ΕΘΝΙΚΟ ΜΕΤΣΟΒΙΟ ΠΟΛΥΤΕΧΝΕΙΟ
ΣΧΟΛΗ ΜΗΧΑΝΟΛΟΓΩΝ ΜΗΧΑΝΙΚΩΝ

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ΚΟΣΜΗΤΟΡΑΣ

Προς τα Μέλη ΔΕΠ της
Σχολής Μηχ/γων
Μηχ/κών

<u>ΠΡΟΣΚΛΗΣΗ</u>

Σας προσκαλούμε στην παρουσίαση της Διδακτορικής Διατριβής του Υ.Δ. **κ. Καρπούζα Γεωργίου του Κωνσταντίνου,** διπλωματούχος Μηχανολόγος Μηχανικός του ΕΜΠ, που εκπόνησε στον Τομέα Ρευστών η οποία θα πραγματοποιηθεί την *<u>Πέμπτη 21 Μαρτίου 2019</u>*, ώρα *<u>12:00.</u>* στην αίθουσα Τηλεκπαίδευσης (Πολυμέσων) του κτιρίου της Κεντρικής Βιβλιοθήκης του ΕΜΠ - Πολυτεχνειούπολη Ζωγράφου. Ο ελληνικός τίτλος της Διδακτορικής Διατριβής είναι ο εξής :

«ΥΒΡΙΔΙΚΗ ΜΕΘΟΔΟΣ ΒΕΛΤΙΣΤΟΠΟΙΗΣΗΣ ΜΟΡΦΗΣ ΚΑΙ ΤΟΠΟΛΟΓΙΑΣ ΣΤΗ ΜΗΧΑΝΙΚΗ ΤΩΝ ΡΕΥΣΤΩΝ»
Και ο Αγγλικός ως εξής:
«A HYBRID METHOD FOR SHAPE AND TOPOLOGY OPTIMIZATION IN FLUID MECHANICS»

Ο Κοσμήτορας της Σχολής

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A Hybrid Method for Shape and Topology Optimization in Fluid Mechanics

Υβριδική Μέθοδος Βελτιστοποίησης Μορφής και Τοπολογίας στη Μηχανική των Ρευστών

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PhD Thesis Abstract

Adjoint optimisation is an exciting and fast-growing research and application field in Computational Fluid Dynamics (CFD). It is widely used in shape, topology, flow control, error estimation, inverse, and robust design optimisation problems. The present thesis focuses on the first two categories: shape and topology optimisation. The two methods in question historically have very distinct characteristics and, as a result of these differences, the usage of one or the other method may have clear advantages and/or disadvantages in the context of individual optimisation problems. The method chosen for a specific optimisation problem can, thus, have distinct advantages over the other in terms of how much improvement in design can be practically achieved. Our ultimate aim is to overcome, to a significant extent, these limitations by hybridising the two methods.

To achieve this end, it is necessary to understand both the strengths and weaknesses of the available methodologies and how they arise in the context of the optimisation system. First, the accuracy issue regarding the modelling of the solid regions in porosity-based topology optimisation is examined and it is found that many of the problems relate to the lack of an exact interface between the solid and fluid regions. Extending the topology optimisation framework to incorporate a well-defined interface, using the level-set method, alleviates some of these problems. However, the correct implementation of near-wall turbulence modelling remains an issue. Using the volume-averaged total pressure losses as an objective function, level-set based topology optimisation is used to optimise the design of: i) a right-angled duct; ii) an HVAC duct; iii) the inlet and outlet ducts of a gear-pump; and iv) a cold air intake system (CAIS) of a car.

In the second part of this thesis, a novel method called Generalised Internal Boundary (GIB) is derived, implemented and validated, which allows for the imposition of exact boundary conditions internal to the computational domain. This is achieved without changing the connectivity of the computational mesh, which dramatically improves the algorithms' performance. To realise their full potential, the new boundaries must be able to deform and move. However, transitioning elements over the interface from solid to fluid (and vice versa) introduces discontinuities in the time-history of the solution fields. These time-histories are critical to the solution of governing equations incorporating time-derivatives. Thus, it is necessary to reconstruct the old-time values of the fields, so they appear smooth, yet conservative, from the perspective of the conservation equations. In this context, an Arbitrary-Lagrangian-Eulerian (ALE) framework that incorporates the conservative reconstruction of old time-field values in the presence of strongly discontinuous cell transition events is proposed. The results of the proposed method were compared against the bodyfitted approach of the flow around a moving cylinder and validated against experimental data from a butterfly valve.

With the capabilities of the GIB method in hand, a new adjoint optimisation method is considered and a hybrid between shape and topology approaches is proposed. This has the accuracy of shape optimisation as the boundary it produces is exact in all respects but, at the same time (and similar to topology optimisation), it has the freedom to make arbitrarily large changes in the design. Thus, the new method elegantly does away with most of the drawbacks inherent in both shape and topology optimisation and as a result, provides a universal solution

to a larger subset of adjoint optimisation problems. The proposed hybrid shape-topology optimisation method is used to optimise the design of: i) a right-angled duct; and ii) a manifold with two outlets.

Although not central to the main theme, some improvements are proposed related to the solution of the primal and adjoint equations in terms of computational cost and robustness. These works supplement the development of the hybrid adjoint optimisation method as they enhance the solution of the adjoint equation system. Three main contributions are identified:

- Instabilities caused by the Adjoint Transpose Convection (ATC) term are first highlighted and, then, methods to tackle the problem are proposed.
- The accuracy of the pressure gradient adjacent to the solid walls plays an important role in the flow solution and has a large impact on the convergence of the adjoint equations. A more accurate treatment of this term is shown to have significant benefits in terms of accuracy and stability.
- A block-solver is developed to solve the linear adjoint system implicitly, dramatically improving time to solution and reducing ATC related issues.

Keywords: Computational Fluid Dynamics (CFD), Finite-Volume (FV), Shape-Topology Optimisation, Adjoint Methods, Immersed-Boundary Method (IBM), Arbitrary-Lagrangian-Eulerian (ALE), Block-Solver

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