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PLANAR IMAGING OF SCALAR FIELDS IN A TWO PHASE TURBULENT JET

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ABSTRACT

Laser imaging was applied to a turbulent two phase jet. A water spray was introduced into a flow of air from a round nozzle. The air was seeded with acetone vapor. A UV laser sheet illuminated the flow field of the spray and an unintensified CCD camera imaged the resultant fluorescence. A visible laser sheet, co-planar with the UV sheet, was pulsed to provide a light source for Planar Imaging Velocimetry (PIV). PIV was used to measure the velocities of the droplets and to estimate the relative velocity between the air and the spray droplets. The impact of the dispersed phase droplets on the structure of the scalar field in the jet was found to be slight for the conditions of the experiment. The water droplets of the spray absorbed acetone and gave rise to a strong fluorescence signal that prevented quantitative estimates of scalar dissipation rates from being obtained in the two phase flow. Triple images of droplets with PIV and UV beams suggested that it might be possible to measure particle accelerations in a spray.

INTRODUCTION

The structure of turbulence in two phase flows can be modified by the relative motion of particles and the continuous phase. High relative Reynolds numbers produce wakes behind the particles that can induce fine scale motions. The presence of a spray can modify the scalar field of a jet by altering the large scale velocity field. For example, Hardalupas et al. [1] found that particles added to a jet affected the mean velocity gradients and turbulence production rates. It should be expected that such macroscopic effects will have an indirect effect on mixing. The spray can also have an impact on the small scale turbulence through the presence of wakes behind droplets with the possibility that vortices shedding at high relative Reynolds numbers. Finally, evaporating droplets provide a source of the gas phase scalar quantity (or conversely a sink in the case of absorbing droplets).

EXPERIMENTAL METHOD

A flow of air was bubbled through liquid acetone that was held at a constant temperature of about 30 °C in a water bath. The acetone laden flow was passed through a straight, round nozzle with an internal diameter of 7.5 mm. The flow rate of air was measured with a calibrated rotameter. The mean jet exit velocity (based on the total measured volume flow of air) was 29 m s^{-1}, yielding a Reynolds number of the single phase jet of 15,000. The jet issued into a co-flowing stream of air that had a velocity of 3 m s^{-1}.

Water droplets were introduced into the air stream by atomizing water with a miniature air blast atomizer that consisted of two fine tubes (0.6 mm diameter) located upstream from the nozzle exit. Water flowed through one of the tubes, air through the other. The arrangement of the nozzle and spray injector is shown in Figure 1. Water flow rates to the spray nozzles were metered by calibrated rotameters. The flow rate of water was 4.2×10^{-7} m s^{-1}, yielding a mass loading of water in the flow of 26%.

The optical arrangement is shown in Figure 2. The fluorescence from acetone vapor was excited by a sheet of 288 nm light. The UV beam was obtained by frequency doubling the output of a YAG pumped dye laser that produced radiation at 576 nm. A series of lenses formed the beam into a sheet that was directed across the diameter of the jet. The acetone fluorescence was collected with an inverted camera lens and focused onto an unintensified CCD camera. The fluorescence was sufficiently strong to enable the collection of high quality images without the use of a gated intensifier. The extent of the imaged area in the jet was 6.5 mm wide by 4 mm in the main flow direction. The dimension of a pixel on the CCD corresponded to about 20 μm in the flow field.

Droplet velocities were measured by PIV. A second YAG laser was pulsed with an external Marx bank. Two pulses of light at a wavelength of 532 nm were formed into a sheet that was co-planar with the UV sheet. The PIV pulses were delayed 20 ms from the UV pulse. They were, in turn, separated from each other by 20 ms. It was possible to record the PIV images of the water droplets on the same CCD camera that was used for the acetone fluorescence imaging. PIV results were obtained with and without acetone in the flow.

