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Identifying Triggering Mechanisms and Suppressing Aeroelastic Instabilities by Passive Targeted Energy Transfers: Nonlinear System Identification, Modal Interactions and Resonance Captures

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An analytical and experimental study of triggering mechanisms of aeroelastic instability will be presented for a two-degree-of-freedom, in-flow rigid wing. The study involves careful identification of the nonlinear resonant interactions of the wing modes with the flow. Depending on system parameters, these nonlinear modal interactions appear either as internal resonances (IR), or as resonance captures (RC) between the aeroelastic modes. For example, our theoretical model exhibits a series of transitions from 1:1 transient RC to 3:1 permanent RC. In the experimental system, the aeroelastic instability is associated with 1:1 IR. Analytical tools, such as multi-phase complexification and averaging, are utilized to explain the nonlinear resonant behaviors.

In order to capture the essential features of a dynamical system, it is important to establish the proper slow-flow dynamics, on which its underlying physics driving aeroelastic instability can be explained. A new system identification technique is introduced, utilizing Hilbert-Huang transforms combined with wavelet transforms and complexification and averaging. Theoretical and experimental examples illustrate and validate this technique.

It will be shown that aeroelastic instabilities can be suppressed or even completely eliminated by broadband, passive targeted energy transfers (TETs) from a wing to a single-degree-of-freedom (SDOF), passive, essentially nonlinear energy sink (NES). Because the broadband and passive TETs are governed by nonlinear resonant interactions between the wing and the NES, proper understanding of the underlying instability triggering mechanism is crucial for this passive control method. Three instability suppression mechanisms are revealed: (i) recurrent burst-outs and suppression, (ii) intermediate suppression, and (iii) complete suppression of aeroelastic instability. These mechanisms are all examined analytically and numerically, and are validated experimentally.

Robustness studies of NES-based passive suppression are performed by bifurcation analysis as the parameters of the wing-NES integrated system vary. A numerical continuation code, MATCONT, is utilized for constructing a bifurcation set in three-dimensional NES parameter space. The influence of each parameter on aeroelastic instability suppression is examined, resulting in a parameter zone that guarantees robust aeroelastic instability suppression. Finally, a multi-DOF NES is introduced to demonstrate that robustness of aeroelastic instability suppression can be greatly enhanced by increasing the DOF of the NES without increasing its weight.