Dynamics of large-scale vortices in periodically forced strongly swirling jets and lifted flames investigated by Stereo PIV and DMD

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Keywords: PIV processing, Swirling flames, Large-scale vortices

In their previous study of the propane-air strongly swirling lifted flame Alekseenko et al. (2012, to appear in Combust. Sci. Technol.) observed that the combustion did not fundamentally affect the type of coherent structures in the flow: a pair of secondary helical vortices was induced by a precessing vortex core both in the non-reacting and reacting jet flows. Because a strongly swirling jet is usually insensitive to weak forcing, strong perturbations were imposed to force the formation of ring-like vortices and to investigate the possible outcomes on the combustion process. The forcing provided an increase in the turbulent combustion rate near the flame onset, as the entrainment of ambient air to the rich mixture must have increased. Also, for forcing amplitude typically above the magnitude of reverse flow inside the bubble-type recirculation zone, a suppression of the vortex core precession took place in the reacting case. This effect was accompanied by a quasi-periodical vanishing of the recirculation zone due to interaction of the forced ring-like vortices with the lifted flame. The present work complements to the previous study by investigating dynamics of large-scale vortices in swirling lifted propane-air and methane-air flames under high-amplitude periodical forcing. The measurements were performed in an open combustion rig. During the study, Re_{air} number (based on the nozzle exit diameter $d = 15$ mm, flowrate of the air and viscosity of the air) was fixed at 4,100. A swirler was mounted inside of a burner nozzle. Swirl rate, defined on the basis of swirler geometry, was 1.0. To produce lifted flames at these Reynolds numbers, the equivalence ratio $\Phi = 2.5$ of the propane-air and methane-air mixtures was above corresponding rich flammability limit. For the forcing, a chamber of four loud speakers, connected to an amplifier, function generator and electric power meter, was mounted 0.7 meters upstream the burner exit. The normalized (by d and the bulk velocity of the mixture U_0) forcing frequency, i.e., the Strouhal number, was selected to be 0.6, which is about two times smaller than that of the vortex core precession. A stereo PIV system with acquisition rate 770Hz was used to estimate the instantaneous velocity fields in the reacting and non-reacting flows. Dynamic Mode Decomposition (Schmid et al. 2010, J. Fluid Mech.) and Proper Orthogonal Decomposition were applied to the measured sets of velocity fields.

Figures 1 and 2 compare POD and DMD modes for the unforced and forced propane-air lifted flame. For the unforced case the first three modes correspond to the following two phenomena: the precession of the vortex core (at 275 Hz) and unsteady entrainment (at about 9 Hz) of ambient air in the outer mixing layer. For the forced case both POD and DMD modes demonstrate that the periodic flow dynamics was associated with formation of ring-like vortices. both in the outer and inner mixing layers.

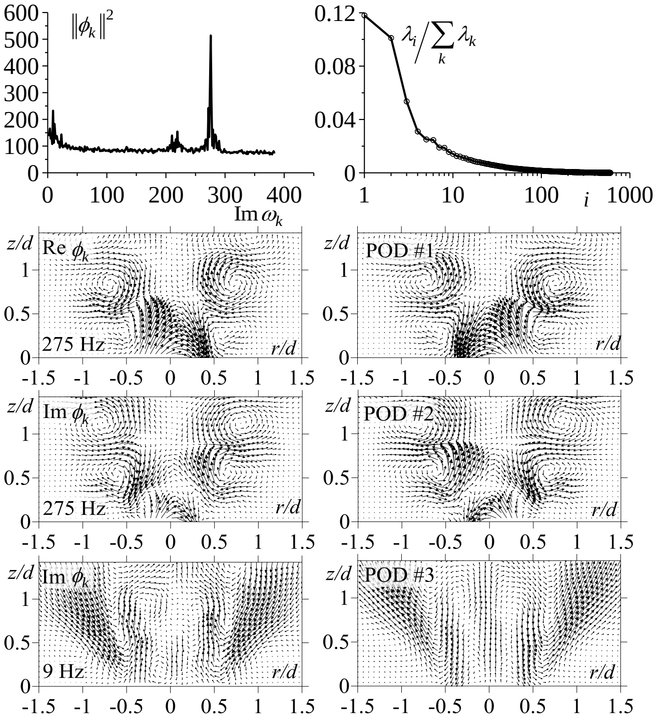

Fig. 1 Normalized spectra and spatial distributions of the most powerful modes for (left) DMD and (right) POD in an unforced propane-air lifted flame.

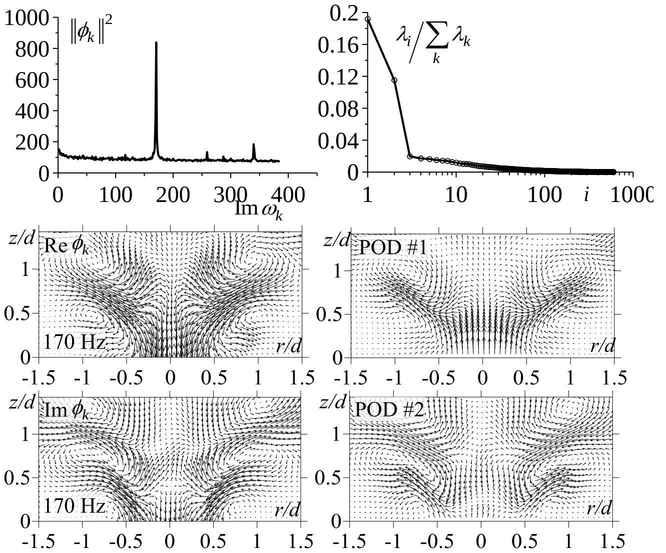

Fig. 2 Spectra and spatial distributions of the most powerful modes for (left) DMD and (right) POD in a forced at 170 Hz propane-air lifted flame.