RESULTS

Measurements of the velocity of the spray by PIV at the nozzle exit showed that the mean droplet velocity was 14 m s^{-1}. Hence, the spray droplets lagged the gas flow field at the nozzle exit. It was not possible to measure accurately the size distribution of the spray with the available apparatus. However, the CCD images indicated that particles smaller than 10 μm and as large as 130 μm were present. The latter particles were undergoing further breakup at the nozzle exit. PIV measurements at 20 D indicated that the average axial velocity of the droplets was 14.3 m s^{-1}. The droplets had accelerated slightly in the flow. although it chosen to optimize the measurements technique itself.

Acetone fluorescence was measured at x/D = 20 on the axis of the jet. The images of acetone fluorescence were corrected for non uniformity in the detector response and for the laser beam profile. Furthermore, the intensity of the fluorescence at the nozzle exit was recorded and used to normalize the images. The raw images were converted to images of mixture fraction, f , a measure of the concentration of nozzle fluid at a point in the flow. The definition and significance of mixture fraction is discussed by Williams [2].

Figure 3 shows a typical image of the combined acetone vapor and water spray at x/D = 20. The images do not show any evidence of the modification of the scalar field due to the presence of a flow wake around theparticle. The "optical wake" that is present behind the large particle in the image should be noted. Bazile and Stepowski [3] found that acetone in the liquid phase absorbed incident radiation strongly. Acetone vapor was readily absorbed by the water spray in the experiments that are reported herein. Consequently, the fluorescence in the rear of the droplets was weaker as a result of the attenuation of the transmitted laser sheet.

The lack of an apparent impact of the spray on scalar dissipation rates can be understood by reference to the relative velocity between the phases at the point in the flow where the images were obtained. A simple calculation of the droplet dynamics in the spray serves to provide further insight into the response of the particles to the carrier fluid and their relative Reynolds numbers. The mean droplet velocities at a cross section of the jet are compared with the gas phase mean velocity in Figure 4.

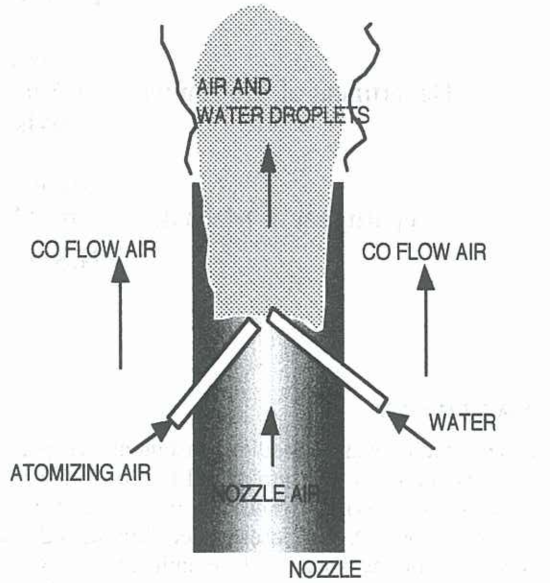

Figure 1 : Flow nozzle and spray injection system

It is apparent from Figure 4 that the particles in the spray are relatively massive and unresponsive to the changing velocity field of the jet. They undergo an initial acceleration as they attempt to catch up with the carrier gas. The Reynolds number of the flow around the droplets is large initially and passes through zero (illustrated approximately in Figure 4 as a result of the plotting routine) as the droplet and gas velocities match. At x/d = 20, the jet has slowed down and the droplets are moving faster than the carrier fluid. The relative Reynolds number based on the mean gas and droplet velocities is about 47 at this point in the flow for 100 mm droplets; the Reynolds for the smaller droplets is less.

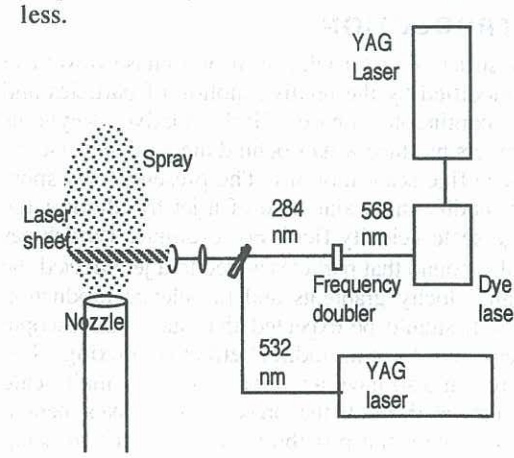

Figure 2 : Optical arrangement for acetone LIF and droplet PIV measurements (not to scale)

