Reduced Order Models for Aerodynamic Applications, Loads and MDO

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Reduced Order Models (ROMs) have found widespread application in fluid dynamics and aerodynamics. In their direct application to Computational Fluid Dynamics (CFD) ROMs seek to reduce the computational complexity of a problem by reducing the number of degrees of freedom rather than simplifying the physical model. Here, parametric nonlinear ROMs based on high-fidelity CFD are used to provide approximate flow solutions, but at lower evaluation time and storage than the original CFD model. ROMs for both steady and unsteady aerodynamic applications are presented. We consider ROMs combining proper orthogonal decomposition (POD) and Isomap, which is a manifold learning method, with interpolation methods as well as physics-based ROMs, where an approximate solution is found in the POD-subspace by minimizing the corresponding steady or unsteady flow-solver residual. In terms of the nonlinear unsteady least-squares ROM algorithm, we present the details of an improved accelerated greedy missing point estimation procedure which is used in the offline phase to select a subset of the unsteady residual for reasons of computational efficiency during the online prediction phase. The issue of how to best "train" the ROM with high-fidelity CFD data is also addressed. The goal is to train ROMs that yield a large domain of validity across all parameters and flow conditions at the expense of a relatively small number of CFD solutions.

The different ROM methods are demonstrated on a wide-body transport aircraft configuration at transonic flow conditions. The steady ROMs are used to predict the static aeroelastic loads in the context of multidisciplinary optimization (MDO), where a structural model is to be sized for the (aerodynamic) loads. They are also used in a process where an a priori identification of the most critical static load cases is of interest and the sheer number of load cases to be considered does not lend itself to high-fidelity CFD. The unsteady nonlinear least-squares ROM approach is applied to modeling discrete gusts of different amplitude and length in the context of rapid evaluation of gust-induced air loads.