Investigation of Chaotic Flutter in a Wind Turbine Airfoil

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Abstract. The occurrence of chaotic motion in a fluttering airfoil is investigated using an efficient analytical predictive model. Flutter is an aeroelastic vibration instability of an elastic structure, such as an airfoil in a fluid, that results from an unstable interaction between the fluid and structural dynamics. Typical engineering applications of airfoils include aircraft wings and wind turbines. The structural equations of motion for the generalised two degree of freedom (pitch and plunge) coupled modes of on airfoil section are combined with unsteady aerodynamics, based on flutter derivatives and a continuous bilinear lift curve under damping and variable angle of attack. The mode coupling instability via dynamic divergence causes limit cycle behaviour via a Hopf bifurcation that breaks up into chaos characterised by period doubling behaviour after the critical flutter speed. Conditions under which chaotic instability occurs are identified and discussed for the case of a wind turbine section. The results provide insight into the occurrence and avoidance of airfoil flutter in aeroelastic structures like wind turbines.

Introduction

Flutter is an aeroelastic vibration phenomenon of an elastic structure in a fluid that results from an unstable interaction between the fluid and structural dynamics. Flutter vibrations occur typically above a lower critical speed and grow to an amplitude determined by the nonlinearities in the aerodynamics and/or structural dynamics. Flutter remains one of the most important issues for aircraft and structural engineering industries, motivating careful design to avoid fatigues failures such as in wind turbine blades. Theodorsen first provided a general theory for airfoil instability under unsteady aerodynamics [1]. Since then, an enormous amount of research on flutter modelling and prediction has occurred, as comprehensively reviewed in [2]. Essentially, the onset of binary flutter has been shown to be due to an unstable coupling of the pitching and plunging dynamics of a cross-section due to aerodynamics of the flow [1], [2]. Chaotic flutter has also been an intense area of research initiated from numerical identification in a two-degree of freedom airfoil with cubic nonlinearities eg [3]. Others have identified and investigated stall flutter chaos with aerodynamic, structural, kinematic and thermal nonlinearities eg [4]. Recently chaotic flutter was identified in an airfoil without the need for structural or thermal nonlinearity [5]. In this paper we extend these numerical and analytical investigations of chaotic flutter in an airfoil section to provide more efficient insight into its occurrence and avoidance in wind turbines.

Results and discussion

A reduced airfoil section model is modified and developed, that includes the dominant flutter mode coupled dynamics, unsteady flutter derivative aerodynamics and a bilinear lift model proposed and validated by [5]. The analytical methods for predicting the critical flutter onset speed, limit cycle amplitude and chaotic flutter for a wind turbine blade section are then described. The full nonlinear time domain model consisting of two autonomous coupled nonlinear second order systems, is numerically solved using the fourth and fifth order Runge–Kutta routine as part of DYNAMICS, written by Nusse and Yorke or the Radua method in MathCad 15.0 at a sampling rate of at least 20 times the flutter frequency. The nonlinear phenomena were investigated using the time history, phase space and bifurcation diagrams of Poincaré maps and Lyapunov Exponents. An example history showing chaotic instability is shown in *Figure. 1*.

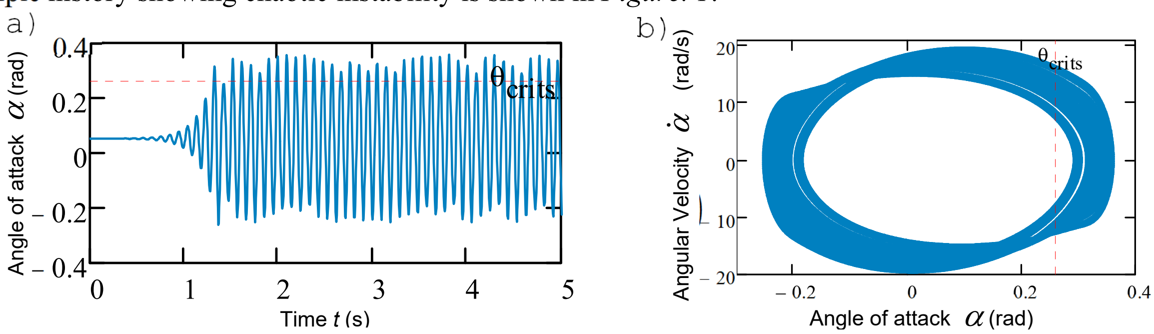

Figure. 1 ***a) Simulated time history and b) phase space of chaotic flutter in an airfoil section, stall angle θcrits***

The conditions under which chaotic instability under various initial section angle of attacks are investigated and identified in both a fundamental and wind turbine blade airfoil section in closed form to provide efficient analytical insight into the occurrence and avoidance of chaotic flutter.

References

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