Journal of Visualization, Vol. 10, No. 2 (2007)145-148

Review Report

Use of PLIF and PIV Techniques to Analyze the Flow Mixing in Dilution Zone of an Aeronautic Combustor

Hébrard, P.*1, Strzelecki, A.*2 and Gajan, P.* 2

*1 Ecole Nationale Supérieure d'Ingénieurs de Constructions Aéronautiques (ENSICA), 1, place Emile Blouin, Toulouse, France.
*2 Office National d'Etudes et de Recherches Aérospatiales (ONERA), 2 avenue Edouard Belin, Toulouse, France.

Received 14 March 2007

1. Introduction

Mixing of flows has significant applications in chemistry, energy or environment industries. The heat and mass transfer controls the effectiveness and the efficiency of systems. In turbulent flows, these transfers depend mainly on the characteristics of the aerodynamic. Experimental methods are needed to analyze the coupling between the instantaneous field and the diffusion of heat or mass. In the last decades, optical methods were developed which permit to analyze these phenomena (Papanicolaou and List, 1988; Hanson et al., 1990; Lemoine et al., 1996; Su and Dahm, 1996; Cowen et al., 2001). Among them, coupled techniques using Planar Laser-Induced Fluorescent and Particles Image Velocimetry were applied on different configurations (Su et al., 2000; Gicquel et al., 2005). These two techniques give useful information on the structural features of the velocity and scalar fields and permit to understand the interactions between large and small scale structures in the velocity field and their implication in the entrainment and mixing processes. Such analysis is useful for the development of numerical tools such than LES methods for which detailed databases are needed to validate the results.

In this paper an application of these new techniques is shown. It concerns the mixing of eight transverse jets in a pipe flow simulating the dilution zone of a gas turbine combustor. On this geometry, two optical methods are applied: PIV for the velocity field characterization and PLIF for the flow mixing analysis.

2. Experimental Setup and Measurement Techniques

2.1 Experimental Setup

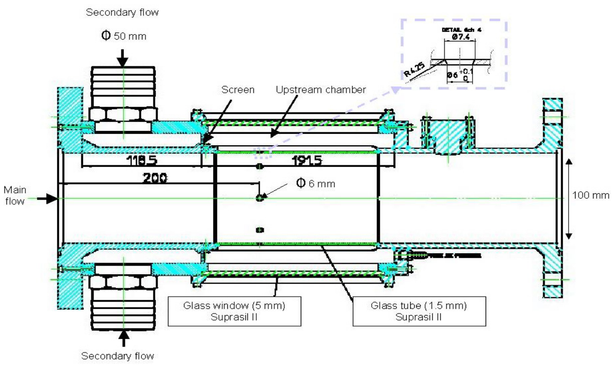


Fig. 1. Sketch of the test section.

A sketch of the test section is presented in figure 1. The main pipe has an internal diameter D of 100 mm. Eight circular orifices with diameters d equal to 6.1 mm are drilled in the 1.5 mm glass wall. These holes are slightly convergent in order to ensure a flat velocity profile at the jet outlets. The tube and the windows are made of Suprasil glass in order to permit UV lightening for LIF measurements. The secondary flow comes into a tranquillization chamber from four entrances before penetrates transversally into the main flow through the eight orifices. The differential pressure occurring between the tranquilization chamber and the pipe controls the jets velocity.

2.2 Experimental Techniques

For PIV measurements, the flow is seeded with glycol droplets injected upstream of the test section, in the jet and the pipe flow. The flow is illuminated by a laser sheet. The images delivered by a CCD video camera (1300 (H) x 1030 (V)) are recorded on a PC computer. The acquisition rate is equal to 3 Hz. The inter-frame times can be as small as 200 ns. Details of the treatment can be found in Lourenço and Krothapalli, 2000. For each fields, 250 pairs of image are acquired.

