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Nonlinear Spatio-Temporal Fluid-Structure Interaction of Elastic Panels in Uniform Flow

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Abstract

The field of fluid-structure interaction (FSI) incorporates a wide range of phenomena that are of great scientific and engineering interest in various disciplines, including aviation, ocean engineering, biology, energy harvesting, heat removal and acoustics. The essence of this interaction is in the information transfer between the structure and the surrounding fluid, where the fluid impels loads on the structure, which in turn complies and disturbs the flow in its vicinity. One of the highly investigated FSI problems is the complex motion of an elastic panel immersed in a uniform stream parallel to its longitudinal direction. In spite of the comprehensive research done to-date, there are large discrepancies between documented experiments and the outcome of proposed simplistic analytical models, especially in the prediction of subcritical flutter thresholds for a cantilever panel and their consequent self-excited oscillations. Moreover, existing analytical and computational studies lack the full insight of the complex physical bifurcation structure, which incorporates non-stationary dynamics culminating with possible chaotic spatio-temporal complexity.

We thus consistently formulate an initial-boundary-value problem (IBVP) incorporating an innovative high-order dissipation mechanism, and employ an asymptotic reconstitution multiple-scales analysis to show that this model is essential to account for the subcritical nature of cantilever panel flutter demonstrating that the singular perturbation analysis of the deduced model gives a good prediction of documented experimentally measured amplitudes. A combined analytical and numerical investigation of the IBVP for a weakly nonlinear simply supported infinite panel immersed in inviscid flow bounded by two rigid walls reveals multiple independent Hopf-bifurcations, which evolve into self-excited periodic limit-cycles, quasiperiodic and chaotic-like solutions. In order to investigate the strongly nonlinear FSI, a finite-difference numerical solver is formulated for both a restrained rigid-body and an elastic panel hinged at the leading edge and immersed in a compressible viscous laminar flow field. The investigation reveals a complex bifurcation structure that includes quasiperiodic and nonstationary chaotic-like solutions evolving from loss of orbital stability of ultra-sub-harmonic limit-cycle oscillations. These bifurcations correspond to spatio-temporal transitions between multiple fluctuation modes culminating with transitions in wake from P type to 2P type formations.