DNS OF TURBULENT BOUNDARY LAYERS SUBJECT TO SURFACE ROUGHNESS

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ABSTRACT

In this investigation, the moderate Reynolds number, zero-pressure-gradient, turbulent boundary layer is investigated from a computational perspective in light of the effect of surface roughness. The range of Reynolds numbers (based on momentum thickness) achieved varied from $Re_\theta = 2000$ to $Re_\theta = 2400$ and the surface roughness was modeled with a roughness parameter of $k^+ = 11$ to match experiments at similar conditions in the transitionally rough regime . For the first time ever, a DNS of a turbulent boundary layer subjected to a true rough surface topography has been realized for both the velocity and temperature fields. The methodology presented here allows one to reduce the computational resources otherwise required to simulate the transition from laminar to turbulence, and focus these resources on simulating higher Reynolds numbers in the presence of other external conditions such as thermal fields and surface roughness. The multi-scale dynamic approach implemented for the current simulation allows the accurate representation of a multi-layered boundary layer structure while dynamically computing the flow parameters, including the friction velocity and friction temperature, which are otherwise difficult to compute when dealing with rough surfaces. The experimental data from several researchers is collected and analyzed here to study the validity and accuracy of the present ground-breaking simulations.

It is shown here that the mean velocity profiles in outer units are changed by the presence of surface roughness. The velocity profiles are affected in such a way that is consistent with the common belief established by experiments. This work, however, is one of the first computational simulations of its kind to show this behavior. Contrary to the beliefs of many, the iso-contours show that the effects of surface roughness can be seen beyond the inner layer of the boundary layer. In terms of the Reynolds stress profiles, it is found that the presence of the roughness causes an upsurge in the peak of the stream-wise Reynolds stress while leaving the Reynolds shear and normal stresses virtually unaffected. This finding is contrary to the previously accepted belief; which states that surface roughness causes a reduction

in the peak of the stream-wise Reynolds stress. Flow parameters such as the skin friction have been computed and an increase is observed due to the presence of the surface roughness. The simulations of the thermal field show an increase in the outer region of all quantities (mean temperature, temperature fluctuations, and turbulent heat fluxes). Computation of the Stanton number shows an increase over the entire range of Re_θ. The $< u'\theta' >$ heat flux component shows evidence of a second peak in the outer region, which is not seen for the smooth surface case.

The results of the current study show that the mesh contains enough grid points to fully resolve all of the scales of the flow; there is enough near-wall resolution to accurately resolve the Kolmogorov length scale. However, the mesh falls short of fully characterizing the sand grit surface topography in the stream-wise direction. Due to limited availability of computational resources, a stream-wise mesh refinement has been designed but not yet implemented.