UNIVERSITY OF LIVERPOOL

The Mechanism Leading to Asymmetry in Transitional Pipe Flow of Shear-Thinning Fluids

Chaofan Wen, Robert J. Poole and David J.C. Dennis
School of Engineering

Abstract

Stereoscopic particle image velocimetry (SPIV) is applied to study the flow asymmetry in transitional pipe flow of shear-thinning fluids. The novel experiment data covers the flow regimes from purely laminar, transitional to fully turbulent using the 0.15 wt% Xanthan Gum. The results reveal the time-varying nature of the asymmetrical flow and give an brief image of this complicated process. Time-resolved data shows the asymmetric flow pattern restores to symmetry in turbulent spots and the low repetition rate data indicates the asymmetry appears prior to the onset of transition, which needs further investigations.

Introduction

❖ What is a shear-thinning fluid?

Shear-thinning fluid is a type of the non-Newtonian fluids, which possesses a property that the viscosity decreases with an increasing rate of shear strain. Some shear-thinning fluids, e.g. dilute polymers in solution, have a strong drag-reducing ability in turbulent flow. Newtonian fluid refers to the fluid whose viscosity is uniform and constant at a given temperature and pressure, for example, the air and water could be both categorized into the Newtonian fluid. The flow curve of different fluids is shown in **Figure.1**.

