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Self-Sustained Limit-Cycle Oscillations in a Flapping-Foil Energy Harvester

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The nonlinear dynamics of an airfoil at low Reynolds number ($Re = 10,000$) constrained by two springs and subject to a uniform oncoming flow is studied numerically. The studies are carried out using open source computational fluid dynamics toolbox OpenFOAM. Under certain conditions related to aerodynamic flutter, this two-degree-of-freedom system undergoes self-sustained limit-cycle oscillations (LCOs) with potential application as an energy harvester. When the system is given a small initial perturbation, it is seen that the response of the system decays to zero at flow velocities below the flutter velocity, or oscillates in a limit cycle at velocities greater the flutter velocity. The flutter velocity at low Reynolds number is shown to deviate significantly from the theoretical prediction (which is derived with an assumption of infinite Reynolds number) owing to the effect of viscosity. The LCOs at freestream velocities higher than the flutter velocity result in unsteady flows that are heavily influenced by leading-edge vortex shedding as well as trailing-edge flow separation. The influence of different system parameters on the onset of flutter and on the limit-cycle response characteristics are investigated in this research. This is done by defining a baseline case and examining the effects of varying paramters such as freestream velocity, pitch-to-plunge frequency ratio and the type of spring stiffnesses. The conditions corresponding to the lowest flutter velocities (and consqeuently the lowest "cut-in" speeds for power extraction) are discussed. The case studies performed are used to identify the parameter space that provides ideal system responses for power extraction (single-period, single-amplitude, harmonic LCOs). Finally, a large database of high-fidelity numerical data for this aeroelastic problems has been made available to facililate the validation and development of low-order numerical algorithms and optimisation approaches for the power extraction problem.