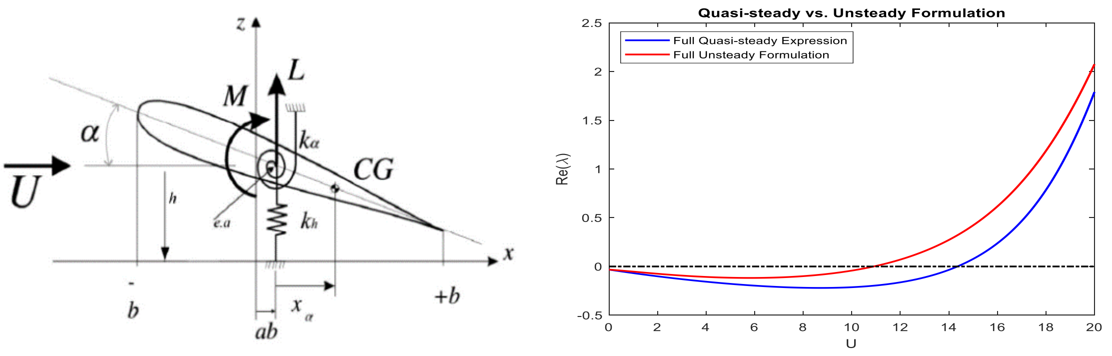
Insights on the stall and unsteadiness effects on the nonlinear responses of flutter-based aeroelastic systems

Adam Bouma*, Widad Yossri*, Rui Vasconcellos**, and Abdessattar Abdelkefi*
**Department of Mechanical and Aerospace Engineering, New Mexico State University, Las Cruces, NM 88003, USA*
***São Paulo State University (UNESP), São João da Boa Vista, SP, 13876-750, Brazil.*

Abstract. A nonlinear analysis is performed on a two degree-of-freedom wing-based system. Nonlinearities are introduced in the pitch degree of freedom using two different forms of aerodynamic representations. Comparisons between quasi-steady and unsteady aerodynamic representations are investigated and discussed including stall effects. The unsteady representation based on the Duhamel formulation is used to model the aerodynamic loads. The nonlinear aeroelastic response is carried out in the presence of quadratic and cubic nonlinearities in the pitch degree of freedom. The effects of the stall and unsteadiness of the flow on the Hopf bifurcation and limit cycle oscillations of the system are investigated. A comparative study between the unsteady and quasi-steady representations from a nonlinear perspective is also carried out.

Introduction

Aeroelasticity is the study of aerodynamic forces acting upon an elastic structure when exposed to fluid flow and has been a main topic of research in aeronautics in the last decade. The aerodynamics must be modeled accurately in order to determine the response of the system. Quasi-steady and unsteady formulations of the aerodynamic loads have been used by researchers to predict the onset of flutter as well as the post-flutter response [1]. In this work, a two degree-of-freedom small-scale inspired wing-based system is considered as a lumped-parameter model. The quasi-steady and unsteady formulations are compared, including quadratic and cubic nonlinearities in the pitch degree-of-freedom. The aeroelastic system seen in Figure 1(a) shows the schematic of a linear 2-DOF typical section [1]. To investigate the effects of the aerodynamic loads on the coupled damping and frequencies, only the linear part of the governing equations is first considered. After validating the linear flutter speeds, the nonlinear effects in the pitch degree of freedom are investigated along with stall effects in the aerodynamic loading and a variation in structural damping. A bifurcation inspection with increasing freestream velocity is also performed with a particular focus on the impacts of the unsteadiness and stall on the system's response.



(a) (b)

Figure 1: (a) 2-DOF typical aeroelastic section under airflow excitation [1] and (b) linear response of the 2-DOF system.

Results and discussion

A comparison is first made between the quasi-steady and unsteady formulations to predict the linear flutter speed based on a difference of aerodynamic loading and can be seen in Figure 1(b). The linear flutter speed occurs at approximately 10.91 m/s for the unsteady formulation and 14.36 m/s for the quasi-steady approximation. The quasi-steady approximation does not account for the wake effects while the unsteady formulation represents the aerodynamic loads as a time-dependent function approximated using the Sears and Pade approximations [2]. After the comparison of these two aerodynamic formulations, a nonlinear investigation of the effects of the noncirculatory terms, unsteadiness and stall of the flow in the system will be conducted, of which more in-depth details will be down in the final version of this conference paper.

References

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