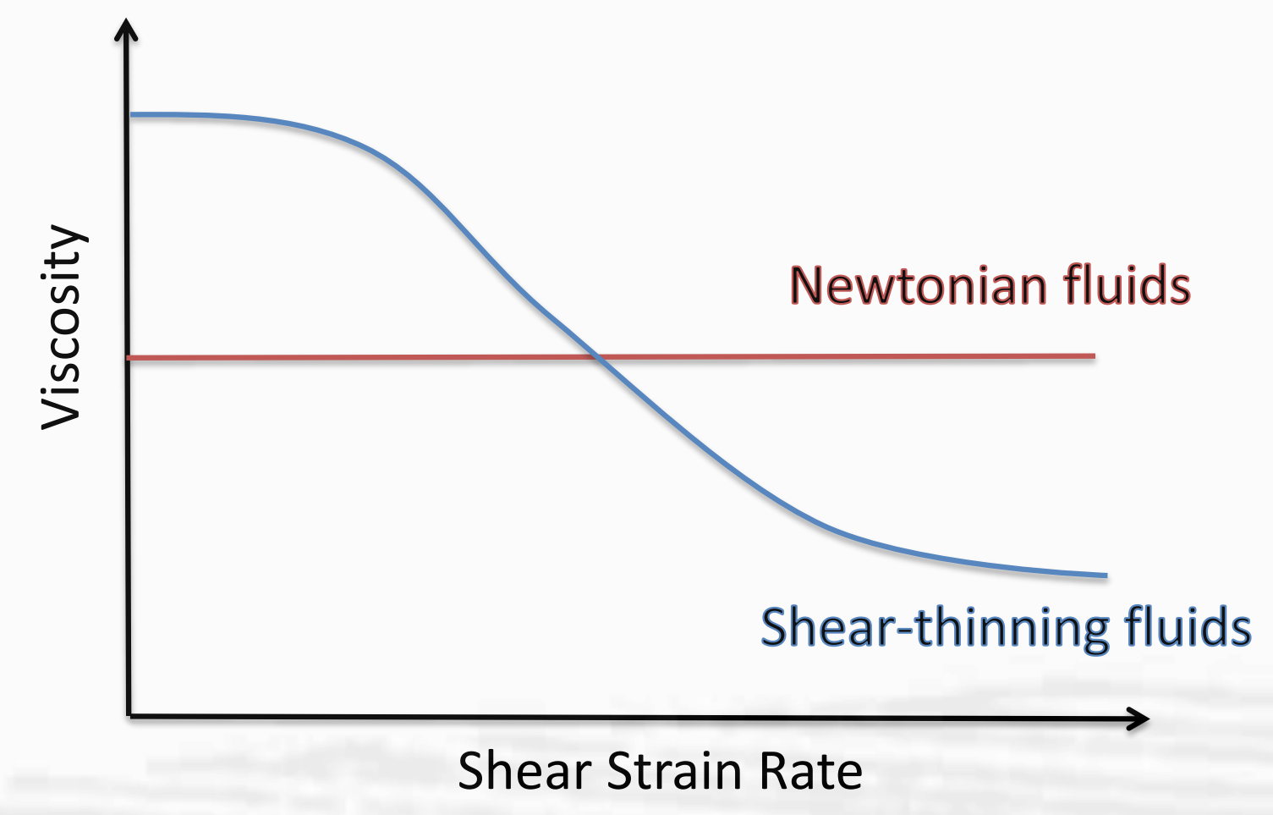

Fig. 1: Viscosity of shear-thinning and Newtonian fluid.

❖ What is laminar-turbulent transition?

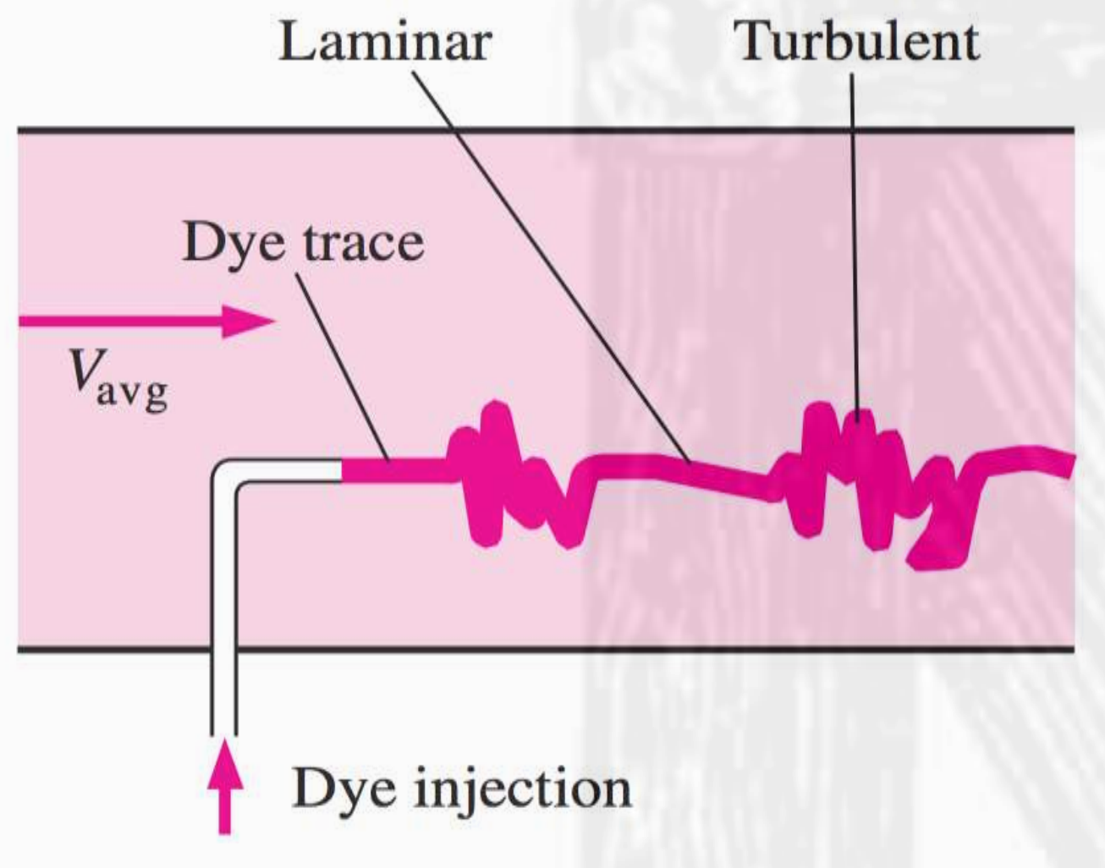

Fig. 2: Transition: flow switches between laminar and turbulent

The process of a laminar flow becoming turbulent is known as laminar-turbulent transition. If we see the dye trace in the transitional pipe flow: the flow regimes switches between the smooth laminar flow state and the chaotic turbulent state. The flow state is characterized by a dimensionless number, which is defined as Re=UD/ν, where U is bulk velocity, D is pipe inner diameter and ν is kinematic viscosity of fluid.

