Advances in Computational Aeroelasticity of Plates with Acoustic and Thermal Effects

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The aeroelastic behavior of plates has been extensively studied as a model for flight vehicle skin panels [1]. In supersonic flow, plates can experience flutter and transition into a post-flutter limit cycle oscillation (LCO) without causing immediate structural failure. This behavior contrasts with larger structures, like wings, where flutter must be strictly avoided. Consequently, understanding the mechanisms of flutter onset and post-flutter LCO is important. Often, one side of the panel encloses a cavity of non-convecting fluid, where structural vibrations generate acoustic pressure perturbations that can couple with the aeroelastic system. Although frequently simplified or ignored, this creates a coupled aero-acoustic-elastic (AAE) problem. Recent findings suggest that the vibro-acoustic coupling can affect flutter, potentially triggering instability at significantly lower dynamic pressures than without a cavity [2].

This presentation outlines a computational approach for analyzing this coupled AAE system along with recent and current developments. **For the structural dynamics** of a thin elastic plate, we employ a Rayleigh-Ritz (RR) formulation that includes geometric nonlinearity [3], recently enhanced by using finite element method (FEM) eigenmodes as basis functions in the RR scheme to accommodate arbitrary transverse boundary conditions and geometry. The hybrid FEM-RR approach efficiently balances the need to capture both global fluid-structure interactions (which in many cases requires only several leading modes to resolve) and localized structural effects while keeping the relatively easily computed nonlinear stiffness terms in modal coordinates. **On the acoustic side**, we use a coupled vibro-acoustic model in modal coordinates, focusing on scenarios where the primary acoustic and structural modes are closely spaced [2]. We also address a recent development in modeling acoustic medium with non-uniform temperature and density fields (e.g., due to wall heating or cooling) which lead to acoustic wave bending that affects the vibro-acoustic coupling. Similar to the structural model, FEM is used to obtain the acoustic eigenmodes for a modal formulation. Finally, to account for aerodynamic heating in high-speed flow, we introduce an ongoing development of **a coupled aero-thermal-elastic analysis scheme**. Building upon literature in this area [4], our scheme aims to loosely couple the timescales of thermal and aeroelastic responses by using steady-state Reynolds Averaged Navier-Stokes (RANS) simulation results as input to transient heat transfer and nonlinear aeroelastic stability analysis. In this setting, the plate may start to flutter and reach LCO while its temperature gradually increases until buckling causes it to stabilize.

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