VERY-LARGE-SCALE MOTION MEASUREMENTS IN PIPE FLOWS AT HIGH REYNOLDS NUMBERS

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Pipe, channel, and turbulent boundary layer flows belong to the noble class of canonical wall-bounded turbulent flows, which are characterised by a (generally accepted) universal (i.e. independent of the Reynolds number) near-wall behaviour when scaled in viscous units. However, large-scale motions, which instead dominate the outer flow, might have a strong interaction with the small-scale fluctuations close to the wall. Indeed, the influence of the large-scale motions is a possible explanation of the failure of collapse, for example, of the inner-scaled streamwise variance profile [5, 1]. Particularly relevant is believed to be the role played by very-large-scale motions (VLSM), which are persistent structures that extend over several outer-length scales (say $O(10)$), and carry more than half of the kinetic energy and Reynolds shear stress (in a fully developed pipe flow) [2]. A better understanding of the role of LSM and VLSM can pave the way to prediction the near-wall turbulence behaviour using only the information extracted from the outer boundary layer region, as demonstrated by [4].

Owing to the very large extent of VLSM and the requirements in terms of spatial resolution, their observation via optical techniques, such as particle image velocimetry (PIV), is extremely challenging. Additionally, time resolution is hindered by hardware limitations. Hot-wire anemometry (HWA), on the other side, provides point-wise time-resolved measurements, but it does not allow to retrieve the instantaneous spatial organisation and interaction of these VLSM and small-scale motion. The Long Pipe Facility at CICLoPE, the Center for International Cooperation in Long Pipe Experiments [7], is, at present, the only pipe flow facility that provides high Reynolds numbers, while keeping the viscous length scale large enough to resolve all time and spatial scales with traditional hot-wire probes [6]. The facility enables access to perform spatially resolved large field-of-view PIV measurement over discrete regions and extensive access for HWA. In this work, synchronised non-time-resolved PIV and time-resolved HWA measurements are exploited to reconstruct dynamic information about the velocity field through modal analysis [3]. The dynamically reconstructed velocity fields are then used to propagate in space the evolution of the VLSM using Taylor's hypothesis. The simultaneously acquired data in combination with the constructed velocity fields can then be exploited to study amplitude modulation effects in a high Reynolds number facility without relying solely on single-point and single component temporal information, and shed light on the Reynolds number effect on the convection velocity of LSM and VSLMs as well as their contribution to turbulence statistics.

References

[1] P. H. Alfredsson, R. Örlü, and A. Segalini. A new formulation for the streamwise turbulence intensity distribution in wall-bounded turbulent flows. *Eur. J. Mech. B-Fluid*, **36**:167–175, 2012.

[2] B. J. Balakumar and R. J. Adrian. Large-and very-large-scale motions in channel and boundary-layer flows. *Phil. Trans. R. Soc. A.*, **365**:665–681, 2007.

[3] S. Discetti, M. Raiola, and A. Ianiro. Dynamic estimation of flow fields through correlation of non-time resolved field measurements and time-resolved point measurements: an algebraic approach. *16Th European Turbulence Conference*, 2017.

[4] I. Marusic, R. Mathis, and N. Hutchins. High Reynolds number effects in wall turbulence. *Int. J. Heat Fluid Flow*, **31**:418–428, 2010.

[5] R. Mathis, N. Hutchins, and I. Marusic. Large-scale amplitude modulation of the small-scale structures in turbulent boundary layers. *J. Fluid Mech.*, **628**:311–337, 2009.

[6] R. Örlü, T Fiorini, A. Segalini, G. Bellani, A. Talamelli, and P. H. Alfredsson. Reynolds stress scaling in pipe ow turbulence–first results from CICLoPE. *Phil. Trans. R. Soc. A.*, **375**, 2017.

[7] A. Talamelli, F. Persiani, J. H. M. Fransson, P. H. Alfredsson, A. V. Johansson, H. M. Nagib, J.-D. Rüedi, K. R. Sreenivasan, and P. A. Monkewitz. Ciclope–a response to the need for high Reynolds number experiments. *Fluid Dyn. Res.*, **41**:021407, 2009.