Bend-Twist Coupling Effects on the Vibration Characteristics and Cavitating Response of Composite Hydrofoils

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The objective of this work is to perform combined experimental and numerical studies to examine bend-twist coupling effects on the vibration characteristics and cavitating response of composite hydrofoils. There is growing interest to use composite and other advanced materials to improve the performance of hydrodynamic lifting bodies such as marine propellers, turbines, rudders, control surfaces, and energy harvesting devices. Compared to traditional metallic alloys, composites offer the advantages of higher strength-to-weight ratio, higher material damping, better fatigue characteristics, higher durability, and better resistance to salt water corrosion and other chemical effects. In addition, the intrinsic bend-twist coupling characteristics of anisotropic composites can be used to enable passive, load-dependent shape adaptation to improve performance in spatially varying wake and in off-design conditions. However, care is needed in the design of these advanced composite hydrodynamic lifting bodies, as they can be intrinsically more sensitive to flow changes and rapid maneuvers, which can excite one or more of the structural natural frequencies. The nonlinear feedback between the flow and body deformations may lead to unwanted effects such as flow-induced vibrations, frequency modulations, lock-in, flutter, resonance, divergence, and eventual material failure. Hence, the objective of this work is to systematically study the dynamic vibration characteristics of composite hydrodynamic lifting bodies. To focus on the physics, cantilevered hydrofoils are used as canonical proxies to more complex lifting bodies such as propellers, turbines, and other control surfaces. The focus is to study the effect of material bend-twist coupling on the foil mode shapes, natural frequencies, and damping characteristics. Results are shown for three composite hydrofoils and one stainless steel hydrofoil, which will serve as the rigid reference. All four hydrofoils have identical unloaded geometry -- unswept, tapered planform with 0.3 m loaded span and linear chord variation from 0.12 m at the root to 0.06 m at the tip, and NACA 0009 cross section. The three composite hydrofoils are made of epoxy resin reinforced with the same nominal layup of carbon fiber reinforced polymers (CFRP) and glass fiber reinforced polymers (GFRP) layers, where the only difference between the hydrofoils is the orientation of the dominant outer CFRP layers. The experiments are conducted in the Cavitation Research Laboratory (CRL) variable pressure tunnel at the University of Tasmania. Both wetted and cavitating results will be shown. To complement the experimental studies, a simple two-degrees-of-freedom numerical model is used to predict the foil performance, and the predictions are compared with experimental measurements.