THE GROWTH OF TURBULENT SPOTS IN PLANE COUETTE FLOW

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Abstract Using Particle Image Velocimetry (PIV) in an experimental plane Couette flow, we investigate the growth of turbulent spots invading formerly a laminar flow. We observe the existence of large scale flows appearing as soon as laminar and turbulent domains coexist. Spectral analysis is used to study the dynamical evolution of these large-scale structures as well as that of the small-scale structure associated with turbulence. Visualisations allow a study of the evolution of the spot growth rate and also the velocity of waves which we observe at the spot edges. All these results show that two mechanisms are at work when turbulent spots grow; a growth by destabilization but also in the same proportion a growth by large-scale transport.

INTRODUCTION

Wall-bounded shear flows often transite to turbulence via subcritical scenarios involving the coexistence of the laminar and turbulent phase. Plane Couette flow (PCF), Hagen-Poiseuille flow or plane Poiseuille flow are typical examples of flows where such a transition occurs. The Reynolds number, the natural control parameter of these systems, is defined in our PCF as $Re = Uh/\nu$, where U is the wall velocity, h the half-gap between the two walls and ν the water kinematic viscosity. Two critical Reynolds numbers, Re_g and Re_t, are especially relevant in our study; above Re_g, turbulent patches can be sustained and above Re_t, a homogeneously featureless turbulence regime is observed. In the nineties, two teams in Saclay[1] and Stockholm[2] studied experimentally spot growth and both observed almost constant growth rates in the streamwise and spanwise directions during the growth. This growth rate increases as a function of the Reynolds number. At the spots edges, waves have been observed to move at a speed slower than the spreading of turbulence. Numerical simulation have been also run and a seemingly key element has pointed out : the large-scale flow that develops around the turbulent growing spot with a kind of quadrupolar structure. This has been first observed in PCF around a turbulent spot by Lundbladh and Johansson[3] and after by Duguet and Schlatter[4].These large-scale structures appear also in model flows[5, 6] and along the regular laminar/turbulent pattern[4]. So far, they have never been observed experimentally in PCF and only very recently in plane Poiseuille[7] in spite of the important role they may play regarding spot growth and pattern sustainment. Regarding the growth mechanism, Duguet and Schlatter[4] suggested a mechanism combining stochastic nucleation of new streaks at the spot edges and their advection by large scale flows to explain the spot growth and its tendency to form oblique patterns simultaneously. The stochastic nucleation of new streaks at the edge of the spot can be explained by a local destabilisation of the velocity profile at the laminar-turbulent interface[8] or by a non-normal growth[9]. We aim to quantify large-scale flow along the growth process but also spot growth rate and waves velocity to understand the mechanisms involved during the growth of a turbulent spot.

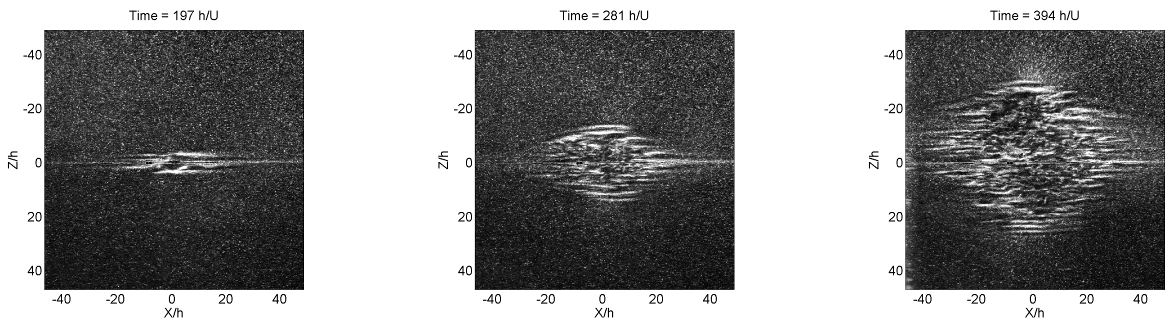

Figure 1. Visualisation of a growing spot for a step experiment (sudden increase of Re from 0 to 403) with a bead at 3 times: 197 h/U,281h/U and 394 h/U

METHODS

A set-up was implemented to approach the ideal PCF developing between two infinite parallel plates. An endless plastic belt links two cylinders of which one is connected to a servo-motor driving the system. In our experiment, we measured the thresholds $Re_g \simeq 305-325$ and $Re_t \simeq 410$. A permanent perturbation that consists of a bead hired by a thin horizontal wire is used to achieve localized and reproducible perturbation. When turbulence develops in a formerly laminar domain, it always occurs first around the bead. Figure 1 shows a typical spot growing around a bead. We performed direct visualisations and PIV velocity measurements.

