Analysis of a nonlinear aeroelastic system with parametric uncertainty under dynamic stall condition

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Abstract. This study focuses on investigating the dynamical signatures of a pitch–plunge aeroelastic system undergoing dynamic stall and subjected to uncertainty in a structural parameter. To that end, the plunge to pitch frequency ratio ($\overline{\omega}$) is assumed to be an uncertain parameter and is modeled through Karhunen-Loeve Expansion (KLE). The nonlinear aerodynamic loads due to dynamic stall on the aeroelastic system are modeled using the semi-empirical Leishman and Beddoes (LB) dynamic stall model. It is observed that based on the intensity and scales of the fluctuations in $\overline{\omega}$ - distinct dynamical signatures, as well as instability boundaries, are encountered. The findings presented in this study are intended to unravel the *qualitatively* rich stochastic dynamical signatures and their hand-in-hand impact on structural safety.

Introduction

There is a growing interest to study stall-induced aeroelastic systems owing to their ubiquitous presence ranging from wind turbine blades to aircraft wings [1, 2]. A key concern in assessing dynamical signatures and safety margins is that uncertainties in structural parameters and/or input wind possess the *uncanny* ability to jeopardize both the safety margin as well as the bifurcation scenarios. Other than a few seminal studies [3, 4], investigating the role of uncertainties in stall flutter problems has received minimal attention. The above studies as well focus on a purely pitching airfoil with a lower order aerodynamic modeling and in turn, have the potential to miss out on key dynamical transitions - see Bethi *et al.*[1] for details of the same. Addressing these concerns forms the focus of this study. Indeed, this study investigates the effect of uncertainties in $\overline{\omega}$ on an aeroelastic system subjected to a dynamic stall. The time histories of the responses along with their marginal probability density function (pdf) and the associated probabilistic assessment of the dynamical signatures are presented next.

Results and discussion

Preliminary results of the stall-induced aeroelastic responses assuming the frequency ratio ($\overline{\omega}$) to be stochastically time varying is shown in Fig. 1. Note that $\overline{\omega}$ is assumed to possess a Gaussian distribution and is mathematically modelled using KLE with, $\overline{\omega}_m$ (mean value of the frequency) as 0.2 and three different fluctuation intensities (σ), namely, 0.1, 0.15 and 0.2 are considered. It is observed that "on-off" type intermittency is present even below the flutter speed (U = 5.6). Similar observations under gusty wind loads were made in [1]. As U increases, the responses qualitatively transform to random limit-cycle oscillations (LCOs) which gradually grow in amplitude. In the probabilistic sense, it is shown that at U = 5.4 the pdfs are concentrated towards $\alpha = 0$. As the value of U increases, the pdfs of the response amplitudes are distributed and go through a qualitative change (random LCOs). Quantifying these changes *vis-à-vis* to instability boundaries will be taken up in detail in the full paper.

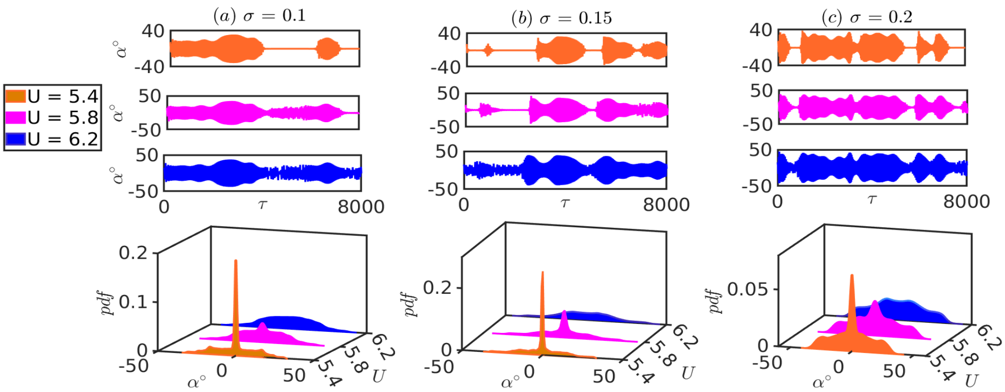

Figure 1: Pitch responses and corresponding pdfs of the aeroelastic system for U = 5.4 - 6.2, under nonlinear aerodynamics and $\overline{\omega}_m$ = 0.2 with $\sigma = 0.1 - 0.2$.

References

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