Vibration localization in weakly coupled airfoils subjected to flutter instability

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Abstract. Very commonly, engineering structures are constituted by unit cells assembled in an axisymmetric fashion. Examples are blisks, turbine and compressor rotors, wind turbines, space antennas and reflectors. Here, a homogeneous cyclic symmetric nonlinear lumped structure constituted by N elastically coupled airfoils invested by a uniform airstream and subjected to flutter instability is studied. Due to the system's nonlinearities, multiple stable spatially localized vibrating states are found. First numerical results are shown, then a minimal model of weakly coupled nonlinear beams is tested experimentally to prove that nonlinear localization may take place in engineering relevant structures.

Introduction

Several engineering structures are constituted by mechanical components assembled in a nearly cyclic and symmetric structure, such as aeroengine turbo fan, turbine rotors and space structures. The repeating unit cell is often constituted by a slender beam (e.g. the blade in a wind turbine), which is jointed to a hub providing the weak elastic coupling between neighbour unit cells. It is known since the 50's, that small disorder in linear mechanical systems could lead to spatial localization of vibration [1], known in turbomachinery as "mistuning". Later studies have shown that vibration localization may take place also in perfectly homogeneous but nonlinear systems [2-3]. A key characteristic of these systems is that the unit cell has multiple co-existing stable solutions (fixed points and/or limit cycles) in certain range of the governing parameters. Here, the case of a homogeneous cyclic symmetric nonlinear lumped structure constituted by N elastically coupled airfoils, with plunge "h" and pitch "α" degrees of freedom, invested by a uniform airstream at velocity V and subjected to flutter instability is studied.

Results and Discussion

The aerodynamic lift and moment exerted on the thin airfoil (the unit cell, Fig. 1a) due to the uniform airstream, are obtained using the model by Fung [4]. By changing the cubic stiffness coefficient of the plunge, the HOPF bifurcation changes its character from super- to subcritical. In the subcritical setting there exists an interval of V for which the single airfoil shows multiple spatially localized vibrating states, which involve a fixed point, a limit cycle or irregular motion. This multiplicity of solutions give rise to coexisting spatially localized vibration patterns (Fig. 1b) when multiple elastically coupled airfoils are considered.

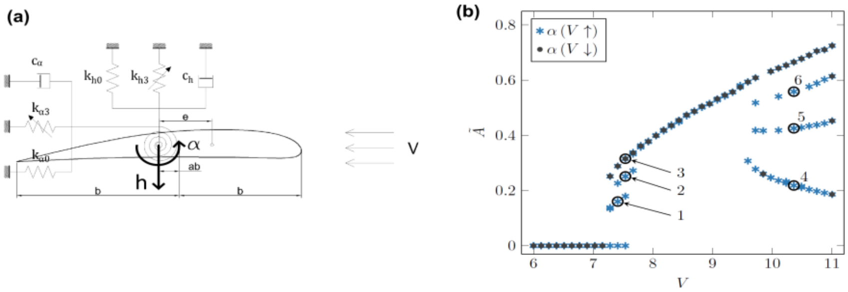

Figure 1: (a) sketch of the single airfoil with plunge "h" and pitch "α" degrees of freedom. (b) Vibration amplitude of the pitch degree of freedom as a function of the airstream velocity

Due to the multiplicity of coexisting stable solutions (Fig. 1b) the question of how likely the system converges to a certain state is addressed. A plausible set of initial conditions is selected and the concept of *basin stability* analysis is exploited to assess, for the structure of N coupled airfoils, the likelihood to converge to a certain state. Lastly, the measurements obtained with a test rig constituted by a chain of weakly coupled slender beams with clearance nonlinearities are shown to prove that the nonlinear localization of vibrations is possible for engineering relevant structures.

References

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