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Titre : Analysis of the energy cascade in a decelerating turbulent boundary layer

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Descriptif :

The Adverse Pressure Gradient (APG) Turbulent Boundary Layer (TBL) is a critically important part of flows around nearly all bodies in motion through air or water as is the case in all transport situations (cars, trains, ships, aircraft, etc). To be able to predict forces on such bodies (drag, lift) and their fluctuations and therefore amounts of power required and structural stability it is important to be able to model the turbulent flow around the body. All turbulence models, whether RANS, URANS or LES, effectively assume the turbulence to be in two-point equilibrium as stated by Kolmogorov's (1941) theory. Kolmogorov's (1941) equilibrium cascade has been a cornerstone of turbulence modeling and theory for the past 75 years. For example, it implies the Smagorinsky subgrid LES modeling approach and the turbulence dissipation scaling used in K-epsilon turbulence models (and other turbulence predicting approaches). However, experimental and computational evidence has gathered over the past 10 years which now shows clearly that there is no Kolmogorov equilibrium cascade in various turbulent flows including grid-generated turbulence, turbulent wakes (Vassilicos ARFM 2015), turbulent jets and even DNS of periodic turbulence (Goto & Vassilicos PRE 2016).

The APG TBL is in some way a combination between a wake flow and a turbulent boundary layer. It is now critically important to ascertain whether the APG TBL is also out of Kolmogorov equilibrium like the turbulent flows mentioned above. In fact, there are already extremely recent indications (Nedic, Tavoularis & Marusic PRL 2017 under review) that the Zero-Pressure Gradient (ZPG) TBL is out of Kolmogorov equilibrium and that the turbulence dissipation in the ZPG TBL obeys the same non-equilibrium scaling found in grid turbulence, turbulent wakes, turbulent jets and periodic turbulence. The chances that the APG TBL is also out of Kolmogorov equilibrium and also obeys the same apparently universal non-equilibrium scaling for the turbulence dissipation are high. The first objective of this research will be to achieve to demonstrate this.

The second objective of this research will be to elucidate the energy transfers in both physical and scale spaces in the APG and ZPG TBLs in terms of the Karman-Howarth-Monin-Hill (KHMH) equation.

This is a turbulence energy balance in its most general form dating from about 15 years ago (Hill 2002) and which is now beginning to be used in turbulence research. We will follow the methodology of Gomes-Fernandes, Ganapathisubramani & Vassilicos (JFM 2015) who used a 2D 2C PIV to estimate a number of the terms in the KHMH equation. They were able, this way, to elucidate clear properties of the turbulence in the very near field of grid-generated turbulence where the flow is at least as inhomogeneous and anisotropic as in the APG TBL. The KHMH equation offers the possibility to understand interscale and interspace energy transfers in complex turbulent flows, something which was not possible till about 15 years ago which is after most if not all current turbulence modelling and prediction strategies has been developed.

Taking benefit of the new specificity of the LML wind tunnel, which is transparent on 20 m and present a boundary layer thickness of 30 cm at high Reynolds number, the aim of the thesis is also to define and conduct new experiments in order to investigate the physics of turbulence in the APGTBL. The most advance optical measurement technique such as time resolved hors high-resolution particle image velocimetry will be used.

We therefore now have a unique opportunity to develop radically new turbulence model approaches based on the KHMH equation, the possibility to use the PIV methods (Foucaut & Stanislas MST 2004, Foucaut et al MST 2014) at the LML wind tunnel, and the new non-equilibrium turbulence dissipation law. In fact, the new non-equilibrium dissipation law implies new mean flow profile scalings in jets and wakes and comes with new Reynolds stress scaling laws too (e.g. Dairay, Obligado & Vassilicos JFM 2015, Castro JFM FoF 2015). The possibilities are therefore very far reaching and may lead to a paradigm shift in the way that turbulent flows are predicted and managed in transport situations.