Volumetric measurements of vortex packet recovery downstream of a perturbation

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HIGHLIGHTS

- Volumetric velocity measurements in the logarithmic region of unperturbed and perturbed boundary layers were compared.
- In unperturbed flow, narrower and longer packets typically spanned the volume depth, becoming wider and shorter with increasing wall normal distance.
- Low momentum regions downstream of a cylinder array with $H = \delta$ often were limited to the lower part of the measurement volume, and cross correlations across the volume did not recover toward unperturbed values over a downstream distance of $4.7\delta$.

ABSTRACT

Volumetric measurements were acquired in the logarithmic region of a turbulent boundary layer with $Re_\tau = 2500$ using a 3-D PTV technique. Flow perturbed by spanwise cylinder arrays with $H = 0.2\delta$ and $H = \delta$ was compared against unperturbed flow at multiple streamwise locations. Measurement volumes were $0.7\delta \times 0.9\delta \times 0.12\delta$ in the streamwise, spanwise and wall normal direction respectively. Cross correlations were obtained between velocity vectors at separate wall-normal locations within the volumes. In unperturbed flow, low momentum regions frequently extended across the wall-normal volume dimension. Cross correlations indicated forward inclined structures and a persistent spanwise scale across the wall normal direction associated with alternating low and high speed momentum regions. Immediately downstream of each array in the perturbed flow, the cross correlations were altered significantly due to the presence of wake structures. Further downstream, the correlation shapes recovered significantly. For $H = 0.2\delta$, the correlations essentially recovered to the unperturbed shape and values by $2.4\delta$ downstream. By contrast, the correlations for the $H = \delta$ case remained altered a distance of $4.7\delta$ downstream. Compared to the unperturbed case, these correlations exhibited smaller peaks, less skew in the streamwise direction, and weaker negative lobes in the spanwise direction implying clear differences in both the wall-normal and spanwise flow organization.

Fig. 1 Unperturbed flow. a) Instantaneous volume from 3-D PTV. Colors show the fractional deviation from the local mean velocity for the plane at $z = 155$. Iso-surfaces show regions with $U < 0.95U_m$, where $U_m$ is the local mean velocity each $z$-plane. Streamwise-spanwise planes of velocity at b) $z = 155$, c) 300 and d) 465. LMR at $y/\delta = 0.2$ extends across volume depth becoming wider and shorter as increases.