Design of mistuning patterns to control the vibration amplitude of unstable rotor blades

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Long Abstract

Introduction

Modern aircraft engines are required to have improved fuel efficiency rates and lower weight. This translates into compressor and turbine designs with fewer stages and higher pressure ratio per stage, which leads to highly stressed blades. On top of that, in order to reduce weight, blade designs are becoming slender and with higher aspect ratio, which makes them much more prone to experience flutter. Flutter is an aeroelastic instability that occurs without any external forcing, and is triggered when the unsteady distortion of the flow produced by the elastic vibration of the blades has a net effect on the blades that tends to increase their vibration amplitude. Once flutter sets in on an unstable rotor, the oscillating amplitude of the blades will increase, producing higher stresses with each cycle of vibration, and decreasing the rotor blade life and consequently compromising the engine operation safety.

Blades are not perfectly identical; they have small geometrical and structural differences typically caused by manufacturing processes and wear. These imperfections, called mistuning, are very small but have a strong effect on the vibration characteristics of the bladed disk [1]. In the case of forced response, mistuning increases substantially the vibration amplitude and gives rise to a localization of the vibration activity to a few blades. On the other hand, it is well known [2] that the effect of mistuning on flutter is usually beneficial, reducing the overall aeroelastic instability level, and that intentional mistuning patterns (alternate pattern in most cases) can be included in the bladed disk as a way to mitigate flutter design constraints [3].

The major part of the experiments performed to study the effect of mistuning on flutter use bladed disk in laboratory conditions, and there are only a few mistuning experiments performed under rig conditions. In this talk we will describe an experiment that, up to our knowledge, has not been performed before in an unstable low-pressure turbine (LPT) rotor in a high speed rotating wind-tunnel. The experiment implements first an intentional alternate mistuning pattern and validates its capability of suppressing flutter, and then, and this is the novel part of the experiment, a second intentional mistuning pattern is also tested to show how the effect of flutter can be controlled and modulated through the inclusion of an appropriate mistuning pattern [4].

The design process of the intentional mistuning patterns is done using a reduced order model, called Asymptotic Mistuning Model (AMM [5]), which is a powerful design tool for the prediction of the aeroelastic stability of the mistuned LPT rotor. The AMM allows us to select two mistuning patterns: (i) the classical alternate mistuning pattern, and (ii) a second mistuning pattern, the half stabilizing pattern, that halves the vibration amplitude of the tuned case. The mistuning patterns are built in the rotor by mounting additional masses in the tip-shrouds, and the measurements of the vibration amplitude are obtained using tip-timing optical probes and casing flush-mounted unsteady pressure transducers. The mistuning patterns are then tested in the frame of the free-flutter experiment [4] where the aerodynamically unstable LPT rotor is brought to flutter in a controlled environment at rig conditions.

Furthermore, the AMM is also used to calculate the aeroelastic stability characteristics of the two mistuned bladed disks, and the results are compared with those coming from detailed FEM and CFD calculations in order to highlight the importance of the crossed aerodynamic work in the estimation of the rotor instability, which can be dangerously underestimated if the crossed works are not taken into account.

References

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