❖ What is Particle Image Velocimetry?

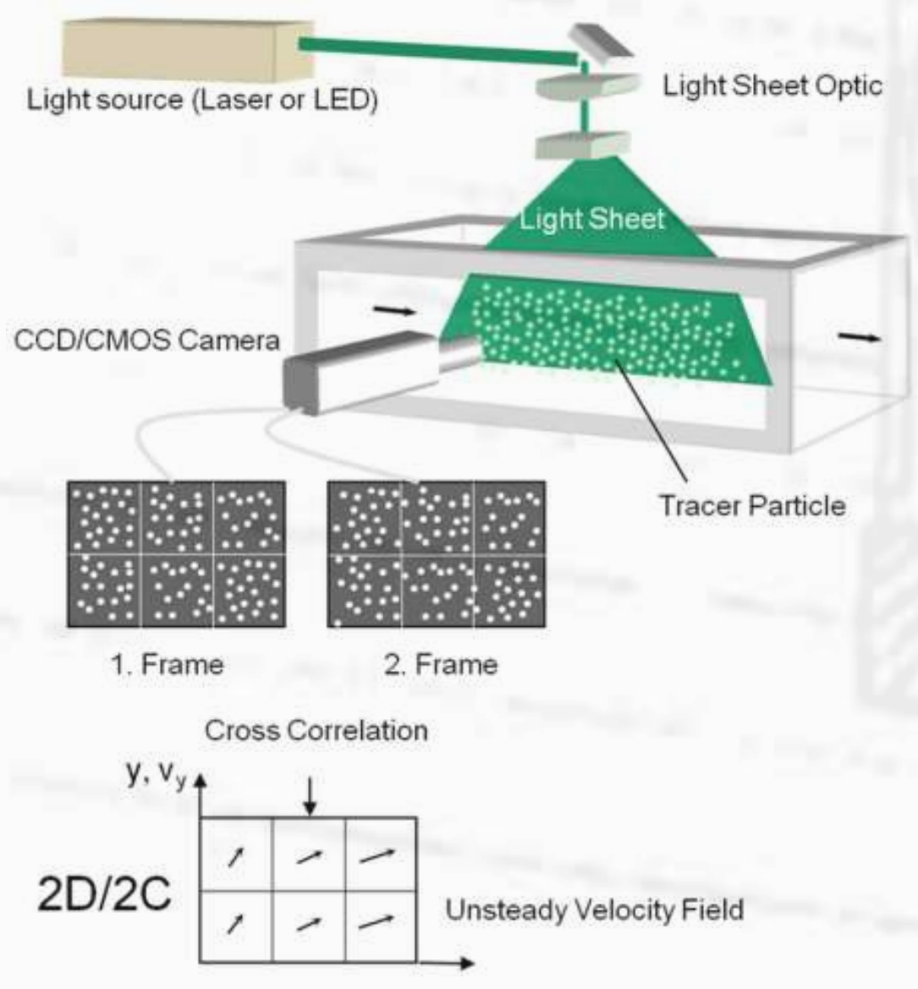

Fig. 3: schematic of a PIV setup

Particle Image Velocimetry (PIV) is an optical method to obtain instantaneous velocity in fluid. The fluid is seeded with tracer particles, assuming these particles could follow the flow dynamics and the motion of the particles is captured by cameras in the illumination of the laser beam.

