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Vortex forcing model for turbulent flow over spanwise-heterogeneous topogrpahies: scaling arguments and similarity solution

WILLIAM ANDERSON, JIANZHI YANG, UT Dallas — Spanwise surface heterogeneity beneath high-Reynolds number, fully-rough wall turbulence is known to induce mean secondary flows in the form of counter-rotating streamwise vortices. The secondary flows are a manifestation of Prandtl's secondary flow of the second kind – driven and sustained by spatial heterogeneity of components of the turbulent (Reynolds averaged) stress tensor. The spacing between adjacent surface heterogeneities serves as a control on the spatial extent of the counter-rotating cells, while their intensity is controlled by the spanwise gradient in imposed drag (where larger gradients associated with more dramatic transitions in roughness induce stronger cells). In this work, we have performed an order of magnitude analysis of the mean (Reynolds averaged) streamwise vorticity transport equation, revealing the scaling dependence of circulation upon spanwise spacing. The scaling arguments are supported by simulation data. Then, we demonstrate that mean streamwise velocity can be predicted a priori via a similarity solution to the mean streamwise vorticity transport equation. A vortex forcing term was used to represent the affects of spanwise topographic heterogeneity within the flow. Efficacy of the vortex forcing term was established with large-eddy simulation cases, wherein vortex forcing model parameters were altered to capture different values of spanwise spacing.

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