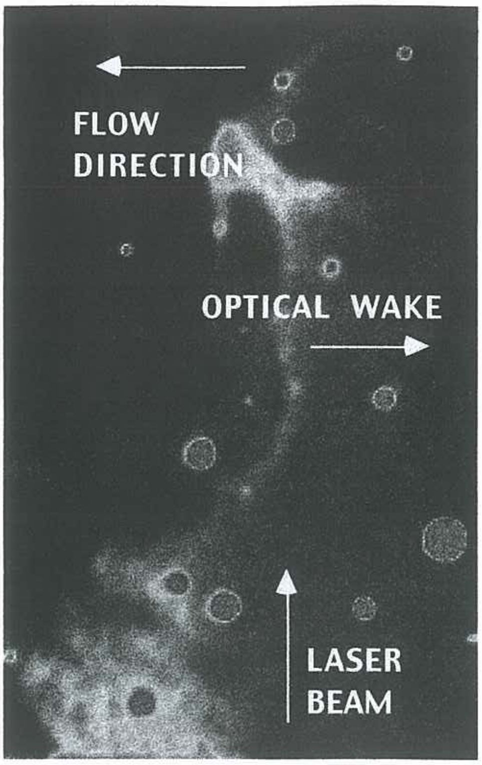

Figure 3 : Mixture fractions at x/D = 20 with spray (note optical wakes behind larger droplets - laser beam propagated from bottom of picture to top)

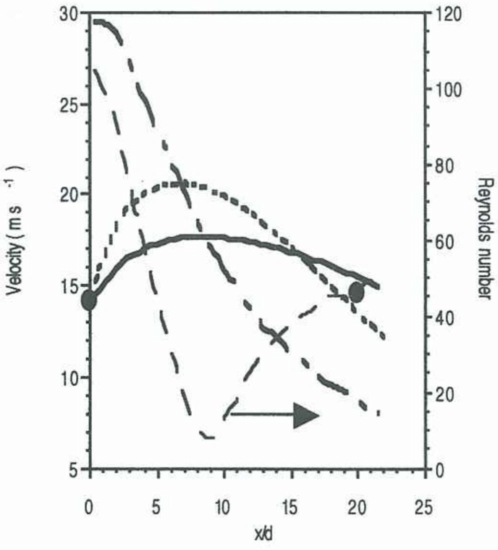

Figure 4 : Mean velocities of 50 and 100 µm droplets compared with the mean gas phase velocities estimated with a Reynolds stress model of the round jet. The relative Reynolds numbers of the 100 µm droplets are also shown. Solid points show PIV measurements of spray velocity.

----- 100 µm drop
—·—50 µm drop
—●— gas phase velocity
— — —Relative Reynolds number 100 µm drop

CONCLUSION

Laser induced fluorescence was applied to a two phase turbulent jet. Acetone was found to absorb onto the water droplets in the spray very quickly so that the spray particles appeared in all the images of acetone fluorescence. At the location in the spray where the measurements were obtained, the velocities of the spray droplets and the gas phase had matched so that there was little possibility of finding significant wakes behind the droplets. Hence, the scalar gradients and scalar dissipation rate were not perturbed in a qualitative sense. A quantitative measurement of the scalar dissipation rate in a two phase flow will be challenging for the following reasons. A suitable vapor and liquid combination must be found in which the vapor is not absorbed by the spray droplets. Furthermore, if such a suitable combination can be identified and applied, the images will still contain the "ghosts" of droplets where a non emitting droplet has displaced fluorescing vapor. The presence of these voids will give rise to large scalar gradients at their perimeters and will pose a challenge to image processing schemes that seek to determine scalar dissipation rates from images of the spray and vapor. Triple images of droplets were observed when a PIV systems was used in conjunction with a UV fluorescence beam. The presence of triple images of droplets may permit particle accelerations to be determined.

REFERENCES

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