APPLICATION OF DMD TO PIV VELOCITY FIELDS MEASURED IN FORCED JETS AND LIFTED FLAMES

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ABSTRACT: 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 affected by a low-amplitude forcing. In particular, periodical forcing is an effective method to control formation of ring-like vortices in initial region of jet flows. The present work investigates the dynamics of coherent structures in a forced jet and also in a lifted flame by a statistical tool Dynamic Mode Decomposition (DMD). DMD was recently developed by Schmid (J. Fluid Mech. 2010, Vol. 311, pp. 37-71) 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 fields 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 and lifted propane-air flame. The experiments were carried out in an open combustion rig consisted of a burner, air fan, plenum chamber, premixing chamber and section for the air and fuel (propane) flowrate control. The burner represented a contracting nozzle with the exit diameter d = 15 mm. The set of the measured velocity fields was processed by DMD algorithm provided information about dominant frequencies of velocity fluctuations in different flow regions and about scales of the corresponding coherent structures. The obtained frequencies showed a good agreement with these estimated from spectra for different flow locations. Superposition of relevant DMD modes approximately described nonlinear interaction of different coherent structures, e.g., pairing of vortices can be seen in Fig. 1. 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 of the flow with 300 Hz.

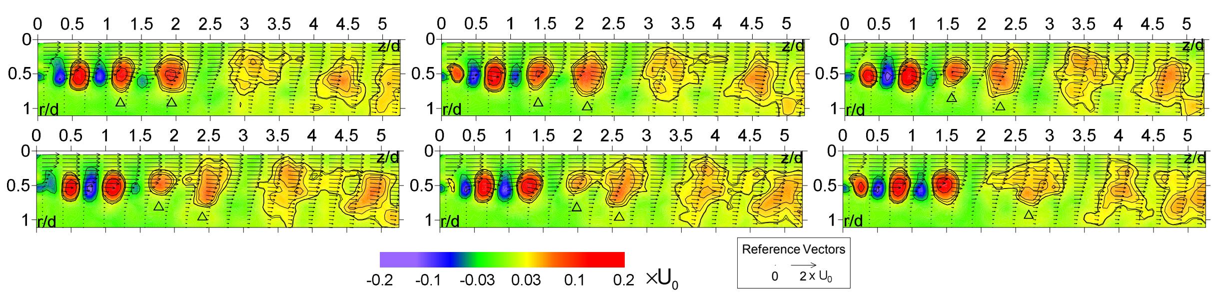

Fig. 1. Low-dimensional reconstruction of a sequence of six velocity fields (time step 1 ms) in a jet flow (the mean flow rate velocity U_0 = 5 m/s; Re = 4, 100) under periodic forcing (Strouhal number St = 1, amplitude a_f = $0.1U_0$). Each 5th vector in z direction is shown. Color map corresponds to the radial component of the velocity.