On the reduced-order modelling based on the Arbitrary Lagrangian-Eulerian formulation for high speed aeroelastic applications

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ABSTRACT

The numerical prediction of the aeroelastic stability of aeronautical components is a necessary step to ensure that the structure is correctly designed to sustain the aerodynamic loads exerted on it. Numerous computations are therefore performed for different flight conditions and manoeuvres to check the stability of the coupled system. These parametric studies are especially time consuming when the flow regime is transonic since simple aerodynamic models (Doublet Lattice e.g.) are inaccurate. In such conditions, the nonlinear compressible Navier-Stokes equations – coupled with the motion of the structure – have to be solved.

During the last decade, reduced-order modelling methods have been developed to reduce the numerical effort while preserving the accuracy of the high fidelity model (Navier-Stokes equations) [1]. Most of the work has focused on the reduction of the flow equations but few attempts have been made to take into account the coupling with the motion of a flexible structure. The first attempt of Anttonen et al. [2] using several bases obtained with the Proper Orthogonal (POD) for different amplitudes of oscillation was not accurate. Placzek et al. [3] proposed a POD based reduced order model formulated in the frame of reference attached to a rigidly moving structure. Liberge et al. [4] introduced a fictitious domain formulation and Stankiewicz et al. [5] used the arbitrary Lagrangian-Eulerian formulation for their POD based reduced order model for incompressible flows.

We propose here to combine the works of Placzek et al. [3] and of Stankiewicz et al. [5] to obtain a reduced-order model of nonlinear compressible flows while taking into account the motion of a flexible structure via the arbitrary Lagrangian-Eulerian formulation. First a POD basis is constructed from a series of snapshots and the continuous Navier-Stokes equations are projected on a truncated basis containing the dominant modes. A second step of calibration is necessary to remove the modelling errors (due to the basis truncation, turbulence model omission…) introduced between the high and reduced order models. The structural motion induces a mesh deformation which is computed with a structural analogy. This allows a simple description of the mesh motion whose projection on the POD basis leads to an explicitly defined operator. The accuracy of the reduced-order model is demonstrated on NLR7301 airfoil in transonic regime. Further developments are planned to improve the turbulence modelisation in the reduced-order model and to extend the formulation in a relative frame of reference for turbomachinery applications.

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