ΕΘΝΙΚΟ
ΜΕΤΣΟΒΙΟ
ΠΟΛΥΤΕΧΝΕΙΟ
ΣΧΟΛΗ ΜΗΧΑΝΟΛΟΓΩΝ ΜΗΧΑΝΙΚΩΝ

Α.Π. : 40843
Αθήνα, 12/9/23

ΚΟΣΜΗΤΟΡΑΣ

Προς τα Μέλη ΔΕΠ της
Σχολής Μηχ/γων
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ΠΡΟΣΚΛΗΣΗ

Σας προσκαλούμε στην παρουσίαση της Διδακτορικής Διατριβής του Υ.Δ. **κ. Σπυρόπουλου Νικολάου,** διπλωματούχου **Μηχανολόγου Μηχανικού ΕΜΠ**, την οποία εκπόνησε στον Τομέα Ρευστών. Η παρουσίαση θα πραγματοποιηθεί τη *Πέμπτη 14/9/2023* ώρα 11:00π.μ στην αίθουσα διαλέξεων του κτιρίου ΑΝΥΜ της Σχολής Μηχανολόγων Μηχανικών ΕΜΠ, Πολυτεχνειούπολη και με δυνατότητα απομακρυσμένης παρακολούθησης στο ακόλουθο link :

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Ο ελληνικός τίτλος της Διδακτορικής Διατριβής είναι :

«Ανάπτυξη Υπολογιστικών Μεθόδων Αεροελαστικής Ανάλυσης Δρομέων με Πλεγματικές ή/και Σωματιδιακές Τεχνικές. Εφαρμογή σε Ανεμογεννήτριες και Ελικόπτερα»

και ο αγγλικός τίτλος είναι :

«Development of Computational Methods for the Aeroelastic Analysis of Rotors using Grid Based and/or Particle Techniques. Application to Wind Turbine and Helicopter Rotors»

Ο Κοσμήτορας της Σχολής

Ι. Αντωνιάδης
Καθηγητής ΕΜΠ

Abstract

«Ανάπτυξη Υπολογιστικών Μεθόδων Αεροελαστικής Ανάλυσης Δρομέων με Πλεγματικές ή/και Σωματιδιακές Τεχνικές. Εφαρμογή σε Ανεμογεννήτριες και Ελικόπτερα.»

«Development of Computational Methods for the Aeroelastic Analysis of Rotors using Grid Based and/or Particle Techniques. Application to Wind Turbine and Helicopter Rotors. »

In this thesis, a high fidelity aeroelastic analysis solver for rotor configurations has been developed. This newly formed computational tool is capable of analyzing complex flow phenomena over a wide part of the sub-sonic region and under the same computational framework. The structural dynamics problem is solved by GAST, an in-house elasto-dynamic analysis module, the development of which started in previous theses and continued in the present. In previous versions of GAST, a Wind Turbine (WT) configuration was approximated as an assembly of linear full stiffness matrix Timoshenko beams discretized through a 1D Finite Element Method (FEM) approach and being sequentially connected in the context of a generic multi-body dynamics representation, not restrained to sequential configurations. During the present thesis, the kinematic and dynamic analysis part was reformed to follow a multi-body dynamics methodology. As a result, GAST may now be used for the structural dynamics analysis of any arbitrary configuration of multiple load paths and connections between slender components (beams). The aerodynamic analysis is based on MaPFlow and HoPFlow. MaPFlow is an in-house conventional Eulerian CFD solver which solves the compressible unsteady Reynolds averaged Navier-Stokes equations under a cell-centered finite volume discretization. Flows in the incompressible region are simulated using Low Mach Preconditioning. HoPFlow is a hybrid Eulerian-Lagrangian compressible CFD solver that combines the standard Eulerian CFD formulation implemented in MaPFlow close to the solid boundaries, with a Lagrangian CFD approach for the rest of the computational space, through a domain decomposition approach. The Fluid Structure Interaction (FSI) framework is formed through a proper communication protocol that has been developed in the present work and connects the individual structural and aerodynamic modules under a strong coupling approach.