Concentration images are obtained using planar laser-induced fluorescence (PLIF). This technique uses a monochromatic light source which is formed into a sheet and passed through the flow field. The light source excites an energy transition in a marker species, which fluoresces upon relaxation (Hanson et al., 1990). In this work, the acetone vapor used as tracer absorbs in the UV light (225-320 nm; 278 nm peak) andemits in the visible (350-550 nm, 435 peak). For each test, 100 images are recorded. Post processing is applied to eliminate the background. On the longitudinal views the concentration is calculated using a linear law giving a concentration of 100 % in the potential zone of the jets and 0 % in the pipe section located upstream of the jets entrance. For cross views which do not visualized the potential region of the jets, the concentration levels are calculated by comparing the profiles obtained on longitudinal and transverse views. A correction is applied on each image in order to take into account the laser intensity decrease induced by the absorption by the acetone molecules and the spreading of the sheet. This correction is based on a comparison of the concentration fields measured on the eight jets.

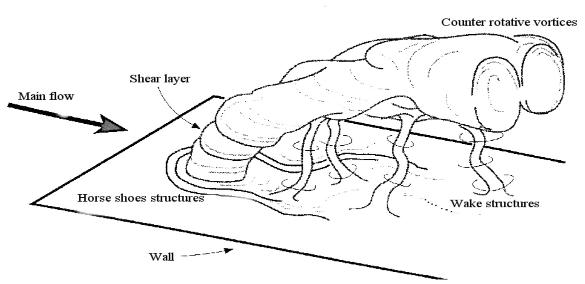
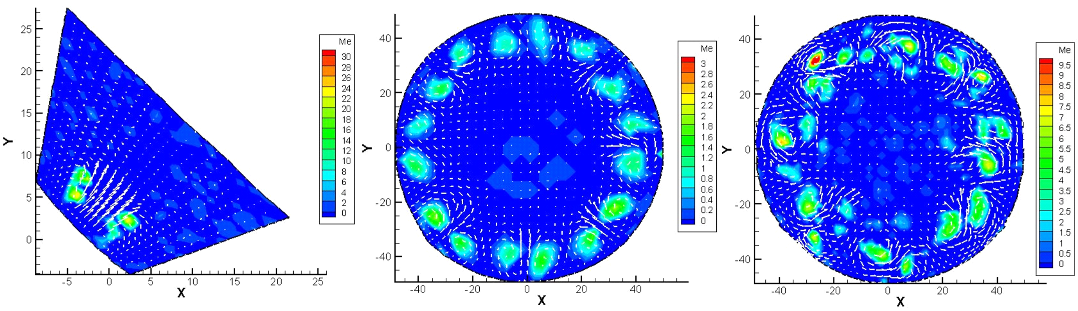


Fig. 2. Instantaneous flow observed in a jet in cross flow (Frick and Roskho, 1994).

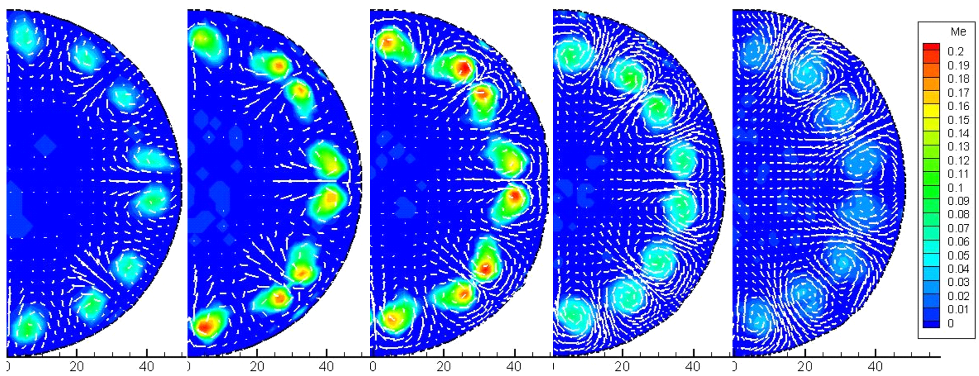
2.3 Flow Conditions

The bulk velocity is fixed to 25 m/s and 5 m/s for PIV and PLIF measurements respectively. Previous works indicate that the jet behavior is mainly controlled by the momentum flux ratio J between the jet and the main flow. For isothermal flows, the velocity ratio R can be used. Two values of this parameter were considered ($R = 2$ and 4). The inlet flow conditions concerns the main flow and the jet flows. The first are determined from LDA. It corresponds to a fully developed pipe flow.



