Recent PIV Studies in Fully Developed Pipe Flow at High Reynolds Numbers

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Abstract Investigating the coherent structures incl. large-scale and very large-scale motions is still progressing and the definition for the sizes of these structures at high Reynolds numbers in fully developed pipe flow is not clear. Recent studies with intrusive measurement techniques show that the streamwise extension of these structures is highly dependent on the Re-number. They are usually represented in wave length (λ) or wave number (*k*). It can be observed that the sizes of these coherent structures can reach even couple of meters along the pipe axis. This phenomenon is going to be investigated with Particle Image Velocimetry (PIV) as a non-intrusive measurement technique to validate and compare the results of Hot-Wire Anemometry (HWA).

Experimental setup

The so called CoLa-Pipe (Cottbus Large Pipe) [1] shown in Figure 1 is a high Reynolds number test facility ($60x10^3 < Re_b < 10^6$) for various purposes ranging from basic to applied researches. It is a closed-return facility with the suction side made of high precision smooth acrylic glass, having an inner pipe diameter of 190±0.23 mm and total length of 148 pipe diameter, i.e. L/D≈148, where L is pipe test section length and D is pipe inner diameter. The facility has a return pipe section also made of smooth acrylic glass with an inner diameter of 342±0.32 mm, and having L/D≈78. The facility is equipped with water cooler to keep the air temperature constant inside the facility test sections, i.e. the suction and the return lines.

The large-scale and very-large-scale structures are quite important with respect to the turbulent kinetic energy and Reynolds stresses. According to [2], [3], [4] and [5] some open questions remain unsettled for identifying accurate sizes of the large-scale motions (LSM) and very large-scale motions (VLSM). The theory of [2] claims sizes of LSM (λ_{LSM}=2R-3R) and VLSM (λ_{VLSM}=8R-16R), but that does not estimate precisely magnitudes of the larger streamwise structures in turbulent pipe flow. The reason is that the experimental studies of [2] had been carried out for lower Re-numbers. The CoLa-Pipe is providing an opportunity to approach higher Re-numbers with better resolution.

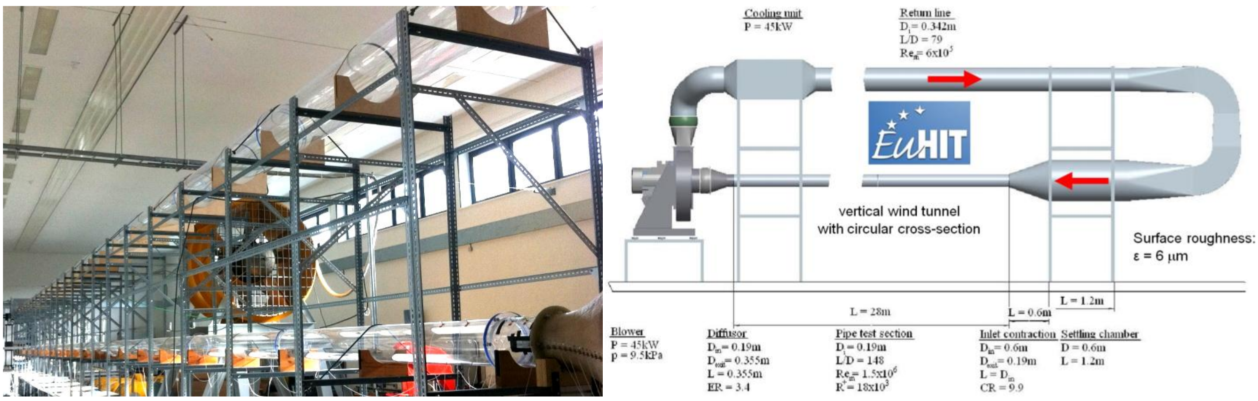

Figure 1. Experimental pipe facility: CoLa-Pipe (Cottbus Large Pipe)

PIV application

As being a high Reynolds number pipe facility, for CoLa-Pipe slightly different PIV setups are necessary in comparison the other pipe facilities. Considering the phenomena "the higher the Re-number the larger the turbulent structures" large laser planes are expected in axial streamwise direction. This step is mandatory for capturing turbulent properties at high velocity ranges. Calibration of the PIV and as well as optimization of the measurement parameters such as spatial resolution, time separation between images, and number of samples should also be done. The relation between these control parameters and the measurement accuracy was already a subject of recent extensive research, see e.g., [6], [7] and [8]

Obtaining turbulent structures at high Reynolds numbers optically with PIV requires long laser plane setups in axial direction. First of all a 2D laser plane will be applied in streamwise direction and axial extensions of turbulent structures can be identified. [9] is using Taylor's hypothesis and proper orthogonal decomposition (POD) to obtain instantaneous fluctuations and turbulent structures.

To extend the investigation to a 3D domain additionally a cross sectional laser plane will be added and with this combination a 3D space can be constructed by using same algorithms as in [9]. This step is necessary to consider the effect of pipe cross section, because the cross sectional laser plane is required to decompose azimuthal structures with streamwise ones. [10]

As shown in Figure 2, a possible PIV setup for streamwise measurements to detect long coherent structures along the pipe axis a stretched laser sheet should be provided by using side mirros. Parallel connected several high resolution cameras will also be used to cover the long streamwise extended laser plane.

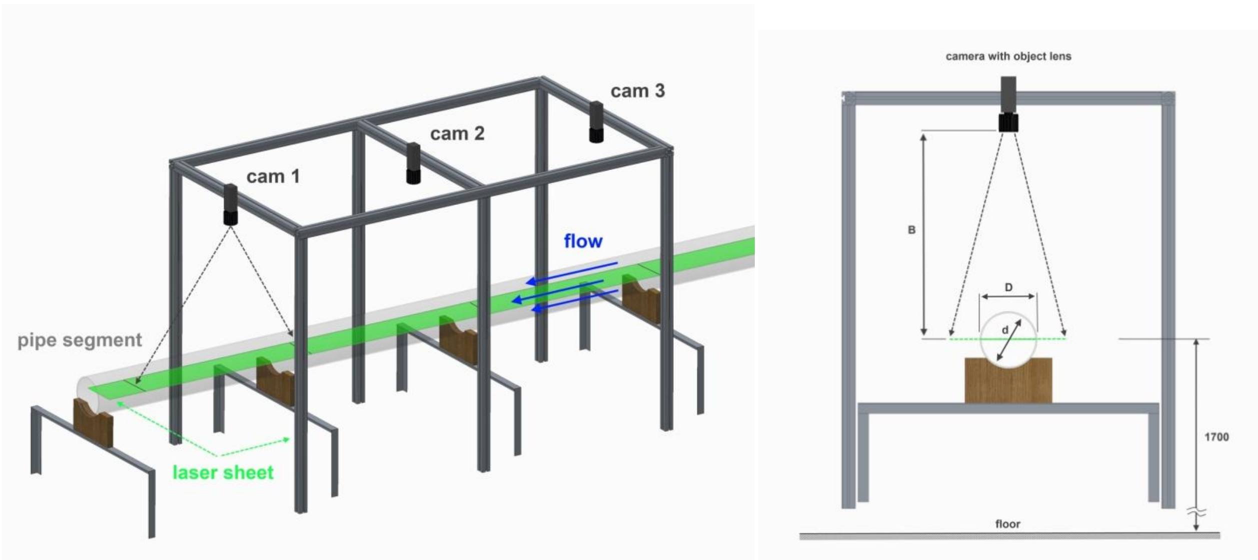

Figure 2. PIV setup for horizontal & streamwise laser light sheet plane

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