NATIONAL TECHNICAL UNIVERSITY OF ATHENS
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PhD Thesis

ADJOINT FORMULATIONS FOR THE ANALYSIS AND DESIGN OF TURBOMACHINERY CASCADES AND OPTIMAL GRID ADAPTATION USING A POSTERIORI ERROR ANALYSIS

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Summary

This PhD thesis aims at the development and programming of adjoint methods for CFD applications related to shape optimization problems in turbomachinery and external aerodynamics. The proposed adjoint formulations are applied to (a) the computation of the objective function gradient with respect to the design variables, which is used to drive a gradient-based shape optimization algorithm (b) the optimal unstructured grid adaptation in CFD problems ensuring the computation of certain functionals with predefined accuracy and (c) the support of a new type artificial neural network, which is trained on both the responses and their gradient, and can be used as a metamodel in evolutionary optimization algorithms. These three different domains of application of the adjoint methods define the three thematic areas of the thesis.

This thesis develops both continuous and discrete adjoint methods, with emphasis on the former which gives better insight to the concept of duality. The adjoint formulations cover inviscid and viscous (laminar and turbulent) compressible flows through or around 2D and 3D aerodynamic shapes, using either structured or unstructured grids. The flow and adjoint equations are solved using a finite volume, vertex centered discretization, using the Roe's upwind scheme for the convection terms and the time marching method. The one-equation Spalart-Allmaras model is used to account for turbulent flows. Contributions of the thesis to this scientific area are (a) an objective function expression which is free of field integrals of metrics or other geometrical quantities, avoiding, thus, the repetitive refinement and increasing accuracy while reducing the total CPU cost, (b) a unique formulation which is valid for any grid type and (c) the handling of new objective functionals which express losses in turbomachines, in terms of either entropy generation or total pressure losses. It is the first time that these two functionals are used together with the continuous adjoint formulation. The method is validated in inverse design and loss minimization problems of 2D and 3D turbomachinery and external aerodynamics applications, concerning the functional gradient accuracy, the functional value convergence and the total computational cost.

The second thematic area of the thesis, which makes extensive use of the adjoint formulation developed in the first part, is concerned with the application of the discrete adjoint approach to the error estimation in the computation of integral quantities such as the lift/drag coefficients in external aerodynamics and the entropy generation in turbomachinery cascades. The estimated error is used as a sensor for optimal grid adaptation, resulting to the estimation of integral functional values with predefined accuracy on the coarser possible computational grid.

In the third part of the thesis objective function derivatives computed through the adjoint approach are used to train a new radial basis function network, with improved predictive capabilities for use along with evolutionary algorithms as a surrogate evaluation model. The method is applied to the inverse design of 3D turbomachinery blades.

Key words: Thermal Turbomachines, Computational Fluid Dynamics, Adjoint Techniques, Aerodynamic Optimization – Design, Artificial Neural Netwotks, A Posteriori Error Estimation.