Turbulent Channel Flow in Four Spatial Dimensions

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ABSTRACT

The objective of this work is to investigate numerically stability of 3D turbulent channel flow with respect to 4D perturbations and to analyze possible 4D turbulent solutions in order to have a new look on turbulence in channel flow from the 4D point of view. Four-dimensional incompressible Navier-Stokes equations are solved numerically using the generalization of the method [1]. The fourth spatial coordinate is introduced formally to be homogeneous and mathematically orthogonal to the others, similarly to the spanwise coordinate. Exponential growth of small 4D perturbations superimposed onto 3D turbulent solutions was observed in the Reynolds number range from $Re = 4000$ to $Re = 10000$. The growth rate of small 4D perturbations expressed in wall units was found to be $\lambda^+_{4D} = 0.016$ independently of Reynolds number. This shows that 4D instability has a near-wall character. The growth rate of 4D perturbations is lower than that of small 3D perturbations, $\lambda^+_{4D} = 0.021$, found recently in [2,3]. Nonlinear evolution of 4D perturbations leads either to attenuation of turbulence and solution return to the laminar Poiseuille-flow state or to establishment of self-sustained 4D turbulent solution (4D turbulent flow). Both results of flow evolution were obtained at the lowest Reynolds number, depending on the grid resolution, pointing on the proximity of $Re = 4000$ to the critical Reynolds number for 4D turbulence. Self-sustained 4D turbulence appeared to be less intensive compared with the 3D one in terms of mean wall friction, which is about 55% of that, predicted by the empirical Dean's law for turbulent channel flow at all Reynolds numbers considered. Thus, the law of resistance of 4D turbulent channel flow can be expressed as $C_f = 0.04Re^{-0.25}$.

REFERENCES

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