# Identifying route to flutter in a stochastic nonlinear aeroelastic system using recurrence networks

Arvind Raj*, Sirshendu Mondal ** and **Venkatramani Jagadish** *

*Department of Mechanical Engineering, Shiv Nadar University, Greater Noida, India

**Department of Mechanical Engineering, National Institute of Technology Durgapur, India.

**Abstract**. We investigate the aeroelastic responses of a nonlinear airfoil subjected to input stochastic wind loads. Accordingly, the noise-induced intermittency route to flutter is characterized in terms of recurrence networks. We systematically identify the presence of homoclinic orbits in noise-induced pre-flutter responses and map this topological change quantitatively using recurrence networks. It is shown that the noise-induced aeroelastic signatures in the pre-flutter regime are largely scale-free complex networks that culminate into a regular scale structure in the vicinity of flutter onset. Next, we demonstrate that the transition from scale-free networks can be described by invoking the concepts of stochastic P-type bifurcations. Finally, we show that the physical insights gained from this study can be successfully exploited to develop precursors to flutter instability.

## Introduction

A specific concern in the study of nonlinear aeroelastic systems is the ubiquitous presence of input stochastic wind - transforming the underlying problem to a stochastic nonlinear dynamical system and in turn giving rise to noise-induced intermittent oscillations [1]. However, physical insights into such noise-induced transitions in nonlinear aeroelastic systems are yet far from complete. In specific, a one-one mapping of the input stochastic wind with respect to the scaling features in the stochastic output aeroelastic responses remains open. The present study devotes itself to address this concern using numerical investigations. A pitch-plunge aeroelastic system with a cubic hardening stiffness nonlinearity is considered. The input wind load is assumed to be randomly time-varying and possessing either long or short time scale fluctuations. Using mean flow speed as the bifurcation parameter, we systematically obtain the aeroelastic time responses for the stochastic long and time scale input flow fluctuations. Subsequently, we identify the presence of homoclinic orbits in noise-induced intermittent responses using recurrence quantification (RQ) technique. Next, we show that the transition from scale-free complex networks to a regular scale structure in aeroelastic dynamics can be captured using recurrence based network analysis [2]. By corroborating the same with the topological changes in the joint probability density function of the aeroelastic responses and its instantaneous derivatives, we finally show that this noise-induced transition can be described using the concepts of Phenomenological or P-type bifurcations.

## Results and Discussions

Preliminarily, the noise-induced intermittency route to flutter observed in the presence of long and short time scale random flow fluctuations is presented in Fig. 1. We systematically present these time responses for various correlation structures and noise intensities for the input stochastic wind and subsequently carry out an RQ analysis. From the same, the presence of homoclinic orbits is identified. En-armed with this insight, we demonstrate the collapse in dynamical signatures from a state of scale-free networks to regularity in the aeroelastic dynamics. Interesting observations pertaining to this complexity transition is presented from the purview of stochastic bifurcations [1]. Finally, directions to apply the nonlinear dynamical insights from this study towards prognostic usages, such as flutter prediction is suggested.

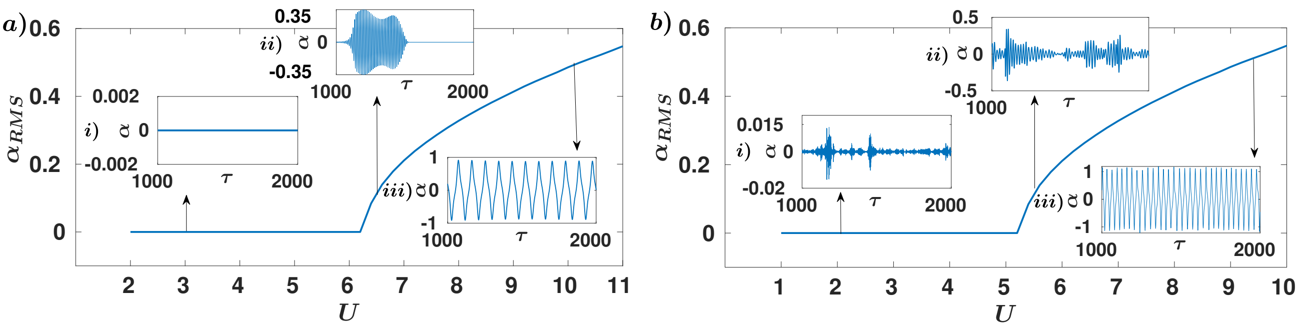


Figure 1: Intermittency route to flutter obtained for long time scale input gusts (left image) and short time scale input gusts (right image) respectively.

## References

[1] Venkatramani, J., Sarkar, S., and Gupta, S. (2018). Intermittency in pitch-plunge aeroelastic systems explained through stochastic bifurcations. Nonlinear Dynamics, 92(3), 1225-1241.

[2] Godavarthi, V., Unni, V. R., Gopalakrishnan, E. A., and Sujith, R. I. (2017). Recurrence networks to study dynamical transitions in a turbulent combustor. Chaos: An Interdisciplinary Journal of Nonlinear Science, 27(6), 063113.