x/d = 0   x/d = 0.67   x/d = 2

Fig. 3. Instantaneous fields measured from PIV technique (R = 4) (Colors correspond to the Mergulian operator and vectors to the two tranverse velocity components (abritary scale)).



x = 0.67 d   1.33 d   2 d   5 d   10 d

Fig. 4. Averaged fields obtained from PIV measurements (R = 4) (Colors correspond to the Mergulian operator and vectors to the two tranverse velocity components (abritary scale)).

3. Results and Discussion

3.1 PIV Results

Previous works based on flow visualizations (Werlé, 1968; Fric and Roshko, 1994) show that the interaction between a jet and the main flow induces the formation of different categories of vortical structures (Fig. 2). Instantaneous fields obtained in different cross sections for $R = 4$ are plotted in figure 3. For $x/d = 0$, a zoom of one jet exit is presented. The vectors are the projection of the velocity on the cross section. The color scale corresponds to the amplitude of Mergulian operator exhibiting the intensity of the vorticity linked to structures (Jeong and Hussain, 1995).

On the first cross sections ($x = 0d$), the injection velocity between two time steps is quite constant close to the wall but varies further inside the pipe. Further downstream the counter rotative vortices are observed. The jets become more unstable and great oscillations of the vortices are put in evidence. Averaged fields plotted in Fig. 4 indicate that, for each jet, the twin structures are symmetrical. Their intensity increases close to the jet outlet then decrease further downstream through diffusion effects.

3.2 PLIF Results

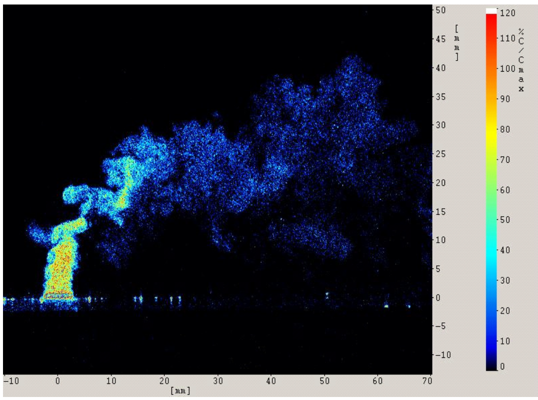


Fig. 5. Instantaneous concentration field measured from PLIF technique.

The instantaneous concentration field shown in Fig. 5 exhibits the jet deflection and the shear layers vortices. Further downstream the spreading of the jet towards the pipe axis and the wall is observed. Averaged distribution of acetone vapor and r.m.s. distribution plotted in Fig. 6 permit to observe the potential core close to the jet exit and the tracer diffusion further downstream. The r.m.s. iso values exhibit the potential core and the high level zone linked to the shearing at the jet boundary. From these fields the streak lines can be visualized and averaged trajectory and the envelope of the jets are calculated (Fig. 7). The trajectory path corresponds to the maximum of concentration on each x line. The jet envelope is defined as the y coordinate b where the concentration is equal to half the maximum concentration on each profile. Note the x and y origins are set at the jet outlet in its centre.

