Response analysis of coupled non-smooth nonlinear aeroelastic system subjected to stochastic input fluctuations

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Abstract. This study focuses on investigating the response characteristics of a coupled non-smooth nonlinear aeroelastic system subjected to randomly fluctuating flow. The non-smoothness in the structure is modelled as a freeplay nonlinearity and the aerodynamic loads are dictated by a dynamic stall condition. It is demonstrated that the stochastic inflow gives rise to noise-induced intermittency (NII) as the mean flow is varied. Deriving impetus from the observations of discontinuity-induced-bifurcations (DIB) in the deterministic non-smooth nonlinear aeroelastic systems, it is pivotal to understand the physical mechanism of NII near the transition boundaries. To that end, a qualitative and quantitative stochastic bifurcation analysis on the intermittent transition route is carried out. Subsequently, the regimes that can impact the safety of aeroelastic operations are identified by computing the corresponding fatigue damage using rain-flow counting (RFC) algorithm.

Introduction

Discontinuity-induced-bifurcations (DIB) lead to abrupt jumps in the response dynamics and is often detrimental to the structural integrity, when encountered in aeroelastic systems. Recent studies on non-smooth nonlinear aeroelastic systems subjected to deterministic flows [1], have shown a variety of DIB including border collision and rapid bifurcations and its hand-in-hand impact on the stability boundaries. However, the ubiquitous presence of input stochastic flow fluctuations may significantly alter the bifurcation scenarios [2]. Therefore, investigating the bifurcation scenarios in a stochastic non-smooth nonlinear aeroelastic system and characterizing the impact of these dynamical signatures on the safety of the aeroelastic system becomes a necessity. The present study is devoted towards addressing this concern. To that end, we systematically study the response dynamics of a pitch-plunge aeroelastic system subjected to stochastic inflow fluctuations, and subsequently carry out a stochastic bifurcation analysis - both from qualitative and quantitative parlance. The input stochastic flow is modelled to possess time scales longer than that of the system. Finally, the fatigue damage incurred owing to these stochastic dynamical behaviors are quantified using RFC algorithm.

Results and discussion

Preliminary cases of NII and its abrupt transitions to LCOs and back to intermittency is shown for various values of U_m. The non-dimensional correlation time of the considered fluctuating inflow is computed to be of $\mathcal{O}(10^4)$, which is much higher than the non-dimensional system time scale which is computed to be of $\mathcal{O}(10^1)$. Based on the underlying deterministic signature, and the scale and intensity of the input stochastic wind, the stochastic response dynamics is observed to often involve abrupt transitions. Characterizing and quantifying these abrupt intermittent transitions from a fatigue damage purview remains as the primary focus of this study. The response dynamics is investigated through a qualitative and quantitative stochastic bifurcation analysis by invoking Shannon entropy based measures [2]. The fatigue damage analysis, on the other hand, is carried out using an RFC algorithm-based damage estimation to identify stable operating regimes.

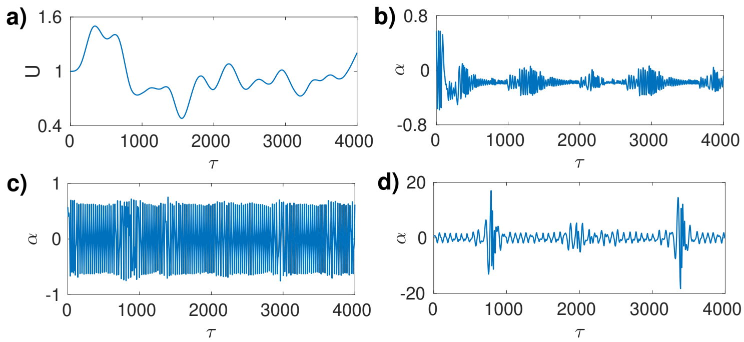

Figure 1: (a) Time variation under long time scale flow fluctuations for U_m = 1, and pitch ($\alpha(\tau)$ in degrees) time responses for (b) U_m = 0.9, (c) U_m = 1, and (d) U_m = 4.5. The corresponding freeplay gap is δ = 1°.

References

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[2] Venkatramani, J and Sarkar, Sunetra and Gupta, Sayan (2018) Intermittency in pitch-plunge aeroelastic systems explained through stochastic bifurcations. Nonlinear Dynamics, **92 (3)**.