GENERALISED QUASILINEAR APPROXIMATIONS OF TURBULENT CHANNEL FLOW. STREAMWISE NONLINEAR ENERGY TRANSFER

Carlos González Hernández[1], Qiang Yang[2] and & Yongyun Hwang[1]
[1]*Department of Aeronautics, Imperial College London*
[2]*State Key Laboratory of Aerodynamics, China Aerodynamics Research and Development Centre*
E-mail: cg1116@ic.ac.uk

A generalised quasilinear (GQL) approximation [1, 2] is studied in turbulent channel flow at $Re_\tau \simeq 1700$ (Re_τ is the friction Reynolds number). The focus of the present study is given to its application in the streamwise direction to explore the nonlinear interactions between energy-containing streamwise waves, which have been understood to originate from the streak instability and/or transient growth mechanism in the self-sustaining processes at different length scales. Waves, vortices and streaks are interrelated (causal) in wall-bounded turbulent shear flows; e.g. there cannot be streaks without vortices and viceversa. In this fashion, the GQL approximation provides a robust interventional tool to explore scale interactions, given that it is capable of suppressing particular triadic interactions in a controlled manner [3]. The GQL approximation decomposes the flow into two groups, the former of which contains a set of low-wavenumber Fourier modes and the latter are composed of the rest high-wavenumber modes. The former low-wavenumber group is then solved by considering the full nonlinear equations, while the latter high-wavenumber group is obtained from the linearised equations around the former. The performance of the GQL approximation is compared with that of the QL model [4], in which the low-wavenumber group only contains zero streamwise wavenumber. The QL case has been found to exhibit the most anisotropic second-order turbulence statistics throughout the entire wavenumber space of the spectra, in agreement with the previous studies [4, 5]. Only a small increase in the number of streamwise modes allowed to interact nonlinearly has resulted in a rapid recovery of the scaling of the streamwise wavelengths with the distance from the wall, which was absent in the streamwise spectra of the QL case. These cases also exhibited spectra extending over a wider range and reaching out to smaller scales, when compared to the QL case whose spatial spectra were highly localised in the wavenumber space. The production spectra of the QL model have also been found to be highly localized and the turbulent transport is inhibited in the streamwise direction. In effect, it is found that the QL model exhibits a considerably reduced multi-scale behaviour at the given moderately high Reynolds number. Finally, it is proposed that the energy transfer from the low to the high-wavenumber group in the GQL approximation, referred to as the 'scattering' mechanism [2], depends on the neutrally stable leading Lyapunov spectrum of the linearised equations for the high wavenumber group. This has explained the gradual extension of the spectra of the GQL model over a wider range, when the cut-off streamwise wavelength for the velocity decomposition in the GQL model is sufficiently large. This is also consistent with the emergence of the trivial solution in the high-wavenumber group, when the cut-off wavelength is sufficiently small (figure 1).

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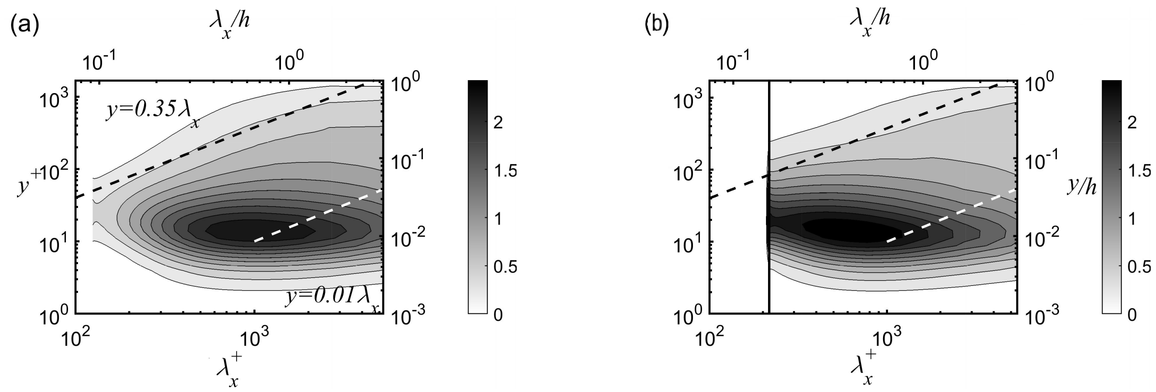

Figure 1. Premultiplied streamwise wavenumber spectra of $k_x^+ \Phi_{uu}^+(y^+, \lambda_x^+)$ for (a) LES and (b) GQL25 (25 streamwise modes).

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