Tomographic Particle-Image Velocimetry Measurement in a Turbulent Wavy Channel Flow

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Turbulence has been investigated for decades. Most approaches to find a closure model for fluctuating quantities and their higher moments use some kind of local statistic assumption. While there are many different models that have proved reasonably successful in many applications, limits of each modelling approach exist leaving room for improvement.

One attempt to address this and better represent geometric structures was proposed by Wang and Peters [3]. The method is based on a fluctuating scalar such as absolute velocity, turbulent energy, or individual velocity components and decomposes the scalar field into individual monotonic structures which are called “dissipation elements”. Each element consists of all possible gradient trajectories connecting a particular pair of local maximum and minimum points. Since the local gradient is unambiguously defined for each point, the resulting gradient trajectories cannot overlap. Consequently, the dissipation elements method can be viewed as a way to partition an instantaneous flow field yielding a room filling ensemble of monotonic structures.

To expand this approach beyond generic shear cases and standard channel flows that have been investigated in previous experiments towards more complex flows, tomographic particle-image velocimetry measurements in a channel flow with modified geometry were conducted. To impose a streamwise pressure gradient, a sinusoidal surface profile was introduced as one channel wall. The absolute velocity is chosen as the underlying scalar of the dissipation element method to provide data comparable to streamline segment analyses. This analysis focuses on statistical quantities such as element length, scalar difference along such elements, and their directionality in flows driven by a local pressure gradients. It is attempted to predict local statistical properties based on larger scale mean flow properties such as local mean acceleration.

All experiments were performed in the Eiffel-type wind tunnel at the Institute of Aerodynamics at RWTH Aachen University. Its cross section measures 100 mm x 2000 mm (height x width). Transition is forced by two strips of sandpaper on the channel walls directly downstream of the wind tunnel nozzle. After passing a 9 m long inlet section, the flow reaches the test section. Upon entering the test section, a steady and fully turbulent velocity profile matching direct numerical simulation (DNS) results by Niederschulte [2] has developed. The test section itself measures 2.5 m in length. One wall possesses a sinusoidal wall contour. Its wavelength measures 100 mm with an amplitude of 2.5 mm. While the contour crests reach 5 mm into the channel, the trough maintains the original flat wall position. The sinusoidal wall contour covers 1.5 m of the test section with 15 individual crests. The wave between the 13th and 14th crest is equipped with pressure taps leading to a micro-manometer to record steady pressure differences with respect to the ambient pressure. The final part of the test section maintains the flat walls on both sides.

Based on the 2D reference data, four measurement volumes spanning 15 x 15 x 8 mm representative for the crest (C), expansion slope (ES), trough (T), and tapering slope (TS) of the wave were selected and recorded at Reynolds numbers of 16 300 and 32 600. Figure 1 shows their locations in the channel.

Fig. 1 Sketch of recorded the 2D plane and 3D volumes

The element length distributions for all volumes show an exponential decrease for lengths larger than the mean element length which is in good agreement with the log-normal length scale distribution proposed by Aldudak and Oberlack [1]. In volumes of high accelerations, elements tend to be shorter on average. There was no noticeable difference in element length distributions between the two Reynolds numbers as predicted by Wang and Peters.

All conditional means of scalar differences along the elements exhibit a linear behavior within the resolved scales. The resulting slopes are nearly constant across all volumes for a given Reynolds number. The conditional means for the higher Reynolds number exhibit slopes about twice as steep when compared to the lower indicating an approximately Reynolds-number-proportional behavior in the given flow regime. The linear approximations also show an offset which was found to be proportional to the absolute local mean acceleration.

References