To have the option of an holistic and cost-effective design tool, especially for WTs, and for rotor applications in general, the Actuator Line (AL) methodology has been implemented in MaPFlow. In the AL approach, the blades of a rotor are simulated as a set of control points along their axes; they are allowed to move freely inside the computational grid and their aerodynamic loads are applied to the flow--field as source terms on the computational cells they slice during their rotation. In this way, multi-body and aeroelastic simulations are facilitated, while computational cost is restrained. AL has been widely used in studying the generation and convection of WT rotor wakes, due to the detailed description of the flow-field that the CFD framework offers. However, in this study, it is found capable of predicting also the loads of both WT and helicopter rotor blades in accuracy and under moderate computational requirements. Moreover, to reproduce the true (atmospheric) conditions in which a WT operates, the method of Generation Zone (GZ) has been implemented in MaPFlow and is used for the first time in order to impose pre-defined turbulent fields (produced with Mann's model) onto an averaged flow-field within a CFD context. It is found that GZ is able to create turbulent fields that are

closer to the turbulent field produced by the Mann's model, compared to conventional methodologies found in literature.

The validation of this new high accuracy, but cost--effective aeroelastic module (coupled GAST--AL module) consists of:

i) aeroelastic simulations of the \ac{DTU 10MW RWT} \cite{Bak2013} under constant wind and atmospheric (turbulent) conditions;
ii) aeroelastic simulations of the \ac{MR} of the model BO105 helicopter used in the HeliNoVi experimental campaign \cite{Langer2005}, under low, medium and high flight speed in forward flight conditions.

AL results are compared against Blade Element Momentum Theory (BEMT) and Lifting Line (LL) models results in the case of the WT, whereas LL and measured data are considered in the helicopter cases. AL results show significant differences compared to BEMT predictions that get more intense as the flow conditions get more complex. However, excellent agreement between AL and LL is observed in all the examined cases, due to the detailed representation of the flow-field by the CFD and the Free Vortex Wake (FVW) frameworks respectively. Hence, AL proves to be as reliable as LL in terms of loads and deflections predictions. The main advantage of the AL method is that the effect of the rotor and ground on the local turbulent inflow can be accounted for in detail within the CFD context, under moderate computational requirements.

Simulations of both WT and helicopter rotors, considering the actual geometry of the rotor blades, are performed using the coupled GAST-HoPFlow aeroelastic solver. The simulated cases concern:

i) aerodynamic analysis of the model \ac{WT} rotor used in the New MEXICO experimental campaign \cite{Schepers2014,Boorsma2016} for an axial flow case at 14.7 m/s;
ii) aeroelastic analysis of the \ac{MR} of the model BO105 helicopter used in the HARTII experimental campaign \cite{VanDerWall2011} for the Base--Line descent case at 33 m/s flight speed.

The accuracy and the features of this newly formed, high fidelity aeroelastic solver are assessed in complex local flow conditions and over a wide part of the sub-sonic region. In the root region of a WT rotor, characterized by lower Mach values, detached flow conditions occur. On the other, weak shock waves appear near the blades tip of the helicopter rotor, where higher Mach values are encountered. Results are compared against experimental measurements and predictions produced by other CFD based aeroelastic codes. In both cases, the aerodynamic loads of the blades are predicted in great accuracy (comparable to that of standard CFD solvers). The resulting structural loads and the corresponding deflections are estimated fairly well. The same remark is made for the flow-field developed in the region close to the rotors. The above remarks confirm that the coupling method between the Eulerian and the Lagrangian sub-domains that determines the boundary conditions for the confined Eulerian grid is adequate and consistent. The same conclusion is drawn for the coupling between the structural module and the aerodynamic solver.