Effects of system parameters on the synchronization characteristics of a pitch-plunge aeroelastic system with coupled non-smooth nonlinearity

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Abstract. The dynamics of a pitch-plunge airfoil possessing coupled non-smooth nonlinearities, namely freeplay nonlinearity in the structure and dynamic stall in the aerodynamics, are systematically investigated by varying the system parameters, e.g. the mass ratio (μ), frequency ratio (ϖ), Mach number (M) and the extent of freeplay nonlinearity. The responses dynamics, so obtained from the systematic parametric variation, is mapped hand-in-hand with the non-smooth behavior of the input aerodynamic loading by invoking the concepts of synchronization. It is demonstrated that depending on a set of key system parameters, one can encounter different routes to synchronization, and in turn different genres of flutter in the aeroelastic response.

Introduction

It is well known that the inclusion of non-smooth nonlinearities in an aeroelastic system can give rise to discontinuity-induced bifurcations (DIB) such as border collision, rapid bifurcations and grazing bifurcations [1]. Recent studies [2] have highlighted the pivotal role played by the aeroelastic system parameters (e.g. frequency ratio (ϖ) between the pitch and plunge modes) in dictating the genres of the response dynamics under dynamic stall. Extending this insight, one can conjecture the importance played by a variety of parameters such as solid-to-fluid added mass ratio (μ), extent of freeplay nonlinearity (δ), and the flow Mach number (M) on the DIB and, in turn, on the structural safety of the aeroelastic system. The necessity for such a DIB study is exacerbated in the presence of coupled non-smooth nonlinearities arising from a freeplay in the structural stiffness and dynamic stall in the flow. To that end, the response dynamics are investigated from the purview of synchronization [3] so as to map the output aeroelastic dynamics possessing DIB hand-in-hand with the input non-smooth dynamic stall behavior.

Results and Discussions

A preliminary case of an airfoil with coupled non-smooth nonlinearity (freeplay gap (δ) = 1°, pitch angle $\alpha(0) = 15°$) is considered and a bifurcation plot of the response dynamics as U (flow speed) is varied is shown in Fig. 1. Rich phenomenological dynamics including period-doubling route to chaos and transition to sustained limit cycle oscillations in the aeroelastic responses can be observed. It is to be noted that these signatures undergo *abrupt* change to different dynamical signatures via DIB when key parameters are altered. Consequently, the genre of aeroelastic response and its corroboration with the input dynamic stall becomes necessity and is addressed in this study from the vantage of synchronization [3]. It is intended that the findings from this study are of two-fold significance, namely (i) characterizing the nonlinear aeroelastic signatures from DIB, and (ii) resolving the genre of aeroelastic output via synchronization concepts. Both these findings are aimed to augment better aeroelastic designs.

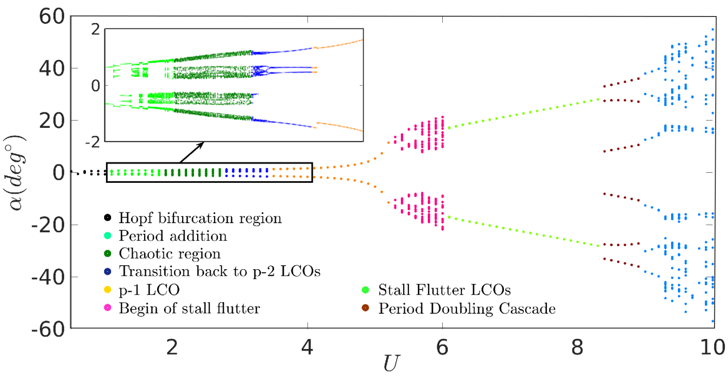

Figure 1: (a) Bifurcation for the aeroelastic system with coupled nonlinearities having δ = 1°, μ = 100, ϖ = 0.2. (b) The zoomed part of the bifurcation occurring between $U = 1 - 4$ is shown.

References

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