

Characterization of vortex flow transition using PIV in the Couette-Taylor system

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The Couette-taylor system is composed of two coaxial differentially rotating cylinders; it represents a good prototype for investigation of centrifugal instabilities and the transition to turbulence in closed flows. Visualization by means of small anisotropic reflective particles, e.g. Kalliroscope, have been widely used in experimental studies. It was shown that the Couette-Taylor system possesses a rich variety of pattern depending on geometrical and physical parameters. Since two decades, the visualization techniques have been complemented with velocimetry, e.g. Particle Image Velocimetry (PIV). Unfortunately, no clear answer has been provided so far to the following question: which flow information is given by the Kalliroscope particles?

The experimental system consists of two vertical coaxial cylinders immersed in a large square Plexiglas box filled with water maintained at a controlled temperature. The radius ratio is $\eta=0.8$ and the aspect ratio is $\Gamma=45.9$. The inner cylinder (IC) is rotated at angular speed Ω while the outer cylinder (OC) is fixed. We use distilled water, ($\nu=0.98 \cdot 10^{-2} \text{ cm}^2/\text{s}$ at $T = 21.1 \text{ }^\circ\text{C}$) and define $Re=\Omega ad/\nu$ where $d=1\text{cm}$ is the gap between the cylinders and $a=4 \text{ cm}$ the IC radius. For the visualization, we have added 2% volume of Kalliroscope AQ1000, which is a suspension of 1% to 2% of reflective flakes. The water properties are not modified significantly. A fluorescent tube arranged parallel to the cylinder axis was used for homogeneous illumination, and the light reflected by Kalliroscope platelets is recorded along the cylinders axis. This intensity distribution $I(z)$ is recorded at regular intervals in order to produce space-time diagrams $I(z,t)$. Using a laser sheet, cross sections in the r - z plane are visualized to obtain $I(r,t)$ data. For PIV, the flow was seeded with spherical glass particles of diameter 8-11 μm in concentration of about 10^{-4} %. The PIV system include two Nd:YAG laser sources and a Kodak CCD camera. The time delay between the two laser pulses varies from 0.5 to 25 ms, depending on Re . The velocity fields were computed using intercorrelation.

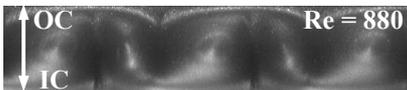


Fig. 1 : Cross-section (Kalliroscope) of Wavy Vortex Flow.

The spatiotemporal properties of the flow have been determined for various Re from $I(z,t)$ and $I(r,t)$. From the PIV velocity measurements, we have deduced different quantities characterizing the flow fluctuations, e.g. kinetic energy, $\partial v_r/\partial z$, etc. The instantaneous velocity components can be superposed chronologically at regular time intervals in order to obtain space-time diagrams (e.g. Fig. 2, red color is positive velocity, blue is negative). Space-time diagram of the radial velocity component $v_r(z,t)$ and $v_r(r,t)$ from PIV measurements are very similar with those obtained from visualization by Kalliroscope flakes.

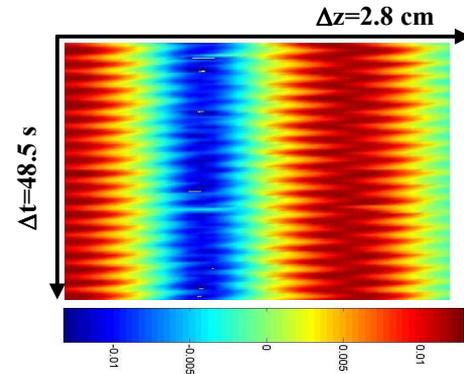


Fig. 2: Space-time diagrams of $v_r(z,t)$ from PIV for $Re = 880$ (WVF), taken at $r-a = 0.5d$ (color scale: $\text{m}\cdot\text{s}^{-1}$).

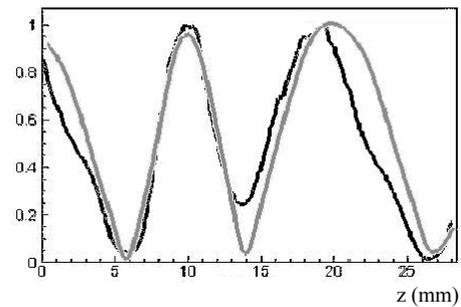


Fig. 3: Axial profile taken at $r-a = 0.5d$, $Re = 880$ (WVF). **black:** I/I_{max} (Kalliroscope), **grey:** $abs(v_r/v_{r,max})$ from PIV.

We have compared the time-average profile of the light intensity reflected by Kalliroscope particles with PIV velocity profile for the Taylor Vortex Flow and (Fig. 3) WVF. These plots highlights the fact that Kalliroscope particles give a signature of the radial velocity component measured in the centre of the gap ($r-a = 0.5 d$). Comparison done with space-times envelopes leads to the same conclusion.

The visualization technique by means of reflective particles has been a big issue in Fluid Mechanics for a long time and has been addressed regularly in literature. Recent numerical simulations (Gauthier et al., 1998) have shown that the Kalliroscope or Iridin particles may be related to the v_r , but no measurement were provided to sustain these arguments. The comparison of the space-time diagrams obtained from flow visualization and PIV measurements performed for different flow regimes has allowed us to confirm that in the case of the fixed outer cylinder the reflective particles in the flow give information on the radial velocity component v_r . Therefore, the commonly admitted conjecture that the reflective particles give information on the shear rate is in contradiction with the results of the Figure 3. A further investigation is underway for the case of the spiral vortex flow in the counter-rotating cylinders.