

Spatio-temporal Proper Orthogonal Decomposition of turbulent channel flow

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We present the results of spatio-temporal Proper Orthogonal Decomposition (POD) applied to the wall layer of a turbulent, incompressible flow in a channel at $Re_\tau = 590$ (based on wall units). The novelty of the new decomposition lies in the separation of temporal and spatial scales of the flow based on energy content, thereby overcoming the weakness of classical POD. The resulting eigenfunctions from this decomposition are associated with individual spatial wavenumbers and frequencies due to the statistical symmetries of the flow.

We show that the most energetic spatial eigenfunctions are characterized by time scales in the range of 200-300 in wall units (see Figure 1), which are close to the time scales of coherent structure regeneration¹. A characteristic frequency can be identified from the energy spectra in the frequency space. The eigenfunctions present self-similarity features and almost coincide on the common domain when the POD is applied to the full domain along wall-normal direction, indicating the coherence over the height of the layer.

A measure of convection velocity of the structures is naturally formulated through the decomposition, and has a characteristic value of $12u_\tau$ which is in agreement with classical results². We also present the energy budget equation, which separates the contribution of different terms to the energy of each mode, and we discuss the energy balance for the most energetic modes. The budget equation also provides a closure relationship for the quadratic terms which can pave way for further investigations.

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¹J. Jimenez, Near-wall turbulence, *Physics of Fluids* **25**, 10 (2013).

²P. A. Krogstad, J. H. Kaspersen, S. Rinestead, Convection velocities in a turbulent boundary layer, *Physics of Fluids* **10**, (1998).

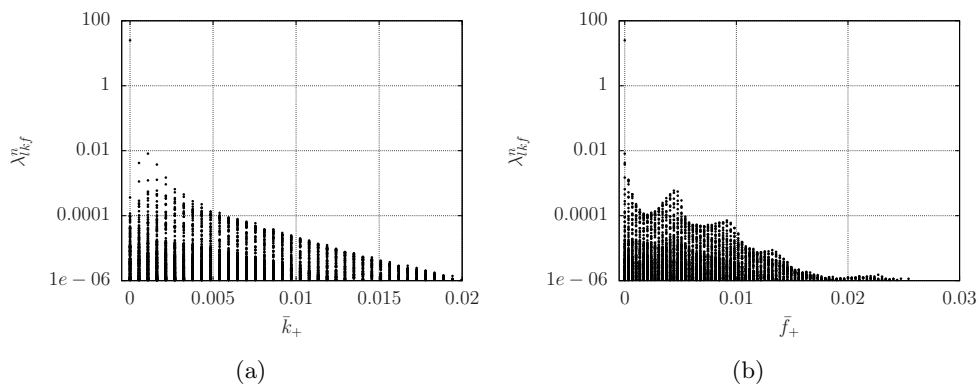


Figure 1: Distribution of the largest 5000 eigenvalues $\lambda_{k,f}^n$ as a function of a) spanwise wavenumber \bar{k}_+ and b) frequency \bar{f}_+ .