Experimental study of the subcritical transition in channel flow

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ABSTRACT

It is well established that confined flows, such as pipe or channel flows, present different regimes increasing the Reynolds number. Between the laminar flow at low Reynolds number and the turbulent regime at high Reynolds number, there is co-existence of laminar and turbulent regions. The linear stability theory failed to predict the transition process in Poiseuille flow. Indeed, the critical Reynolds number predicted by the linear stability theory for the plane Poiseuille flow is $Re = 5772$, where the Reynolds number is $Re = u_0 h/\nu$ with u_0 the center line velocity, h the half channel height and ν the kinematic viscosity of the fluid. This is to compare to the experimentally observed critical Reynolds numbers ranging between 1000 and 2000 [1]. The transition process in pipe and channel flows remain one of the most fundamental and practical problem still unsolved in fluid dynamics.

In the present work, we are studying this transition process in a dedicated water channel which is 3000 mm long with a 20×150 mm cross section. The x,y and z axis are respectively the streamwise, the spanwise and normal to the walls coordinates, with $z = 0$ in the middle of the channel. The design of the inlet section, together with the smooth connections between all parts of the channel, minimize the upstream perturbations leading to a laminar flow at least up to $Re = 4000$. It is then possible to study the influence of a well controlled perturbation on the transition process. The perturbation is induced by injecting water normally to the wall with a velocity u_{jet}. In this regime, each jet creates a pair of counter-rotating streamwise vortices which can also be observed in the natural transition [1]. The velocity field is studied using Particle Image Velocimetry (PIV) in the (x-z) plane in the center ($y = 0$) of the channel. Mean velocity profiles are time-averaged over 200 snapshots and spatially averaged along $\Delta X = 3h$ (5.10^4 profiles).

As proposed by Chapman [2], we assume that the minimum amplitude of the perturbation scales with the Reynolds number

$$u_{jet,c} = O(Re^{\gamma})$$

where $u_{jet,c}$ is the minimal amplitude of the perturbation that can trigger transition. In order to find the exponent γ of the scaling law, we consider that the flow is laminar if $u > 0.99$ where u is the centerline mean velocity divided by the unperturbed center line mean velocity. Indeed, as soon as the mean velocity profile changes from the unperturbed parabolic mean profile to a plug like profile, the flow becomes turbulent. We have done a parametric study of the flow and $u_{jet,c}$ clearly scales with the Reynolds number with a well-defined exponent $\gamma = -1.48$ in very good agreement with the scaling proposed by Chapman $\gamma = -3/2$ [2,3]. In addition, we study the dynamical evolution of the global parameters.

REFERENCES

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