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Designing Large-Eddy Simulation of High Reynolds Number Wall-bounded Flows

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Large-eddy simulation (LES) of the high Reynolds number boundary layer systematically over-predicts the mean velocity gradient in the shear-dominated inertial surface layer, destroying the law-of-the-wall. This “overshoot” is especially apparent in LES of high Reynolds number boundary layers where the viscous layer either does not exist, such as in the rough-surface atmospheric boundary layer (ABL), or is not resolved by the LES grid. In hybrid LES, where the grid integrates RANS in the viscous layer with large-eddy simulation above, the error appears as a “mismatch” in the log profile for mean velocity. The overshoot in mean shear produces a wide range of negative effects, including a strongly enhanced stream-wise coherence and an incorrect eddy structure. In the presence of buoyancy-driven motions, as in the moderately unstable ABL, the error infects the entire thermal structure and affects vertical transport of heat, humidity and scalar. Furthermore, the overshoot precludes a grid-independent prediction for mean velocity. In this discussion I shall describe the fundamental source of the overshoot as arising from the combined effects of nonphysical friction in the subfilter-scale (SFS) stress model and numerical algorithm, grid aspect ratio, and grid resolution in the vertical. From this new understanding we develop a framework in which a large-eddy simulation should be formulated in order to both resolve the overshoot and capture the law-of-the-wall. The theory indicates that three critical parameters must be exceeded, defining a “high-accuracy zone” (HAZ) within the framework. We verify the theory with well over 100 large-eddy simulations of the neutral ABL and show that as the simulation moves into the HAZ, the overshoot is resolved, the law-of-the-wall is captured, a grid-independent prediction is attained, and the LES becomes more sensitive to the lower boundary condition. I shall argue that the framework should be used in the systematic improvement of LES models. [This work was carried with Dr. Tie Wei, and was supported by ARO.]