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ΠΡΟΣΚΛΗΣΗ

Σας προσκαλούμε στην παρουσίαση της Διδακτορικής Διατριβής του Υ.Δ. **κ. Flavio Gagliardi,** κατόχου BSc in Energy Engineering και MSc in Nuclear and Energy Engineering από το Πολυτεχνείο του Τορίνο (Ιταλία) , την οποία εκπόνησε στον Τομέα Ρευστών. Η παρουσίαση θα πραγματοποιηθεί την *Παρασκευή 30 Οκτωβρίου 2020* , ώρα 10:00π.μ. διαδικτυακά*. Ο τίτλος της Διδακτορικής Διατριβής είναι ο εξής :

«Shape Parameterization and Constrained Aerodynamic Optimization, Applications Including Turbomachines»

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Shape Parameterization and Constrained Aerodynamic Optimization. Applications Including Turbomachines

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PhD Thesis Abstract

Recently, with the continuous development of analysis tools and the growth of computational power, numerical optimization is increasingly being used to design new shapes with improved (aerodynamic/hydrodynamic) performance using Computational Fluid Dynamics (CFD) simulations. Since CFD simulations for complex problems are expensive, numerical optimization methods should perform as efficiently as possible. Recent progress with CFD adjoint solvers allows computing objective function gradients at a cost which does not scale with the number of Degrees of Freedom (DoFs), making gradient-based optimization a valuable option. At the same time, progress with gradient-free optimization methods (such as evolutionary algorithms) makes them attractive to globally explore design spaces and find improved shapes, even according to more than one criterion. This thesis uses both gradient-based and gradient-free methods for shape optimization in both internal and external aerodynamics, including the design/optimization of turbomachinery blade rows.

A CFD-based shape optimization method involves several tools other than the CFD evaluation software and the search method itself. The parameterization and mesh displacement techniques as well as methods for handling constraints are among them. This thesis focuses on these tools by proposing new methods, as described below.

Shape parameterization is fundamental in all aerodynamic shape optimization problems. It determines the design space and the variety of reachable geometries; thus, it has a leading role in the cost and success of the optimization. In industrial workflows, in particular, shape optimization usually begins with a shape designed using Computer-Aided-Design (CAD) software. This starting geometry defines the DoFs of the case and their bounds, should the latter be necessary. In an industrial environment, an evident requirement is that the solutions found by running the optimization loop must also be compatible with the CAD software, to enable the manufacturing process. For this reason, this thesis focuses on CAD-compatible parameterization methods that are able to export a Boundary-Representation (B-Rep) model of the shape; B-Rep is a method to represent shapes largely used in CAD software.

In the turbomachinery field, in specific, this dissertation uses and extends software for modeling turbomachinery blade rows. This is referred to as the Geometric Modeler for Turbomachinery (GMTurbo), and has been developed by and used in the Parallel CFD & Optimization Unit (PCOpt) of the NTUA; GMTurbo software was the outcome of a recently integrated PhD thesis at NTUA. In the present thesis, new features and tools that allow its integration into automatic, CAD-based, optimization loops are developed and tested. This includes the differentiation of the parameterization procedure to support adjoint-based optimizations, and software to import existing geometries into GMTurbo.

A new method, which will be referred to as B-Rep-Morpher, is proposed to support shape optimization by offering a free-form deformation environment for generic aerodynamic geometries which remain in standard B-Rep format. The proposed technique introduces a small number of “handles”, strategically placed around or on the shapes to be optimized. Displacement vectors associated with these handles are used as the DoFs. Using the Radial Basis Function (RBF)-based interpolation method, these displacements are transferred from the handles to the Non-Uniform Rational B-Spline (NURBS) control points of the B-Rep model; the updated surface remains in B-Rep format and is, thus, exportable to a Standard for the Exchange of Product model data (STEP) file. The B-Rep-Morpher is differentiated since this is required in adjoint-based optimization.

Over and above performance criteria, shape optimizations are driven by constraints. Therefore, part of this thesis concerns constraint imposition, including turbomachinery design cases. Two families of constraints are considered. The first one comprises geometric constraints related, for instance, with the minimum thickness of the designed turbomachinery blades or the space necessary for mounting the blades on the casing. Some geometric constraints are merely satisfied by imposing appropriate bounds on the DoFs of the parameterization method, whereas others must be considered as non-linear constraints. For instance, this thesis illustrates a constraint parameterization technique to handle the space into the blade profiles that is necessary to cut the thread to mount it on the casing. The second family comprises performance constraints, such as the total pressure losses in a turbomachinery row. In this dissertation, gradient-based and gradient-free numerical techniques are used to solve constrained shape optimization problems. These are carried out using already available Sequential Quadratic Programming (SQP) methods and Evolutionary Algorithms (EAs). The latter implies the use of the Evolutionary Algorithm System (EASY) software developed by the PCOpt/NTUA.

A CAD-based shape optimization framework is developed, coupling the flow solver of PCOpt/NTUA and its adjoint, GMTurbo or B-Rep-Morpher and gradient-based and -free optimizers. Within this framework, the adaptation of an existing CFD mesh to the new boundaries of the computational domain is also essential. This facilitates the CFD evaluation of new shapes by avoiding costly and hardly automated re-meshing. To this end, this thesis proposes a method to update an existing surface mesh, associated with a shape parameterized as above. The displacement of the surface mesh nodes is used to adapt the CFD volume mesh. Mesh displacement based on RBF interpolation is used for this task; RBF interpolation is known for its ability to preserve mesh validity and quality, even for large displacements, without being affected by mesh connectivity. However, in case of large meshes, such as those used in real-world CFD applications, standard RBF interpolation becomes excessively expensive. Methods to accelerate the mesh displacement are investigated, and a new, two-step, RBF-based mesh displacement method is proposed. In this method, the Fast Multipole Method (FMM) and the Sparse Approximate Inverse (SPAI) preconditioner are used to reduce the computational cost of the RBF interpolation.

The programmed framework is applied to shape optimization cases to assess its performance. These cases include the optimization of the following shapes: (a) a double elbow duct, to minimize total pressure losses, using SQP; (b) a compressor stator blade, to minimize the deviation of the exit flow from the axial direction and total pressure losses while imposing geometric constraints, using SQP and EAs; (c) a turbine stator to maximize the capacity and minimize the total pressure losses, using EAs; (d) an aircraft, to minimize the drag and maximize the lift, using EAs.

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