Nonlinear characterization of the structural discontinuity effects on whirl flutter of a rotor-nacelle system

Anthony Quintana*, Rui Vasconcellos**, and Abdessattar Abdelkefi*

**Department of Mechanical and Aerospace Engineering, New Mexico State University, Las Cruces, NM, USA.*
***Sao Paulo State University, São João da Boa Vista, Brazil.*

Abstract. Whirl flutter is an aeroelastic instability that can be affected by structural or aerodynamic nonlinearities. This instability may affect the failure prediction model that could lead to potentially dangerous behaviors. The destructive nature of whirl flutter is inherent to the physical limitations to rotor nacelle systems, which are presented through fatigue failure. In this study, a freeplay nonlinear reduced-order model for a nacelle-rotor system, considering quasi-steady aerodynamics, is implemented. Multiple polynomial nonlinearities in the two degrees-of-freedom nacelle-rotor model are tested to simulate possible structural nonlinear effects. A nonlinear characterization is carried out in order to identify the type of existing bifurcations in the system.

Introduction

Rotor operated aircraft, manned and unmanned, are a largely as a means of thrust by many aerial vehicles operated in the commercial and military, as well as the wide spectrum of unmanned aerial vehicles. The rotor nacelle is a relatively simplistic concept, utilizing airfoil technology to propel an aircraft in the desired direction used for flight. However, there are inherent physical limitations to these systems which are presented through fatigue failure cause by several aspects. One prominent aspect for this type of failure can derive from nonlinearities in the material stiffnesses of the system. The cause of nonlinear failure in the rotor nacelle systems is known as whirl flutter.

Whirl flutter is a potentially disastrous aeroelastic instability faced by propeller driven aircraft. Whirl flutter can cause propellers and the surrounding structures to fail and therefore must be accurately predicted. Whirl flutter is the result of a coupling of the structure of the wing, the aerodynamic forces and moments on the wing and the rotor, and the gyroscopic effect of the rotor [1-3]. The onset of whirl flutter is difficult to predict and the inclusion of the additional degree of freedom from the rotating rotors makes this an even more challenging task. Oftentimes, nonlinearities are neglected in modeling of these systems for simplicity, but these systems commonly have nonlinear characteristics and behaviors due to the aerodynamics and the structural inherent nonlinearities in the system [4]. The rotation of the rotors also causes nonlinearities in the system, such as freeplay caused by aging and wear. These nonlinearities make the flutter prediction a more challenging task and if they are not accurately accounted for could cause catastrophic system failure.

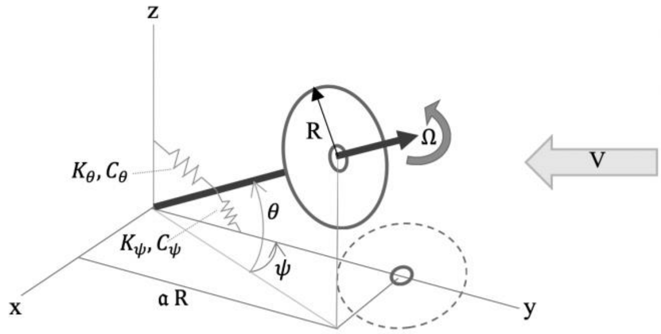

Figure 1: Schematic of a nacelle-rotor two degree of freedom system.

Results and Discussion

Preliminary results show that the presence of hardening structural nonlinearities introduces limit cycle oscillations to the system in the post-flutter regime. Moreover, the inclusion of quadratic piecewise nonlinearity introduces asymmetric oscillations, and subcritical/supercritical Hopf bifurcation, large and potentially dangerous deformations can be reached before the predicted linear flutter speed. In the final version of this paper, a nonlinear characterization will be carried out on the freeplay nonlinearity effects on the responses of whirl flutter of rotor-nacelle system.

References

[1] Park, J. S., Jung, S. N., Lee, M. K., & Kim, J. M. (2010). Design optimization framework for tiltrotor composite wings considering whirl flutter stability. Composites Part B: Engineering, 41(4), 257-267.
[2] Čečrdle, J. (2017). Aeroelastic Stability of Turboprop Aircraft: Whirl Flutter. Flight Physics–Models, Techniques and Technologies, Ed.: Konstantin Volkov, InTech Publications, Rijeka, Croatia, 1, 139-158.
[3] Janetzke, D. C., & Kaza, K. R. (1983). Whirl flutter analysis of a horizontal-axis wind turbine with a two-bladed teetering rotor. Solar Energy, 31(2), 173-182.
[4] Mair, C., Rezgui, D., & Titurus, B. (2018). Nonlinear stability analysis of whirl flutter in a rotor-nacelle system. Nonlinear dynamics, 94(3), 2013-2032.