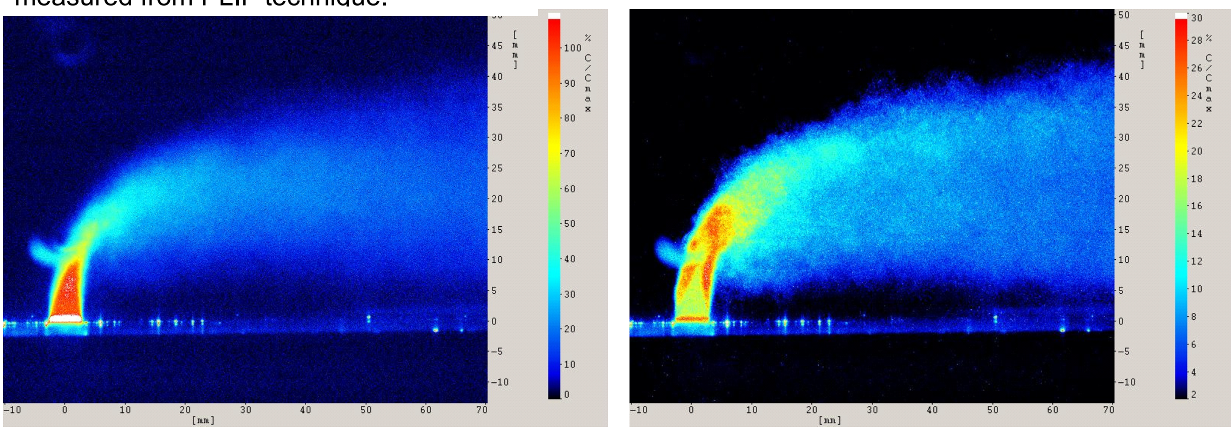


Fig. 6. Mean and r.m.s. concentration fields measured in a plane perpendicular to the wall including the jet axis: R = 4.

3.3 Comparison between Velocity and Concentration Fields

The comparison between the velocity and the concentration fields indicates that, for each jet, the maximum concentration zone is located between the twin vortices and the pipe axis (Fig. 8). A similar result was observed on the velocity field obtained by LDA. In this case, a zone of high longitudinal velocity is located above the two counter rotative structures.

4. Conclusions

This paper presents a study using PIV and PLIF techniques to investigate the mixing of eight jets flowing transversally into a pipe flow. These methods permit to identify the unsteady and steady features of the flow. The different vortical structures are revealed and quantitative information is obtained to characterize the mass transfer between the different flows. The analysis of the instantaneous velocity field indicates that the two counter rotative structures typical of this flow configuration, are stable close to the jet exit and become unsteady further downstream. The PLIF techniques applied on acetone permits to analyze the mixing of the different jet. Mean trajectories are determined with respect to the *R* ratio and the spreading of the jets is analyzed. Comparison between the velocity and the concentration results reveals the coupling between the aerodynamic and the mixture fields. Further treatments can be done in order to identify the influence of the Schmidt number on the mass and momentum diffusion. All these results were used to validate LES calculations (Prière, 2005)

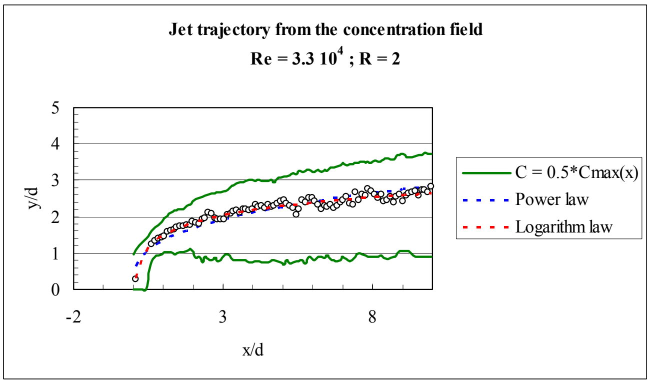


Fig. 7. Jet trajectory and envelopes deduced from the concentration (R = 4).

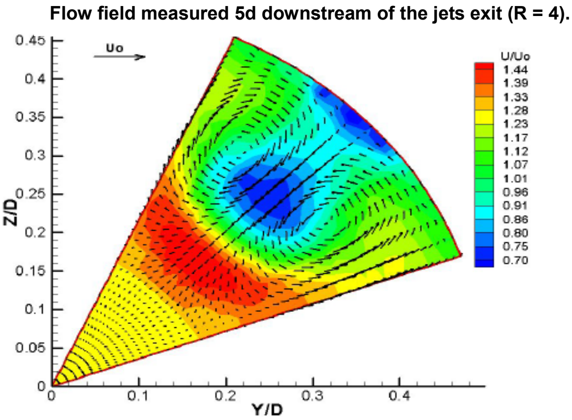


Fig. 8. Comparison of averaged velocity (vectors) and concentration fields (R = 4; Re = 3.3 10^4; x/d = 5).

