Investigating dissipative roughness effects on turbulent drag using a stochastic turbulence model

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Assessment of roughness effects is important for reliable rate-limiting transfer functions, e.g., in engineering devices such as heat exchangers, fuel cells, and catalytic reactors. Jiménez[1] suggests a minimal friction Reynolds number of $\mathrm{Re}_\tau \sim 4000$ being required in order to systematically carry out parametric investigations on roughness effects. Direct Numerical Simulation (DNS) can be performed only for selected cases using state-of-the-art high-performance computational architectures. Extensive parametric studies remain, in that sense, virtually unfeasible. As a reference, smooth-wall turbulent channel flow has only been extended from $\mathrm{Re}_\tau = 5{,}200$ to 10,000 over the last decade[2,3]. In order to formulate a feasible problem, we utilize a reduced-order model, the stochastic One-Dimensional Turbulence[4] (ODT) model, which yields computationally efficient flow simulations with a fully resolved range of scales utilizing baker's maps to represent turbulent advection along a 1-D physical coordinate. Full-scale resolution is necessary for the assessment of distinctive flow regimes on the basis of different length scale ratios in rough-wall turbulent flows[1,5]. We discuss one way in which roughness effects can be incorporated into the ODT framework for different regimes of roughness effects, extending previous approaches which were aimed solely for atmospheric boundary layer flows[6,7]. Due to the 1-D setting, simulations cannot capture roughness directly. Instead, roughness is modeled with a Parametric Forcing Approach (PFA) in an otherwise smooth-wall channel configuration. The PFA has been used previously for DNS, and allows capturing leading-order effects on drag, for transitional and fully rough flows, while also including k-type and d-type roughness[1,8]. Fig. 1 shows preliminary ODT results utilizing PFA in channel flow. In the talk, we will address the predictive capabilities of the approach with emphasis on drag.

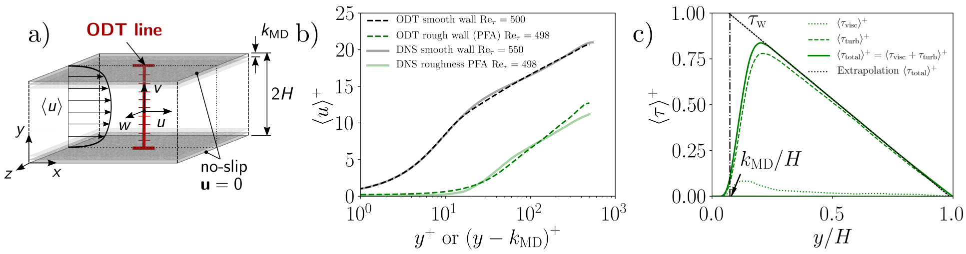

Figure 1: (a) Sketch of the configuration. (b) Mean velocity $\langle u \rangle$ boundary layer for ODT and DNS[3,7] (melt-down height $k^+_{\mathrm{MD}} = 67$, $k_{\mathrm{MD}}/H = 0.12$) demonstrating absence of the buffer layer over roughness. (c) ODT turbulent and total stress $\langle \tau \rangle$ with indication of the equivalent smooth-wall location obtained by extrapolation with the wall-shear stress τ_{w}. The superscript $(\cdot)^+$ denotes inner scaling.

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