DMD Analysis of Coherent Structures in a Turbulent Forced Jet

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Dynamics of large-scale vortices are crucial for heat and mass transfer in turbulent flows. It's well known that formation of the vortices in shear flows can be controlled by a low-amplitude forcing. In particular, periodical forcing is an effective method to control formation of ring-like vortices in initial region of a jet. However, as it was shown in [2], vortex formation in forced jets can be rather distinctive (depending on forcing frequency and amplitude), since dynamics of the nonlinear open system is strongly affected by a feedback from downstream events of vortex roll-ups and pairings. The present work investigates the dynamics of coherent structures in a forced jet flow by using a statistical tool Dynamic Mode Decomposition (DMD). The studied regime of forcing corresponded to a stable pairing process with modulated quarter harmonic (enhanced/delayed double-pairing) [2]. DMD was recently developed by Schmid [1] from Koopman analysis of nonlinear dynamical systems. Application of DMD to an ensemble of time-resolved Particle Image Velocimetry (PIV) data provides a set of eigenvectors (dynamic modes) and the corresponding eigenvalues (spectrum), which contain valuable information about dynamic processes in the original data set. As a result, DMD identifies the dominant frequencies contained in spectrum and the associated spatial coherent structures contained in modes. Moreover, the superposition of the dominant dynamic modes allows to reconstruct a low-dimensional model of the velocity field that can be used to describe evolution and, the most importantly, interaction of large-scale coherent structures. In the present work, a PIV system with 1.1 kHz repetition rate was used for the measurements of the instantaneous velocity fields in a turbulent jet without and under periodic forcing (frequency 300 Hz, amplitude 10% of the mean velocity). Ensembles of 2 400 fields were measured for each case. The experiments were carried out in an open jet facility consisted of a contraction nozzle, plenum chamber, forcing chamber, air fan and section for the air flowrate control. The used forcing system was made similar to that described in [2]. The set of the measured velocity fields was processed by a DMD algorithm, which provided information about dominant frequencies of velocity fluctuations in different flow regions and about scales of the corresponding coherent structures. The characteristic frequencies were in a good agreement with these estimated from time-spectra in different flow locations. Superposition of relevant DMD modes approximately described nonlinear interaction of coherent structures, e.g., pairing of vortices can be seen in Fig. 1. Vortex structures are visualized by positive values of swirling strength criterion [3]. The depicted low-dimensional reconstruction from three relevant DMD modes (0 Hz, 150 Hz and 300 Hz), demonstrates the formation of large-scale structures at the distance $z/d \approx 2.5$ due to the pairing of smaller structures (marked by triangles) which were formed in the shear layer near the nozzle exit due to the periodical forcing the flow with 300 Hz.

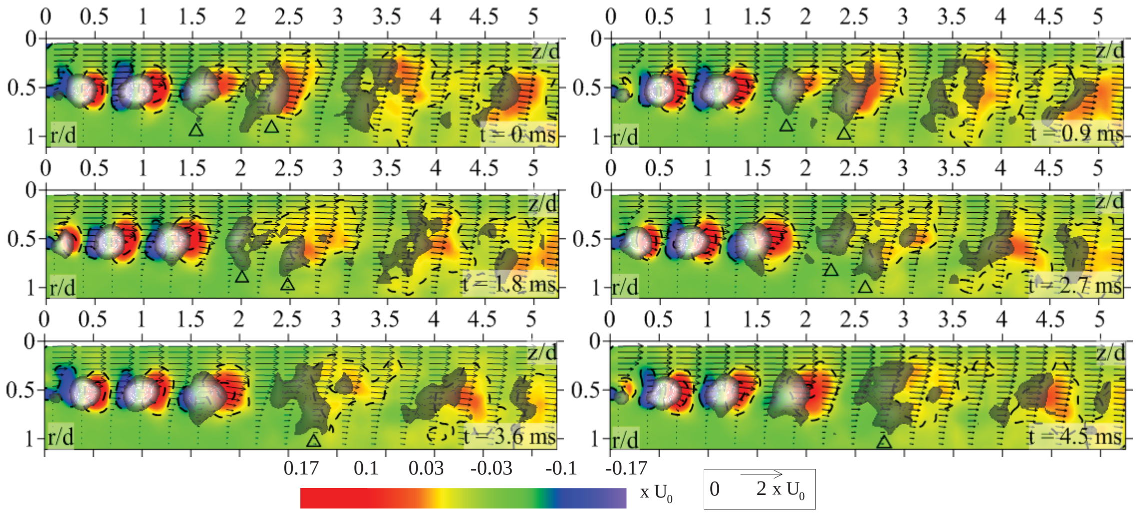

Fig. 1. Low-dimensional reconstruction of a sequence of six velocity fields (time step 0.9 ms) in a jet flow (the mean flow rate velocity U_0 = 5 m/s; Re = 4 800) under periodic forcing (Strouhal number 1, amplitude 10% of U_0). Each 5th vector in *z* direction is shown. Color map corresponds to the radial component of the velocity. Partially transparent layer shows swirling strength [3].

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References

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