RESULTS

Spatial spectral analysis of spanwise and streamwise velocity fields shows two peaks of energy for a snapshot corresponding to a time when a spot grows; one associated with streaks, the typical structure of shear turbulent flow and one associated with the large-scale flow. This scale separation allows us to define a cut-off wavelength to extract the large-scale and small-scale flows by low-pass and high-pass filtering. Figure 2 presents a snapshots of U_z for a time when a spot grows around the bead at $Re = 347$. The turbulent spot fills about half the PIV field of view. The arrows correspond to the velocity associated to large scale structure. We observe a large-scale recirculation not only within the laminar area but also in the turbulent one. Around the localized spot, it consists of quadrupolar recirculation. The amplitude evolution of large-scale structure and streaks have been studied depending of the value of Re. We conclude that as soon as laminar and turbulent areas coexist in the experiment, even if turbulence eventually decays, large-scale flows develop not only around the fronts but also far into the laminar and turbulent domains. Large-scale flows exist all along the growth process till turbulence has spread over the whole spanwise direction. Depending to Re, different scenarios are possible with regard to the simultaneous evolution of large-scale and streak amplitude.

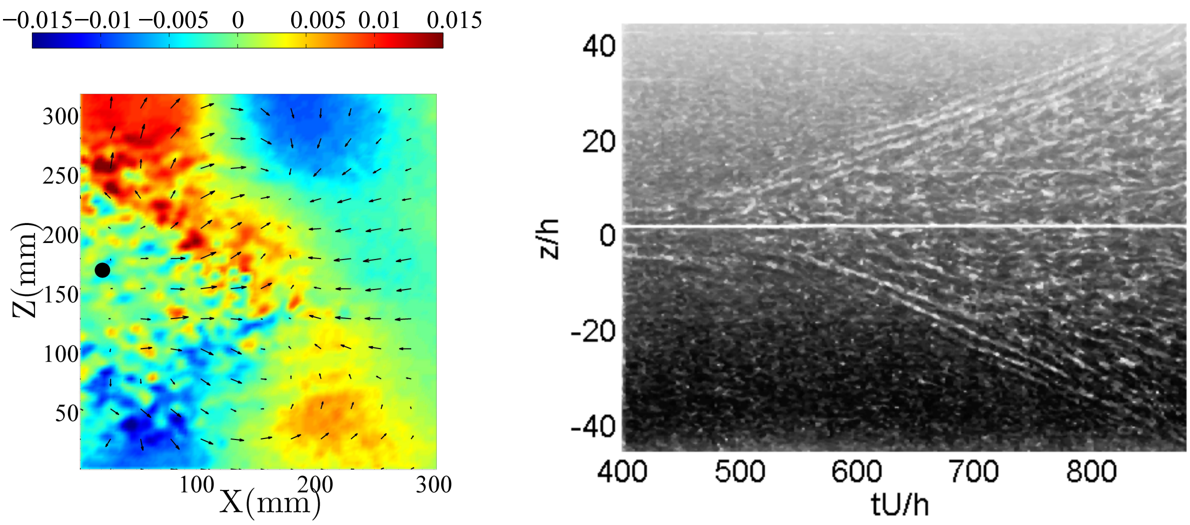

Figure 2. Left: U_z velocity field in (x, z) plane for a bead experiment. The arrows corresponds to the large scale. Measurements are done at $y/h \sim 0$, $Re = 347$. The bead is situated at the black dot. Right: space-time diagramm

An other intriguing and interesting feature is the role played by large-scale recirculations in the spreading of turbulence. We studied the growth rates of turbulent spots in bead experiments through high resolution visualisations as on figure 1. During the growth, we observe featureless turbulence inside the spot but also waves at its edges. These waves can be seen as a signature of the destabilization of the velocity profile occurring at laminar turbulent boundaries. We studied the time and Re evolution of the spot growth rate as well as the velocity of waves. Figure 2 on the right shows a typical space time diagram for a given spanwise line from which we extract waves and spot front to study these velocity as a function of time and Re.The associated results show that two mechanisms are at work when a turbulent spot grows; a growth by destabilization but also in a the same proportion a growth by the large-scale transport.

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