Evolution of near-wall backflow region in wall-bounded flows

X. Chen*, Y. M. Chung† and M. Wan*

The rare backflow of near-wall negative instantaneous streamwise velocity and the associated strong local fluctuations of wall friction are of great importance for the control of flow separation, drag reduction and the understanding of interaction between the large-scale motions (LSM) and the near-wall cycle. This study investigates the evolution of the backflow in channel and pipe flows at Reynolds numbers up to $Re_\tau = 1000$. The unclear process and cause of the splitting and merging of backflow are evaluated regarding their interplay with the near-wall structures. We also investigate the unknown formation process of the wall-detached backflow.

The backflow forms at the tail of a large-scale low-speed structure adjacent to the wall where it is joined by a large-scale high-speed structure induced by vortical structures in the buffer region[1,2]. It is found that on average, approximately 3% of the backflow can split, and about 0.2% can form detached away from the wall. The split backflow regions are caused by the spanwise shearing of near-wall high- and low-speed streaks. Conditional average results showed that the split backflow regions are on average, larger and more spanwise-elongated[3] which are just enough to span over the near-wall streaks[4]. The backflow can form away from the wall at $y^+ > 2$ when the tail of the 'carrier' low-speed structure is obstructed away from the wall by the near-wall high-speed streaks. The backflow regions being wall-detached for the whole life cycle with insufficient lifespan to reach the wall cause no critical of zero wall-shear stress beneath the backflow region. The example in figure 1 shows that backflow regions initially form wall-detached which merge as approaching towards the wall. After reaching and resting on the wall, the backflow region is then successively split by the near-wall streaks. As the LSMs penetrate towards the wall, breaking down the near-wall streaks and causing extreme events such as the rare backflow, the near-wall structures in turn, can cause complex behaviours of the backflow region.

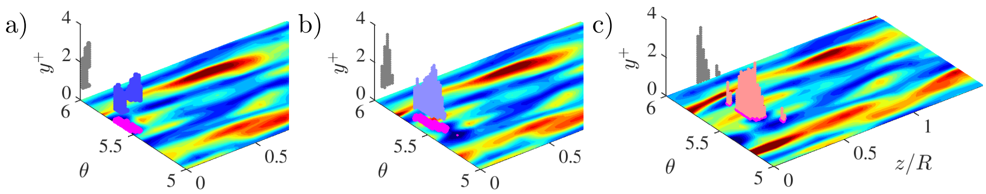

Figure 1: The evolution of backflow on the instantaneous contours of the streamwise fluctuation at $y^+ = 1$ during its lifespan, T_{life} at (a) $(t - t_0)/T_{\text{life}} = 0.1$, (b) 0.3 and (c) 0.7.

*Dep. Mechanics and Aerospace Engineering, Southern University of Science and Technology, Shenzhen, 518055, China

†School of Engineering, University of Warwick, Coventry CV4 7AL, UK

[1] Lenaers et al., *Phys. Fluids* **24** (3), 035110 (2012).

[2] Guerrero et al., *J. Fluid Mech.* **933**, A33 (2022).

[3] Cardesa et al., *J. Fluid Mech.* **880**, R3 (2019).

[4] Smith and Metzler et al., *J. Fluid Mech.* **129**, 27-54 (1983).