ADVANCED STRATEGIES FOR SUSTAINABLE AND EFFICIENT ENERGY HARVESTING

SEMINAR

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Fluid–structure interaction (FSI) systems offer significant potential for sustainable and advanced energy harvesting, as appropriate tuning of structural and flow parameters can enable efficient extraction of energy from the surrounding fluid. Motivated by this prospect, immersed boundary method (IBM)-based direct numerical simulations are performed to investigate the complex flow physics and propulsive characteristics of FSI systems. As a representative three-dimensional configuration, a pitching plate oscillating about its leading edge is examined at a Reynolds number of (Re = 1000) over a wide range of pitching frequencies, corresponding to Strouhal numbers, $0.2 \leq St \leq 2$. At moderate pitching frequencies, the wake exhibits a reverse von Kármán vortex street, which bifurcates into two distinct branches connected by vortex strands at higher Strouhal numbers. For panels with larger aspect ratios, an avalanche of large, highly entangled three-dimensional vortex structures emerges for $St \geq 1.5$. Strong spanwise wake compression is observed in these cases, significantly influencing the development of secondary instabilities at increased pitching frequencies. However, no direct correlation between the growth of secondary instabilities and the spanwise pressure gradient is established. With increasing Strouhal number, a stable central wake region develops, accompanied by a higher concentration of small-scale vortical structures near the jet plane. Continuous wavelet transform analysis reveals complete synchronization of the shed vortices with the pitching Strouhal number for the low-aspect-ratio panel. In contrast, the spectral response of the high-aspect-ratio panel at St=1 is dominated by a narrow band of low-frequency cells, and a period-doubling phenomenon is observed in the spanwise cells during space–time reconstruction of the velocity signals. Across the investigated range of Strouhal numbers, both thrust and lift signals exhibit constant-amplitude oscillations, with the lift amplitude being approximately twice that of the thrust. Furthermore, the root-mean-squared thrust and lift coefficients increase monotonically with both Strouhal number and panel aspect ratio.

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