Advancements in measuring the wall-normal velocity fluctuations in a turbulent boundary layer

C. Byers¹, M. Fu¹, Y. Fan¹, K. Kokmanian¹ and M. Hultmark¹∗

¹: Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, NJ, USA 08540.
∗Correspondent author: hultmark@princeton.edu

A novel velocity sensor has been developed and characterized for use in turbulent flows. The new strain-based sensor uses a free-standing nano-ribbon exposed to the flow, which results in a geometrically determined sensitivity to a single velocity component. A nano-ribbon deflects under the action of fluid forcing, causing an internal strain which can be calibrated to the fluid velocity. An anisotropic sensitivity to forcing enables measurements of turbulent fluctuations orthogonal to the free-stream flow using only one sensing element. The sensor is deployed in a turbulent boundary layer, with sensitivity to fluctuations in the wall-normal direction. Operation of the sensor is simple and, in contrast to constant temperature hot-wire anemometry, does not require a feedback circuit. The predicted frequency response is $O(10^3)$ Hz, making the sensor an interesting alternative for turbulence measurements.

By utilizing water as the working fluid, the unique geometry of the NSTAP results in a capability of obtaining velocity measurements under the new EFV mode of operation demonstrated by Fu et al. (2016). In the presence of forcing from the mean stream-wise velocity, the geometry of the NSTAP results in the EFV mode of operation being preferentially sensitive to the wall-normal fluctuations, allowing measurements of $\overline{v'^2}$. Initial characterization indicates that the sensor has an anisotropic sensitivity to velocity. If deployed at small angles of attack, the streamwise component of velocity has negligible influence on the wire strain. Deploying at 90° to the flow resulted in a sensitivity that followed the theoretical prediction of Fu et al. (2016).

As seen in figure 1, deploying the EFV sensor in a zero pressure gradient turbulent boundary layer resulted in well-resolved measurements of the wall-normal fluctuations, $\overline{v'^2}$. However, it was shown that due to the need to operate at a non-zero angle, to avoid buckling of the sensing element, the signal is contaminated by the streamwise velocity component and additional information is needed to fully differentiate between the streamwise and wall-normal components. Nonetheless, the results show a promising direction towards obtaining accurate wall-normal velocity fluctuation measurements at an enhanced spatial resolution.

The sensor employed in this study was an NSTAP operated in a cold-wire fashion. By coupling this mode of operation with a high current hot-wire mode, an accurate measurement of the instantaneous velocity could be obtained. This would enable more accurate extraction of the instantaneous angle of the flow, and thus a better calculation of the wall-normal velocity without contamination from the streamwise component. Additionally, coupling the hot- and cold-wire modes would allow a single sensing element to extract multiple Reynolds stresses, including covariance measurements.

REFERENCES