ME – PhD Thesis Colloquium

Effect of Heave-Pitch Phase Angle on Coupled Mode Stall Flutter and Effect of Inter Blade Phase Angle on Transonic Flutter

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ABSTRACT

Cascade flutter in turbomachinery is a critical aeroelastic instability that can compromise the structural integrity and aerodynamic performance of compressor and turbine stages. This thesis presents a comprehensive experimental study of two closely related aspects of cascade flutter: the effect of heave–pitch phase coupling on subsonic stall flutter, and the role of inter-blade phase angle and neighbouring-blade interactions in transonic flutter. The work combines purpose-built low-speed and transonic experimental facilities with controlled blade oscillations and simultaneous force and flow-field measurements.

In the first part, low-speed experiments are carried out on a three-blade linear cascade operating at post-stall incidence. The central blade and its neighbours are subjected to coupled heave–pitch motion over a wide range of reduced frequencies, heave–pitch phase angles, inter-blade phase angles, and incidence. The mean aerodynamic power coefficient is used as the primary stability metric and is complemented by phase-locked flow-field PIV measurements. The results show that the heave–pitch phase angle is the dominant parameter governing aerodynamic stability in coupled-mode stall flutter. Positive phase angles consistently lead to aerodynamic excitation over a much broader reduced-frequency and inter-blade phase-angle range than pure heave motion, whereas negative phase angles lead to strong damping. This indicates that single-mode flutter analyses based only on heave or pitch can significantly underestimate the extent of unstable operating conditions.

Phase-locked velocity-field measurements reveal that the key physical mechanism underlying these trends is the phase relationship between the blade motion and the separated shear layer at the leading edge. Exciting cases correspond to phase lead of the shear-layer oscillation relative to the blade displacement, so that the aerodynamic forces add energy to the motion and produce net positive work per cycle. Damping cases correspond to phase lag of the shear-layer oscillation, so that the aerodynamic forces remove energy from the motion and lead to net negative work per cycle. Thus, it is the timing of the shear-layer dynamics, rather than their amplitude, that primarily determines stability.

In the second part, transonic cascade experiments are conducted on a compressor-stage configuration at started and unstarted operating conditions, distinguished by passage shock and detached shock structures. In the transonic tests, only the central blade is heaved, and the unsteady forces on the central and neighbouring blades are measured. Using the aerodynamic influence-coefficient method, these measurements are linearly superposed to obtain the aerodynamic work as a function of inter-blade phase angle, so that the effect of different travelling-wave patterns can be inferred from a single oscillation case. The results show that shock configuration and reduced frequency jointly control the dependence of aerodynamic work on inter-blade phase angle, with excitation possible at both positive and negative phase angles. Neighbouring blades are found to make non-negligible contributions to the net aerodynamic work, and their influence can either enhance or mitigate flutter depending on inter blade phase angles. Collectively, the low-speed coupled heave–pitch experiments and the transonic cascade tests highlight the critical roles of mode-shape coupling, shock topology, and neighbouring-blade effects in robust flutter prediction and the design of safer, more efficient compressors and turbines.

ABOUT THE SPEAKER

Dipanjan Barman is a PhD scholar at the Flow Physics Lab, Department of Mechanical Engineering, Indian Institute of Science, Bengaluru, working with Prof. Raghuraman N. Govardhan. He received his Bachelor's degree in Mechanical Engineering from Jadavpur University, West Bengal, and Master's degree in Mechanical Engineering from Indian Institute of Science, Bengaluru. His research broadly focuses on fluid structure interactions and turbomachinery.