Experimental Setup

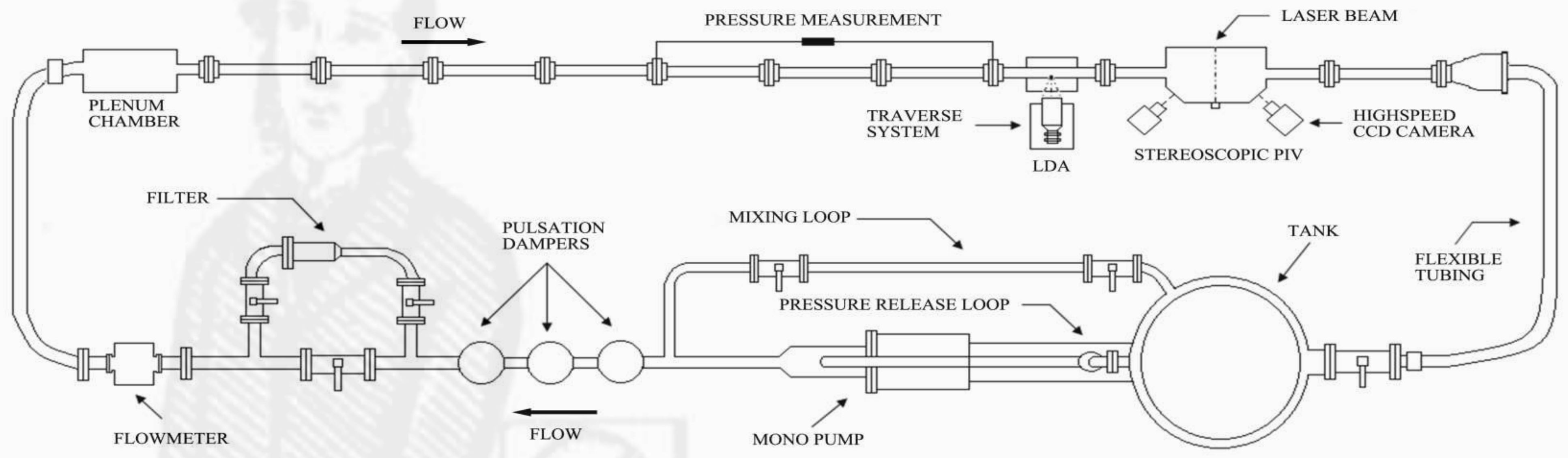

Fig. 3: Schematic of Very Large Scale Pipe Flow facility (top view). At the inlet, axis-symmetric design is implemented in the plenum chamber to remove the asymmetry in the inflow. Scheimpflug configuration is conducted in the SPIV system to obtain the time-resolved three components of the velocity vectors.

Result

1. Validation of the asymmetry

First of all, the flow asymmetry is validated in SPIV measurements as shown in **Figure 4**. This plot presents time-averaged streamwise velocity in 330 seconds. The flow patterns from the SPIV data manifest axisymmetric velocity profiles for both laminar and turbulent flows and significant asymmetry in transition, which is consistent with previous LDV measurements (see Ref [1]).

2. The time-varying nature of the asymmetrical flow

The general consensus of these previous experiments was that the location of the peak velocity remained at a fixed point in space. We present new experimental data which demonstrates that this is in fact not the case. Although the asymmetry preferentially appears in certain azimuthal positions, it is not stationary. The top plot in **Figure 5** shows the preferred azimuthal position in the cross-sectional plane. The time scale of this pattern is far more longer than other patterns (in the order of one minute) and the domination of the preferred flow pattern explains the asymmetry after the long-time average. Some other flow events, for example, the swing of the flow pattern around a preferred position is also observed. The time scale of the oscillation is around 10 seconds and the physics under this oscillation needs further investigation. We also observed the "breakdown" process of this asymmetry as presented in the bottom plot. This breakdown process is linked with the turbulent spot in the transitional regime and details are shown in **Figure 6.** Following the breakdown process, a brief visit to an alternative asymmetric location can be observed and then returns to the preferred asymmetric position (see Ref [2]).

3. Investigation of the mechanism behind the asymmetry

The onset of the asymmetry is still under investigation but interestingly by monitoring the pressure fluctuation level from laminar to turbulent, we observed the asymmetry appears *prior to* the onset of transition.

