Effect of time-scale in the flow fluctuations on a sub-critical aeroelastic system

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Abstract. This study investigates the effect of time-scale in the flow fluctuations on a 2 DOF pitch-plunge aeroelastic system. The structure is supported by nonlinear soft springs and the fluid loads are evaluated using a semi-empirical model. The flow fluctuations are modelled as an OU process. It is seen that long time-scale noise advances the onset of intermittency but delays the onset of LCO when compared to short time-scale noise, presenting new design challenges.

Introduction

Stochastic noise has been known to play a major role in altering the dynamics of FSI systems[1, 2, 3]. They have been known to induce dynamical states like intermittency[2, 3] and change the jet-switching characteristics in the flow-field[1]. These studies show that the time-scales in the flow fluctuations are of utmost importance and hence, we investigate the effect of time-scale in the flow fluctuations on a sub-critical aeroelastic system. The structure is modelled as a 2 DOF pitch-plunge elastic system with nonlinear soft springs[4]. The fluid loads are calculated using the semi-empirical Wagner function[4]. The non-dimensional equations describing the aeroelastic system (with the flow fluctuations) take the form of an Ito SDE as given in Equation 1.

$$\begin{aligned} d\vec{\mathbf{X}} &= f(\vec{\mathbf{X}}, \tau; U)\, d\tau \\ dU &= \lambda(U_m - U)\, d\tau \;+\; \sigma\, dW \end{aligned} \tag{1}$$

where $\vec{\mathbf{X}}$ represents the system variables which include the auxillary variables needed to calculate the fluid load, τ the non-dimensional time, U the flow velocity. The flow fluctuations in U are modelled as an OU process [1] with mean U_m, time-scale parameter λ ($1/\lambda$ is the correlation time), W the Standard Wiener process and σ the noise intensity. Equation 1 is studied for two cases: $\lambda = 0.005$ (long time-scale); $\lambda = 0.5$ (short time-scale).

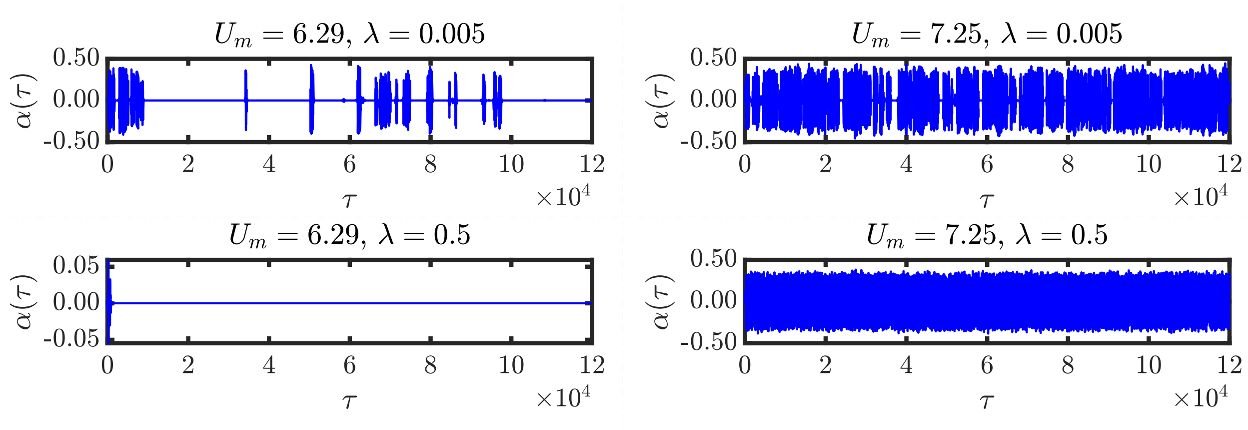

Figure 1: Pitch time series ($\alpha(\tau)$) for $U_m(= 6.29, 7.25)$ and $\lambda(= 0.005, 0.5)$

Results and Discussion

To study the effect of λ, the variance of the OU process in Equation 1 is taken as 1 ($\sigma^2/(2\lambda) = 1$). Figure 1 shows the pitch time series ($\alpha(\tau)$) for $U_m = 6.29, 7.25$. It is observed that for the initial conditions chosen (deterministically the system evolves to a LCO at $U = 6.29$), there is a delay in the onset of LCO as U_m is varied. The long time-scale case ($\lambda = 0.005$) has the system in a state of intermittency at $U_m = 6.29$, whereas at this U_m, the short time-scale case ($\lambda = 0.5$) evolves to the $\vec{0}$ state (Figure 1). However at $U_m = 7.25$, the $\lambda = 0.5$ case displays full-fledged LCO behaviour but intermittency persists in the $\lambda = 0.005$ case (Figure 1). Thus the long time-scale noise advances the onset of intermittency but delays the onset of full-fledged LCO when compared to the short-time scale noise. The time-scales of the input flow fluctuations affect the onset of different dynamical behaviour and hence is an important parameter for consideration during design.

References

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