SIMULTANEOUS VELOCITY AND CONCENTRATION MEASUREMENTS OF TURBULENT JET MIXING FLOWS

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Simultaneous information of a passive scalar and velocity field is desirable in many fluid flow investigations like mixing in combustion chambers or distributions of drugs in biomedical applications. The possibility of measuring velocity and a scalar at the same time with high spatial and/or temporal resolution is also of fundamental importance for the validation and development of models of turbulence and turbulent mixing. For example, in turbulent jet mixing flows, the species concentration field ξ is determined by molecular diffusion and transported by the turbulent flow field. When considering the Reynolds-averaged scalar conservation equation, the effects of turbulent transport appear in terms of the correlation between the concentration and velocity fluctuations, i.e. expressions such as $\overline{u'\xi'}$ and $\overline{v'\xi'}$. Experimental characterization of these correlation terms is needed for the development and validation of physical models, and requires the simultaneous measurements of the velocity and concentration fields.

INTRODUCTION

Scalar quantities, such as tracer concentration or temperature, are often used to visualize flow patterns and infer general flow structures. A good example is the use of fluorescent tracers along with laser induced fluorescence (LIF) for visualization of liquid or gas phase flows. LIF images are routinely used to make inference about the vortical structures and their dynamics in various flow phenomena, even though it is known that such inference can sometimes be misleading. The ability to simultaneously visualize the flow structure and measure its underlying velocity/vorticity field would serve as a valuable tool in discovering and understanding the physics of flow.

With the rapid development of modern optical techniques and digital image processing techniques, whole-field optical diagnostics, such as Particle Imaging Velocity (PIV) and Planar Laser Induced Fluorescence (PLIF) techniques, are assuming an ever-expanding role in the diagnostic probing of fluid mechanics. The advances of PIV and PLIF techniques in recent years have lead them to be mature techniques for the whole-field measurements of velocity and concentration or/and temperature in a plane or over a volume of an objective fluid flow. A high-resolution PIV-PLIF combined system, which can achieve the simultaneous measurements of instantaneous spatial distribution of velocity and concentration in a fluid flow, has been developed by the authors (1). The simultaneous velocity and concentration measurements thus obtained allow to investigate the characteristics of the mass transport process (by the PLIF measurement) and the momentum transport process (by the PIV measurements). The relationship between the two processes in jet mixing flows is the main object of the present paper.

METHODS & RESULTS

Figure 1 shows the schematically experimental set-up used in the present research. A test circular nozzle (D=30mm) was fixed in the middle of a water tank (600mm*600mm*1000mm). Fluorescent dye (Rhodamine B) for PLIF or PIV tracers (hollow glass particles d=8-12μm) was premixed with water in a jet supply tank, and jet flow was supplied by a pump. The pulsed illumination laser sheet was generated by a double-pulsed Nd:YAG Laser system (Quantel Inc.). After passing through a second harmonic generator cell, the wavelength of the light beams emitted from the double-pulsed Nd:YAG Laser system is 532nm. By using a set of optics (cylindrical lens and mirrors), the laser beam was bundled in a planar laser sheet with thickness being about 1.5 mm. The frequency of the double-pulsed illumination is 10 Hz. The pulsed illumination duration is 4ns, and power is 200 mJ/pulse.

In order to achieve the simultaneous measurements of the concentration and velocity fields by using PLIF and PIV techniques, a simultaneous image recording system was designed by using optics and two high-resolution CCD cameras (TSI PIVCAM10-30, 1K by 1K resolution). The diagram of the simultaneous image recording system was shown on the right upper corner of the Figure 1 schematically. Rhodamine B was used as fluorescent dye in the present study. It was known that the emission peak of Rhodamine B is about 590nm, and the wavelength of the illuminating laser light scattered by the PIV tracer particles is 532nm. Two kinds of optical filters were used in the present study to separate the LIF lights from scattered laser lights, and then recorded them separately to obtain PLIF and PIV image simultaneously. As shown in the right upper corner of the Figure 1, the combined light including both LIF light (peak at 590nm) and scattered laser light (532nm) were divided into two light beams by using a beam splitter. Once light beam is go straight to CCD camera #1 for PIV image recording. A band pass optical filter (532nm±5) was installed at the head of the camera #1. Therefore, only the scattered laser light is transmissible to form PIV image on the CCD sensor of the camera #1, and the LIF light is blocked out. Another light beam from the beam splitter was reflected by a mirror before it enters into the camera #2 for PLIF image recording. A high pass filter (>580nm pass) was installed in the head of the camera #2 to filter out the scattered laser light (wavelength 523nm). The LIF light (peak at 590nm) pass through the optical filter to generate LIF image on the CCD censor of the camera #2. The two CCD cameras were mounted on a mini- optical bed, and the positions of the two cameras were adjusted meticulously to get the same magnification and maximum overlap view for the two cameras. Such arrangement may also simplify the position calibration for the two image recording cameras. The double-pulsed Nd:YAG Laser and the simultaneous image recording cameras were connected to a host computer via a synchronizer (LaserPulse TSI INC.), which controls the timing of laser illumination and image acquisition. The host computer is composed of two high-speed CPU (800MHz, Pentium III CPU), colossal image memory and Hard disk (1GB RAM, Hard Disk 100GB). It can acquire the continuous image pairs up to 250 frames every time at the framing frequency of 10 Hz.

