PROPOSITION DE SUJET DE THESE

Intitulé : Experimental analysis of the turbulence impact on the local loads of airfoils.

Référence : **MFE-DAAA-202507**
(à rappeler dans toute correspondance)

Début de la thèse : 01/10/2025	**Date limite de candidature : 15/06/2025**

Mots clés

Turbulence, experiments

Profil et compétences recherchées

Engineer diploma or second year Master specialized in fluid mechanics.

Programming skills (Matlab / Python / Fortran or equivalent).

Autonomy, dynamism, determination.

Présentation du projet doctoral, contexte et objectif

Maritime transport represents 3% of global greenhouse gas emissions, comparable to aeronautical sector (Cammas, Mehnert, et Pichon 2020). Wind assisted propulsion is a promising solution to address the objectives from International Maritime Organization (50% of reduction by 2050). It can reduce fuel consumption by around 5% to 20% on existing ships et until 80% for new ones specifically designed for that (Cammas, Mehnert, et Pichon 2020; Hussain et al. 2018).

Various prototypes are being developed using flexible sails (e.g. TOWTS), inflatable sails (e.g. WISAMO - MICHELIN), rigid sails (e.g. AYRO) and rigid sails foldable (e.g. SOLID SAIL from Chantiers de l'Atlantique and ENSTA Bretagne). These sails will have to resist and to perform well in the turbulent and gusty wind existing at sea. To achieve these two objectives, we need to be able to take turbulence into account in the design of these systems. We focus on rigid sails which are equivalent to the wings existing in aeronautics.

On the previous example, turbulence changes the properties of the flow, which become highly unsteady. The turbulence unsteadiness has a direct effect on the spatial and temporal variations of the aerodynamic forces generated locally on the wings.

The problematic of interaction between turbulence and airfoils is also present in aeronautical applications such for Vertical Take Off and Landing vehicules (VTOL) which evolve in the atmospheric boundary layer where a rate of turbulence between 10% and 15% is measured (Veiga Rodrigues et al. 2010). The lifting surfaces interact by the atmospheric turbulence but also with the highly turbulent wakes behind the propellers. These interactions need to be understood and require experimental and theoretical research for that.

Objective of the thesis:

- Assess the turbulence impact on the aerodynamic forces local fluctuations for different wind propulsion configurations or airfoils configurations. In particular, we will focus on a scale-by-scale analysis (Kolmogorov 1941; Mücke, Kleinhans, et Peinke 2011; Valente et Vassilicos 2015; Yao et al. 2024) to understand how the different turbulent scales impact the fluctuations of local aerodynamic forces. These results may be used in the future by start-ups and industries to design new wings for a given unsteady wind, and anticipate structural problems (fatigue, deformation and vibration).

- The turbulence intermittency will also be measured and analysed as it may impacts the fatigue loads of the wings as it does for wind turbines (C. M. Schwarz et al. 2018; Carl Michael Schwarz, Ehrich, et Peinke 2019; Bock et al. 2024; Gontier et al. 2007; Mücke, Kleinhans, et Peinke 2011). Therefore, the intermittency should be measured and related to the performance of existing turbulent models used in simulations.

- Propose dedicated geometric modifications of the wings to take into account unsteady effects.

- Carry out highly resolved PIV (Particle Image Velocimetry) measurements of turbulent flows around wings models to assess the performance of numerical simulation turbulent models for these applications. The purpose is also to relate these models with the physics of the turbulent energy cascade (Germano 2007b; Brun, Friedrich, et Da Silva 2006; Cimarelli et Angelis 2014).

The research direction will also evolve depending on the results obtained and the initiatives from the PHD candidate.

Bock, Marcel, André Fuchs, Jan Friedrich, et Joachim Peinke. 2024. « The Use of LES to Analyse Higher-Order Moments of Two-Point Statistics ». *Journal of Physics: Conference Series* 2767 (9): 092080.

