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Influence of entrained turbulent fluid on jet and boundary layer flows

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Abstract In this contribution we first review the relatively small amount of literature on the influence of entrained turbulent fluid on turbulent shear dominated flows and then present own measurements of interacting jets and a wind tunnel generated boundary layer flow. Due to the recirculation zone between the jets, the fluid which is entrained by the jets is highly turbulent. This leads to a much faster spread compared to free jets.

In the boundary layer flow, Irwin-senors were used to measure the surface shear stress. It was found that roughness elements and spires, which are commonly used to generate developed boundary layer flows, do increase the turbulence and shear stress levels in the log layer while having negligible influence on the surface shear stress.

Introduction

There has been only little work published on the effects of turbulence of entrained fluid on shear dominated flows like jets or boundary layers. Hancock & Bradshaw [1] measured that skin friction of a boundary layer on the surface is increased with increased free stream turbulence and depends on the length scale of the free stream turbulence. This was also found by Veeravalli & Warhaft [7] for interpenetrating turbulent fluids. Recently, Horender [2] reported a study on interacting jets, which have a recirculation zone between each other, and therefore entrain turbulent fluid, which leads to a much larger spread of the jets.

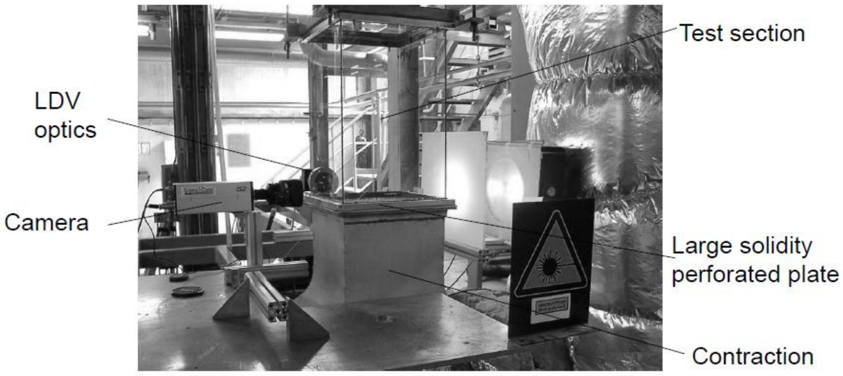

Figure 1. Experimental setup for the jet array.

Results

The measurements of streamwise velocity characteristics in a flow downstream of a perforated plate with 96% solidity were obtained using a single component Laser Doppler system, see figure 1. The channel bulk velocity was 1 m/s, the diameter D of the holes 5 mm and the Reynolds number of the flow through the holes was around 10,000. In comparison with literature data the mean velocity decay on the centre line was much larger than for a free jet but smaller compared to a confined jet, see figure 2. There was a mean reverse flow between the jets and flow visualizations and LDA measurements showed that the entrained fluid is highly turbulent and the eddy length scale was comparable to the that of the jets at x/D=6 to 12. This suggests that the penetration of turbulent fluid is larger compared to that of laminar or low turbulence fluid.

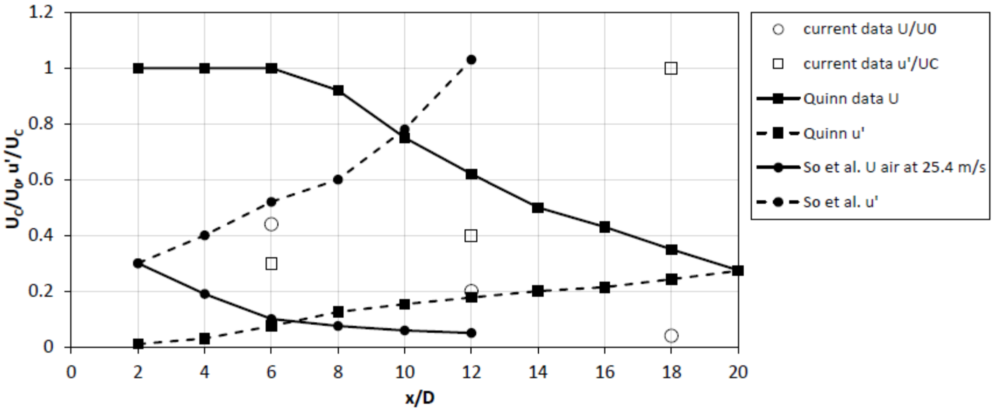

Figure 2. Mean and rms velocity decay of the jets in the jet array in comparison to literature Quinn [5] (free jet) and So et al. [6] (confined jet).

The results in the boundary layer indicate that the spires and roughness elements commonly used to establish developed wind profiles over rough terrain for the current geometry do produce a turbulent velocity field which does not increase the surface stress. Figure 3 shows the shear stress profiles measured with hot film anemometry. While for the “clean” floor case the constant stress layer could be observed around z = 100 mm, the case with spires and roughness elements shows around 20 % larger shear stress at z = 200 mm. However, with the pressure measuring based Irwine senors, which were calibrated to measure the surface shear stress, no increase could be observed due to the spires. This result can be explained by investigating the length scales of eddies in the boundary layer and the free stream [1,3] and the relevance of the results will be discussed with respect to wind blown sand and snow in the atmosphere and for wind tunnel studies.

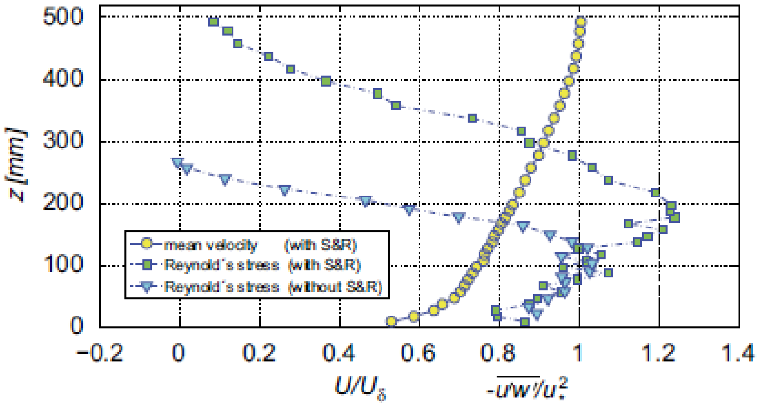

Figure 3. Mean velocity and turbulent shear stress profiles in a boundary layer flow with and without spires and roughness elements [4].

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