SUMMARY

Figure 2 shows an example of the instantaneous measurement result of the PIV-PLIF combined system in a circular jet flow at the Reynolds number level of 6,000. More detailed results, which include the ensemble-averaged velocity fields, ensemble-averaged concentration field, the instantaneous and ensemble-averaged vorticity fields, the distribution of the correlation terms between the concentration and velocity fluctuations, i.e. expressions such as $\overline{u'\xi'}$ and $\overline{v'\xi'}$, will be given in the full paper of the present study. Based on the simultaneous velocity and concentration measurement results of turbulent jet mixing flows, the physics of the mixing process in jet mixing flows and will be discussed in detail.

REFERENCES

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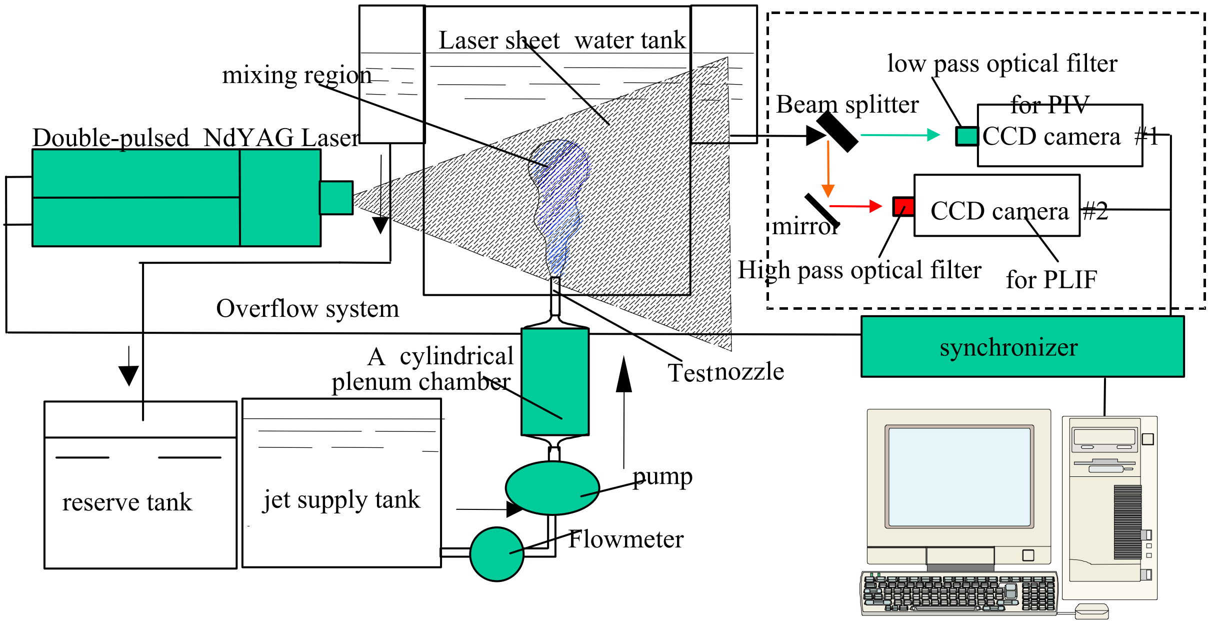
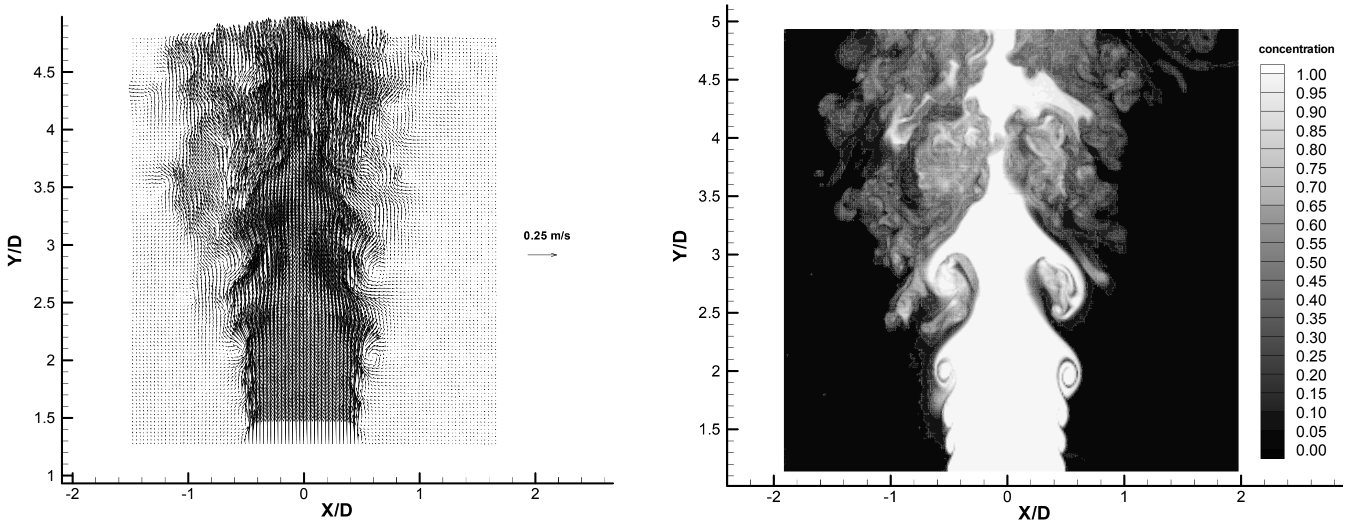


Figure 1. Experimental system setup



a. PIV measurement results b. simultaneous PLIF measurement results

Figure 4. Typical instantaneous meansurement results of the PIV-PLIF combined system in a circular jet mxing flow (Re=6,000)

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