Turbulent characteristics in the cylinder near wake estimated by SIV measurements

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Abstract Turbulent characteristics have been measured in the near wake of a circular cylinder in a cross flow. Smoke Image Velocimetry (SIV) technique has been employed yielding the dynamics of velocity vector fields with high spatial and temporal resolution. Profiles of turbulent statistics have been plotted for some representative locations of the cylinder near wake. The SIV measurements have been compared with experimental and numerical results obtained by other authors.

1. Introduction

A circular cylinder in a cross flow is a canonical case of the global separation of flow and a flow configuration frequently encountered in engineering applications. Many research papers dealing with experimental and numerical studies of the cylinder wake flows can be found in literature. But the problem of numerical simulation of a cross flow past a circular cylinder still cannot be considered resolved. Near wake of the cylinder is particularly interesting as it defines the absolute instability of flow that leads to the onset of the Karman vortex street [1], as well as a secondary instability that induces the transition to turbulence in the wake [2]. Direct numerical simulation (DNS) provides a full picture of turbulent characteristics distributed over the cylinder wake. The DNS resolves all spatial and temporal scales of the flow and, in theory, excludes all empirical information. However, the applicability of DNS is limited to flows with relatively simple geometry and low Reynolds numbers. Reynolds-averaged Navier-Stokes (RANS) equations are predominantly used in practice. The RANS closure requires additional equations, of which the most popular are the second moment closure models and Reynolds stress equation models. However, the case of a cross flow past a cylinder is one of the most illustrative examples of poor performance of RANS models.

To solve the problem of RANS closure simulating flows with global separation regions and in order to provide deeper insight into the flow structure, the experimental information on regularities of spatial and temporal distribution of the terms of turbulent fluctuation energy transport equation is required.
2. Experimental setup and procedure

The experimental setup employed in the studies is shown in figure 1. The test section 3 was a rectangular 0.15×0.115 m channel with the length of 0.3 m and transparent walls allowing visual observation and video recording of flow patterns. A 150-mm long cylinder with the diameter of 15 mm was mounted at the distance of 60 mm downstream of the smooth inlet of the test section. The air flow rate was generated by a centrifugal compressor. The mean velocity was adjusted by a set of critical flow nozzles 6. A detailed description of the experimental setup can be found in [3]. The flow was seeded with tracer particles (glycerin vapor). Monochrome high-speed camera 7 Fastec HiSpec was used to record the flow pattern in a light sheet generated by a continuous laser KLM-532/5000.

![Figure 1 Schematic of experimental setup.](image)

Smoke visualization images were processed using SIV technique [4], which yielded the dynamics of velocity vector fields on the basis of frame-by-frame processing of high-speed videos. Velocity vector fields in SIV are estimated from the measured displacements of turbulent structures visualized by smoke in the light sheet over a fixed time interval between two consecutive frames. Recording frequency in this experiments was 15 kHz with spatial resolution 11×11 pix (scale factor \( k = 0.045 \text{ pix/mm} \)).

Results and discussion

The near-wake flow behind the circular cylinder was studied experimentally at the Reynolds number \( \text{Re} = 3900 \). This case was chosen as the most representative in terms of the available amount of numerical and experimental studies in literature.

We should mention here that not all the experimental data published in literature are mutually consistent that confirms further the relevance of the considered problem. Turbulence intensity upstream of the cylinder measured by a hot-wire anemometer was equal to 1%.
Measurements of the vector fields yielded the profiles of streamwise, \( u \), and transverse, \( v \), velocity components, their rms fluctuations, \(<u'u'>\) and \(<v'v'>\), and Reynolds stress, \(<u'v'>\), for a number of representative locations along the cylinder wake. The SIV results were compared with experimental and numerical data of other authors. Figure 2 demonstrates the distribution of streamwise velocity component over the distance from the cylinder center along the channel axis. The SIV measurements exhibit fairly good agreement with the results obtained by other authors for all the distances from the cylinder. Perfect congruence with DNS and experiments performed by Lourenco and Shih is observed in figure 3.

The analysis of data presented in figure 4 shows that SIV results agree well with the Reynolds stress profiles obtained from numerical simulation on a fine grid [6]. The deviation is more pronounced at \( y/D = 0.5\ldots1 \) and \( y/D = -0.5\ldots-1 \). Such difference can be attributed to significantly lower turbulence intensity in DNS as well as to higher blockage ratio implemented in SIV measurements which could affect the reattachment length. Besides, the present paper demonstrates the capability of SIV to measure the spectrum of turbulent velocity fluctuations up to the Kolmogorov scale owing to the spatial resolution of the technique. This enables studying the processes featuring the frequencies of more than 10 kHz. The frequency of Karman vortices is clearly distinguishable in the obtained spectra (figure 5).
Figure 4. Reynolds stress profiles at 1.06d and Re=3900. 1 – DNS on a fine grid[6]; 2- DNS on a coarse grid [6]; 3 - SIV

Conclusions
The profiles of turbulent statistics have been measured at some representative locations along the cylinder near-wake. A comparison of the results of present paper and information available in literature has shown that the profiles of turbulent statistics in the cylinder wake differ significantly from each other. However, comparison of SIV measurements demonstrated good agreement with DNS results obtained on a detailed grid. The obtained experimental data can be used when constructing the closure models of the Reynolds-averaged Navier-Stokes equations as well as when verifying of different simulation methods for turbulent separated flows. Besides, it has been shown that the spectrum of turbulent velocity fluctuations can be estimated using an optical measurement technique.

References
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