PROPOSITION DE SUJET DE THESE

Intitulé : Wind tunnel simulations of environmental turbulent shear flows and atmospheric-like turbulent boundary layers

Référence : **MFE-DAAA-2020-03**
(à rappeler dans toute correspondance)

Début de la thèse : octobre 2020	**Date limite de candidature :** avril 2020

Mots clés

expérimentation, soufflerie, couche limite atmosphérique, turbulence

Profil et compétences recherchées

Strong competencies in fluid mechanics and experimental metrology. Team work. Proficiency in oral and writing communication.

Présentation du projet doctoral, contexte et objectif

There is a constant engineering need for generating tailored environmental turbulent shear flows and thick atmospheric-like turbulent boundary layers in wind tunnels for simulations of wind turbine or bridge or skyscraper or naval vessels responses to realistic wind fields. The size of buildings is in general such that they operate inside the earth's boundary layer. For example, buildings or wind turbines can have heights comparable to the statue of liberty and higher. Scaled-down wind turbine experiments in conventional wind tunnels require the generation of thick boundary layers, thick enough for the scaled-down turbine to be inside it.

Current wind tunnel simulations of atmospheric-like turbulent boundary layers thick-enough to envelop a scaled-down wind turbine or other structural model follow empirical methods developed in the 1970s by Counihan using "spires", fences and a combination of roughness elements (Counihan 1967). These methods require long working sections, at least 5 to 10 times in length the boundary layer thickness being generated, to give a turbulent boundary layer with some of the desired characteristics. More recently, Hearst & Ganapathisubramani (2017) proposed the possibility of independently controlling mean flow and turbulence intensity using an active grid. They produced shear flows with small shear rates and generated profiles of varying turbulence intensity and high Reynolds numbers. However, the active grid methodology is rather costly to implement, and the establishment of control protocols remains fully empirical, as the work of Hearst & Ganapathisubramani (2017) did not provide quantitative relations between control parameters and desired turbulence characteristics.

Whereas it is relatively easy to get the mean profile correct and rather more difficult to achieve the correct turbulence intensity profiles it is very difficult to achieve anywhere near the correct turbulence length scales. The requirements are therefore thick wall-normal profiles of the mean flow with specified turbulence intensity and longitudinal integral scale profiles. There is no method to date, which can reproduce all of these sufficiently accurately at the scale required. This is, therefore, the problem to be addressed in this proposal and we plan to address it by using the concept of inhomogeneous multiscale profilers introduced last year by Zheng et al (2018). These authors have demonstrated that inhomogeneous multiscale profilers/grids can be designed and used to generate desired mean flow and turbulence intensity profiles in short wind tunnel test sections, and they have even established simple relations between inlet parameters and downstream turbulence profile characteristics which can be used to tailor bespoke turbulent flows. Inomogeneous multiscale grids are much easier and cheaper to use than active grids and hold more promise for the additional design of integral length-scale profiles than active grids. They have enough degrees of freedom to play with in a systematic way instead of the current methods which are based on 'recipes' and empiricism. In particular, fractal/multiscale grids have inbuilt multiple scales which can be used to generate the inhomogeneous turbulence of a simulated environmental turbulent shear flow or a thick turbulent boundary layer in a short streamwise distance if organised in the appropriate inhomogeneous manner.

Research subject, work plan:

We will investigate the breadth of potential of inhomogeneous multiscale grid/profiler design with the aim to establish the range of turbulent shear flows that can be produced by this passive method. The special case of homogeneous turbulent shear flows has not been attempted yet with inhomogeneous multiscale grids and this will be the very first grid to be designed because of the long standing fundamental interest in such turbulent flows. Depending on time and on a judgement on research opportunities to be made during the project, we may use inhomogeneous multiscale grids to study the turbulent energy dissipation scaling in homogeneous turbulent shear flow following the work of Nedic & Tavoularis (2016).

However, the main thrust of the project will be, firstly, on developing new inhomogeneous multiscale grids, which can be used to generate desired mean flow, turbulence intensity and integral length-scale profiles at once. This part of the project will also attempt to extend the measurement distances and increase the mean shear rates achieved by Zheng et al (2018). Secondly, the thrust will be on developing general relations between inlet grid/profiler parameters and desired turbulence characteristics at desired lengths from the grid. This will be done by further developing the turbulent kinetic energy model of Zheng et al (2018) using measurements with multiple hot-wires or Particle Image Velocimetry to help understand the neglected terms in their predictive model. The development of a robust such model will be important for increasing the range of mean shear rates and mean shear rate profiles that can be simulated in the wind tunnel given the turbulence producing (mean shear modifying turbulence) and Reynolds stress (turbulence modifying mean shear) interactions between mean shear and turbulence.

The proposed work will make use of the LMFL's exceptionally long 20m × 2m × 1m LMFL wind tunnel (longest in France and one of two or three longest in Europe) specialising in turbulent boundary layers, able to attain values of Re_θ as high as 20,000, with full optical access for PIV measurements and temperature regulation for accurate hot wire anemometry. Given the length of our wind tunnel, we will also be able to compare with Counihan methods and will also be able to combine Counihan's approach with our own multiscale inhomogeneous profilers which can actually be placed at various positions in the tunnel, not only at the inlet.

If time allows we may conclude the project with a study of the interaction of two or more wind turbine wakes placed in the same simulated thick turbulent boundary layer in the wind tunnel, small scale buildings or naval airships.

References:

J. Counihan, "An improved method of simulating an atmospheric boundary layer in a wind tunnel", Atmospheric Environment, 3(2), 197-200 (1967).

R.J. Hearst & B. Ganapathisubramani, "Tailoring incoming shear and turbulence profiles for lab-scale wind turbines", Wind Energy, 20(12), 2021–2035 (2017).

J. Nedic & S. Tavoularis, "Energy dissipation scling in uniformly sheared turbulence", Phys. Rev. E, 93, 033115 (2016).

Zheng S., Bruce P.J.K., Graham J.M.R. & Vassilicos J.C., "Weakly sheared turbulent flows generated by multiscale inhomogeneous grids", J. Fluid Mechanics, 848, 788--820 (2018).

Collaborations envisagées

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