Abstract

A novel twin-protuberance hydrofoil design mimicking the two prominent tubercles present on a Humpback whale flipper is developed, and its hydrodynamic performance including lift, drag, and pitching characteristics are investigated using experiments and CFD methods. Comparative studies with respect to forces, efficiency, and vortex shedding patterns are presented with unmodified baseline designs to assess the hydrodynamic influence of the leading-edge modifications.

In the basic study performed with a NACA 63_4-021 section hydrofoil of span/ chord ratio of 2, it was observed that the counter-rotating chord-wise vortices shed from the two protuberances can restrict the separation zone at high angles of attack and increase the post-stall lift coefficient while reducing the pre-stall maximum lift. The amplitude and spacing of the protuberances are important factors in determining the pre-stall and post-stall lift characteristics of the modified designs. Further, the influence of the hydrofoil's section profile, aspect ratio, and sweep angle is investigated on the performance benefits due to protuberances. The leading-edge modifications are observed to be more conducive for lift enhancement for thin foil sections (for example, NACA 0012) having a smaller stall angle as compared to the other profiles investigated. The effect of the protuberances is found to be Reynolds number dependent.

Experiments and Computational fluid Dynamics (CFD) analyses on pitching foils with NACA 0012 section show that the protuberances result in higher thrust coefficient and efficiency for higher pitching amplitudes (> 15 deg) and at higher reduced frequencies (> 2.5). The wake vortices show the influence of the leading-edge vortex, which gets modified when the protuberances are present. The transition from 2S (two vortices of opposite signs are shed per oscillation period) wake to 2P (two vortex pairs are shed per oscillating period) wake with the increase in the amplitude of oscillation is captured in the numerical investigations. The velocity components in the wake of pitching foils are measured using Acoustic Doppler velocimeter. The foil thickness impacts the leading-edge suction peak, and hence the effect of design modifications during pitching.

The hydrodynamic study for different geometries presented in the thesis sheds light on the applications of the leading-edge designs for hydrofoils, wings, and control surfaces in general. The results of pitching performance investigations for different conditions may be utilized for potential applications in flapping foil propulsion.

Keywords: *Leading-edge protuberances; CFD; Experimental hydrodynamics; Pitching Hydrofoil; Vortices.*