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On alignments and small scale structure in turbulent pipe flow

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The data base of an extensive DNS of turbulent flow in a pipe (Eggels et al. J. Fluid Mech. 268 (1994) 175) at Re = 7000 (based on the pipe diameter and the centerline velocity or Reτ = 360 based on the friction velocity uτ) has been used to study some of the alignments discovered recently in quasi-isotropic and shear turbulent flows and attracted considerable attention. These are the alignments between the velocity u→ and vorticity vectors ω→, between the vorticity ω→ and the eigenvectors of the rate of strain tensor sij, and between ω→ and the vortex stretching vector Wi = ωjsij. Comparison of these alignments strongly indicates that the quasi-two-dimensional (QTD) state of turbulent pipe flow in regions of strong alignment between ω→ and the intermediate eigenvector λ→int of the rate of strain tensor sij is qualitatevly different from purely two-dimensional one. This is manifested in stronger alignments between ω→ and W→ in these regions as well as in larger enstrophy generation ⟨ωi ωj sij ⟩≡⟨ωi Wi ⟩ and large ⟨W^2 ⟩, which are identically zero for a purely two-dimensional flow. The same is true of regions with concentrated vorticity, most of which are embedded into the regions with strong alignment between ω→ and λ→int.