Dependence of the critical Reynolds number on temporal acceleration in transitional channel flows

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Several studies[1 2 3] investigated the apparition of turbulence in temporally accelerated pipe flows and found a power-law dependence of the critical friction Reynolds number on the acceleration parameter. The present study focuses on similar effects in rectangular channel airflows. A rectangular channel flow is accelerated from rest to $Re_h = U_h h/\nu = 11000$ for different mean accelerations from 1.0 m.s^{-2} to 3.0 m.s^{-2}. The channel dimensions are $L = 200$ cm in the streamwise direction (x), $2l = 20$ cm in the spanwise direction (z) and $2h = 4$ cm in the vertical direction (y). Velocity measurements are made using a Particle Image Velocimetry system in the half-width plane of the channel, between $x/h = 83$ and $x/h = 87$ which corresponds to a plane of 75×40 mm^2. Figure 1 shows the evolution with time of the velocity components obtained from the PIV velocity fields for a flow accelerated from rest to a bulk velocity, defined as the velocity at the centerline, of 8.6 m.s^{-1} with an acceleration of 2.0 m.s^{-2}. The evolution of the streamwise velocity shows a laminar behavior until a critical time $t_{\text{cr}} = 3.62$ s at which fluctuations appear. The same behavior is observed on the spanwise velocity component. All the cases studied showed the same trend: first a smooth increase, then the apparition of turbulence during the acceleration period and finally the reaching of the steady turbulent flow at $Re_h = 11000$ corresponding to $U_h = 8.6$ m.s^{-1}. To determine the onset of turbulence we used the vertical velocity signal as it exhibits higher relative fluctuations than the streamwise one. We visually identified the transition time t_{cr} at which the vertical velocity showed the first fluctuation and we extracted the corresponding streamwise velocity $U_{h,\text{cr}} = U_h(t = t_{\text{cr}})$ as represented in figure 1. Figure 2 displays the critical Reynolds number based on h and $U_{h,\text{cr}}$ found for the different mean accelerations studied. In this figure we can see an increase of the critical Reynolds number with acceleration. These results are in good agreement with what was found for pipe flows even though they used the Reynolds number based on the friction velocity while we used the bulk velocity. The authors interpretation of the present behavior is that the energy needed for an instability to develop and disturb the streamlines of the flow increases with the rate at which the flow is accelerated. Small perturbations are hence damped, or contained between streamlines, at first and cannot develop into larger ones and induce turbulence. However, when the velocity becomes sufficiently high, the inertia of small perturbations is enough for them not to be damped anymore and they propagate, the whole system then becomes turbulent. These results are of interest for the study of microparticles resuspension by transient airflows and will be further studied during a PhD financed by the Pays de la Loire region and the French Agency for Innovation and Defense.

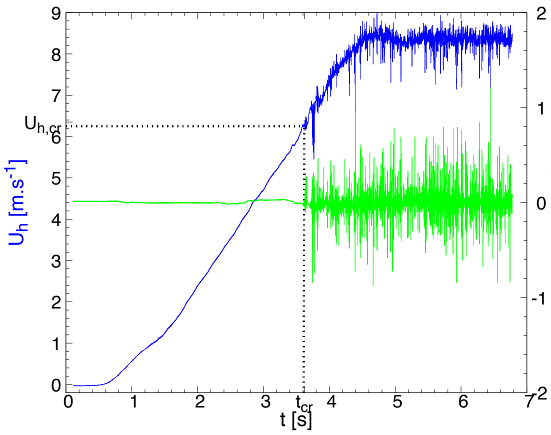

Figure 1: Time evolution of the velocity components for a flow accelerated at 2.0 m.s^{-2}

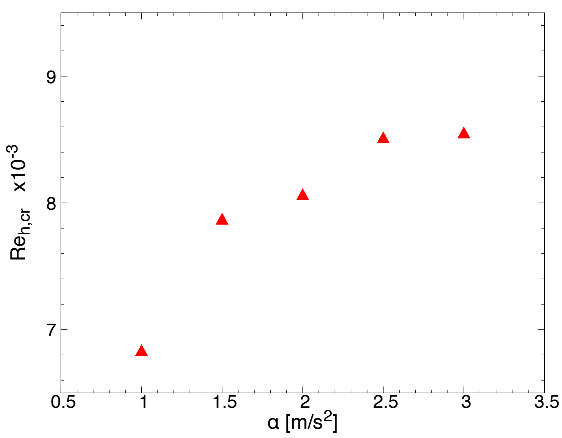

Figure 2: Critical Reynolds number dependence on mean acceleration of the flow

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