Phase synchrony between the pitch and plunge modes in aeroelastic systems leading to stall flutter

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Abstract. The underlying physical mechanism of stall flutter, giving way to limit cycle oscillations (LCOs), is still not completely understood. To that end, this study adopts a synchronization framework to explain the transitions observed in the response of a pitch-plunge aeroelastic system, subjected to dynamic stall, in a low speed wind tunnel. In addition to different flutter boundaries, a phenomenologically rich response dynamics, including period doubling, asymmetric LCOs, beats, intermittency and internal resonance, is observed. Overall as well as frequency specific synchronization is characterized using measures, such as phase locking value and phase difference ($\Delta\phi$). A variety of different synchronization dynamics, such as complete synchronization, intermittent phase synchronization (IPS), phase trapping, phase flipping and aynchrony are observed, that underpin the underlying physics of stall flutter.

Introduction

Traditionally, stall flutter is represented by pitch dominant LCOs. From the purview of synchronization, stall flutter has recently been identified through frequency response as the ‘suppression of natural dynamics’ - wherein also the pitch mode dominance is observed [1, 2]. Numerical investigation shows that route to stall flutter manifests through an asynchronous regime that finally culminates into a complete synchronization [1]. However, various dynamical signature may arise from stall flutter, which are observed in experiments, but are not captured yet numerically [2, 3]. The present study aims to address this gap by conducting synchronization analysis on stall-induced responses obtained from wind tunnel experiments at different control parameters. Here, we characterize synchronization between two interacting modes through relative phase dynamics and phase locking value. Finally, we present unique synchronization routes observed during the transition to stall flutter along with the traditionally known synchronization paradigms.

Results and Discussion

Experiments are carried out, considering the flow speed (with and without noisy fluctuation), the frequency ratio and the elastic axis position as control parameters. An instance of transitions in synchronization dynamics for a NACA 0012 airfoil (see Fig. 1a for the setup) undergoing pitch-plunge aeroelastic oscillations is shown in Fig. 1b. The details regarding the experiments can be found in our previous work [2]. The onset of the stall flutter LCOs is observed to be at the flow speed (U) = 5.8 m/s, which gradually grow in amplitude with the flow speed (see Fig. 1b). The synchronization study shows asynchrony despite the flutter onset at U = 5.8 m/s (Fig. 1b-i). At U = 6.1 m/s, the synchronization switches to an IPS, containing multiple regimes of phase synchronisation and phase slips (Fig. 1b-ii), and subsequently a complete synchronization is achieved at U = 7.1 m/s (Fig. 1b-iii). Thus, a possible route to synchronization in stall flutter can be through a regime of asynchrony and IPS. However, alternate synchronization routes, leading to period doubling, internal resonance etc., may be present for different structural parameters. Finding the same can be beneficial for the aeroelastic system design and is the key focus of this study.

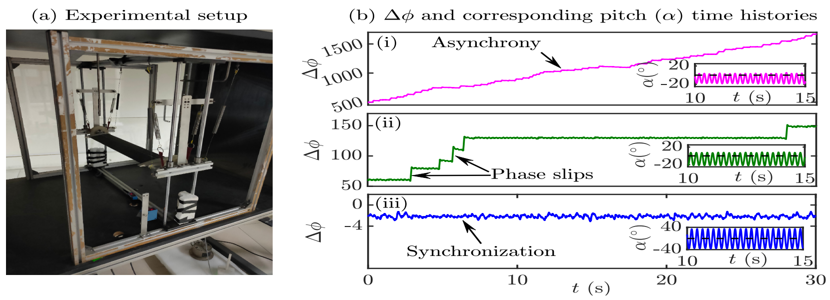

Figure 1: (a) Experimental setup; and (b) the synchronization dynamics for U (i) 5.8 m/s, (ii) 6.1 m/s, and (iii) 7.1 m/s.

References

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