Application of PIV to estimation of turbulent energy balance in jet flows

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The need to develop of new mathematical models for complex turbulent flows assumes the comprehensive experimental information to be retrieved. This allows, from one side, to provide the basic correlations for models closure research, and from the other side, to exploit the large data arrays for models verification. For adequate description of complex flows, such as impinging jets, the advanced models are usually applied and they require deep information about the flow structure (triple statistical moments, differential characteristics, such as turbulent energy dissipation rate etc.).

Particle Image Velocimetry is one of the most modern non-intrusive methods for flow diagnostics. The possibility of instant measurements of spatial velocity distributions allows to obtain a wide spectrum of characteristics – spatial velocity derivatives, correlations etc. Besides, experimental PIV data can be directly utilized for comparison with results of LES modelling. However for correct calculation of above mentioned quantities it is necessary to elaborate a number of post-processing procedures, such as the proper data validation methods, the approaches for interpolation of velocity fields which is caused by removal of spurious vectors. Also appropriate differencing schemes assuming physically justified balance between low-pass and high-pass filtering have to be developed.

Present work is devoted to the experimental study of hydrodynamic structure of axisymmetric free and impinging jet flows using PIV. Main emphasis has been done on the correct calculation of spatial velocity derivatives and estimation of turbulent kinetic energy balance. Experimental setup represented closed hydrodynamical contour equipped with the system of pumps, flowmeters and temperature stabilizing device. Working section of 200×200×400 mm^3 dimensions was made transparent in order to provide PIV measurements. Convergent nozzles with diameter $D = 10$ mm for free jet and 15 mm for impinging jet could be inserted into working section through the bottom. In the latter case the impingement surface was located at the distance of $H/D = 3$ from the nozzle exit. In free jet experiments the measurements were performed in the area up to 20 nozzle diameters. Both unforced jets and jet flows under the conditions of external low-amplitude periodical forcing with the frequencies from the range of most sensitivity of a jet shear layer has been tested. Reynolds number defined on the basis of nozzle diameter and mean flow rate velocity at the nozzle exit was varied in the range 7,600 ÷36,000. 3D PIV system “POLIS” consisting of double pulse NdYAG laser, couple of CCD cameras, synchronization device and package of processing algorithms “ActualFlow” were used for measurements. For flow field processing the different adaptive correlation approaches were employed. In order to provide high enough spatial resolution (up to 0.13 mm/vector) the whole flow field was separated into elementary zones where measurements have been performed independently. The schemes of experiment are shown in Fig. 1.

Velocity vectors rejected at different stages of PIV data validation have been substituted with interpolated values to provide the calculation of spatial velocity derivatives. For interpolation aims the several schemes of 2nd order with different weight coefficients have been analysed and the proper schemes for inner and boundary zones of measurement area were chosen. After a set of tests for calculation of spatial derivatives, the approach [1] has been chosen, which represents certain compromise between the order of filter, number of used points, noise amplification and frequency response. Figure 2 demonstrates the results of estimation of turbulent kinetic energy balance for self-similar region of free axisymmetric jet for both forced and unforced conditions. The term with pressure diffusion for isobaric free jet flow was neglected as well as the term with viscous diffusion which is also negligible in comparison with turbulent diffusion. The dissipation rate calculated directly from experimental data is shown to be close enough to one obtained as a residual term in energy balance equation. This confirms the correctness of above assumptions.

For confined jet flows, however, the isobaric condition is not valid, so usually both dissipation and pressure diffusion are considered as common residual term [2]. In such cases the possibility of direct calculation of kinetic energy dissipation rate is rather important. The example of direct calculation of normalized dissipation rate ε for axisymmetric impinging jet is presented in Fig.3. The dissipation profiles in the cross section parallel to impingement wall are shown in Fig. 4 for both forced and unforced impinging jets. For forced jet the maximum of ε is some smaller than for unforced one, and that partially confirms the fact described earlier by authors that during forcing a resonance amplification of large scale coherent structures occurs with simultaneous suppression of broad-band turbulence. In the region of wall jet flow, on the contrary, dissipation is more intensive under the forced conditions.

The turbulent statistics have been also obtained for free and impinging jet flows under unforced and forced conditions including approach of conditional averaging. Data obtained include a complete set of statistical moments up to 4th order in order to characterize the peculiarities of turbulent transport in studied flows as well as to evaluate the advanced closure models.

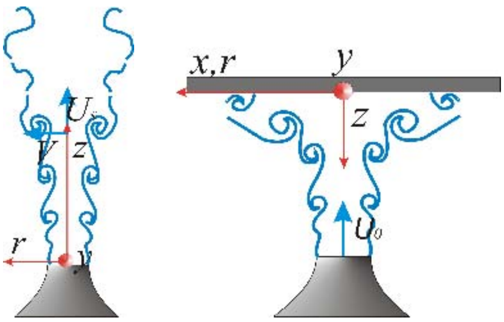

Fig. 1. Schemes of free and impinging jets

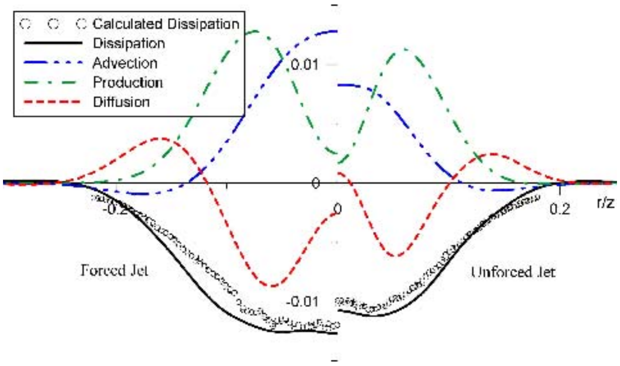

Fig. 2. Turbulent kinetic energy balance for free jet. f Re = 25,000. Z/D = 12.1 (forced jet), Z/D = 15.3 (unforced jet).

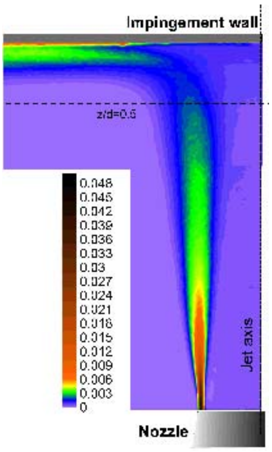

Fig. 3. Distribution of normalized dissipation rate for unforced impinging jet.
Re = 36,000, H/D = 3

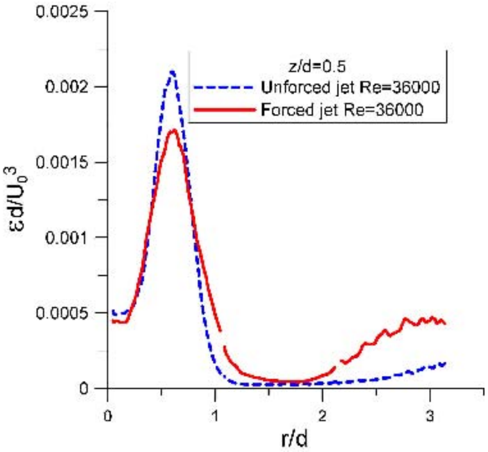

Fig. 4. Comparison of dissipation profiles for unforced and forced impinging jets.
Re = 36,000, H/D = 3, Z/D = 0.5

Acknowledgements

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