Frequency selection in heaving airfoil wakes using a high-order numerical method

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The unsteady flow over streamlined bodies is one of the most important problems in fluid dynamics. The interest for these flows is motivated by their highly non-linear and unsteady nature, which make them almost impossible to solve analytically. With the increase in computing power the use and development of high-order computational methods has become an attractive alternative for the numerical modelling of unsteady flows over streamlined configurations. In this work we conduct numerical simulations of steady and unsteady flows over motionless and heaving airfoils using a high-order Spectral Element method for the first time. Our simulations confirm the suitability of this method to model and characterize in very good spatial and temporal detail the flow structures and wake transitions. The results are validated against previously published experimental and computational studies. Heaving airfoils shed vortices as they oscillate, and these wakes are classified into drag, neutral and thrust-producing wakes, depending on the nature of the force produced by the airfoil. In this work drag, neutral and thrust wakes are successfully simulated, and also the transitions from one wake to another. Two new modes are observed in this investigation and added to the wake classification. We question the assumption that the Strouhal number is the main and only parameter to characterize the wake configurations, and thus the nature of the forces produced for oscillating airfoils. Our findings show that, in order to characterize such flows one needs to consider the amplitude and frequency of oscillations as independent parameters, and that the Strouhal number alone is not sufficient to characterize oscillating airfoil wakes. Finally, we explore the frequency regimes for oscillating airfoils. These regimes depend on the forcing frequency and the forcing amplitude and on the relation between the forcing frequency and the natural frequency of the airfoil. Three frequency regimes are defined in the literature: the natural regime, the harmonic regime and the lock-in regime. These different frequency regimes are successfully simulated in this investigation. They are related to the shedding process through which the wake undergoes a transition from a Karman street to a reversed Karman street. The transition between the different frequency regimes is simulated at both constant frequency and constant amplitude. We found that the frequency regimes are strongly related to the wake type exhibited. Wake-types with multiple-vortices-per-half-cycle of oscillation are found in harmonic regimes and wake-types with one vortex-pair shed per cycle are in the region where one distinct frequency is in control (lock-in and natural regimes). Wakes where the leading-edge vortices contribute to the shedding process are also simulated.

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