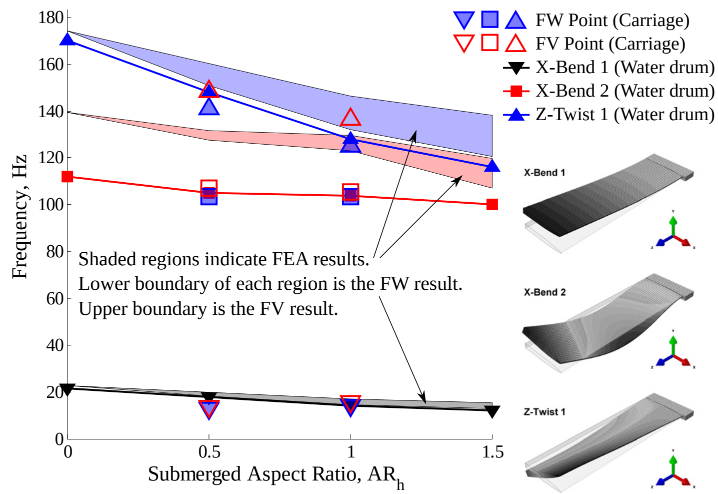
The struts are also towed in the 110-meter-long University of Michigan towing tank at low-to-moderate depth-based Froude numbers $0.5 \leq Fn_h \leq 4$ to measure the vibratory response of the struts in fully wetted (FW) and fully ventilated (FV) flows. Additionally, a finite element analysis (FEA) was used to model the free vibration of the aluminum and PVC struts in wetted and ventilated flows, assuming infinitely-large Froude numbers. The air and water domains were modeled by acoustic fluid elements with respective fluid properties.

2. Results and Contributions

Initial results are shown in figure 1b for the aluminum strut. Experimental results using the setup in figure 1a are shown as filled symbols with lines connecting them. Different symbols and line colors denote different mode shapes; the first three modes are shown, and FEA predictions of the mode shapes are shown on the right. The results indicate that larger depths of immersion – corresponding to increased AR_h – cause reduced modal frequencies, with the reduction being dependent upon the respective mode shape. This occurs because a greater proportion of the strut is surrounded by high-density liquid as it is more-deeply immersed in the water. Large open and filled symbols indicate modal frequencies obtained from impulse tests on the aluminum hydrofoil on the towing-tank carriage. Open and filled symbols denote results from fully ventilated and fully wetted flows, respectively. The open symbols indicate that fully-ventilated flow causes an increase in modal frequencies, as a result of air (a light fluid) displacing water (a heavy fluid). Results will be shown for the modal frequencies and inferred hydrodynamic forces (added mass, damping, and stiffness terms) with differing material properties, with varying depths of immersion, varying flow speed, and in wetted and ventilated flow conditions. A combination of frequency-domain, time-domain, and orthogonal decomposition will be used to analyze the hydroelastic responses of the two struts. The completion of this study is expected to provide valuable insight into the FSI response of flexible marine systems in multiphase flow.



(a) Experimental setup used to measure vibratory response of struts. Dashed lines along the span of the strut indicate the locations of shape-sensing spars (installed in PVC strut only)



(b) Preliminary results showing the change in modal frequencies of the aluminum strut with varying immersion depth and in ventilated flow. The results of FEA simulations are shown as shaded regions, bounded below by the fully wetted (FW) results and bounded above by the fully ventilated (FV) results.

Figure 1. The experimental setup is depicted in (a). Preliminary results for the Aluminum strut are shown in (b).

References

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[3] Deniz Tolga Akcabay, Eun Jung Chae, Yin Lu Young, Antoine Ducoin, and Jacques Andre Astolfi. Cavity induced vibration of flexible hydrofoils. *Journal of Fluids and Structures*, 49:463 – 484, 2014.