THE ROLE OF STREAMWISE STRUCTURES IN THE NEAR-FIELD ENTRAINMENT OF PLANE JET

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Free shear flows, like those of mixing layers and jets, typically have inflectional mean velocity profiles and, hence, are subject to inviscid instabilities. The initial Kelvin-Helmholtz instability develops similarly for both types of flows, as does the subsequent rollup of the shear layers into primary vortical structures that appear as a sequence of 2D vortices. Secondary instabilities also form in both types of flow, which develop into streamwise vortex structures that interact with the primary structures. It is known that certain two-dimensional, nonlinear states (coherent, spanwise vortical modes) are strongly unstable to small, three-dimensional perturbations, and that these perturbations can evolve into streamwise, counter-rotating vortices. One important manifestation of these instabilities is the counter-rotating vortices, or 'ribs', that develop in the braids between the two-dimensional vortex cores. After this stage in the development of the jet, the potential core region (approximately $x / b < 5$) ends and the centerline velocity starts to decay.

In this paper we report on an experimental investigation of the effect of the streamwise structures (streaks) on the near-field entrainment characteristics of a plane jet. It is shown that shear layer of plane jet, at certain initial conditions, is subjected to spanwise instability as '*primary*'. It means that longitudinal streamwise structures could develop from the very beginning of jet flow independent on the inviscid 2D vortices. We found the longitudinal streamwise structures are secondary unstable to high-frequency disturbances growing on them, which leads to turbulization. We have used a combination of flow visualization and hot-wire velocity measurements to investigate the primary and secondary instabilities and the evolution of streamwise vortical structures in transitional jets.

The experiments were conducted at Chalmers University of Technology. The jet facility used in the present work is shown in *fig.* 1. The air was supplied by a centrifugal blower connected by a rubber tube with a settling chamber. Secondary air motions in the settling chamber are eliminated by a splitter plate, a perforated plate and a honeycomb. The high-speed fluid was injected through a slot of height b = 10 mm, with an aspect ratio of 50:1. To create a uniform 'top-hat' mean velocity profile with a low turbulence level, the inlet device was designed with a contraction ratio of 10:1. Adjacent to the contraction one honeycomb and two fine screens were located. The efflux velocity varied between 4.4 and 12.2 ms^{-1}, which corresponds to the Reynolds numbers based on the nozzle dimension b, between 3×10^3 and 8×10^3. The broadband turbulence intensities, r.m.s. u' / U_o, at the center of the flow and in shear layer (at their maximum) were approximately 0.4 and 1.5 % near the jet exit at $U_o = 7.3$ ms^{-1}. In the visualization study the jet was seeded with smoke particles into the blower produced by a smoke generator. The visualization was made by a light sheet. For velocity measurements we used single hot-wire.

At jet exit velocity $U_o = 4.4$ ms^{-1} visualization shows both 2D Kelvin-Helmholtz vortices and streamwise streaks are competitive in the jet shear layer. At higher velocity 7.3 ms^{-1} longitudinal instability modes start to dominate. Visualizations in *fig.* 2 show that shear layer is composed mostly of streamwise structures. These coherent, longitudinal streaks were found to be the result of the unstable response of the layer to three-dimensional perturbations in the upstream conditions. Perturbation level in the shear layer has been varied by roughness elements placed on the lip of the nozzle. Spanwise scale of instabilities depends on the thickness of the shear layer. Further downstream one can see the secondary disturbances growing on the streaks at *fig.* 2, *a* that leads to breakdown. *Fig.* 2, *b* shows that two shear layers, upper and bottom, 'feel' each other, it is eliminated by staggered order of streaks in the layers. Hot-wire velocity measurements (*fig.* 3) show shear layer to be self-similar up to $x / b = 3$ where disturbances start rapid growth. *Fig.* 4 represents the 3D sketch of the streamwise structure in the plane jet that summarizes the visualization study.