Figure 6 shows the puff structure at the transition regime. When the puff appears, which is indicated by the swirl strength |λci|, the asymmetry of the flow pattern drops to a low degree. It explains the reason why in the fully turbulent flow the asymmetry vanishes as the turbulent spots change the flow pattern and make the instantaneous axial velocity distribution symmetric.

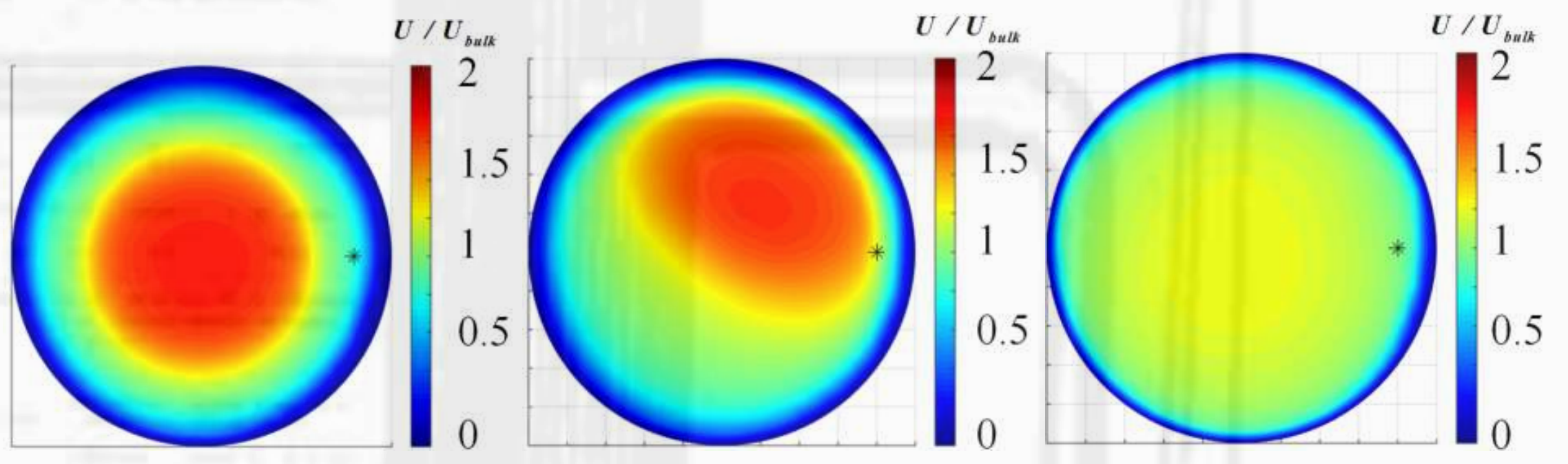

Fig. 4: Time-averaged streamwise velocity profile for laminar, transitional and turbulent flow, from left to right respectively.

