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A unified theory for wall turbulence via a symmetry approach

ZHEN-SU SHE, XI CHEN, College of Engineering, Peking University, FAZLE HUSSAIN, Department of Mechanical Engineering, Texas Tech University — First principle based prediction of mean flow quantities of wall-bounded turbulent flows (channel, pipe, and turbulent boundary layer - TBL) remains a great challenge from both physics and engineering standpoints. Physically, a non-equilibrium physical principle governing mean properties in turbulent flows is yet unknown. Here, we outline a recently developed symmetry-based approach which derives analytic expressions governing the mean velocity profile (MVP) from an innovative Lie-group analysis. In analogy to the order parameter in Landau's (1937) mean-field theory, we develop a concept of order functions which are assumed to satisfy a dilation group invariance - representing the effects of the wall on fluctuations - allowing us to construct a set of new invariant solutions of the (unclosed) mean momentum equation (MME). The theory is validated by recent experimental and numerical data, and identifies a universal bulk flow constant 0.45 for all three canonical wall-bounded flows, which asymptotes to the true Karman constant at large Reynolds numbers. The theory equally applies to the quantification of the effects of roughness (She et al. 2012), pressure gradient, compressibility, and buoyancy, and to the study of Reynolds-averaged Navier-Stokes (RANS) models, such as k-ωmodel, with significant improvement of the prediction accuracy. These results affirm that a simple and unified theory of wall-bounded turbulence is viable with appropriate symmetry considerations.

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