Investigating Amplitude Death as a Possible Flutter Suppression Mechanism in a Pitch-Plunge Aeroelastic System

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Abstract. Flutter is a dynamic instability, wherein at a critical flow speed, there is a continuous extraction of energy from the flow to the structure, and in turn posing a threat to the integrity of the structure. Hence, developing precursors and suppression mechanisms to combat flutter has been an important topic of research in the aeroelastic community. In this study we use the phenomenon of amplitude death as a measure to mitigate flutter in aeroelastic systems. To that end, we consider two identical pitch-plunge airfoils, which are subjected to uniform and stochastic flow conditions. The airfoils are coupled using a torsional spring. The coupled interactions of the airfoils are then analysed by obtaining the pitch and plunge responses. Further, the strength and the nature of the coupling between the airfoils are systematically varied to investigate its effect on the regime of AD.

Introduction

The inclusion of a coupling between two nonlinear dynamical systems can result in a host of phenomena such as synchronization, oscillation death and amplitude death (AD). In specific, the phenomenon of amplitude death, which leads to the oscillators exhibiting identical, stationary dynamics on coupling has received widespread attention in literature, emphasising its nature to suppress oscillatory instabilities [1]. Motivated by the same, we investigate the possibility of suppressing dynamical instabilities, such as, flutter in aeroelastic systems using the principle of AD. Elastic structures, such as aircraft wings when subjected to fluid flows, leads to the formation of a feedback loop between the flow and the structure. The feedback loop results in the sustained transfer of energy from the flow to the structure, leading to the dynamic instability called flutter[2]. The onset of flutter is typically associated with limit cycle oscillations (LCOs), posing a threat to the structural integrity of the system. Thereby, mitigating flutter has been a focus of research in the aeroelastic community. This study is devoted to address this concern using the principle of AD. Accordingly, two identical, two degree of freedom airfoil in the form of pitch (torsion) and plunge (bending) modes are considered. The airfoils are coupled using a time delayed, linear torsional spring. The coupled nonlinear responses are systematically investigated by varying the strength of the coupling and the time delay in interaction.

Results and discussion

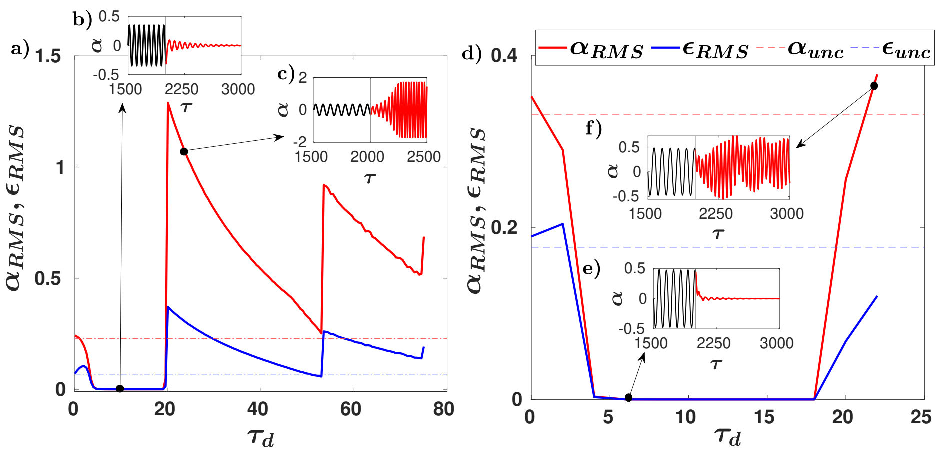

Figure 1: (a) Plot between the RMS of the pitch (α_{RMS}) and plunge (ϵ_{RMS}) responses vs the time delay (τ_d) of the first airfoil with (a) cubic hardening nonlinearity, and (d) cubic softening nonlinearity. In the time delay range τ_d = 4 - 19, the responses completely die down, exhibiting AD. The same can be observed in the inset (b), where the pitch oscillations of the uncoupled airfoils exhibiting LCOs, completely die down after being coupled with the second airfoil. However, beyond time delay $\tau_d = 22$, the oscillations "blow-up", exhibiting large amplitude oscillation, as observed in the inset (c). Similar behaviour is observed for airfoils with a cubic softening nonlinearity, as shown in (d).

On coupling, the oscillators exhibited (i) AD, leading to the cessation of oscillations, and, (ii) blow up, leading to oscillations which are higher in magnitude than their uncoupled state. The same is illustrated in Fig.1. To gain further insight into the physics behind the nature of response, we look to analyse the coupled interaction between the airfoils by estimating the energy of the oscillators prior and after coupling, and the phase delay in interaction between the coupled oscillators.

References

[1] Resmi, V., Ambika, G. and Amritkar, R.E., (2011). General mechanism for amplitude death in coupled systems. *Physical Review E*, 84(4), p.046212.

[2] Fung, Y.C., (2008). An introduction to the theory of aeroelasticity. Courier Dover Publications.