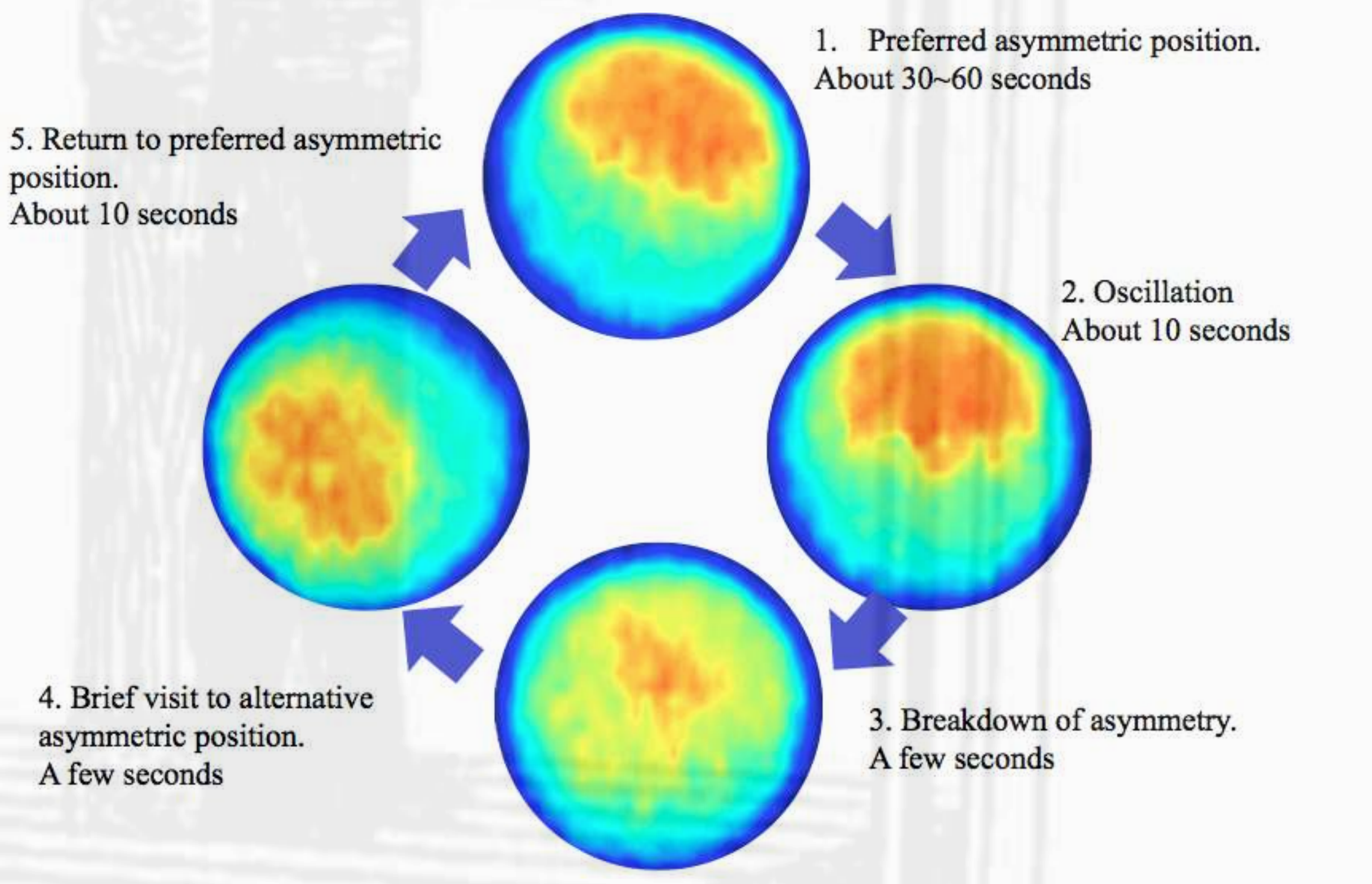

Fig. 5: Variations of asymmetric flow patterns in transitional regime. The instantaneous velocity profiles manifest the time-varying nature of the asymmetrical flow. Different flow events are observed in different time scales.

