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Reduced Order Models in Unsteady Aerodynamic Models, Aeroelasticity and Molecular Dynamics

Earl H. Dowell[*], Kenneth C. Hall[*], Jeffrey P. Thomas[*], Robert E. Kielb[*], Meredith A. Spiker[*], Charles M. Denegri, Jr.[†]

[*]Duke University, Durham, North Carolina, United States
dowell@mail.ee.duke.edu

[†]U.S. Air Force SEEK EAGLE Office, Eglin Air Force Base, Florida, United States

ABSTRACT

The state of reduced order modeling of unsteady aerodynamic flows for the efficient calculation of fluid-structure interaction (aeroelasticity) is discussed. Reduced order modeling is a set of conceptually novel and computationally efficient techniques for computing unsteady flow about airfoils, wings, and turbomachinery cascades.

Starting with either a time domain or frequency domain computational fluid dynamics (CFD) analysis of unsteady aerodynamic flows, a large, sparse eigenvalue problem is solved. Then, using just a few of the resulting aerodynamic eigenmodes, a Reduced Order Model (ROM) of the unsteady flow is constructed. The aerodynamic ROM can then be combined with a similar ROM for the structure to provide a Reduced Order Aeroelastic Model that reduces computational model sized and cost by several orders of magnitude. Moreover, the aerodynamic and aeroelastic eigenvalue and eigenmode information provides important insights into the physics of unsteady flows and fluid-structure interaction.

The method is particularly well suited for use in the active control of aeroelastic (fluid-structural) and unsteady aerodynamic phenomena as well as in standard aeroelastic analysis. As an alternative to the use of aerodynamic eigenmodes, Proper Orthogonal Decomposition (POD) has also been explored. POD is an attractive alternative because of the greater simplicity of calculating POD modes rather than fluid eigenmodes per se. Moreover once the POD modes have been used to construct a Reduced Order Model, this ROM may be used to find a good approximation to the dominant aerodynamic eigenmodes.

After the Hopf Bifurcation (flutter) condition is determined for the fluid-structural system, a novel High Dimensional Harmonic Balance (HDHB) solution method for the fluid (and structural) model(s) proves to be a very efficient technique for determining limit cycle oscillations in fluid-structural systems. In this approach one exploits the knowledge of the aeroelastic eigenmode determined from the aeroelastic ROM.

Several examples will be discussed including the limit cycle oscillations (LCO) of the F-16 aircraft and the limit cycle oscillations (LCO) of the Von Karman vortex street behind a cylinder in a cross-flow. The latter is a prototypical example of self-excited fluid oscillations that occur for bluff bodies including wings at high angles of attack. Correlation of theoretical calculations with experiment will also be shown.