VOLUMETRIC INVESTIGATION OF VORTEX PAIRING IN A WALL JET IN AIR

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Abstract Vortex pairing is a key mechanism for energy transfer of small to large coherent vortices. This paper describes the three dimensional pairing process under predefined conditions on the basis of 3D Least-Squares-Matching (LSM). Therefore, the bottom edge of a nozzle outlet is aligned horizontally to a wall. The nozzles' system pressure (and thereby the Reynolds number) as well as the camera position downstream the wake can be varied. Shear layer roll-up is observed close to the nozzle forming typical roller structures, which undergo streamwise instabilities further downstream. With increasing Reynolds number, the rollers start to interact with each other; the instabilities trigger localized vortex pairing. The triggering process is documented in the results which provide insight into the three-dimensional vortex pairing dynamics.

Introduction

Skupsch et al [1] pointed out, there is a temporal coherence between the vortex pairing frequency and fluctuations in the wall sheer stress. This was done by using a micro-pillar array and a long distance microscope that measures the deflection of the pillars. Figure 1 shows a flow visualization in center plane perpendicular to the wall. The results at a Reynolds number of 1090 show a roll-up frequency of 625 Hz as well as a significant peak in the spectrum of wall shear stress fluctuations at the same frequency see figure 2.

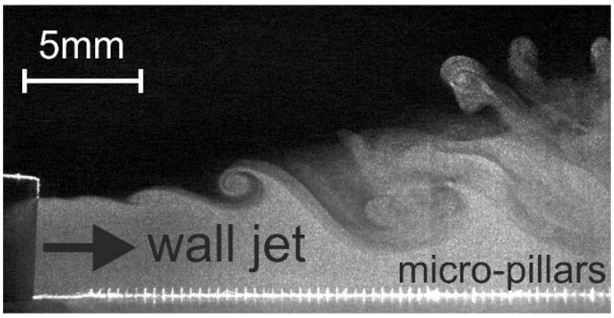

Figure 1: Fig.1: Cross-sectional image of a wall jet exiting a nozzle. Micro-pillars are attached to the wall to detect the wall shear stress. The maximum streamwise velocity is u=7m/s, the jet Reynolds number is Re=1200. The flow direction is from left to right.

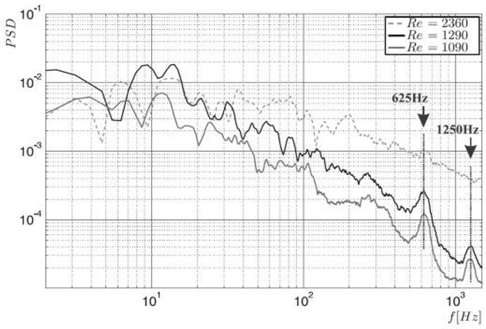

Figure 2: Spectrum of wall shear stress fluctuations in the transitional wall jet at $1 < x/d < 1.2$. The frequency of the shear layer roll-up f = 625 Hz and its doubling are highlighted [1].

Experimental setup and method

In order to get a deeper insight in the vortex roll-up and pairing process, the flow is analysed experimentally by a 3D tomographic approach. Therefore, the same high-aspect nozzle as in [1] (span width: 100 mm, height:5 mm) was used together with four double shouter cameras with 2 k by 2 k pixel²s resolution. The cameras mounted in a cross-like arrangement at an angle of 22.5° normal to the wall. The experimental set up is sketched in figure 3, it also shows the volume of interest within the red cuboid about 50 x 50 x 15 mm³ in size. For ease of handling the setup, the cameras are fixed at their positions after calibration. Nozzle, wall and the calibration target and a linear motor are mounted on a linear rail system. This helps varying the measuring position after the calibration. Pressurized air is pumped through the nozzle. Varying the pressures also varies the flow velocity as well as the Reynolds number. The flow is seeded by atomized DEHS, which is passed into the nozzle. The DEHS particles are illuminated by a 200 mJ Nd:YAG laser. After imaging the illuminated particles, the particle volume is reconstructed from the different camera views. The flow velocities of two subsequent volumes is then analysed by using a 3D Least-Squares Matching algorithm. Since this process requires a lot of computational cost, a phase locking of the vortex roll-up is applied by using a speaker. The used excitation frequencies are determined within classical 2D-PIV in the mid-section of the nozzle. By freezing the roll-up and thereby the vortex pairing it gets possible to investigate the roll-up process by images recorded with a phase shift relative to the excitation frequency. This only works at low Reynolds numbers. Otherwise the amount of instabilities induced in the flow is too large. Mean flow velocities of about 1.5 m/s are adjusted on the nozzle, this results in a Reynolds number of about 250 [2]. The typical vortex roll-up frequency is 80 Hz.