References

Cowen, E. A., Chang, K. A. and Liao, Q., A single camera coupled PTV-LIF technique, Exp. In Fluids, 31 (2001), 63-73.

Fric, T. F. and Roshko, A., Vortical structure in the wake of a transverse jet, J. of Fluid Mech., 279, (1994), 1-47.

Gicquel, P., Brossard, C., Bresson, A. and Grisch, F., Simultaneous velocity, temperature and concentration measurements in a turbulent heated jet using combined PIV and 2 l-PliF, 6th Int. Symp. On PIV (Pasadena), (2005).

Hanson, R. K., Seitzman, J. M. and Paul P. H., Planar laser-fluorescence imaging of combustion gases, Appl. Phys. B, 50 (1990), 441-454.

Jeong, J. and Hussain, F., On the identification of a vortex, J. of Fluid Mech., 285 (1995), 69-94.

Kelso, R. M. and Smits, A. J., Horseshoe vortex systems resulting from the interaction between a laminar boundary layer and a transverse jet, Phys. Fluids, 7 (1995), 153-158.

Lemoine, F., Wolff, M. and Lebouche, M., Simultaneous concentration and velocity measurements using combined laser-induced fluorescence and laser Doppler velocimetry: Application to turbulent transport, Exp. In Fluids, 20 (1996), 319-327.

Lourenço, L. and Krothapalli, A., True resolution PIV: a mesh-free second order accurate algorithm, 10th Int. Symp. on Applications of Laser Techniques in Fluid Mechanics (Lisbon), (2000).

Papanicolaou, P. N. and List, E. J, Investigation of round vertical turbulent buoyant jets, J. Fluid Mech., 195 (1988), 341-391.

Prière, C., Gicquel, O., Gajan, P., Strzelecki, A., Poinsot, Th. And Berat C., Experimental and Numerical Studies of Dilution Systems for Low-Emission Combustors, AIAA journal, 13-8 (2005), 1753-1766.

Smith, S. H. and Mungal M. G., Mixing, structure and scaling of the jet in cross flow, J. Fluid Mech., 357 (1998), 83-122.

Su, L. K. and Dahm, W. J. A., Scalar imaging velocimetry measurements of the velocity gradient tensor field in turbulent flows. II. Experimental results, Phys. Fluids, 8 (1996), 1883-1906.

Su, L. K. and Han, D., Miraflor R.M., Mungal, Measurements of scalar and velocity fields in turbulent crossflowing jets with low velocity ratio, AIAA paper 2000-0815, (2000).

Werlé, H., Flows with very large velocity fluctuations, Motion picture film, 575 (1968), ONERA, Chatillon.

Yuan, Lester, Street, Robert, Ferziger Joel H., Large eddy simulation of a round jet in crossflow, J. of Fluids Mech., 379 (1999), 71-104.

Authors Profile

P. Hébrard (Picture): Engineer diploma of ENSICA in 1967, Doctor engineer in 1969, Sciences Doctor in 1973, Researcher and department head at ONERA from 1969 till 1992, Present position: Director of training and research at ENSICA.

A. Strzelecki: ONERA Researcher since 1984, PhD in 1989, Specialist in aerodynamics, flow metering and two phase flows, Spend 1 year in Stanford University with Prof Mungal on PLIF/PIV techniques, Associate Professor in the Conservatoire des Arts et Métiers in Paris.

P. Gajan: Doctor of the University of Rouen 1983, Sciences Doctor in 1988, Research Engineer at ONERA since 1987, Specialist in flow metering and two phase flows.