Flutter vibration amplitude saturation by friction forces in a mistuned bladed disk

Carlos Martel, Dept. Applied Mathematic to Aerospace Engineering, Universidad Politécnica de Madrid, 28040 Madrid, Spain

Roque Corral, Advanced Engineering Direction, Industria de TurboPropulsores S.A., 28018 Madrid, Spain

Long Abstract

Introduction

The final vibration amplitude of an aerodynamically unstable bladed disk is a magnitude of extreme practical importance: it constitutes an essential information for the prediction of the level of high cycle fatigue of the blades, and for the subsequent estimation of its operative life span. The aerodynamic instability (flutter) is a linear process that gives rise to the exponential growth of some of the travelling wave modes of the bladed disk (unstable modes), this increase in the vibration level is then saturated by the nonlinear damping introduced by the friction forces at the interfaces between blade and disk, or at the included dampers. The computation of the final amplitude of the saturated travelling wave requires to solve a quite complicated nonlinear problem, which can be reduced to a single sector with phase lag boundary conditions, and requires to consider several time harmonics in order to capture the details of the nonlinear periodic oscillation that sets in [1]. The situation becomes even more complicated if the small unavoidable differences among blades (mistuning) are also taken into account. Mistuning has a beneficial effect on flutter, reducing the growth rate of the aerodynamic instability. But the presence of mistuning breaks the cyclic symmetry of the problem, giving rise to a final vibration distribution along the bladed disk that is composed of a combination of several travelling wave modes, and, therefore, the solution of the mistuned vibration problem requires to consider not a single sector but the complete bladed disk. The method presented in this talk allows to drastically simplify the problem by taking into account the fact that all three effects present (flutter growth, nonlinear friction damping, and mistuning) are, in most practical situations, small effects that develop in a time scale that is much longer than that associated with the elastic vibration frequency of the tuned system (see Figure 1). Using multiple scales techniques [2], a simplified model is derived, and used to analyze the characteristics of the final vibration state of the mistuned bladed disk.

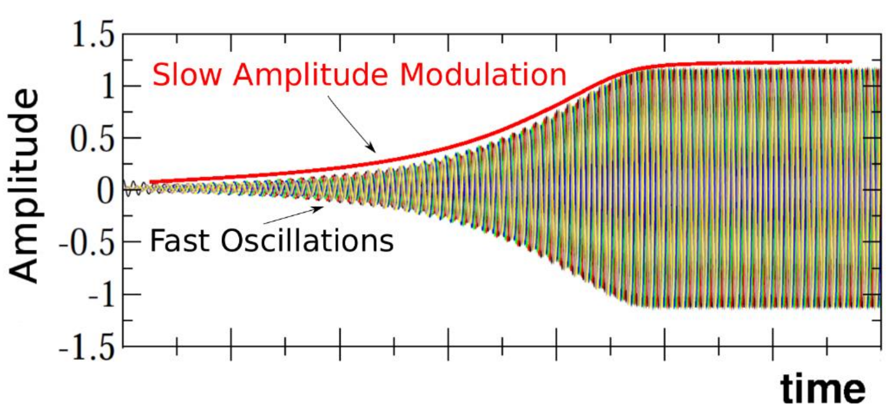

Figure 1. Sketch of the time history of the vibration amplitude showing: (i) the fast elastic oscillation time scale, and (ii) the slow time scale modulations associated with flutter, friction and mistuning.

1. Methods

A simple model of the bladed disk will be used to illustrate the application of the multiple scales methodology (see Figure 2). The model includes one degree of freedom per sector to represent the airfoil vibration (x), and one micro-slip degree of freedom (y) to account for the effect of friction at the blade disk interface. The coupling between blades takes place only through the aerodynamic forces, and the mistuning is included through small variations of the stiffness of the blades. The model is a generalization of the model used in [3] and [4] to include mistuning effects.

$$m_b \ddot{x}_j + k_{b_j}(x_j - y_j) + F_{aerodynamic,j} = 0$$

$$m_f \ddot{y}_j + k_{b_j}(y_j - x_j) + F_{friction,j} = 0$$

The multiple scales methodology will be applied first to the tuned case to analyze the travelling wave content of the final state [1,3,4]. Then, two very different mistuned configurations will be considered: (1) the case when the flutter unstable mode is a disk dominated mode with frequency separated from the rest of the modes, and (2) the case when the aerodynamic instability occurs in a blade alone modal family, with many modes having very similar frequencies. Finally, the extension of this methodology to a realistic bladed disk FEM will be also discussed.

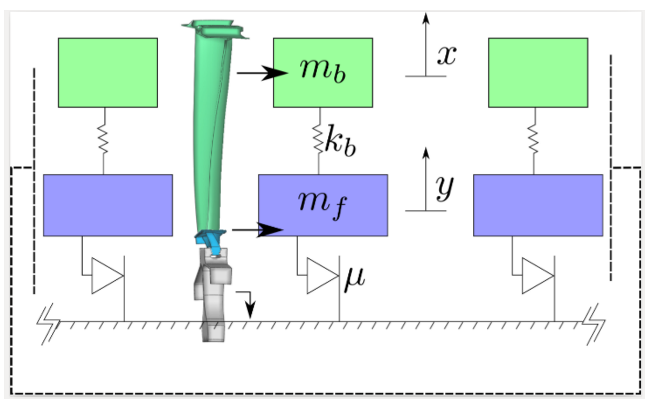

Figure 2. Simplified model of the bladed disk with the elastic vibration motion of the blade (x), and the micro-slip at the fir-tree (y).

References

[1] M. Krack, L. Salles and F. Thouverez. Vibration prediction of bladed disks coupled by friction joints. *Arch. Computat. Methods Eng,* Springer, 1–48, 2016.

[2] C. M. Bender and S. A. Orszag, Advanced Mathematical Methods for Scientists and Engineers I: Asymptotic Methods and Perturbation Theory, Springer, New York, 1999.

[3] R. Corral and J. M. Gallardo. Nonlinear dynamics of bladed disks with multiple unstable modes, AIAA Journal, 52 (6) 1124-1132, 2014.

[4] C. Martel, R. Corral and R. Ivaturi. Flutter amplitude saturation by nonlinear friction forces: reduced model verification, *Journal of Turbomachinery*, 137:041004-1–8, 2015.