Controlling the large-scale motions in a turbulent boundary layer

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Turbulent boundary layers are common in many applications and it has long been a challenge to quantify and possibly control these flows in relation to their impact on turbulent skin friction, heat transfer, mixing, acoustic noise and vibrational loading. Over the past several decades, there has been growing understanding that turbulent boundary layers, despite their obvious randomness, possess certain recurrent features, commonly termed as 'coherent structures', and recent studies considerably expanded this view (Adrian 2007). Recent studies at high Reynolds number flows in pipe, channel and flat-plate boundary layers have revealed the presence of very large-scale motions (VLSMs, also referred to as 'superstructures') in the logarithmic regions of turbulent boundary layers (Hutchins & Marusic 2007). Furthermore, it has been observed that these superstructures maintain a footprint at the wall, seeming to modulate the near-wall cycle. Using this information, Hutchins *et al.*(2011) constructed a three dimensional conditional view of these structures and also investigated how these features modulate with the small-scale fluctuations near the wall.

In a more recent study conducted by Beresh *et al.*(2011), the focus was switched to wall pressure field. Interestingly, they observed similar large-scale motions in the wall pressure fluctuations beneath a supersonic turbulent boundary layer and attributed that such motions are the most possible explanation of the observed low-frequency pressure fluctuations in flight-vehicle vibrations. Putting all these together, it is natural to correlate the skin-friction to the wall pressure field and probe the possibility of affecting the shear stress signature at the wall as a means of affecting the acoustic noise and turbulence levels across the depth of the boundary layer.

In this paper we consider an approach to attempt to manipulate the largest scale motions in turbulent boundary layers by using wall-normal jets to induce large-scale roll-modes into the flow. Measurements were made using two spanwise arrays of skin-friction sensors, a wall-normal jet and a traversing hotwire probe to study the effect of a wall normal jet on the large-scale structures. A rectangular wall-normal jet is used to target the large-scale structures as detected by an upstream spanwise array. A second spanwise array, located downstream of the jet records any modifications to the large-scale structure. In addition, a traversing hot-wire probe is mounted above the second spanwise array of sensors to study the effects across the depth of boundary layer. It is found that the jet is able to create a low-speed region and when targeted on a high speed structure, changed the associated footprint at the wall.

The experiments were carried out in the high Reynolds number boundary layer wind tunnel (HRN-BLWT) at the University of Melbourne, at a friction Reynolds number $Re_\tau \approx 14000$ ($Re_\tau = U_\tau \delta/\nu$). The experimental setup is shown in figure 1. Figure 2(a) shows the three dimensional conditional structure associated with a high skin-friction event at the wall, consistent with those reported in Hutchins *et al.*(2011). The unmodified two dimensional view of high skin-friction event is shown in figure 2(b) and the corresponding modified result is shown in figure 2(c). The result shows the possibility of modifying the large-scale structure with the use of a wall-normal jet. A more in-depth study is currently being investigated by looking at the changes across the depth of the boundary layer, and these results will be reported in the full paper.

References

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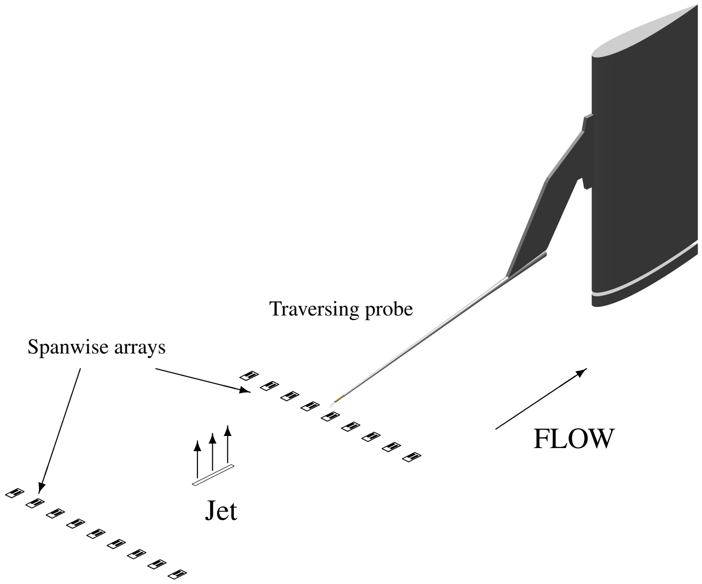

Figure 1: Schematic drawing of the experimental setup (figure not to scale)

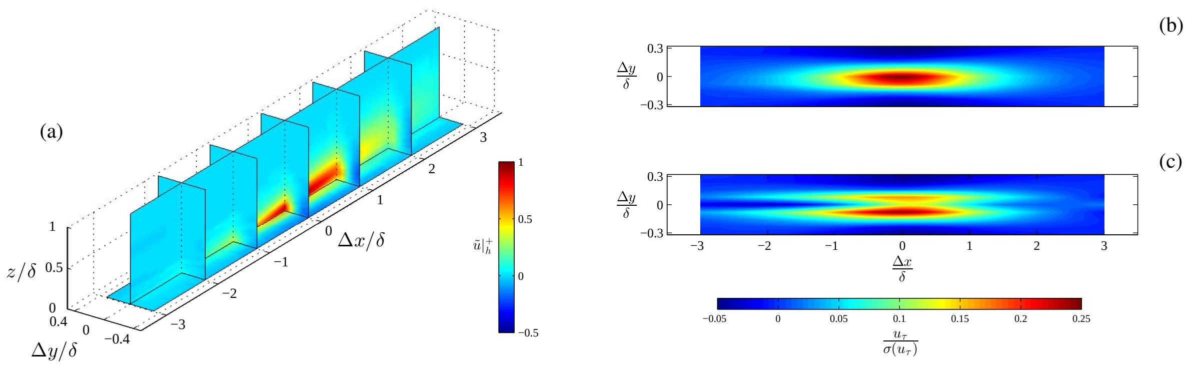

Figure 2: (a) Iso-contours of u^+ velocity fluctuations conditionally averaged on a high skin-friction event. Two dimensional high skin-friction footprint at the wall,(b) unmodified flow; (c) modified by the 'jet'

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