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ΚΟΣΜΗΤΟΡΑΣ

Προς:
τα Μέλη ΔΕΠ της Σχολής Μηχανολόγων Μηχανικών ΕΜΠ

<u>ΠΡΟΣΚΛΗΣΗ</u>

Σας προσκαλούμε στην εξέταση-παρουσίαση της Διδακτορικής Διατριβής του Υποψήφιου Διδάκτορα **κ. FARHIKHTEH Mohammaderfan του Maroufali,** Διπλωματούχου Πολιτικού Μηχανικού του Ισλαμικού Πανεπιστημίου AZAD-Ιράν και κατόχου Μεταπτυχιακού Τίτλου στη Δομική Μηχανική από το Πολυτεχνείο Μιλάνου-Ιταλία, με τον τίτλο:

Στα Αγγλικά: **«Continuous Adjoint for Aerodynamic and Aeroacoustic Shape Optimization and Robust Design. Applications to External Flow Problems, Including Wind Turbines»**
Στα Ελληνικά: **«Η Συνεχής Συζυγής Μέθοδος για την Αεροδυναμική και Αεροακουστική Βελτιστοποίηση και το Στιβαρό Σχεδιασμό. Εφαρμογές σε Προβλήματα Εξωτερικών Ροών, συμπεριλαμβανομένων Ανεμογεννητριών»**

Η παρουσίαση θα γίνει στην Αγγλική γλώσσα και θα *πραγματοποιηθεί <u>τη Δευτέρα 16 Δεκεμβρίου 2024 και ώρα 12:15, στην Αίθουσα Διδασκαλίας στον πρώτο όροφο του Εργαστηρίου Θερμικών Στροβιλομηχανών της Σχολής Μηχανολόγων Μηχανικών ΕΜΠ (Κτίριο Ο), με δυνατότητα και διαδικτυακής μετάδοσης.</u>*

Για πληροφορίες σχετικά με την απομακρυσμένη σύνδεση παρακαλείστε όπως αποστείλετε ηλεκτρονικό μήνυμα στη διεύθυνση: kgianna@mail.ntua.gr

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Continuous Adjoint for Aerodynamic and Aeroacoustic Shape Optimization and Robust Design. Applications to External Flow Problems, Including Wind Turbines

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Summary

This PhD thesis presents advancements in aerodynamic and aeroacoustic optimization techniques using the adjoint method, and also focuses on Robust Design Optimization (RDO) under uncertainties related to flow conditions and manufacturing imperfections. The developed methods are applied to horizontal axis wind turbine (WT) blades and other aerodynamic bodies, including a car geometry.

The work starts with the development/extension of continuous adjoint equations for the Spalart-Allmaras (SA) turbulence model in a rotating reference frame, by incorporating the linearization of the Coriolis and centrifugal forces. This adjoint method for flows governed by the SA model is assessed by comparing sensitivity derivatives with those derived from the finite difference (FD) method. Aerodynamic shape optimization is, then, applied to the blades of the MEXICO and NREL Phase VI WTs, aiming for maximum torque. Verification of the flow simulation code against numerical and experimental results precedes the optimization process, which also includes blade parameterization and mesh morphing using volumetric B-Splines. A constraint is imposed in the optimization of the NREL Phase VI blade to maintain the blade volume during optimization. The pressure coefficient and peripheral force distribution along the optimized and baseline blades are investigated to better understand the source of torque maximization. Additionally, optimizations at nominal and off-design conditions, with re-evaluations at other operating points, are carried out.

Then, the dissertation elaborates on continuous adjoint equations for the κ-ω SST turbulence model in a rotating reference frame. This is extended to aeroacoustic shape optimization in 2D and 3D, integrating Proudman's formula into the continuous adjoint equations coupled with the RANS equations, for the first time in the corresponding literature. The Proudman's formula computes acoustic emissions of turbulent flows, based on the turbulent kinetic energy and turbulent dissipation rate fields. The objective function is defined as the integral of generated acoustic sources in a user-defined volume around the body, to be minimized. The sensitivity derivatives computed by the developed adjoint method are verified against FDs, on an airfoil case by computing the trailing edge noise. A parametric study is performed to investigate the impact of the integration volume size on the objective function. Aeroacoustic shape optimization is successfully performed for airfoils, the MEXICO WT, and the DrivAer car model, aiming to minimize acoustic sources at the trailing edge, blade, and side mirror, respectively. The broadband noise generated by a trailing edge airfoil, computed by the Proudman's formula and specific spectral properties, is validated against experimental data at the same microphone location. Also, the sound power level of the MEXICO WT blade is validated against numerical and experimental results. Finally, a comparison of broadband noise generation of the optimized and baseline geometries for both the isolated airfoil and MEXICO WT blade is made.

In this PhD thesis, a RDO technique in aerodynamics, under manufacturing imperfections, based on the non-intrusive Polynomial Chaos Expansion (niPCE) and the Karhunen-Loève Expansion (KLE) for 3D geometries, is also developed and applied. The niPCE is used in Uncertainty Quantification (UQ) to model and analyze the impact of input uncertainties on the statistical moments of the performance. By constructing a polynomial representation of the system's response, the niPCE estimates statistical moments of the Quantity of Interest (QoI). Gauss Quadrature (GQ) is used for multi-dimensional numerical integration to compute the PCE coefficients; in specific, the Full Grid and Smolyak Sparse Grid (which is really appreciated in case of many uncertain variables) are employed. The KLE is used to generate stochastic perturbations on the baseline 3D geometry surface in the normal to the wall direction. Initially, using the Full Grid, an RDO with uncertainties related to the flow conditions is performed for the MEXICO WT blade, to maximize the blade torque. Then, using the niPCE and KLE codes, the RDO of an isolated airfoil with manufacturing imperfections, using the Full Grid and Smolyak--based UQ methods for different polynomial orders, is performed. Finally, the KLE is used to generate imperfections on the NREL Phase VI WT blade surface for performing RDO, with the goal of maximizing the blade's torque.

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Keywords: Continuous Adjoint Method, Computational Fluid Dynamics, Aerodynamic, Aeroacoustic, Shape Optimization, Uncertainty Quantification, Proudman's Formula, Wind Turbines, Robust Optimization, non-intrusive Polynomial Chaos Expansion, Karhunen-Loeve Expansion

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