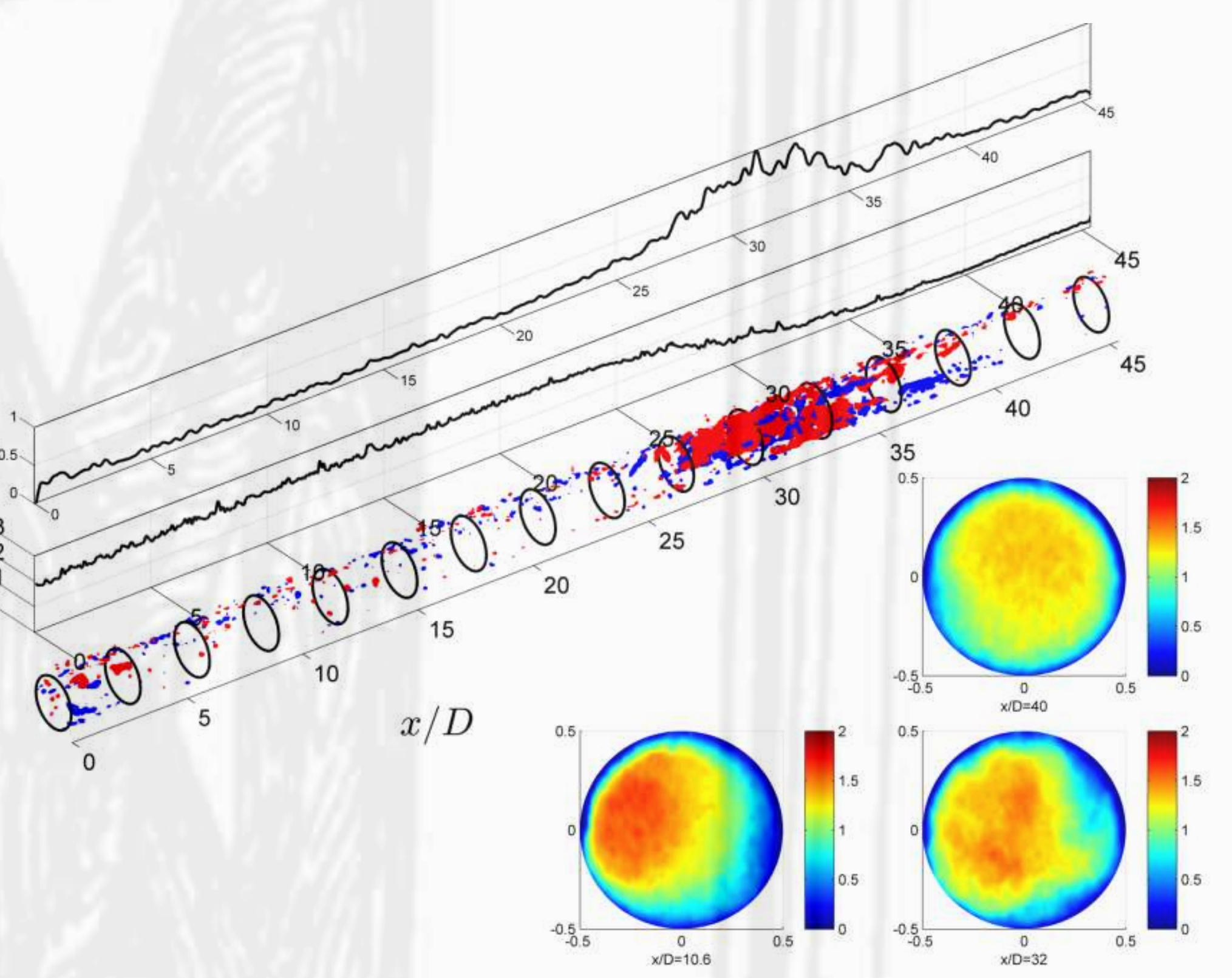

Fig. 6: Visualization of puff structure. The swirl strength is indicated by |λci| and flow pattern turns into symmetric after the puff. The instantaneous velocity profile is at x/D=10.6, 32 and 40, respectively.

Conclusion

This study first reveals the time-varying nature of the asymmetrical flow of a shear-thinning polymer solution in transitional pipe flow by SPIV investigation. The time-resolved SPIV data shows a complicated process of the asymmetrical flow: the asymmetrical flow pattern stays in a preferred position, then oscillation, breakdown and experience a brief visit to an alternative location. The breakdown of the asymmetrical flow pattern is due to the dynamics of the puffs and this explains the elimination of the asymmetry in fully turbulent flow. Interestingly by monitoring the pressure fluctuation level, we observed the asymmetry appears prior to the onset of transition and this phenomenon needs a further investigation.

Reference

1. M.P. Escudier, R.J. Poole, F. Presti, C. Dales, C. Nouar, C. Desaubry, L. Graham, and L. Pullum. Observations of asymmetrical flow behaviour in transitional pipe flow of yield-stress and other shear-thinning liquids. J. Non-Newt. Fluid Mech., 127(2):143–155, 2005
2. C.Wen, R. Poole, D. Dennis, New insights into the nature of the asymmetrical flow of shear-thinning polymer solutions in transitional pipe flow. Proceedings of the 67th Annual Meeting of the Division of Fluid Dynamics of the American Physical Society, San Francisco, California, 2014.