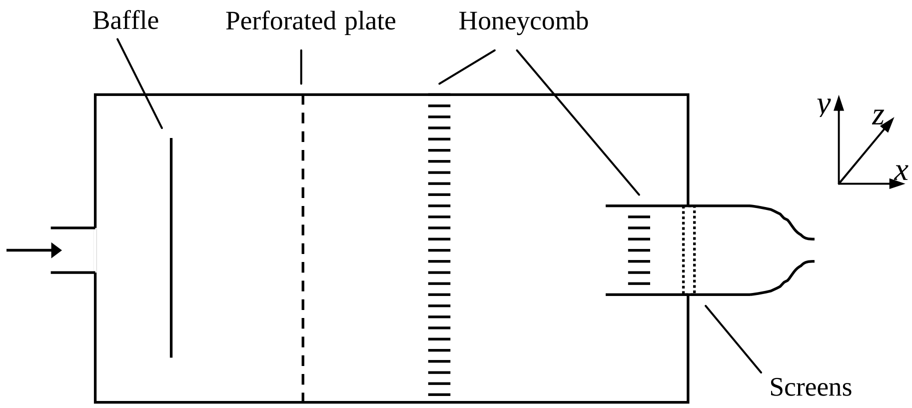

Figure 1. The plane jet facility.

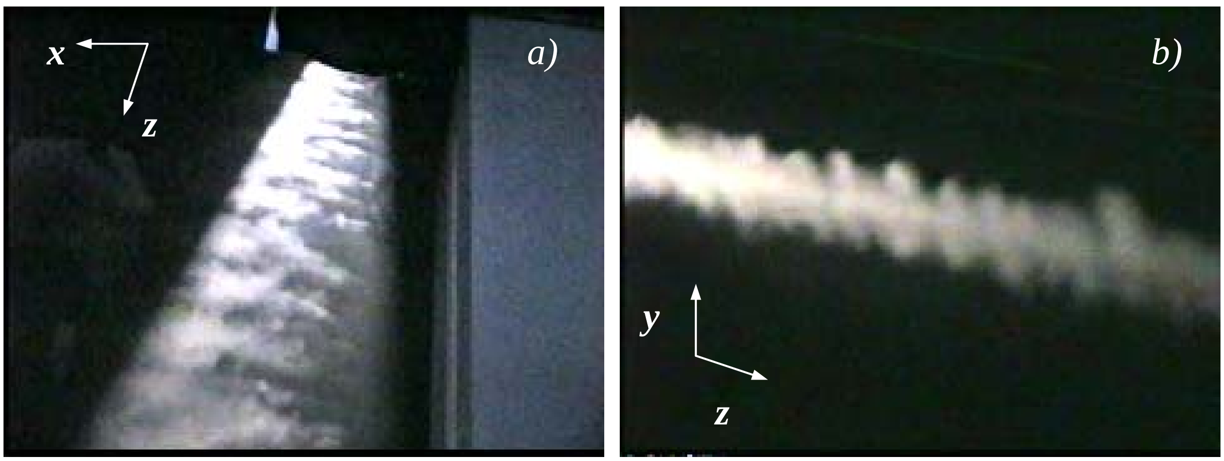

Figure 2. Streamwise structures in plane jet shear layer. U_0 = 7.3 ms^{-1}.
a) Top view in *(x, z)*-plane, the jet nozzle on the right. *b)* Front view in *(y, z)*-plane.

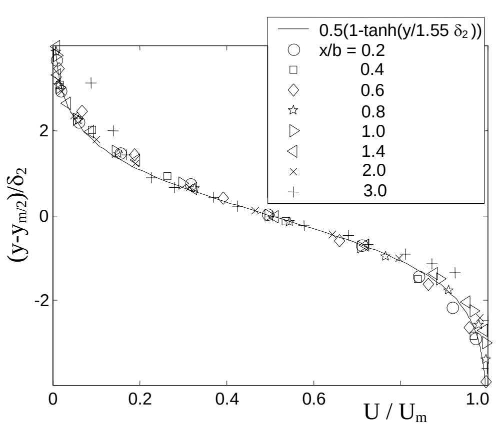

Figure 3. Shear layer of the plane jet. U_0 = 7.3 ms^{-1}.

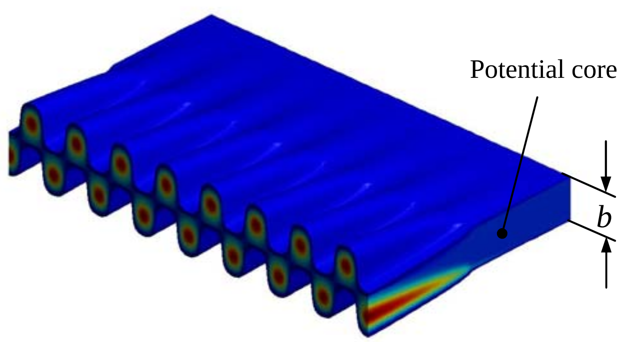

Figure 4. Sketch of the longitudinal structures in plane jet.