Recent Advancements in Turbine Flutter: Understanding and Design Analyses

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Introduction

The blades and vanes in the aft stages of power turbines and commercial aircraft low pressure turbines are prone to flutter. Careful design analysis and development testing are required to eliminate this potential problem. Over the last 20 years, the understanding of turbine flutter mechanisms and design parameters has significantly improved. This presentation summarizes these improvements and describes recent advancements.

Parameters Controlling Turbine Flutter

Flutter is typically encountered on the blades and vanes of aft turbine stages in either the 1st or 2nd natural frequency. The blades are relatively long, slender, and can contain shrouds that structurally couple the blades. Reduced frequency is a ubiquitous design parameter for all aeroelastic problems, and is defined as

$$k = \frac{\omega b}{V},$$

where ω is the frequency in radians per second, b is the half-chord, and V is the exit relative velocity. The half-chord and exit velocities are usually taken at 75-85% of span. This reduced frequency was the first (empirically identified) design parameter and had mode dependent design magnitudes of approximately (greater than) 0.1 and 0.3 for the 1st bending and 1st torsion mode, respectively. However, these criteria are of limited accuracy. More recent understanding of the mode shape was improved and resulted in criteria known as the tie-dye plot (Ref. 1), which maps the minimum design reduced frequency for all possible rigid body modes.

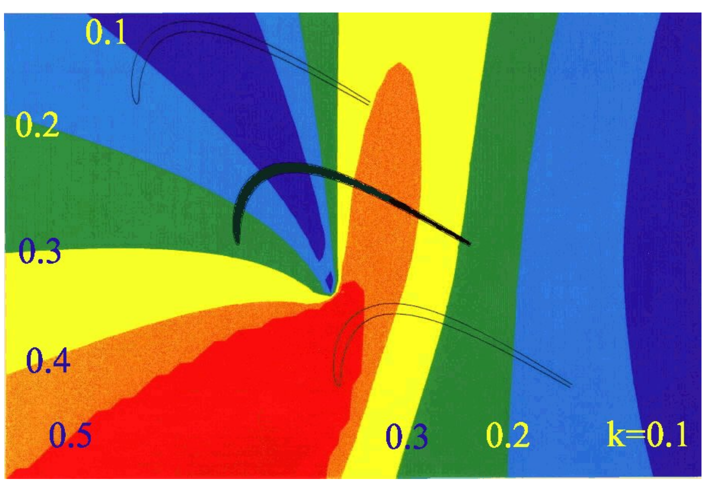

Figure 1, Critical Reduced Frequency as a Function of Pitching Axis Location

To use this plot each mode shape is represented by three rigid-body motions (two translations and one rotation) at the spanwise location of maximum displacement. These three motions then prescribe the ‘‘pitching axis.’’ That is the axis about which all points on the blade rotate. The critical value of reduced frequency, k_c, is determined by placing this pitching axis location on the plot shown in **Fig. 1** and reading off the critical reduced frequency. By comparing this critical k with the actual reduced frequency, the stability is determined. As can be seen by the large range of k_c and high gradient regions, the mode shape has a very strong effect on flutter.

The third controlling parameter is steady loading. This is a subject of current and future research (Ref. 2). Limited studies have shown that for a constant reduced frequency, certain mode shape regions may experience increasing, decreasing, or non-monotonically changing stability as loading is increased. For one blade design, it has been found that the loading effects can be described by classifying the mode shape into one of four types. Once this type is determined the design criteria the flutter susceptibility can be determined.

Future research will concentrate in three areas: 1) Physical understanding of how loading/shocks influence stability 2) Generalization to other blade geometries and 3D mode shapes 3) Preliminary design tools.

References

[1] Panovsky, J., and Kielb, R. E., January 2000. “A Design Method To Prevent Low Pressure Turbine Blade Flutter”. *Journal of Engineering for Gas Turbines and Power, 122*, pp. 89–98.

[2] J. Waite and R. Kielb. Mode Dependent Shock Structure Effects In Low-Pressure Turbine Flutter Analyses**.** Proceedings of 14th International Symposium on Unsteady Aerodynamics, Aeroacoustics & Aeroelasticity of Turbomachines, ISUAAAT14, 8-11 September, 2015, Stockholm, Sweden

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