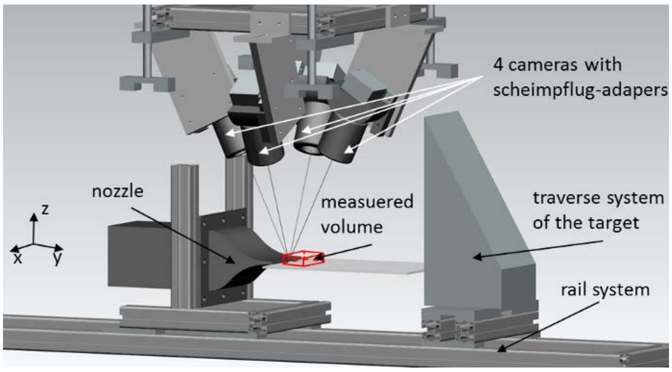

Figure 3: Experimental setup with nozzle, optical tomographic setup, and traverse system for calibration.

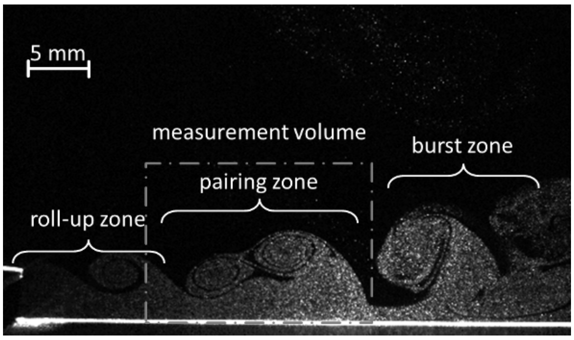

Figure 4: PIV image showing the vortex evolution from the roll-up to the pairing at a phase-locking frequency of 80 Hz.

Figure 4 depicts an image of the PIV characterisation. with three different zones: the roll-up zone, where the vortex roll-up takes place, a vortex pairing zone, as well as a burst zone. In the burst zone the roller starts to deform. The cross-section of the volumetric measurement volume is indicated by a dash-dotted line. Most of the volume covers the vortex pairing zone.

Results

3D-LSM is applied to a voxel volume 1000 x 1000 x 300 voxels in size. The cuboid size is 57 x 57 x 57 voxels with an overlap of 75 %. This results in 10^5 vectors within the measurement volume, corresponding to 1.4 vectors per mm². The top view in figure 5 shows the roller pairing. Obviously, two roller-fronts do not approach parallel. The pairing starts at touching ligaments and continues over the roller-front. In spanwise direction this can be compared to a slide fastener. In streamwise direction it seems that each subsequent roller is drawn into its predecessor, which is in accordance to figure 4.

Due to simplification, this process is described on the basis of 2D raw images. Figure 6 illustrates the complexity of the 3D flow structure. More detailed information regarding the three-dimensional roller pairing will be given in the presentation.

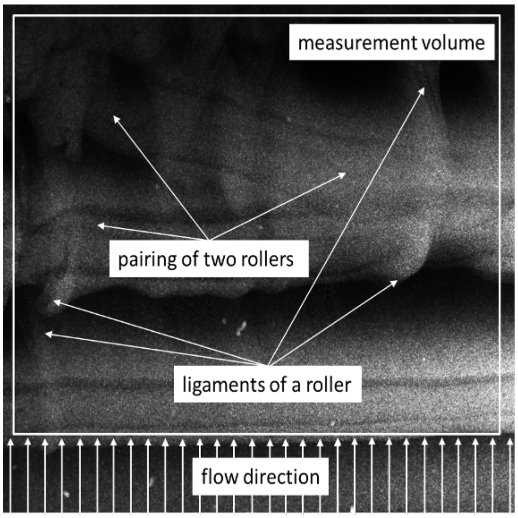

Figure 5: Top view on a flow structure showing roller pairing.

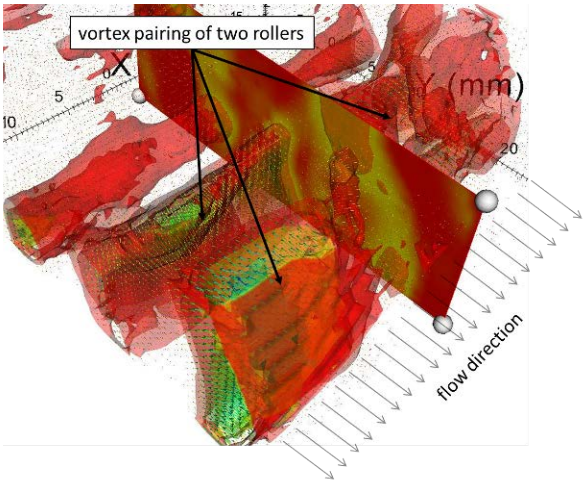

Figure 6: Rotated 3D LSM result of the same time step as in figure 5. The image contains vorticity iso-contours and vectors representing the local flow velocity.

References

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[2] J. G. Eriksson, R. I. Karlsson, J. Persson. *An experimental study of a two-dimensional plane turbulent wall jet*. Exp. Fluids **25**: 50-60, 1998