Brun, Christophe, Rainer Friedrich, et Carlos B. Da Silva. 2006. « A Non-Linear SGS Model Based On The Spatial Velocity Increment: Application to LES of Fully Developed Pipe Flow and Round Turbulent Jet ». *Theoretical and Computational Fluid Dynamics* 20 (1): 1-21.

Cammas, Franck, Denis Mehnert, et Antoine Pichon. 2020. « DÉVELOPPEMENT D'UNE FILIÈRE de TRANSPORT MARITIME à VOILE ». CGEDD n° 013343-01, IGAM n° 2020-066.

Cimarelli, Andrea, et Elisabetta De Angelis. 2014. « The Physics of Energy Transfer toward Improved Subgrid-Scale Models ». *Physics of Fluids* 26 (5).

Germano, M. 2007b. « The elementary energy transfer between the two-point velocity mean and difference ». *Physics of Fluids* 19 (8).

Gontier, H, A P Schaffarczyk, D Kleinhans, et R Friedrich. 2007. « A Comparison of Fatigue Loads of Wind Turbine Resulting from a Non-Gaussian Turbulence Model vs. Standard Ones ». *Journal of Physics: Conference Series* 75 (juillet):012070.

Hussain, Md. Daluar, Md. Shahnewaz Tuhin, Shahariar Kabir, et Osman Md Amin. 2018. « Numerical investigation of the stability and power prediction of a sail based wind propulsion system for a cargo ship ». *AIP Conference Proceedings* 1980 (1): 060006.

Kjellberg, Martin, Frederik Gerhardt, et Sofia Werner. 2023. « Sailing Performance of Wind-Powered Cargo Vessel in Unsteady Conditions ». *Journal of Sailing Technology* 8 (01): 218-54.

Kolmogorov, A. N. 1941. « The Local Structure of Turbulence in Incompressible Viscous Fluid for Very Large Reynolds Numbers ». *Doklady Akademii Nauk SSSR* 30 (1941): 301-5.

Mücke, Tanja, David Kleinhans, et Joachim Peinke. 2011. « Atmospheric Turbulence and Its Influence on the Alternating Loads on Wind Turbines ». *Wind Energy* 14 (2): 301-16.

Schwarz, C. M., S. Ehrich, R. Martín, et J. Peinke. 2018. « Fatigue Load Estimations of Intermittent Wind Dynamics Based on a Blade Element Momentum Method ». *Journal of Physics: Conference Series* 1037 (7): 072040.

Schwarz, Carl Michael, Sebastian Ehrich, et Joachim Peinke. 2019. « Wind Turbine Load Dynamics in the Context of Turbulence Intermittency ». *Wind Energy Science* 4 (4): 581-94.

Valente, P. C., et J. C. Vassilicos. 2015. « The Energy Cascade in Grid-Generated Non-Equilibrium Decaying Turbulence ». *Physics of Fluids* 27 (4).

Yao, Hanxun, Michael Schnaubelt, Alexander S. Szalay, Tamer A. Zaki, et Charles Meneveau. 2024. « Comparing Local Energy Cascade Rates in Isotropic Turbulence Using Structure-Function and Filtering Formulations ». *Journal of Fluid Mechanics* 980 (février):A42..

Collaborations envisagées

LHEEA, Centrale Nantes

Laboratoire d'accueil à l'ONERA

Département : Aérodynamique, Aéroélasticité, Acoustique

Lieu (centre ONERA) : Meudon

Contact : Paul Beaumard

Tél. : 01 46 23 51 65 Email : paul.beaumard@onera.fr

Directeur de thèse

Nom : Laurent Perret

Laboratoire : LHEEA, Centrale Nantes

Tél. : 02 40 37 16 78

Email : laurent.perret@ec-nantes.fr

Pour plus d'informations : https://www.onera.fr/rejoindre-onera/la-formation-par-la-recherche