Turbulent plane wall jets over rough surfaces
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Synopsis
Large-eddy simulations are carried out to study the effects of surface roughness on plane wall jets. Results of the simulations over both smooth and rough surfaces were validated by available experimental data. Investigations of both instantaneous and mean flow fields reveal that, for the Reynolds number and roughness height considered in this study, the effects of roughness is mostly confined to the near wall region of the wall jet.

Introduction
Plane wall jets, which are the subject of the current presentation, can be generated by injecting fluid from a rectangular nozzle along the wall. The nozzle should be wide enough that the changes of the flow statistics in the cross stream direction are negligible [1]. While extensive effort has been devoted to study wall jets, there are a few studies that have taken into account the surface roughness. Roughness exists on almost all surfaces. Prediction of roughness effects on turbulence, skin friction, and heat and mass transfer is crucial in engineering applications.

Methods and Results
We performed large-eddy simulations of flow over both smooth and rough surfaces using a well-validated staggered finite-difference code. To represent the random roughness elements, the virtual sandpaper model proposed by Scotti [6] and an immersed-boundary method (IBM) based on the volume-of-fluid (VOF) approach is used. The flow parameter are chosen the same as the experiment by Rostamy et al. [2] for validation purposes. Existence of surface roughness results in a loss in momentum in the near-wall region that is characterized by a downward shift in the log-law, $\Delta U^+$, for turbulent boundary layers $\Delta U^+$ is a function of roughness height only, $k_r^+$. In the current study and Rostany et al. study [2], this shift is also only a function of roughness height (figure 1), in agreement with the turbulent boundary layer. But, other available data in the literature suggest that there might be a Reynolds number dependency of the shift in the log-law of turbulent wall jet over rough surfaces. Profiles of Reynolds stresses scaled with inner layer scaling parameters (figure 3) show a decrease in the level of the Reynolds stresses with roughness in the inner layer of the wall jet. However, roughness does not only modify the level of the Reynolds stresses; the shapes of the profiles of Reynolds stresses also change. All researchers reported an increase in the thickness of the inner layer of the wall jet as roughness was added to the flow, but always questioned the extent by which the near-wall interactions of the roughness and the inner layer is affecting the flow further away from the surface. For the Reynolds number and roughness height considered in this study, roughness does not affect the scaling nature of the profiles of Reynolds stresses in the outer layer (figure 2).

Conclusions
We performed large-eddy simulations of a plane wall jet over both smooth and rough surfaces. For the Reynolds number and roughness height considered in this study, roughness does not show any significant effect on the outer layer structures of the flow but modifies the inner layer of the wall jet. Investigation of the current simulation and the data available in literature suggests that unlike turbulent boundary layers, the roughness function, $\Delta U^+$, does not only depend on roughness height.

References