Wall Shear stress measurements in the atmosperhic surface layer

Ivan Marusic, Jason Monty, Nicholas Hutchins, and Min Chong

Walter Bassett Aerodynamics Laboratory, Mechanical and Manufacturing
Engineering, University of Melbourne, Victoria 3010 Australia.
`montyjp@unimelb.edu.au`

The difficulty of measuring mean wall shear stress, $\overline{\tau_w}$, in a turbulent boundary layer is a constant hinderance to the experimental researcher. Hence it is not surprising that a considerable amount of research into shear stress measurement techniques has been conducted [6]. Measurements of the fluctuating component of the shear stress, τ_w', are often more difficult but can provide interesting information. In fact, from this study of atmospheric τ_w' data, valuable contributions have been made to the physical understanding of turbulence over an unprecedented range of Reynolds numbers.

The shear stress measurements were made at the unique SLTEST (Surface Layer Turbulence and Environmental Science Test facility) site on the great salt lakes of Utah, pictured in figure 1. Winds over the site are known to remain strong and consistent for extended periods. Upstream of the measurement site, the surface is extremely flat and smooth over many kilometres [5]. The geophysically driven air flow is therefore thought to share important characteristics with common wind-tunnel boundary layers, albeit at three orders of magnitude higher Reynolds number. Thus, another goal was to further understand similarities that may exist between the SLTEST surface layer and the wind tunnel boundary layer. For such comparisons, neutrally buoyant conditions are required; figure 2 confirms that these conditions were present throughout the night. From extensive sonic anemometer measurements under these conditions, turbulence statistics were calculated which exhibit laboratory-boundary-layer-like behaviour.

Beyond sonic anemometery, the present work followed on from that of Heuer & Marusic [3] who developed a floating-element-type shear stress sensor, specifically designed to measure τ_w' in the atmospheric surface layer. By determining peaks in the two-point correlations of shear stress and streamwise velocity (with neutral buoyancy), [3] showed that a characteristic inclination angle of around 15° existed. This result is more conclusively shown from the current analysis and an illustration is provided in figure 3. This figure displays contours of the shear stress-velocity correlation over a range of wall-normal

Fig. 1. Photograph of the SLTEST measurement site in Utah, USA.

distance and streamwise separation. It is interesting to note that Brown & Thomas[2] performed a very similar experiment in a low Reynolds number laboratory boundary layer. Their conclusions were strikingly similar, i.e., that structures of approximately 18° inclination characterise the flow. The literature contains a number of other low Reynolds number studies also finding similar angles [1, 7, 4]. It is therefore confirmed that the characteristic struc-

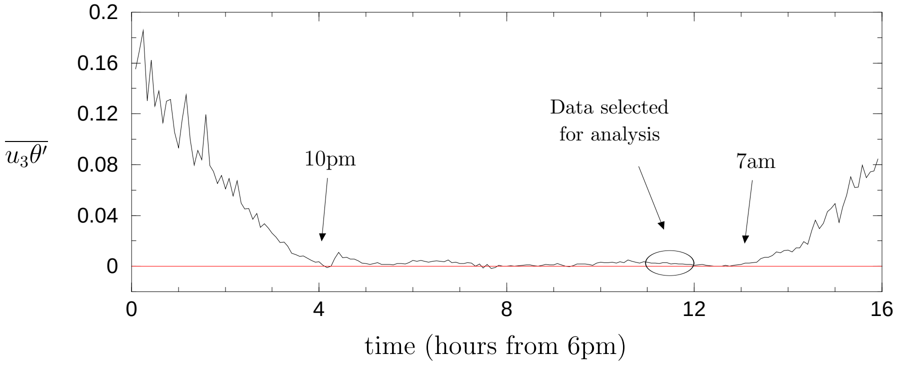

Fig. 2. Heat flux distribution throughout the evening, night and morning. u_3 is the wall-normal velocity fluctuation and θ' is the temperature fluctuation. Zero heat flux indicates neutrally buoyant conditions.

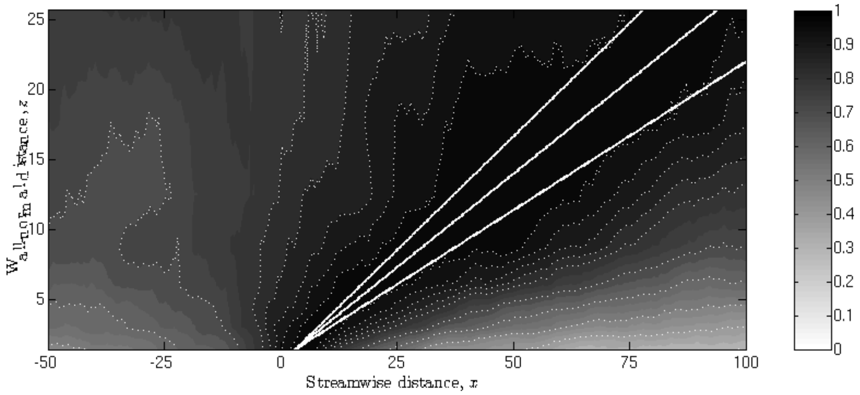

Fig. 3. Normalised τ_w'-u' correlation contours for neutrally buoyant conditions. Selected contour lines are marked with white dotted lines for clarity. Solid white lines indicate angles of 12°, 15° and 18° (note the figure axes are of different scale).

ture angle maintains a constant value over orders of magnitude Reynolds number range.

There are many other interesting results which will be presented but could not be included here for brevity. These include wall shear stress statistics, spanwise shear-velocity correlation, non-neutral buoyancy effects and comparisons with low Reynolds number numerical simulations. The compilation of all the results gives us an insight into turbulent flow structure from low to extremely high Reynolds numbers.

References

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