Phase averaged turbulence properties in the near wake of a circular cylinder at high Reynolds number using POD

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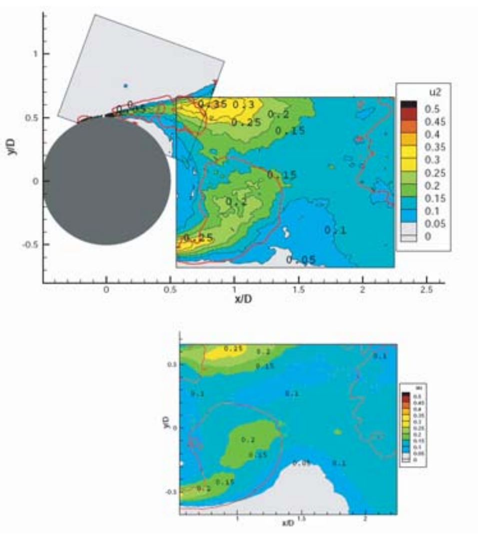
In this study, the flow past a circular cylinder is analysed by means of PIV, Stereoscopic PIV and Time Resolved PIV techniques. The cylinder is placed in a confined environment, with a low aspect ratio (4.8) and a high blockage coefficient (20.8%), to facilitate comparisons with numerical simulations made on a confined domain corresponding exactly to the experimental geometry. The Reynolds number based on the inflow velocity and the cylinder diameter is 140,000. Previous measurements have shown that the flow is at the beginning of the critical regime (The 'drag crisis' occurs at a lower Reynolds number than in other experiments because of the confined environment and the free-stream turbulence intensity of 1.5%). The measurements have been focussed in the near wake of the cylinder.

In the first step, phase averaging of the acquisitions has been performed using the pressure signal on the cylinder at =70° as a trigger signal. Both conditional sampling and Linear Stochastic Estimation have been applied with comparable results. A cartography of the phase averaged velocities and the turbulent stresses in the near wake is thereby obtained. Furthermore, the contributions of the quasi-periodic fluctuations and the random motion to the time independent stress tensor have been evaluated. In accordance with other studies, both contributions have similar topology and levels, despite the very differing nature of the motion. As observed by many authors, the so-called 'random motion' obtained by the phase averaged decomposition is due not only to the actual turbulent motion, but also to the modulation of the vortices from one cycle to the next. This paper evaluates a possible alleviation of this effect, using the POD coefficients to determine the phase of the shedding, instead of the pressure signal.

Time Resolved PIV measurements are used to analyse the coherent and random parts of the motion. First, streak lines have been calculated, allowing the visualisation of the vortex shedding and the regions of high turbulence intensity. Then, the spectra of fluctuating velocities are evaluated. A good agreement is found with LDV results of a companion study for the same flow conditions. As expected, the spectra exhibit a peak at the Strouhal frequency which corresponds to the vortex shedding, and a continuous part corresponding to the random motion. From these spectra, the contribution of both coherent and chaotic motion to the time independent normal stresses are evaluated. The spectra of both quasi-periodic and random components issued from the phase averaging are then evaluated. It is shown that a residual peak remains in the spectrum of the incoherent fluctuation (continuous part of the spectrum) which is due to cycle-to-cycle variation of the shedding. The level of this peak is about 10% of the level of the Strouhal peak. This quantifies the level of which the contribution of the random motion derived using the phase averaging is overestimated.

Proper Orthogonal Decomposition has been applied to the low frequency measurements (on the largest domain), to extract the vortex pattern and to compare it with that obtained by phase averaging. As expected, the reconstruction of the instantaneous fields with N first modes exhibits clearly the vortex shedding. In accordance with related studies, the two first modes are linked with the convection of the vortices. The coefficients obtained by the projection of the instantaneous fields on these two first modes allows the determination of a phase angle representative of the vortex shedding. This phase angle derived from each instantaneous field is then used, instead of that of the pressure signal, for phase averaging. The phase averaged vortices obtained with this method are found to be less smeared, the topology of the turbulent stresses better follows the evolution of the coherent motion and furthermore the contribution of both the quasi periodic and random motions agree better with those evaluated from the spectra. These enhancements are a consequence of the determination of the phase angle directly from the velocity fields to be averaged.

As mentioned, this experimental set-up was partially conceived to provide an ideal test for various computational methods. Indeed, the test case is being used in the EU FLOMANIA and DESIDER projects for this purpose. A comparison with Detached-Eddy Simulation (DES) results is also presented, which illustrates the levels of comparability obtainable.



$\langle u^2 \rangle$ at =45°.

(upper: phase averaging with pressure signal lower: phase averaging with POD coefficients)