Continuous Adjoint in Shape Optimization, with Applications in Aeroacoustics

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Abstract

Hybrid methods are efficient tools for the computation of the aeroacoustic noise radiated by unsteady flows; they use unsteady CFD simulations of the near–field flow field and an analogy for the acoustic propagation to far–field. In gradient-based shape optimization with aeroacoustic criteria relying upon such a hybrid model, the adjoint method computes the gradient of objective function(s) with respect to (w.r.t.) the design variables. Here, the basic CFD tool is the GPU-accelerated, Unsteady RANS (URANS) equations solver PUMA (Parallel Unstructured Multi–row Adjoint), for compressible fluids, developed by the PCOpt Unit of NTUA. This is extended with noise prediction capabilities based on the permeable surface Ffowcs Williams and Hawkings (FWH) equation solver, expressed in the frequency domain. The continuous adjoint to the hybrid URANS/FWH solver is presented and its use is demonstrated. The aeroacoustic objective function is the total energy contained in the sound pressure spectrum, defined in the frequency domain. The sensitivity derivatives of this objective function w.r.t. the shape controlling parameters (design variables) are expressed as the sum of surface and field integrals, according to the so–called Field Integral (FI) continuous adjoint formulation. The effect changes in the eddy viscosity and the distances from the nearest walls, due to shape changes, have on the gradient are taken into account by additionally solving the adjoint to the Spalart-Allmaras turbulence model equation as well as the adjoint to the Hamilton-Jacobi equation that computes distances from solid walls. Discussion on the correct development of the continuous adjoint equations and the consistency of discretization schemes for the adjoint partial differential equations is provided.

Among the various cases that will be presented for the verification of this method, the optimization of the geometry of an aero–engine intake, conducted within the MADELEINE project funded by the EU, is presented. In this particular case, to reduce the computational cost, the domain is kept as small as possible using periodic boundary conditions and a moving reference frame which leads to steady flow and adjoint runs. A continuous circumferential distribution of receivers at a given radius and axial position is used for the objective function. The unsteady flow fields required for computing the gradient are achieved by properly rotating the steady flow fields.

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