Accurate and efficient direct numerical simulation of turbulent drag reduction via riblets

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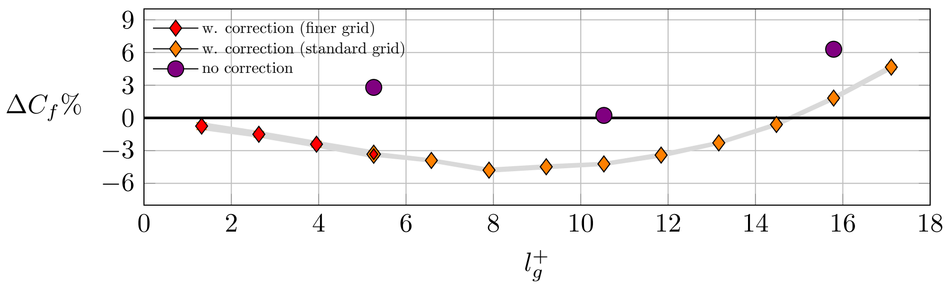
Riblets, two-dimensional surface protrusions capable of reducing skin-friction drag in turbulent flows, have been extensively studied over the past 50 years, particularly in experimental works[1]. Triangular or trapezoidal ridges aligned with the flow yield ∼8% of drag reduction and have been found particularly effective. The corresponding numerical verification of riblet drag reduction is extremely challenging but would enable the detailed analysis of the riblet physics and the optimisation of their shape, both necessary steps for their success. The challenge lies in the need for high-fidelity direct numerical simulation (DNS) combined with the geometric singularity at the riblet tip. Such singularity is known to be directly responsible for the drag reduction effect but is difficult to represent numerically even at the unreasonable cost of an extremely fine resolution around the riblet tip.

In this contribution, we enable the accurate and efficient simulation of turbulent drag reduction via riblets by introducing an analytical correction of the instantaneous flow solution around the riblet tip and embedding it into an immersed boundary method. The correction exploits the fact that the flow in the very vicinity of the singularity behaves as the analytically-known Stokes flow around a sharp corner[2]. We include the corner correction into a staggered-grid, second-order solver of the incompressible Navier–Stokes equations[3]. At the conference, we describe the corner correction, its necessity, and demonstrate fidelity and performance of our approach by performing DNSs of full-size turbulent channels flows with various riblet geometries, such as the sawtooth riblets with 60° tip angle and various sizes, whose drag reduction as relaive change in C_f with the respect to the flat channel is shown in the figure below at $Re_\tau = 200$. Most datapoints required approximately $39{\cdot}10^3$ CPU hours each, since the spatial resolution was only marginally finer than a standard DNS.



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