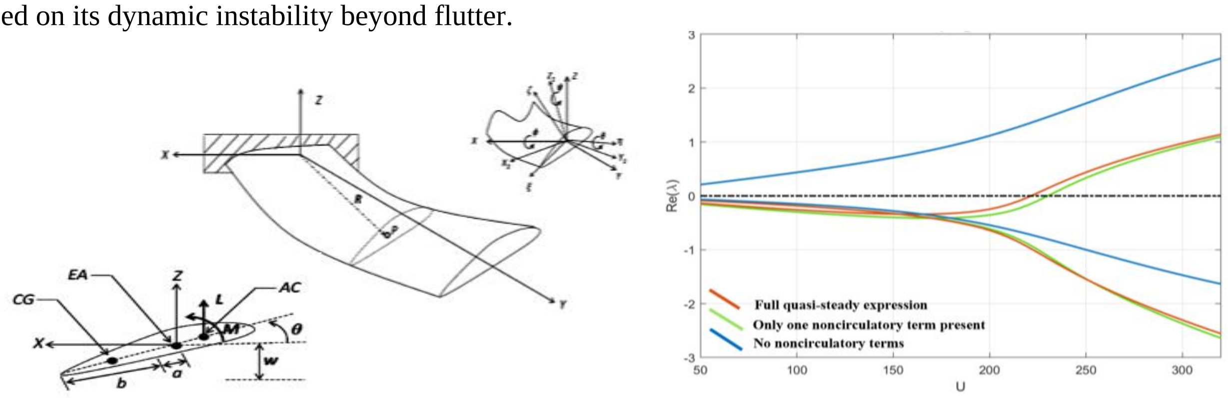
Comprehensive nonlinear aeroelastic analysis of wing-based systems

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

Abstract. Wing-based systems represent prime built-in components of a variety of structures in many fields. In this work, the nonlinear reduced-order model of a wing-based system's aeroelastic response is derived using the extended Hamilton's principle and Galerkin discretization. The impacts of the non-circulatory terms, unsteadiness, and stall on the linear and nonlinear characteristics of the aeroelastic system are investigated and discussed throughout this in-depth study. A comprehensive aeroelastic model should be the outcome of this investigation which will be used by the aeroelastic community for pre- and post-flutter analyses for numerous kinds of systems including wings, energy harvesters, and wind turbine blades.

Introduction

Aeroelastic systems are characterized by an interaction between the surrounding field and the systems' structure. Consequently, their overall responses cannot be accurately determined unless the interplay between the coupled dynamics of the fluid and structure is accurately represented. Commonly, the quasi-steady formulation was used to predict the onset of flutter as well as the post-flutter response of various kinds of systems. Yet, Abdelkefi et al. experimentally showed that for a two-dimensional spring-supported rigid aeroelastic system, the quasi-steady formulation predicted larger flutter speed values in comparison with those obtained experimentally [1]. In this study, instead of the previous lumped model representation of the aeroelastic system, our system is modelled to be continuous which provides a means of calculating the deflection characteristics of the wing studied as is shown in Figure 1-a. A Galerkin discretization approach that is based on a cantilever beam's mode shapes is used to derive the nonlinear reduced-order model that portrays the aeroelastic response of the wing and investigate the effect of the system's parameters as well as the wind speed on its dynamic instability beyond flutter.



(a)

(b)

Figure 1: Wing-based system configuration a) The adopted simplified wing geometry for equations of motion derivations [2] b) Linear response of Goland wing system without structural damping.

Results and discussion

Firstly, a comparison between the quasi-steady and the unsteady formulation is conducted. Conventionally, the aerodynamic loads used for predicting the beginning of flutter are determined from the quasi-steady approximation. The latter formulation does not account for the wake effect in the aerodynamic loads. On the other hand, the aerodynamic loads in the unsteady formulation case are represented as a time-dependent function that shall be approximated using the Sears and Pade approximations [3]. After the comparative study is addressed, the effect of the structural damping as well as the noncirculatory terms on the system shall be profoundly analyzed for each formulation case. Figure 1-b shows the Goland wing system's preliminary linear response for different noncirculatory terms arrangements in the absence of any structural damping, deeper investigation and results will be shown in the final version of this conference paper.

References

[1] Abdelkefi, A., Vasconcellos, R., Nayfeh, A.H.: An analytical and experimental investigation into limit-cycle oscillations of an aeroelastic system. Nonlinear Dyn (2013) 71:159–173 DOI 10.1007/s11071-012-0648-z.

[2] Nayfeh, A.H., Ghommem, M., Hajj, M.R.:Normal form representation of the aeroelastic response of the Goland wing. Nonlinear Dyn (2012) 67:1847–1861 DOI 10.1007/s11071-011-0111-6

[3] Edwards, J.W., Ashley, A.H., Breakwell, J.V.: Unsteady aerodynamic modeling for arbitrary motions. AIAA J.17,365–374 (1979)